CREATING A RESILIENT FOOD SYSTEM FOR THE METROPOLITAN CHICAGO REGION

Prepared by Delta Institute
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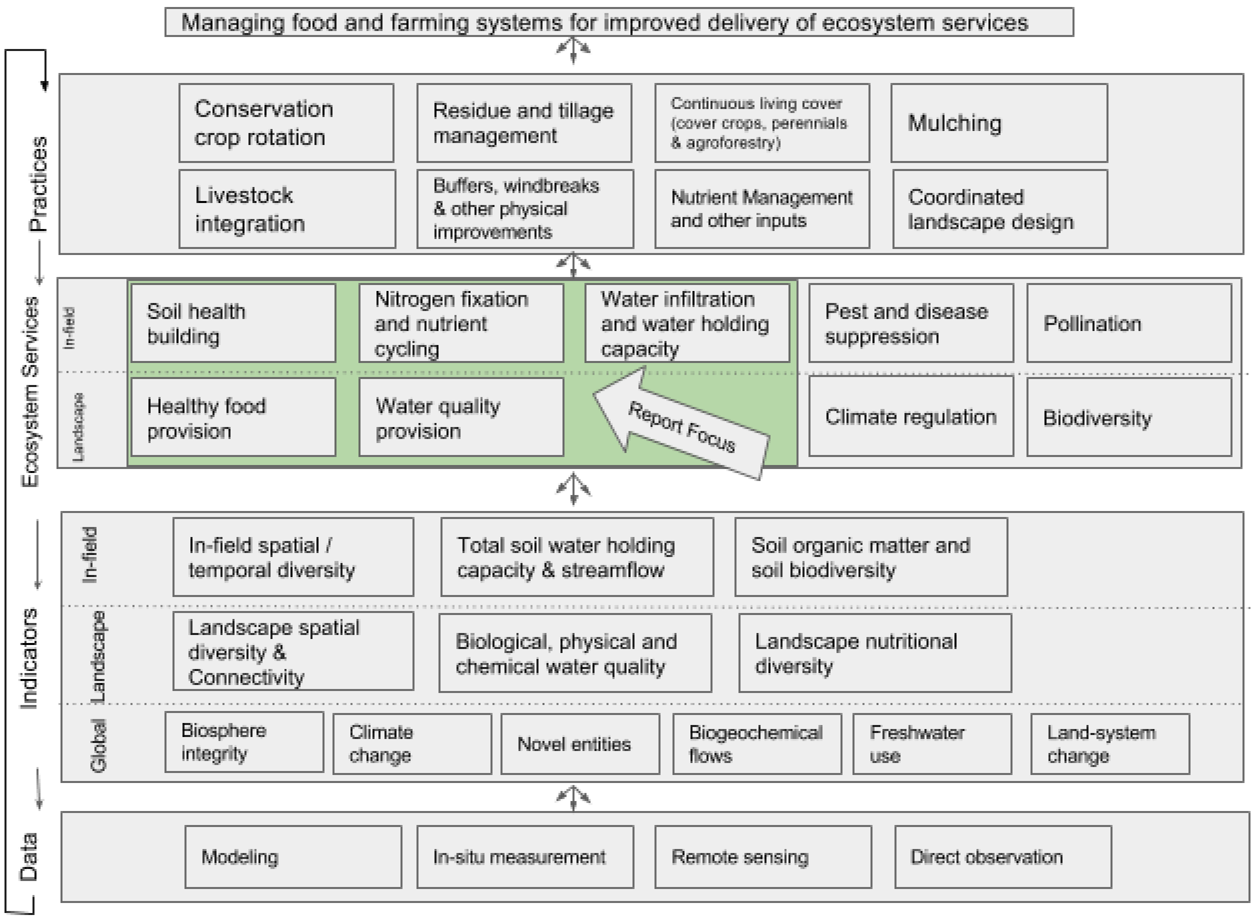
INTRODUCTION

Building on the *Chicago Regional Food System Study*,[1] this paper outlines a strategy to measure and monitor the ecosystem services from agricultural production within the study region (38 counties in Illinois, Indiana, Michigan, and Wisconsin that make up the Chicago Wilderness region) as production shifts to meet local and regional demands. Traditionally, agricultural land has been managed to maximize a single ecosystem service: food production. In many cases, while food production has increased dramatically, this has come at the expense of other ecosystem services.[2] Here, we explore how a shift to diversified farming systems[3] would benefit ecosystem services, with a focus on soil and water stewardship.

To track the changes in ecosystem services from agricultural landscapes, we developed a framework with built-in adaptive feedback loops that can be used to track changes in ecosystem services with the expansion of production of food and feed for more localized consumption (Figure 1). This framework includes a series of practices that can be used on-farm where implementation leads to co-benefits among the provision of food and other ecosystem services. The use of these practices is related to the provision of a suite of ecosystem services, and those ecosystem services can be tracked by the use of a set of indicators at the field, farm, and landscape scales. These indicators are informed by data that can be collected from a range of sources. As indicators related to the delivery of ecosystem services change over time, farming practices, or the incentives to implement farming practices, can be altered to meet stated goals.

