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CHAPTER 16

Using environmental metrics to promote sustainability and resilience in agriculture

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Introduction

Under current projections of human population growth and improving standards of living, worldwide demand for food is expected to more than double by 2050 (Hunter *et al.* 2017). Already, cultivated cropland covers about one-quarter of the Earth's land surface (Millennium Ecosystem Assessment, 2005). When land used for the grazing of livestock is added in, roughly 40% of the world's terrestrial area is dedicated to producing food for people (FAO, 2013). This makes agriculture the single largest land use on the planet (Foley, DeFries, Asner *et al.* 2005).

Over the last 15 years agriculture has been intensifying (higher production per unit of land area). Total agricultural land area worldwide has not increased since 1998, with agricultural expansion in South America, Southeast Asia, and much of Africa being offset by a decline in agricultural lands elsewhere (Figures 16.1 & 16.2). At the same time, food produced per capita has increased (Figure 16.3). However, increasing food prices have recently begun to accelerate land conversion for new farms and pasture (FAO, 2013, Figure 16.2). If current trends continue, roughly 1 billion ha of new land will have to be cleared by 2050 to meet demand (Tilman *et al.* 2011). Faced with these trends in human population growth and the potential for an acceleration of land conversion, it is clear that one key to maintaining biodiversity and ecosystem function is guiding the future path that agricultural development takes.

Figure 16.1. Percentage change in each country's agricultural land area (annual row crops, pasture / rangeland, and permanent crops) between 1998 and 2011. Countries with darker red color indicate greater agricultural expansion, countries with darker red color indicate greater agricultural contraction. Data from FAO 2013.

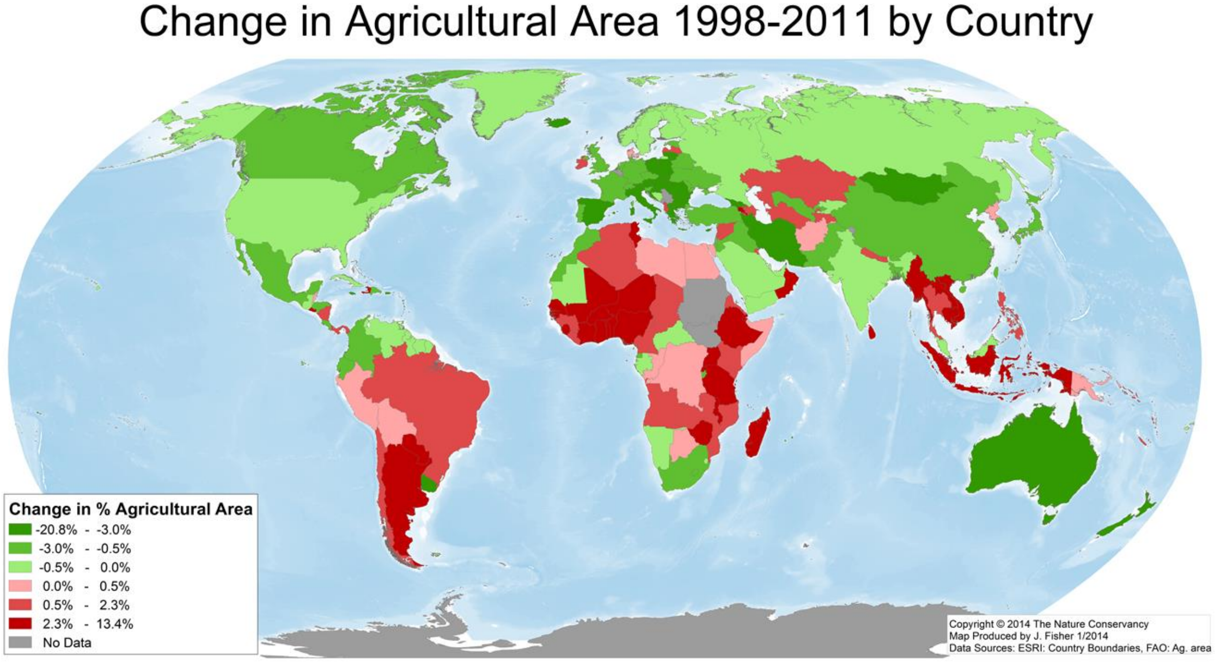


Figure 16.2. Global land area used for agriculture (annual row crops, pasture / rangeland, and permanent crops) from 1961 to 2011, with the period of decline from 1998 to 2011 indicated. Note that y-axis does not begin at 0 to show the variation more clearly. Data from FAO 2013.