At its core, farming is a local activity with each field managed for a desired suite of social, ecological, and economic outputs. The ecosystem services or "dis-services"[4] from farming activities can have a range of positive and negative impacts over both space and time. For instance, tilling soil might lead to a local increase in food production because of a reduction of weed pressure. Concurrently, water quality in the region might decrease if precipitation after a tillage event carried loose soil particles to a nearby water body. As soil carbon is oxidized after a tillage event, carbon sequestration, which is an integral part of the global provision of climate regulation, would also decrease. This example demonstrates the complexity of the relationship between local actions and their local to global impacts, whose trade-offs must be understood and managed using a holistic perspective.

Figure 1: Ecosystem services framework



This report introduces a framework to manage local food and farming systems for improved delivery of ecosystem services. The framework is built around four main sections: practices, ecosystem services, indicators, and data with the intention that data collected will be used to inform changes in management, creating the necessary conditions for a more adaptively managed system. The practices included here lay the foundation for diversified farming systems with an emphasis on crop and livestock rotations, perennial and other living cover on the soil throughout the year, and internal recycling of nutrients. These practices improve the delivery of ecosystem services, especially those related to soil and water. They also help to improve other ecosystem services like carbon sequestration and ones related to biodiversity. The ecosystem services are divided into those whose services are mostly delivered locally and those changes that are more relevant at the landscape level. Changes in these ecosystem services are tracked through the use of indicators that are informed by data collected through various observations, measurements, and models.

PRACTICES

The mix of practices that a farmer chooses to implement sets the course for the delivery of ecosystem services across both spatial and temporal scales. As working lands transition to provide healthy food, cleaner water, and healthier soils, decisions will need to be made from the field to the farm to the landscape of how to balance resource, economic, and cultural needs to produce the optimal basket of outputs. Through decades of research, trials, experimentation, and refinement, a general set of practices has been identified that contributes to the delivery of the landscape stewardship and provision of nourishing food. Many of these practices have been identified by the USDA Natural Resources Conservation Service as part of their suite of Conservation Practice Standards,[5] and many in this list have been adapted to better meet the stated water, soil, and food goals that this effort is promoting (Table 1). The majority of these practices are performed at the field scale, like conservation crop rotations, while others are implemented at the landscape scale, like coordinated landscape design, which can help to amplify the ecosystem service delivery from a connected set of farms. The selection of these practices will vary depending on the goals of the farmer, and it may not be financially, physically, or logistically possible to implement all practices in a single location or over a single season.

Table 1: Land stewardship practices and ecosystem services

Practice name	Practice description
Conservation crop rotation	Growing crops in a planned sequence on the same field.[5–11]
Residue and tillage management	Limiting soil disturbance to manage the amount, orientation, and distribution of crop and plant residue on the soil surface year-round.[5,6]
Continuous living cover (e.g. cover cropping, perennials, agroforestry)	Planting crops, including grasses, legumes, and forbs, for seasonal cover and other conservation purposes.[5] Perennial crops are harvested multiple times without the need to replant and include grains, biomass, and forages. Agroforestry is the inclusion of trees into the landscape that provide food and/or feed.[6,7,9,10,12–15]
Mulching	Applying plant residue, or other suitable material produced off-site, to the land surface.[5,6]
Nutrient management and other inputs	Managing the amount (rate), source, placement (method of application), and timing of plant nutrients and soil amendments.[6]
Livestock integration	Planned inclusion of livestock into annual and perennial agricultural systems for the provision of animal products and the management of soils, crops, weeds, and other landscape elements.[16–18]
Buffers, windbreaks, and other physical improvements	Shrubs, grasses, trees, or other living cover.[19–23]
Coordinated landscape design	Deliberate planning of land use and connectivity of managed parcels to optimize delivery of ecosystem services.[23–27]

ECOSYSTEM SERVICES

Traditionally, agricultural systems have been managed to maximize provision of food, at the cost of other ecosystem services such as clean water and healthy soil. This explicit trade-off has been recently re-examined as producers across a variety of agricultural systems work to balance the ecosystem services and dis-services that result from their management decisions.[4,28] This report focuses on management practices that can reduce negative externalities from agricultural production, such as air and water pollution, soil erosion, and increase the balanced provision of positive ecosystem services. Management practices deliver different types of services across spatial and temporal gradients. Benefit delivery of some practices may be very localized, like increasing organic matter and soil health, which have direct impacts on yield. Other practices deliver services to downstream or otherwise distant stakeholders, as seen with improving water quality or reducing greenhouse gas emissions. In this context, we divide the ecosystem services by those that are provided in-field (Table 2) and those provided across the landscape (Table 3). Many of the services have strong dependencies and interrelationships with other services, such as the connection between healthy soil and its ability to help in nutrient cycling, water infiltration, carbon sequestration, and other services. This set of ecosystem services are provided to track the outputs of a diversified farming system in support of local food production. If the landscape were managed for only a subset of these services, then there is a risk that the broader goals of local and regenerative food systems may not be met. Certain services that are important to agriculture at both the in-field and landscape levels are acknowledged below, but are outside the scope of this report. Social and cultural ecosystem services are also outside the scope of this report.