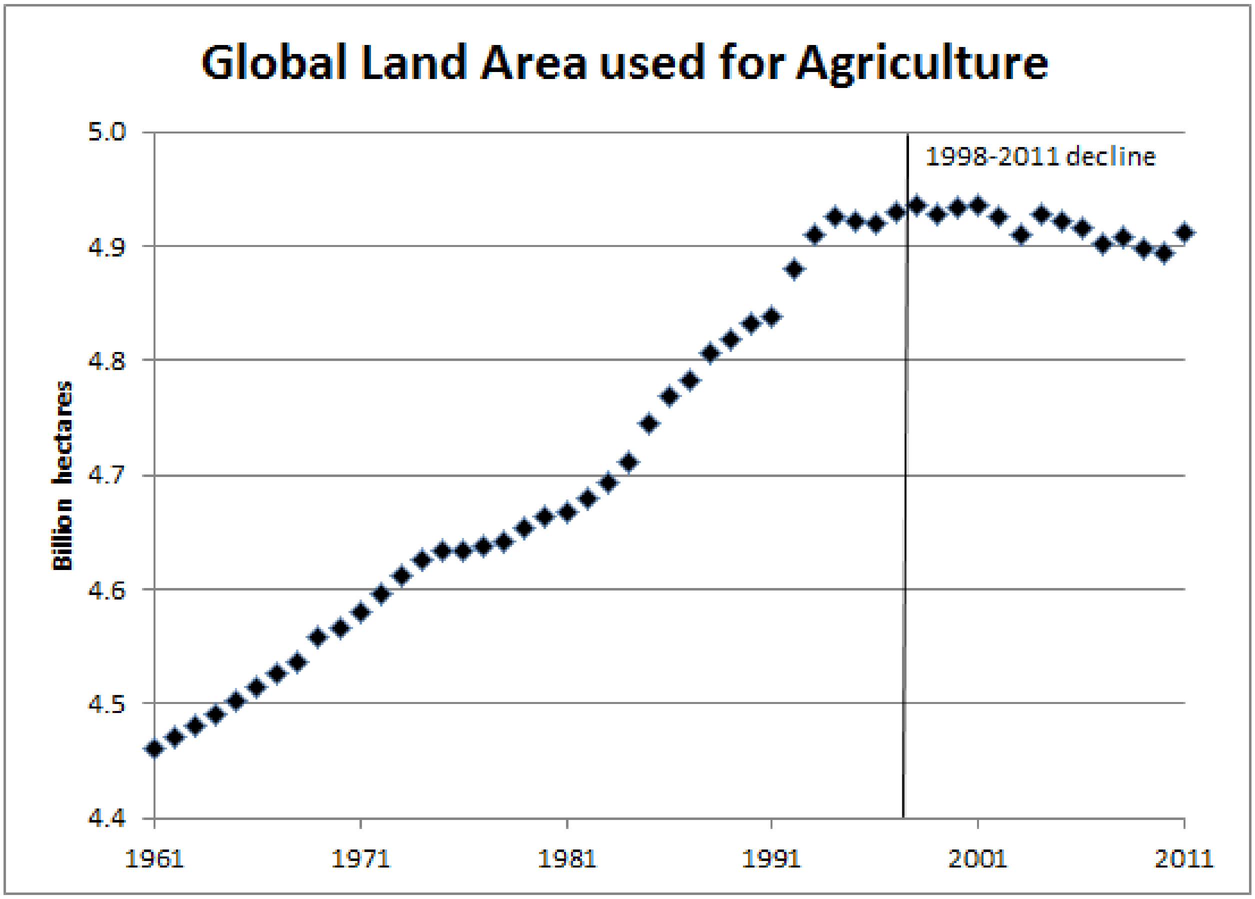
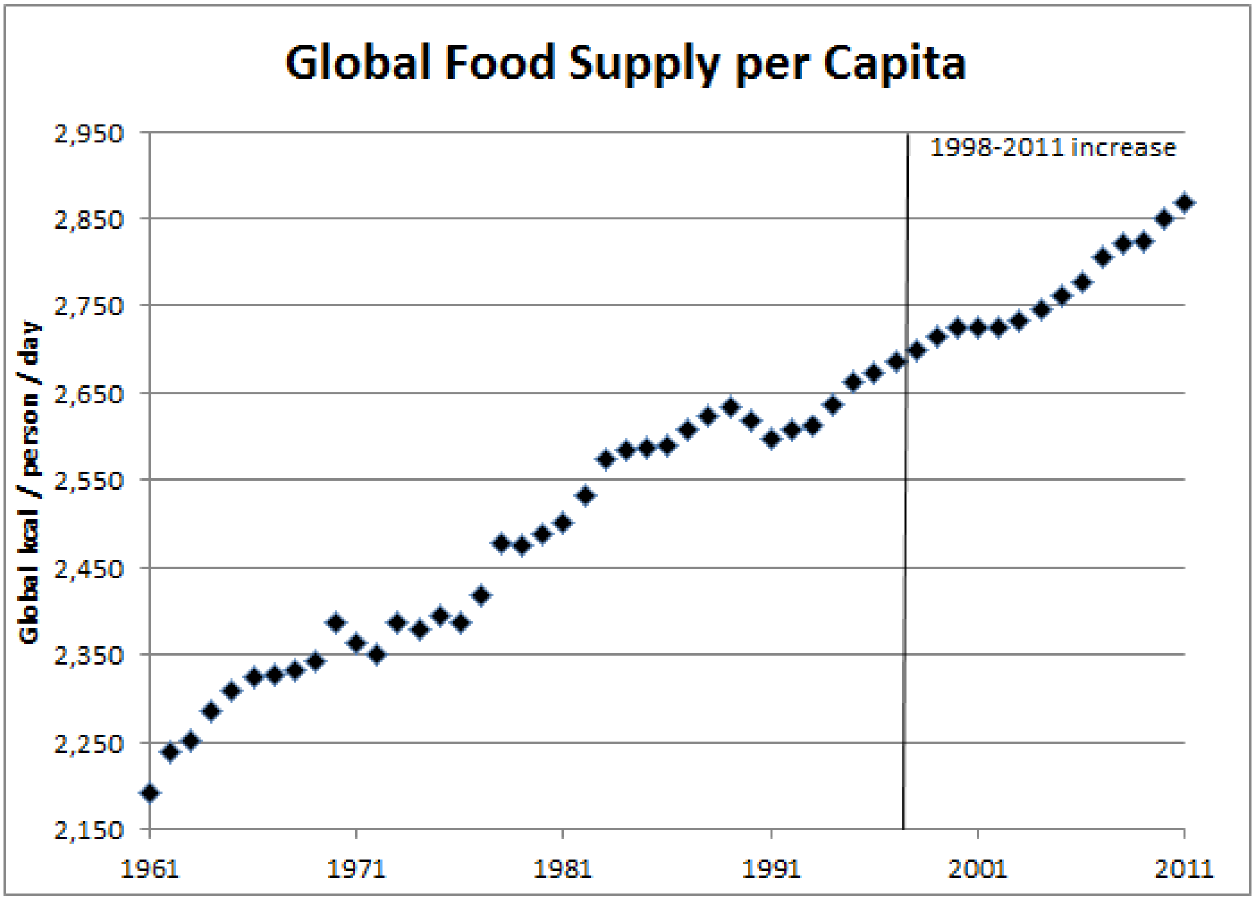