Table 2: Ecosystem services provided in-field

Ecosystem Service	Service description
Soil health building[6,29–38]	The ability of the soil's dynamic physical, chemical, and biological processes to deliver desired outcomes to people and ecosystems. The health of the soil is directly related to its resilience to disturbance and its ability to function across other important ecosystem services related to nutrients, water, carbon, biodiversity and food production.
Nitrogen fixation and nutrient cycling[38–41]	The ability of the crop-soil-atmosphere system to cycle incorporate, use, and cycle nutrients without excessive environmental losses. Excessive use of nutrients or the inability of the crops, animals or soil to efficiently use or cycle nutrients has negative consequences for people and ecosystems. Appropriate use of external inputs and practices like cover crops, the use of crop rotations, and the inclusion of nitrogen fixing legumes can improve productivity and reduce nutrient loss.
Water infiltration and water holding capacity[42–44]	The ability of the soil to capture, store, and make available water resources for use by crops. Soil facilitates water infiltration and prevents excessive water and soil losses. Water available within soils increases resilience to drought and reduces the need for irrigation.
Pest and disease suppression	It is acknowledged that these ecosystem services play a role in the structure and function of diversified farming systems, but they are outside the scope of this report.
Pollination	

Table 3: Ecosystem services provided across the landscape

Ecosystem Service	Service description
Healthy food provision[45–49]	The provision of diverse, nutrient-dense, and healthy food provided from agroecosystems. Providing people with healthy food requires a number of key inputs, from locally adapted seeds, to healthy soil that helps transfer nutrients from the soil into plants, to an appropriate diversity and availability of food.
Water quality provision[50–52]	The ability of agroecosystems to provide clean water, free of excessive sedimentation, nutrients, and agrochemicals to downstream users. Water quality is a regionally aggregated indicator that is affected by stewardship across the landscape and is a representation of the effectiveness of farm-level interventions on broader scale outcomes.
Climate regulation	It is acknowledged that these ecosystem services play a role in the structure and function of diversified farming systems, but they are outside the scope of this report.
Biodiversity	

ECOSYSTEM SERVICE INDICATORS

Ecosystem services are a useful framework that provides decision-makers and other stakeholders input to their deliberative decision-making processes when both market and non-market values, as well as public and private goods, are included. While ecosystem services have been incorporated into many decision frameworks, the delivery of those services needs to be supported by indicators that inform how the services change and who are the recipients of those services. In this case, we have outlined a series of indicators that relate the changes on the ground to the delivery of ecosystem services. These indicators represent a discrete way to measure the changes in ecosystem service delivery and take into account the trade-offs between data availability, cost of data acquisition, and scientific certainty. Like the ecosystem services defined above, the indicators are divided between those that are measured or monitored in-field versus across the landscape. A set of global indicators are included to illustrate the connection between local and regional actions and global outcomes and the ability to eventually connect changes made on the ground to larger scale policy-relevant indicators and targets such as planetary boundaries[53] and the UN Sustainable Development Goals.[54]

Table 4: In-field spatial / temporal diversity

Increasing the diversity of crops and livestock within a given field can be accomplished by managing rotations of crops and livestock over space and time.[55–57] For example, intercropping, relay cropping and cover cropping with a multi-species mix add to the diversity of crops within a given year. Similarly, rotations between different crops (e.g. grains and vegetables) and livestock between seasons can add to the diversity of a field. Increasing diversity aids in building healthy soil, reducing pest pressures, and rebalances soil-plant nutrient cycles.

	Methodology	Availability	Geographic scope / scale	Precision	Cost
Baseline	Data on in-field diversity is not widely available outside of individual farmer records Historical aerial photography / remote sensing may be able to discern crop diversity	Varies on farmer records and availability of historical imagery	Remotely sensed data could be available at a field / farm scale	High resolutio n for satellite imagery	Costs vary from free (public products) to $1000 per image for commercial imagery
Data collection	On-farm surveys, or farmer surveys	Will depend on access to the farm	Will be done on a field-by-field basis, and up to several times a year	Field scale	Time / interest of the surveyor or farmer
Future considerations	Regular fly-overs by drones or other unmanned aerial vehicles could be a cost-effective method to capture data over large, diverse farms with limited resources.				

Table 5: Total soil water holding capacity & streamflow

The ability of the soil to infiltrate and hold precipitation and the eventual release of water into streams is an indicator of healthy soil function.[56,58–60] Healthy soils maintain airspaces that fill with water during precipitation events and limit water that exits the field as runoff, potentially eroding soils and carrying away nutrients. Many agricultural lands in the study area have tile drains installed that enable the land to be more easily farmed, but also contributes to nutrient loss. Increasing water holding capacity by building soil health can reduce the impacts of extreme precipitation events on streamflow, prevent nutrients from leaving a field, and increase the resiliency to drought.