Figure 16.3. Global food supply per capita (in kilocalories per person per year) from 1961 to 2011, with the period of decline from 1998 to 2011 indicated. Note that y-axis does not begin at 0 to show the variation more clearly. Data from FAO 2014.



The pressing question is: how can the world's lands and waters meet the needs of both food production and biodiversity protection? A truly sustainable agricultural system needs to be capable of meeting human food and fibre needs over long time periods, have minimal adverse effects on the environment, and be practical (and profitable) for farmers to implement. It also must be resilient to ordinary stresses (such as dry weather), extreme weather (heat waves or unusual drought), novel pests, and natural disasters such as floods, and climate change (Pretty, 2008). This requires considering the entire "agroecosystem" (not only the crop, but all of the other living and abiotic components and their relationships) rather than a traditional definition of a farm (Conway, 1985; Kremen, Iles & Bacon, 2012).

One path forward that has been advanced as a solution to the challenge of producing more food without degrading the environment is what has been labelled "sustainable intensification." Sustainable intensification is the process of "increas[ing] food production from existing farmland in ways that place far less pressure on the environment and that do not undermine our capacity to continue producing food in the future" (Garnett Appleby, Balmford *et al.* 2013). Given the projected increase in demand for food, it is critical to find ways to sustainably intensify production in order to avoid the conversion of natural habitat to new agricultural lands. It is also important to consider that sustainability initiatives that offer a profit incentive for farmers (via increased yields and/or improved resilience) are much more likely to be adopted than practices with environmental benefits but no direct economic benefits to the farmer. There is evidence that yield and sustainability can be increased simultaneously; a review of 198 sustainable agriculture projects in the developing world reported a mean relative yield increase of 79% relative to yields prior to the sustainability improvements (Pretty, Noble, Bossio *et al.* 2006).

However, while sustainable intensification is an admirable aspiration, intensification is sometimes achieved at the cost of decreased diversity (both crop genetic diversity, and biodiversity more broadly in the surrounding ecosystems) and thus carries with it a risk of decreased system resilience (Matson *et al.* 1997; Thomas, 1999; Tscharntke *et al.* 2005). Complicating matters is the fact that ideas about what type of agriculture is good for the environment can be based more on opinions than evidence. Beliefs about food and food production systems can be strongly rooted in culture and political ideology (Harmon, 2014; McWilliams, 2009). For this reason, there is a need for objective, practical metrics that could be applied to any given agricultural plot or landscape in order to assess the degree to which different combinations of practices are indeed sustainable.

For metrics to be more than simply academic they need to be responsive on a timescale that is actionable. In other words, metrics have to respond fast enough that if a new agricultural practice is undermining sustainability (or simply failing to improve it), the negative impact can be detected and used as feedback to farmers, policy makers, and businesses. Conversely, if a new practice is improving sustainability, the farmer or business implementing that new practice deserves to get credit for it and others should be able to find out about it and replicate their success. Ideally, credible sustainability metrics can be a lever for altering the behaviour of major agribusinesses, by holding the major links in food production systems (retailers such as Walmart, food distributors such as Unilever, agricultural producers / traders such as Cargill, and food processers such as General Mills) accountable. Consumers also have a role to play as well through the pressures they put on industry via market forces and choices. But consumers need credible, transparent labels – and here again sustainability metrics can play a role in evaluating whether a “green label” is well-deserved. Later in this paper we elaborate on the potential for environmental metrics in shaping both agribusiness and consumer choice.

The challenge of assessing sustainability and resilience in agroecosystems

In considering how to measure sustainability, there are several choices. One could simply measure *resource inputs/costs* such as the money being spent on soil management or the amount of water withdrawn for irrigation. Alternatively the measures could focus on *conservation actions* like the number of acres on which best management practices (BMPs) are implemented. Finally, actual outcomes could be measured like volume of water consumed or fish species richness in a stream. There are several organizations promoting measurement schemes for sustainable agriculture. In the United States the two largest are Field to Market and The Sustainability Consortium (TSC). Globally, the Sustainable Agriculture Network and Rainforest Alliance are the most widely used. While all of these organizations have likely helped to foster improvements in agriculture, they generally focus on agricultural practices rather than achievement of anything that could be rigorously called sustainable production. For example, one question TSC asks is “How is your organization engaging this product's supply chain to address energy consumption during fertilizer manufacturing?” and the top score is for buying fertilizers from companies that have an energy management plan (The Sustainability Consortium, 2013a). Such questions do not provide any information about conservation actions or resource inputs, much less about whether the production system is truly sustainable in the sense of durable incomes and productivity without environmental degradation (note that since this chapter was written they have started shifting towards more quantitative outcome metrics). Other groups ask questions that are more directly related to farming practices, such as “How many pounds of nitrogen were added per ton of crop harvested?” (Stewardship Index for Specialty Crops, 2013). But even here the long term consequences of specific nitrogen regimes, and the impact of other biophysical variables go unmonitored on farms.

At its most essential level, sustainable agriculture should ensure that future generations can obtain food and the many other ecosystem services that nature provides. Measures of soil and water depletion and degradation, and changes to habitat and biodiversity all capture some elements of sustainability, as do metrics of yield and profit. The more challenging questions concern resilience to shocks, and the possibility of crossing some sort of threshold, from which ecosystem recovery (or crop production recovery) is difficult. A good example of potentially reduced resilience is the loss of pollinator biodiversity and increasing dependence on the domesticated species *Apis mellifera* (the European honeybee). At least 87 crop types (70% of the major crop species, representing roughly 1/3 of global food supply) are dependent on pollinators (Klein, Vaissiere, Cane *et al.* 2007). Declining diversity of pollinators and reliance almost exclusively on *Apis mellifera* could potentially lead to lower crop production (Allen-Wardell, Bernhardt, Bitner *et al.* 1998; Hoehn *et al.* 2008). Such yield losses are not yet detectable at a global scale (Aizen *et al.* 2008) and crop yields are still on the rise thanks to synthetic fertilizers, irrigation, chemical pesticides, and better management in many places. But UNEP cautions that widespread reports of honeybee colony mortality and an increase in the fraction of our food crops that require pollinators puts the stability of our food production systems in peril due to pollinator scarcity (UNEP, 2010).

Maintaining pollination services requires the conservation of sufficient resources for wild pollinators within agricultural landscapes, including both suitable habitats and sufficient floral resources for pollen and nectar (Kremen *et al.* 2007; Williams *et al.* this volume; Garibaldi et al, 2016).

Soil biodiversity may also play an important role in providing ecosystem services to agricultural systems and enhancing their resilience. Garbeva *et al.* (2006) found the highest suppression of a soil borne potato pathogen in plots with the highest soil microbial diversity and it is possible that such diversity-based suppression might be present in other systems as well. Similarly, mycorrhizal diversity contributes positively to nutrient and water use efficiency and plant productivity (Brussaard, de Ruiter & Brown, 2007; Maherali & Klironomos 2007; van der Heijden *et al.* 1998). The more diverse the mycorrhizal community, the better able plants are to extract nutrients and water, and thus to tolerate adverse conditions. If seeking to optimize yield leads to a decline in the diversity of mycorrhizae and other soil biota, it is likely that the resulting system will have decreased resilience. In fact, there are a range of ecosystem services in agroecosystems that have been shown to increase under diversified farming systems (Kremen, Iles & Brown, 2012). Soil science is re-evaluating several long held beliefs, and while there is not yet a clear and consistent relationship between soil diversity and other outcomes, the importance of microbial activity as drivers of key soil properties is increasingly evident (Lehmann and Kleber 2015).

Other examples of possible thresholds and collapse of systems include overgrazing to the point of desertification, and excessive nutrient loading that causes algal blooms and anaerobic conditions or dead zones. In the Cerrado of Brazil, where cattle production is on the rise, “sudden death” outbreaks due to poisonous plants associated with overgrazing may represent a threshold whereby intensified production yields a collapse of the entire production system (Merrill & Schuster, 1978).

In the face of relentlessly increasing greenhouse gas emissions, increased droughts, and extreme weather events, sustainability requires resilience to a rapidly changing and uncertain climate. In a constant environment it is challenging enough to identify appropriate measures of soil condition, water use, and landscape change that indicate sustainability. In a changing environment, there are no fixed standards that can be counted on to guarantee sustainability over the long term, but there is a clear need for learning. Human communities and societies vary widely in their ability or willingness to adapt to climate change (Palmer & Smith, 2014). In the context of agriculture, adaptability to climate change will be essential, and this adaptability is likely to depend on networks of farmers that experiment with new cropping systems and practices (MacMillan & Benton, 2014).

It is doubtful that any of the sustainability metrics discussed in this paper could identify key thresholds and a heightened risk of ecosystem collapse. However, the metrics should be able to reveal accelerated change, which could be a harbinger of an approaching threshold (Scheffer, Carpenter, Lenton *et al.* 2012). By implementing standardized sustainability metrics with extensive and meaningful reporting on a regular basis, it should be possible to test which of the proposed indicators of sustainability are linked to higher resilience to pest and pathogen outbreaks, and a reduced likelihood of suffering productivity collapses. The ideal metrics should allow the comparison of different intensification strategies such as the planting of one genetically modified clone (which might reduce resilience due to a loss of genetic variety) vs. precision agriculture which uses highly targeted micro-applications of fertilizer (which could improve resilience by delivering nutrients in response to the need of the plants as soil and climate conditions change, rather than using a fixed approach). The increased availability of remote sensing data, coupled with computerized inventory tracking systems and advances in ecosystem modelling suggest we have an unprecedented opportunity to manage for improved sustainability and test hypotheses about what system attributes confer resilience.

The Importance of Outcome Metrics

The problem with focusing on actions or practices is that they may not achieve desired outcomes in spite of the best intentions. For example, Lemke, Kirkham, Lindenbaum *et al.* (2011) found that implementation of wider riparian buffers and conservation tillage had no impact on water quality in the watershed where these best practices were implemented. In the watershed where this study took place, the presence of tile drainage allowed nitrate dissolved in water to flow directly into the stream, bypassing the improvements on the soil surface.