	Methodology	Availability	Geographic scope / scale	Precision	Cost
Baseline	USDA Web Soil Survey & USGS Water Data	Freely available from USDA	Across the study region, at a field scale (soil) and regional (water)	Field-level for soil & on selected streams for water	Free
Data collection	Soil sampling, per NRCS guidelines can calculate water holding capacity of a given soil The study area has an established stream monitoring network, and may not need to be expanded to meet project goals	Soil water holding capacity can be included in the suite of tests run on a given soil sample	Grid sampling can be completed in a field for high accuracy	Depending on soil heterogeneity, results of soil test may be broadly applicable	~$10-20/ sample
Future considerations	Satellite sensors, such as the Soil Moisture Active Passive report on changes in soil moisture, which are related to water holding capacity and can be used as a proxy. In-field soil moisture sensors are also being rapidly developed and deployed and could be used in this context.				

Table 6: Soil organic matter and soil biodiversity

While the concept of soil health was introduced several decades ago, no single agreed upon quantitative measurement or indicator exists to describe it. Generally, healthy soils are resilient to disturbance and provide a suite of valuable ecosystem services related to nutrient cycling, water usage, carbon sequestration, and biodiversity. Measuring the organic carbon component of the soil and the diversity of soil organisms that contribute to plant and soil health is one way to estimate how the functioning of the soil changes over time.[61] New quantitative tests have recently been introduced to better measure soil health, but there has not yet been general agreement in the scientific or practitioner communities as to the value of these tests in the long-term management in agricultural systems.

	Methodology	Availability	Geographic scope / scale	Precision	Cost
Baseline	USDA Web Soil Survey (soil organic matter) Data on in-field soil biodiversity is not readily available	Freely available from USDA (soil organic matter)	Across the study region, field- scale (soil organic matter)	Field-level for soil organic matter	Free
Data collection	Soil sampling analysis routinely includes organic matter calculations New tests are being developed to better characterize soil biodiversity, including analysis of phospholipid fatty acids, the Haney soil health test, and the Solvita soil test	Soil organic matter can be tested by most private and university soil labs As soil health testing methodologies are refined, they will likely be available by additional testing facilities	Several samples per field will be required	n/a	$20-$100/ sample
Future considerations	Non-analytic methods for characterizing soil biodiversity include counting the number of earthworms per shovel of dirt.				

CATALYZE

Table 7: Landscape spatial diversity and connectivity

While some ecosystem services are delivered at the field scale, others are seen at larger spatial scales. The scientific field of landscape ecology has emerged to help relate the structure of landscapes to their functionality and delivery of ecosystem services. These theoretical foundations can also be applied to agricultural landscapes and show how advanced planning and coordinated landscape design can enhance the overall provision of services. While some of these relationships are not well understood, it is generally accepted that the level of diversity across a larger geographic area and the connectivity of fields managed for the provision of ecosystem services increases overall ecosystem service delivery.[10,27] Targeted programming and investments to maximize the connectivity of lands that are being managed for sustainable local food production will likely increase the net ecosystem service benefits.

	Methodology	Availability	Geographic scope / scale	Precision	Cost
Baseline	USDA Quickstats	Always available and updated regularly	County / Region	Data aggregated to the county level	Free
Data collection	Remote sensing (airplane, satellite, drone) will provide the most cost effective, high quality data on spatial diversity and connectivity of ecosystem service producing lands Commonly used landscape ecology metrics can be used to assess connectivity [62]	Freely available imagery (e.g. Landsat) to more expensive private and customized imagery providers	The scale of imagery depends on the method of capture, but ranges from sub-field to region	Field to regional metrics can be produced	Free to very expensive, depending on the data sources used
Future considerations	Combining field-scale survey data, remotely sensed imagery, and environmental sensor data will provide deeper insights into the delivery of ecosystem services across the region.				

Table 8: Biological, physical, and chemical water quality

The quality of the water that leaves farm fields is based on the observed biotic and abiotic components.[63,64] Water from irrigation, rainfall or snowmelt that is not infiltrated into the soil has the potential to runoff and carry with it soil, nutrients and any agricultural inputs that were applied to plants, livestock or soil. Cover cropping and mulching are two ways to reduce runoff from within the field and buffer and filter strips can aid in reducing edge-of field soil loss. These practices can improve soil health can improve the biological, physical and chemical water quality components.