Even promoting efficiency, which seems like an obvious component of sustainability, can backfire. With more efficient irrigation, more water is typically delivered to the root zone of the crops and transpired (consumed), which means less of it returns to streams and groundwater. So even though less water is “wasted” (applied but not used by the crop), water withdrawals often remain nearly the same after efficiency improvements, and as a result water *consumption* may go up meaning less water is available for other downstream users (Samani, Skaggs, Bawazier *et al.* 2012; Ward & Pulido-Velazquez, 2008; Ward, 2014). For example, a data-rich economic model applied to 800,000 ha of irrigated mixed cropland in Southern Idaho predicts that improving irrigation efficiency from 60% to 80% would result in a reduction in water applied to the field by 15%, but still lead to a 3% increase in total water consumed (Contor & Taylor, 2013).

Proper water accounting is essential to understanding the role of both technology and policy in achieving desired outcomes (Foster & Perry, 2010). Richter *et al.* 2017 lays out a framework of how to actually reduce agricultural water consumption, and highlights the importance of being able to transfer water savings to other users as a critical element along with water budgeting and changes in crop water use. The failure of increases in efficiency to reduce consumption (the ‘Jevons paradox’) has also been observed in relation to energy use (Polimeni *et al.* 2008). The key point is not that efficiency is an unwise objective, but rather that outcomes are more important than actions. Hence sustainability metrics need to focus much more on ecological outcomes (in this case, groundwater levels and stream flows) than on practices and actions than has been the case up until now (see also Buckwell; this volume Chapter 15).

Can remote sensing become a foundation for sustainability metrics?

In agriculture, there are several scales at which sustainability metrics can be useful. At the broadest scale (i.e. global or national levels), sustainability metrics will generally be limited to highlighting areas of concern. Ecologically, the landscape or watershed level is perhaps the most relevant scale; outcomes such as water quality, landscape characteristics and biodiversity can be measured at this scale and compared with aggregated metrics of agricultural practices. Finally, certain outcomes would be best measured at the field or plot scale (e.g. soil organic carbon), either on the ground or with high resolution imagery (e.g. up to 77% accuracy in detecting soil organic carbon levels on bare soil has been achieved, Chen *et al.* 2000). The field scale is also probably best for engaging farmers in learning networks that test ideas about how to adapt to climate change and climate shocks (MacMillan & Benton, 2014). Fisher *et al.* (2014) provides a framework for sustainability measures that is outcome-based, and can be applied from the field to the global scale, along with potential data sets available to measure each characteristic at the various scales (Table 16.1).

Table 16.1 Proposed metrics for sustainable agriculture, adapted from Fisher *et al.* 2014.

Category	**Metric**	**How to Measure**
Soil	Soil Erosion	Modelled based on soil / site, ag management practices & climate
	Soil Organic Carbon	Field samples, for large areas remote sensing may be useful in reducing samples needed
Water	Water Consumption	Modelled evapotranspiration using climate data (adjusted for crop type and water availability)
	Water Quality	N & P concentration (measured in stream, or modelled using land cover for landscapes)
Landscape Ecology	Habitat Conversion	Remotely sensed land use (% of study area covered by natural habitat)
	Habitat Composition	Remotely sensed land use (# land cover classes, indicating habitat diversity)

	Habitat Connectivity	Remotely sensed land use (calculated connectivity score)
Biodiversity	Species Richness	Field samples (richness relative to reference natural landscape)
	Species Abundance	Field samples (abundance relative to reference natural landscape, i.e. the most undisturbed nearby similar habitat)
Agronomy	Yield / Area	Harvested mass of crop per unit area over a 5-year rolling average, perhaps using geometric mean to penalize variation in yield

While there are many other potential metrics available, these were chosen for the combination of impact / importance, relevance at multiple scales, and practicality. For example, greenhouse gas emissions are certainly important at a global scale, but they cannot practically be independently measured (instead requiring information from companies and farmers), and are less useful when considering local impacts. This does not mean they should not be measured, but it requires a different approach. Similarly, Fisher *et al.* (2014) recommend focusing on birds and amphibians in part because of the widespread availability of data on these taxa, but other taxa (e.g. aquatic macroinvertebrates) may be more appropriate for a specific area or as local data availability varies. The intent is to provide a simple framework that can be applied almost everywhere, rather than to provide a complete framework.

Finally, we have added a simple agronomic metric (geometric mean of yield per area, measured over 5 years to capture some information on resilience) to the original suite of environmental performance metrics. We recognize that properly integrating economic and social metrics with environmental metrics is not a trivial endeavour, but would argue a minimum first step is some measure of yield that also penalizes variation from year to year (because even a single low yield year could put farmers and food security at risk in spite of a generally high average yield). Further research is needed where ecologists, agronomists, and economists collaborate to determine the most appropriate metrics.

The metrics above can all be normalized to a 0 to 1 scale, where a score of 1 can be considered fully sustainable. Details are available in Fisher *et al.* 2014, but for example a soil erosion score of 1 would mean no soil loss (or even soil accretion), and a water quality score of 1 would mean nutrient runoff is low enough to not significantly impact streams (e.g. below the Total Maximum Daily Load in the U.S.). Additional contextual data will typically be necessary to identify what “fully sustainable” would entail. It is more appropriate to quantify relative sustainability, rather than simply pronounce any system as either sustainable or not.