	Methodology	Availability	Geographic scope / scale	Precision	Cost
Baseline	United States Geological Survey (USGS), state agencies, and wastewater utilities	USGS: Network of stream gages throughout region- www.usgs.gov State agencies: Data available through web portals and upon request Wastewater utilities: Data available through utilities' web portals and upon request	USGS-National/State / Region and County	USGS: Specific monitoring location and watershed scale State agencies: Watershed scale Utilities: Within the service area of the utilities	USGS: Free State agencies: Free Utilities: Free
Data collection	Stream gages, edge of field monitoring, grab samples, stream habitat assessments/survey, continuous monitoring, laboratory analysis	Ongoing monitoring programs provide baseline data with potential for area specific monitoring and projects	Inactive stream gages can be re-activated as needed and new gages can be put online if funding is available	Location specific and watershed wide	Monitoring programs are supported through federal and state funds Budgets can be at risk and limited depending on what programs are utilized
Future considerations	Water monitoring technology coming online allows continuous and cheaper monitoring. Providing onsite equipment can empower farmers to implement and change practices and track progress.				

Table 9: Landscape nutritional diversity

The other indicators presented in this report are related to the environmental outcomes from food production landscapes, and this indicator was selected to ensure that the quality and diversity of food harvested from these landscapes will meet the nutritional requirements of those eating the food. Emerging evidence has shown connections between healthy soil and nutritional density in grains, vegetables and pastured meats, dairy and eggs. Including a nutritional indicator will help decision maker balance environmental and nutritional outcomes of agricultural systems. The data and metrics used in this indicator can be derived from a mix of surveys and laboratory analyses [48]

	Methodology	Availability	Geographic scope / scale	Precision	Cost
Baseline	USDA Quickstats and existing USDA guidelines on nutritional content can be used to develop a baseline scenario for current food production	Data are freely available from USDA websites	Data cover the entire study area	Basic and generalized statistics will create a robust baseline from which to build	Data are freely available
Data collection	Crop and livestock samples can be analyzed in specialty laboratories to determine the nutrient density of the food Representative samples can be compared to USDA average values to track changes in nutritional density over time Input data for the Shannon Entropy diversity metric + Modified Functional Attribute Diversity + Percent of energy coming from non-staples can be gathered from farm-level surveys	Sampling can be analyzed by most major agricultural laboratories for nutrients such as calcium, magnesium, phosphorus, potassium, nitrogen, sulfur, sodium, boron, manganese, copper, zinc, and iron Scale and scope of survey data will be dependent on program design and funding availability	Observed changes will be closely linked to practices, environmental conditions, and historical practices in each field	n/a	TBD
Future considerations	New sensor technology is coming to the market that may allow for smaller, cheaper reporting of the nutritional density of foods, amongst other valuable attributes.				

Global Indicators

It is acknowledged that there are "safe operating spaces" for society and both local and planetary boundaries that relate to the provision of ecosystem services, but they are outside the scope of this report. The framework of analysis proposed in this report is compatible with larger spatial scale (e.g. planetary) metrics for gauging sustainability.[53,65] Taken from the planetary boundaries framework, the relevant indicators are: biosphere integrity, climate change, biogeochemical flows, freshwater use, land-system change, and novel entities.[53] These indicators are included in the report to show the alignment of the ecosystem services focused framework shown here with broader regional, national and global dialogues focused on sustainability. For instance there are explicit connections from this framework to the '4 per 1000' initiative launched in 2015 whose goal is to increase soil carbon sequestration in croplands by 0.4% per year, globally. Similarly, the UN Sustainable Development Goals has a relationship to many of the ecosystem services and related indicators described in this report.

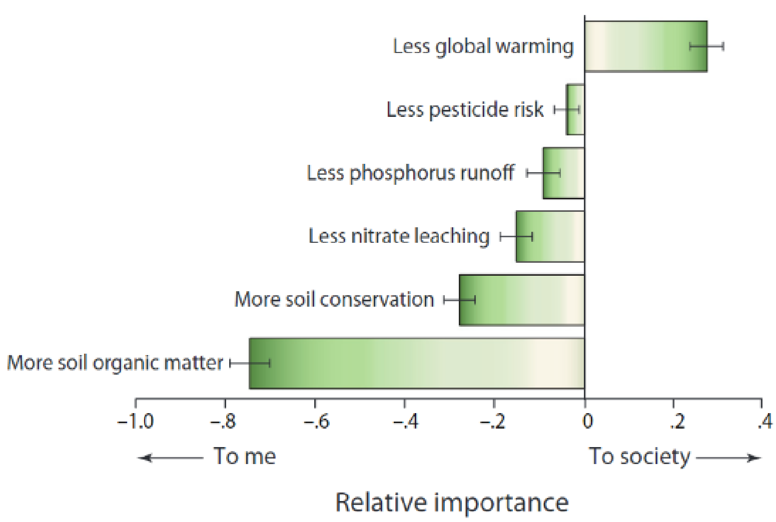
SUMMARIES OF EXPERT CONSULTATIONS

In the preparation of this report, several stakeholders were consulted on their experiences in integrating ecosystem services in decision-making around agriculture and local food systems. Summaries of those expert consultations are included below.