An obstacle to outcome-based measurement schemes for agriculture is a lack of data (or perceived lack of data). Two concerns often cited are physical or budget difficulties in obtaining measurements, and an unwillingness of farmers to collect or share such data. Some characteristics like soil organic carbon and water quality generally rely on in-person sampling, which tends to be time-intensive and expensive, although technology. Farmers often express concern about being “graded” or compared to their neighbours if they share data from their farm. Addressing these concerns will require a dialogue to discover what safeguards or conditions on use of the data (or other incentives) could encourage more farmers to collect and share data. Another opportunity is for large corporations with significant buying power to start requiring their suppliers to share data, or at least to reward those who do share data with longer contracts.

Given the expense of collecting data on the ground, and the large areas devoted to agriculture, remote sensing will play an increasingly critical role in tracking sustainability. For example, there are many ways to measure water consumption, but typically evapotranspiration (ET) is used (Sinclair, Tanner & Bennett, 1984). ET is a good proxy for total consumptive water use, as <1% of water consumed is used to create plant biomass (Condon *et al.* 2004). But directly measuring ET (e.g. via a soil lysimeter) is complicated, so modelling it with remotely sensed climate data (air temperature, wind speed, and relative humidity) is generally more practical (Allen *et al.* 1998; Farahani, 2007; Rana & Katerji, 2000), at least until networked soil probes advocated by companies like Climate Corp become more common. Remote sensing methods are also being developed to measure soil organic carbon in conjunction with field samples (Gomez, Viscarra Rossel & McBratney, 2008), as well as water quality parameters like turbidity (Olmanson, Brezonik & Bauer, 2013). As the resolution of satellite imagery improves, and the use of unmanned aerial vehicles (UAVs or drones) for remote sensing increases, the accuracy and utility of remote sensing should continue to increase. Already UAVs are being evaluated for in-stream monitoring of water quality (Ayana, 2015), and other novel applications are likely in development. It may be that in twenty years most tracking of environmental outcomes for agriculture can be done via remote sensing.

Measurement of outcomes could allow targeting of sustainability practices where they will do the most good

An agricultural innovation that is receiving a great deal of attention and investment is the use of precision agriculture, which promotes the use of varying practices within a field such as altering irrigation and fertilization according to soil and terrain variability (Cassman, 1999; Gebbers & Adamchuk, 2010).

The idea of spatially varied agricultural practices that is the foundation of precision agriculture could also be a foundation for sustainable agriculture more broadly. Often advocates of sustainability tend to promote the same practices not only uniformly within a field, but uniformly across a landscape. Recently some promoters of sustainable agriculture have begun to borrow from the precision agriculture concept and asked where one can get the greatest environmental benefits from site-specific sustainability practices, as opposed to insisting on implementing the same sustainability practices everywhere. For example the Wisconsin Buffer Initiative conducted an analysis to determine which fields had the potential to make the biggest improvements in stream and lake quality (specifically reduced phosphorous and sediment), as well as aquatic biological community health, at the lowest cost (University of Wisconsin, 2005). The focus was on low-cost practices that result in improved water quality as well as healthier fish and invertebrate communities (all of which are being monitored); picking the best practice for each site rather than taking a uniform approach. This approach is being tested with a paired watershed study (comparing water quality in a treatment watershed to a control watershed), and so far has resulted in 55% less phosphorous during storms (when most runoff enters the stream, Carvin et al. 2017). This is one of the first cases where changing agricultural practices has been demonstrated to improve water quality at a landscape scale. This outcome is encouraging as it was achieved with voluntary participation unlike the mandatory framework that has effectively improved agricultural water quality in the Everglades (Daroub et al. 2011) The general idea of spatially targeting sustainability practices where they will do the most good makes ecological sense and could help government incentive programs achieve better outcomes for less money (PCAST, 2011).

Can Corporate Sustainability reporting be a force for improved agricultural practices?

Increasingly agroecosystems are shaped by the decisions of major global agribusiness operations. For that reason, it is worth asking whether these businesses themselves could be levers for promoting sustainable agriculture. There is a revolution going on with global corporations – as a result of stakeholder pressure, reputational risk, and competition for talent, corporations around the world are taking seriously their social and environmental impacts. The Government & Accountability Institute reports the number of S&P 500 companies releasing sustainability reports more than doubled from 2010 to 2011, from 20% to 53% (Clark & Master, 2012). CorporateRegister.com (CR), the largest directory of non-financial reporting, is now adding roughly 1,000 new reporting institutions every year. Interest from mainstream investors in Environmental, Social, and Governance (ESG) integration is also growing so that an increasing number of investors are considering environmental and sustainability information when making investment decisions. A 2012 survey of 4,000 business leaders, including 2,600 executives found that 60% felt that pursuing sustainability is necessary to be competitive (Kiron *et al.* 2013). The top benefits these business leaders saw from pursuing sustainability were better brand reputation and improved innovation (independent of the actual environmental benefits, which may be primarily positive externalities from the business standpoint). Another survey of senior business executives found that 83% identified spending on sustainability (defined here as a company's effort to drive profitable growth while achieving a positive economic, social and environmental impact) as an investment rather than a cost, and 92% said that sustainability is either critical or very important (Accenture, 2012). Admittedly, many business leaders do not think of sustainability in the same way ecologists might, but several multinational corporations are working closely with scientists in order to gain a deeper and more scientific understanding of sustainability and the potential private benefits it may include. Examples include the Dow Chemical Company with The Nature Conservancy (Kroeger *et al.* 2014, Reddy *et al.* 2015) and Unilever with the Natural Capital Project (Chaplin-Kramer *et al.* 2017). Manufacturers and retailers are responding by marketing an increasing number of products as "green"; TerraChoice found a 73% increase in product offerings claiming to be green from 2009 and 2010, following 79% growth from 2008 to 2009 (TerraChoice, 2010).