Farmer

Farmers have to meet many competing demands that include ensuring their financial viability, adapting to uncertainties in weather, and stewarding the land that they farm. Trade-offs in their decision process are inevitable, as there are few scenarios that result in win-win-win outcomes. As alternative farming systems have been developed, mid-to-late career farmers usually transition to more sustainable practices after witnessing the negative consequences of conventional agriculture, from soil erosion to human health impacts. New farmers are usually drawn to more sustainable methods based on their education, worldview, and geography. It can be challenging for early career farmers, especially those without a family farming background to directly start farming using sustainable and ecosystem service oriented methods. This is mostly due to lack of training opportunities, financing, general infrastructure, and coordination in the sector. When choosing to farm more sustainably, which often involves less synthetic inputs, there can be an increased use of tillage to control weeds, which if not managed properly can accelerate soil erosion and water pollution. On the other hand, there are many other opportunities to increase the provision of ecosystem services, whether those that have local or global outcomes. Much of this sentiment has been captured by a survey of Michigan farmers, as illustrated in Figure 2.

Figure 2: The relative importance to Michigan farmers and to society (as ranked by the farmers) of various environmental benefits



Source([69])

Farmland investment portfolio manager

The confluence of investors interested in social and environmental returns, in addition to economic returns and the generational turnover of farmland, has led to an increase in the amount of investor-owned farms. Communicating the expected financial returns to investors is a relatively straight-forward proposition, but it is less clear when communicating about the changes in ecosystem services when transitioning from conventional management to a more sustainability-oriented farm operation. Some investors are satisfied with current certification options, such as organic or non-GMO, while others are more interested in detailed accounts of changes in ecosystem services. Without the development of new measurement, monitoring, and modeling tools, this is not possible. Simple before-and-after pictures of farms have been sufficient to date as a proxy for certain ecosystem services.

Conservation professional

Many state and federal conservation programs are focused on the implementation of practices with limited monitoring of the resulting changes in ecosystem services. Under a new data gathering and analysis initiative, the relationship between soil health promoting agronomic practices and the changes in ecosystem services will be better understood and communicated. While there is still room for improvement to connect local, state, and federal agriculture support programs to the tracking of the resulting outcomes, this new initiative will help producers better manage for soil health. There are also many opportunities to shift production practices such as integrating livestock into production systems, diversifying crops and livestock, and incorporating more perennials into farming systems. Additional education, outreach, training, and incentive programs are needed for these farm to landscape-level changes to take hold and provide significant ecosystem service benefits.

Local food system advocate

Working with farmers who have transitioned land into a diversified farming system, there is anecdotal evidence that there are benefits for ecosystem services. Comparing the soil between a diversified farm and an adjacent conventional farm has shown improvements in the soil even after a few years. These improvements have been seen in the soil structure, increased infiltration, and number of earthworms in the soil. While the number of these types of farms in the study region has increased over the past decade, there are many barriers to be broken down to accelerate the acreage under diversified farm management and the corresponding increase in ecosystem service delivery. Some of the enabling characteristics include:

- Crop varieties better suited to local environments
- Demand for crops grown in diversified rotations, especially small grains
- Specialized machinery and new models for machine ownership or sharing
- Knowledge for farmers needed to transition to diversified farming systems
- Cultural acceptance in rural areas of “alternative” practices

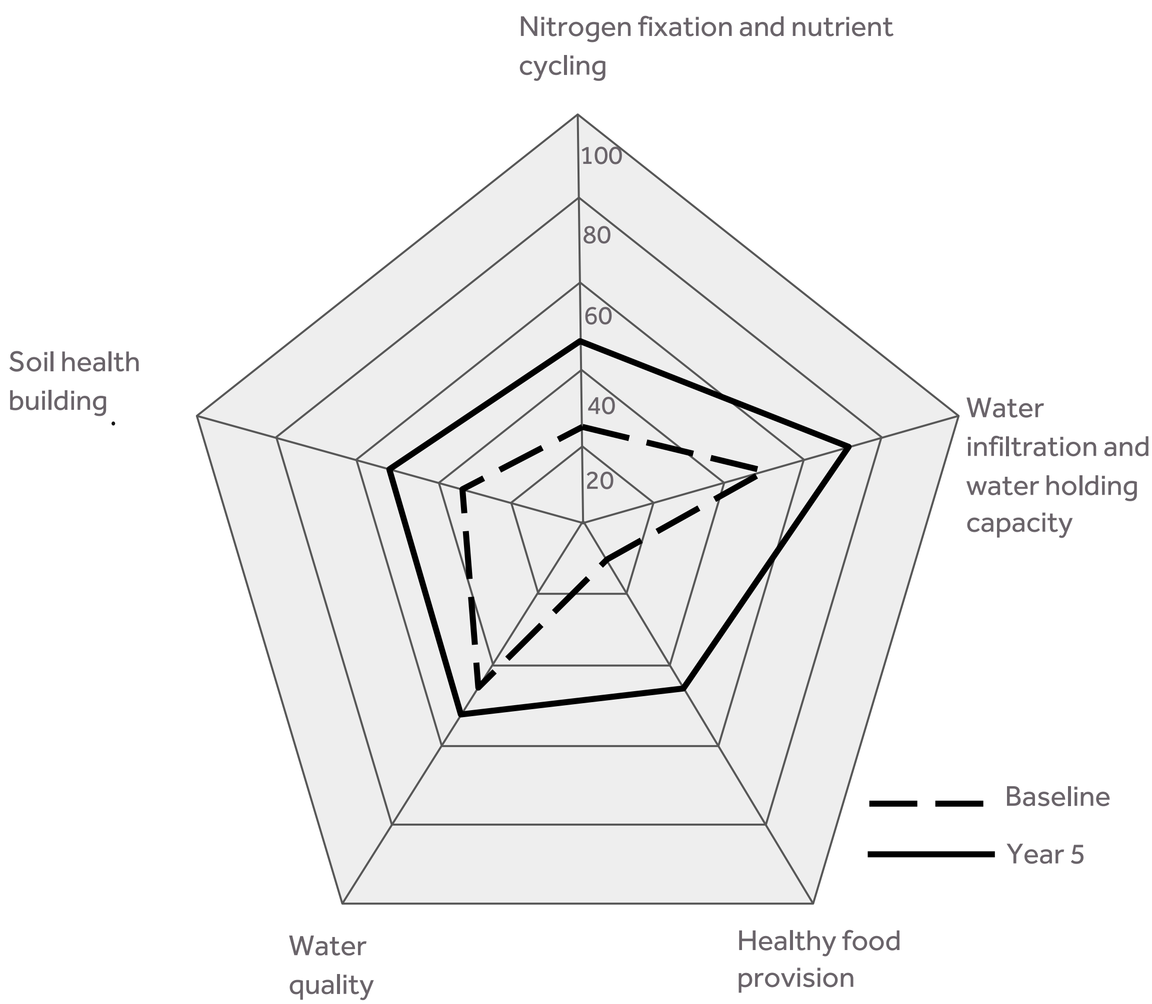
CONCLUSIONS, LESSONS LEARNED, AND NEXT STEPS

Expanding local food production could have a suite of positive benefits across social, economic, and environmental indicators, and can help to meet long-range planning goals. In this report we presented a framework that can be used to measure and monitor the ecosystem services that are generated from the adoption of diversified farming practices, with an emphasis on soil and water ecosystem services. Using the data generated from this process can help guide the targeting of practices to further enhance ecosystem services and the development of incentive structures to further adoption of these practices and farming systems.

The framework that this report presented has the flexibility to be adapted to a range of budgets, availability of data, policy-driven incentives from local to national scales, and interest levels of the farmer or land manager. This report presents a range of ecosystem service-generating practices and the indicators to track changes in the delivery of these services. Depending on the near and long-term programmatic goals related to food, farming and the environment, there will be many trade-offs that need to be managed. We describe several tools that can be used to track, communicate, and value ecosystem services using a range of qualitative and quantitative methodologies. The purpose of these tools is to help distill the data into useful insights that can be used to manage the transition to a more sustainable local food system.

Figure 3: Spider diagrams to communicate changes of ecosystem service delivery over time

Given a set of indicator data over time, it is usually very difficult to compare one indicator to another given that the data likely have different units of measurement. Spider diagrams are a useful tool to visually display how a set of variables changes over time. These types of diagrams have been used in both scientific, public and farmer facing initiatives and are a clear and concise mechanism to display changes in ecosystem services.[66] In this example (Figure 3), each ecosystem service occupies one vertex of the pentagon and the service delivery is scaled from 0-100. The baseline is displayed as a dashed line and future data points can be added for each service to show their change from previous measurements. Showing these changes over time can help to re-allocate resources to priority areas, given limited resources or capacity.



Comparison of values, methods, scales, and methodological approaches for valuing ecosystem services

Analyses of ecosystem services can incorporate monetary, ecological, and socio-cultural values.[67] A number of methods are available in each one of these three value domains, including the applicable spatial scales and whether they are qualitative and/or quantitative in nature. Depending on the stated objectives that need to be met in the transition to a sustainable local food system the appropriate valuation methodology can be selected. The range of input data for these various approaches also varies greatly. Some data requirements can be met from data collected from the ecosystem service indicators described while others would require additional data, such as producer and consumer surveys to determine economic valuation. Not all of these methods will be appropriate for use in the study region, so further research and stakeholder consultation will be needed to narrow down the options of which valuation methodologies would be best.

Connecting indicator data to ecosystem service delivery

Given the wide variation in soils, climate, and past management histories, data collected for indicators on individual fields or farms aren't necessarily able to immediately scale to represent the stocks and flows of ecosystem services across the study region. Many of the relationships between management activities and delivery of ecosystem services are complex, nonlinear, and dynamic over both space and time. For instance, soil carbon sequestration rates have not been observed to increase linearly over time, but eventually reach a plateau where the soil has entered an equilibrium state and little to no additional carbon is sequestered.