While most sustainability reporting and actions focus on energy and greenhouse gas emissions, there is also a growing trend toward whole-system approaches that include dimensions such as land conversion and water quality. Notably, the athletic wear company Puma issues an annual environmental profit and loss report that documents its material debt to the planet and tracks impacts such as land use conversion stratified by habitat type (tropical forest, grassland, temperate forest, etc.) (PUMA, 2011). Remarkably, an increasing percentage of the average corporation's value can be attributed to intangible assets (reputation, management, innovation, employee quality, retention of employees, etc. and other non-physical non-monetary assets). The Ocean Tomo Intangible Asset Market Value study indicates this intangible value has increased to 80% in 2010, from a mere 17% in 1975 (Ocean Tomo, 2010). This reflects the fact that brand, talent, and reputation (along with intellectual capital and innovation) are perhaps more important than physical and financial assets in today's world. The relevance of this to conservation is that reputation provides a pressure point with which to influence corporations to take conservation seriously.

In the agricultural sector, several of the biggest players are already committed to sustainability reporting. The Sustainability Consortium (which was founded in 2009 with support from the Walmart Foundation) has over 100 members, including BASF, Cargill, Dow, Monsanto, Unilever, and more (The Sustainability Consortium, 2013b). Field to Market is another initiative that has attracted considerable interest from large agricultural companies; while this program is more farmer-focused than some other initiatives, its focus on quantitative measures for commodity crops in the US is noteworthy (Field to Market, 2014). The challenge for scientists is to link the corporate desire to improve sustainability to metrics that are ecologically meaningful and that aptly capture impacts on the ground and in the water, rather than simply highlighting sustainability successes for marketing purposes. The key to making this ecologically credible is obtaining spatially explicit information on soil, water, habitat, and farming practices, as well as traceability of food products to their source. While traceability might seem impractical, in fact it is the exact type of information one needs to exercise effective inventory control in addition to being critical to assess environmental impact. We hypothesize that improved traceability can actually help agribusinesses manage their inventories, and even save money under the right conditions (Attaran, 2012, see discussion below).

Food labels and sustainability

There is some evidence that agricultural practices can be driven by consumer choices as well as corporate sustainability concerns (Ottman, Stafford & Hartman, 2006). For example, US sales of organic food and beverages have risen from $1 billion in 1990 to $26.7 billion in 2010 (Organic Trade Association, 2011), representing a startling increase in market share (USDA ERS, 2014). Globally the land area used for organic farming more than doubled from 14.9 million ha (0.4% of all agricultural area) in 2000 to 37.5 million ha (0.9% of all agricultural area) in 2012 (FiBL, 2014). While this still is relatively small, considering the rate of change and the fact that it takes several years for a farm to be certified as organic it is an encouraging start to demonstrating consumer interest in sustainability.

The success of the dolphin-safe label in persuading customers to buy labelled tuna (in conjunction with strong legislative support for the definition of the label) demonstrates the potential for green labels to shape consumer decisions in a way that is relevant to conservation (Ramach, 1996; Teisl, Roe & Hicks, 2002). A recent survey of American consumers found that 35% said they would pay more for “environmentally friendly” products (Mintel, 2010). The proposed metrics above might be too complex for consumers, but there is evidence that consumers are willing to pay more for better performance (Basu & Hicks, 2008), meaning that information beyond a simple binary label (e.g. quantitative data on water quality rather than “organic”) could lead to an increase in willingness to pay. The new requirements in France for certain products to have a label that includes carbon, water use, and biodiversity impacts (under Grenelle 2) provides an opportunity to study how these types of more complex green labels affect consumer choices.

In addition to changing purchases by consumers, label standards can also help drive manufacturers to make improvements (Caswell & Padberg, 1992). For example, several businesses are shifting their seafood procurement in response to rating systems like the Monterey Bay Aquarium’s Seafood Watch and the Marine Stewardship Council’s certification (Aramark, 2008; Compass Group North America, 2009; Whole Foods, 2014).

But while there are several eco-label success stories (Kemmerly & Macfarlane, 2009; Thøgersen, 2000), there is no guarantee that sustainable labelling will be an effective force for change. Information overload and time pressure while grocery shopping limit the willingness of consumers to read labels (Caswell & Padberg, 1992) and sustainability metrics on their own may not be sufficient to sway consumers (Hallstein & Villas-Boas, 2009). Even when consumers want to be sustainable, obstacles include the perception that sustainable products are difficult to find, and that the claims on the labels may not be justified (Tanner & Kast, 2003; Vermeir & Verbeke, 2006). Surprisingly, income or monetary barriers are not significantly related to green purchasing behaviour (Huffman *et al.* 2003; Tanner & Wölfing Kast, 2003). But product quality apart from sustainability remains a primary factor — it appears that consumers must perceive a product to be of high quality in order for sustainability to command a premium (Loureiro & Hine, 2002; McCluskey & Loureiro, 2003). In addition to the actual *content* of a label (the metrics chosen, design, and actual performance of a product), credibility is one of the most important factors in willingness to pay a premium for a more sustainable product (Hicks, 2012).