With a relatively small sample size in a large geographic region, there are many tools available to provide a robust estimation of how changes in management might be affecting ecosystem service delivery. The primary set of tools that can be used to scale individual data points to provide regional generalizations, along with providing useful insights to decision-makers, whether at the farm or policy level, are generally in the class of numerical models. These models range from simple spreadsheets to complex supercomputer simulations, but the set of models most relevant for the ecosystem services of interest and scale of the study region fall between these two extremes. When selecting a model, or suite of models, it is important to consider that there are many models that have been developed for specific applications that can be adapted to new geographies or ecosystem services. When evaluating models there are a number of decision points that need to be considered to ensure that the selected model(s) deliver useful outputs. Some of these evaluative criteria to support tool selection include:[68]

- Output format (e.g. maps, tables, graphs)
- Quantification and uncertainty
- Time requirements
- Capacity for independent application
- Level of development and documentation
- Scalability
- Generalizability

- Nonmonetary and cultural perspectives
- Affordability, insights, integration with existing environmental assessment

There are many strategic opportunities to increase the delivery of ecosystem services from agriculture within the study region. Agriculture, whether intensively or extensively practiced, is not often included in traditional definitions of green infrastructure. Diversified agricultural systems, especially those that incorporate perennial crops can be significant producers of ecosystem services that provide both local and regional benefits. *The Green Infrastructure Vision*[70] has laid the groundwork for the inclusion of agriculture into the regional analysis of ecosystem services, whether they be urban or rural. This framework can act as a convenient method to connect this body of work to the existing ecosystem services focused report and an integral input to the planning and policy process.

Transitioning the study area to one that is more focused on the provision of food for local consumption while improving the delivery of ecosystem services is a challenging proposition. On one hand, existing policy frameworks, established value chains and farmers with little incentive to shift their practices illustrate the challenge in shifting the food system. On the other hand, the explosion of community supported agriculture, farmers markets, local food-oriented restaurants and new certification schemes show the opportunity space that can be capitalized on given appropriate sector development. This could come in the form of incentives, technical support, and consumer education. To date, the environmental impacts of agriculture have been largely outside the core interest of consumers, but this trend has started to shift. Food system planning and policy measures that help to internalize the external costs (e.g. water quality, soil loss and carbon emissions) of agricultural production could be an important measure in setting a level playing field for agricultural systems that provide a range of positive ecosystem services.

As production shifts to meet both ecosystem service delivery goals and local consumer demand, the representative basket of goods and the pathways for shifting production will also likely change. As initially presented in the *Chicago Wilderness Region Local Foods System: Present and Future Supply and Demand*,[71] there are opportunities to re-envision the composition of agricultural value chains that reflect the provision of ecosystem services, healthy food, and improved welfare of both rural and urban residents. An example of how the agricultural value chains might change in the future can be seen in the collaboration between Lakeview Organic Grain and the Blue Hill at Stone Barns restaurant, both in New York state.[72] That partnership has connected a diversified farming system with a focus on soil health to a restaurant that uses the wide variety of meat, grains, and vegetables from the farm in new ways. Crops that were grown to enhance the soil and had little market value now have a higher economic value as they are incorporated into restaurant dishes. Partnerships like this are important models in developing local food systems that not only produce nutrient-dense food for people, but also deliver clean water, healthy soil, and other important ecosystem services.

APPENDICES

Database overview

Scientific papers reviewed for this report were added to the USDA Soil Health Literature Matrix. The database includes over 400 papers and is coded to reflect their topic areas across biological, physical, and chemical properties of soil and relevant social, cultural, and economic variables. (Direct link to database)

Glossary of relevant terms

Term	Definition
Diversified Farming System	Farming practices and landscapes that intentionally include functional biodiversity at multiple spatial and/or temporal scales in order to maintain ecosystem services that provide critical inputs to agriculture, such as soil fertility, pest and disease control, water use efficiency, and pollination.[3]
Sustainable Agriculture	An integrated system of plant and animal production practices having a site-specific application that will, over the long term: satisfy human food and fiber needs; enhance environmental quality and the natural resource base upon which the agricultural economy depends; make the most efficient use of nonrenewable resources and on-farm resources and integrate, where appropriate, natural biological cycles and controls; sustain the economic viability of farm operations; and enhance the quality of life for farmers and society as a whole.[73]
Agroecology	Incorporates ideas about a more environmentally and socially sensitive approach to agriculture, one that focuses not only on production, but also on the ecological sustainability of the productive system.[73]
Organic	Organic agriculture is an ecological production management system that promotes and enhances biodiversity, biological cycles and soil biological activity. It is based on minimal use of off-farm inputs and on management practices that restore, maintain and enhance ecological harmony.[73]
Industrialized agriculture	In general, industrial systems simplify ecosystems and utilize highly specialized, technical information with the goal of maximizing the profitability of a commodity crop or livestock on any given farm.[3]
Ecosystem Service	The benefits people obtain from ecosystems.[38]
Local/Community Food System	A collaborative effort to integrate agricultural production with food distribution to enhance the economic, environmental, and social well-being of a particular place (i.e. a neighborhood, city, county or region).[73]

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