More data on the influence of labels on consumer choice are needed. The use of eye-tracking technology is yielding insights into the degree to which customers read labels, and how label design affects reading the label — which is the first step in altering choice (Jones & Richardson, 2007). One promising proposal for sustainability labelling arranges scores for several aspects of sustainability in a simple diagram where each aspect is scored on the same traffic-light colour scheme (red, green, and yellow: see Sustain, 2007). Ultimately, the truthfulness and correlation of labels to sustainability outcomes is perhaps the biggest hurdle to overcome. Most sustainability labels are at least partially misleading (although they are getting more accurate overall over time); in 2010 95% of “green” labels were found to have at least some form of greenwashing (disinformation that presents a sustainable image) (TerraChoice, 2010). One solution is to combine standardized and transparent metrics with sustainability reporting through institutions such as The Sustainability Consortium (TSC). Key to informative labelling is spatially explicit traceability of foods. While retailers and producers have argued that traceability is too expensive, in fact there are examples of it saving money because it requires better inventory tracking and analysis (Attaran, 2012, Roh, Kunnathur & Tarafder, 2009; Seuring & Müller, 2008). For example, cost savings from adopting RFID tracking can come from reduced theft, decreased labour costs from faster scanning, and the ability to reduce bottlenecks and low inventory levels (Roh, Kunnathur & Tarafder, 2009). Just as sustainable practices can spur innovation in production systems, sustainable labels can spur innovation in inventory management and flow.

Sustainable certification is another potential solution to combat greenwashing; while companies may benefit from overstating their sustainability (Genç, 2013; Laufer, 2003), the organizations who manage certifications have an incentive for it to be meaningful. The International Standards Organization (ISO) laid out guidelines for eco-labels based on certification in 1999 (ISO, 1999) with the goal of promoting rigor and consistency. Products certified by a program complying with these standards have been found to be six times more likely to be free of ‘greenwashing’ (TerraChoice, 2010). Certification can also enhance consumer willingness to pay for sustainable products, and/or give sustainable producers access to additional markets. For example, certification by the Forest Stewardship Council is increasingly providing a price premium (Germain & Penfield, 2010; NEPCon, 2008; Shoji *et al.* 2014) in addition to providing some assurance of sustainability, as does USDA organic certification (Lin, Smith & Huang, 2008). However, even certifications that represent a meaningful difference may still need improvement. For example, although stocks for certified seafood are 3-4 times more likely to be managed sustainably than non-certified stocks, 19-31% of certified fish stocks were still found to be overfished and subject to ongoing overfishing (Froese & Proelß, 2012). In the end, a combination of strong meaningful certification programmes, additional eco-labels that are simpler but meaningful, and educating consumers on how to identify truly sustainable products will likely be needed. The increasing prevalence of online shopping presents an opportunity to test and iterate different approaches in presenting sustainability information to consumers and examining the impact it has on purchasing behaviour.

The answer is yes – environmental metrics are part of the sustainability solution

The concept of sustainability in general, and as applied to agriculture in particular, has been criticized as being vague, circular, and unhelpful (Hansen, 1996; Glavič & Lukman, 2007). While it is clear there are many different uses of the word "sustainability," as soon as specific quantitative metrics for it are proposed, it becomes actionable and potentially useful. It is in this spirit that we argue that properly designed sustainability metrics can promote sustainable food in several ways. First, they allow us to determine whether or not we have been successful in actually *achieving* tangible outcomes, as opposed to simply *working* towards sustainability as measured by implementation of best management practices. Where we are falling short, we can change our approach until we find what works. Metrics also allow comparisons among supply chains and agricultural products or businesses, thereby enabling competition and innovation. Good metrics may mean the difference between meaningful corporate sustainability and greenwashing. Finally, the right metrics will also help us to test hypotheses about system attributes that confer resilience. It is only through such testing that we can promote more resilient systems.

Better incorporation of social and economic metrics with environmental metrics will make sustainability more appealing and practical to a broader audience. Just as farmers have an incentive to care about factors like soil retention and water efficiency in scarce environments (as they are essential to their economic future), environmentalists are starting to understand the importance of yield increases (to reduce the pressure to clear new farms) and profitability (to keep farmers interested in conservation practices without external payments). Better integration of these disciplines should help to identify "win-win" scenarios, such as the potential of fertilizer optimization to reduce water pollution, carbon footprint, and costs to the farmer. In addition, corporate sustainability reporting is catching on, but the key is helping corporations set the right goals, which requires the right metrics. Finally, meaningful, credible labels can help consumers make more sustainable choices, and drive improvement on the manufacturing end. Further research is needed on what label design will best motivate consumers, and what aspects of sustainability they are most willing to act on.

Ultimately, the path to useful and actionable sustainability metrics is affordable and accurate remote sensing technology. Fortunately such technology is at hand, although it cannot be the sole solution to data capture. Increasingly satellite images allow detection of surface soil types and soil moisture, sediment loads in lakes, agricultural management practices, crop yields, vegetation types, and changes in any of these variables. By combining this technology with creative scientific hypotheses concerning sustainability and resilience, and pragmatic metrics that draw on the data, a great opportunity for pursuing sustainable food systems lies before us. The limiting factor now is simply ideas about what metrics to use, what hypotheses to test and finally implementing programs that collect the data. Given the importance of food systems to both humans and the planet, sustainability labelling and reporting should be a priority for agricultural scientists. The fastest progress will be made by working with corporations, consumer groups, and NGOs to make food sustainability part of everyday life as opposed to an academic discussion topic.

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