Title: Agricultural ecosystems and their services: the vanguard of sustainability?

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Abstract

A major opportunity exists in the transition from the disciplinary Millennium Development Goals (MDG's) to the more interdisciplinary Sustainable Development Goals (SDG's) to transform the dialogue around the environment from its current conceptualization as a constraining factor towards its utilization an enabling force for sustainable development. Agricultural ecosystems are the ecosystems closest to human well-being providing 31% of global employment, and the sustenance for the entirety of the global population. Despite this central contribution, agricultural systems or agroecosystems are responsible for driving significant environmental pressures while failing to provide sustainable diets for a world that is increasing either under- or malnourished. Agriculture's dual change is often presented as a trade-off between conservation and development objectives. However, an increasing body of research demonstrates that agricultural systems are both wholly dependent on, and potentially net

providers of ecosystem services beyond food production. Recognizing this dual role allows for greater convergence between conservation and development objectives and leverages environmental management of agricultural system as a means to achieving global sustainability goals. We propose a simple framework for ecosystem services and resilience in agricultural landscapes to better capture and operationalize interactions between ecosystem services provided to agriculture, and those provided from agriculture. We discuss how such a perspective influences definitions of production ecosystem services and emphasize the need for greater focus on resilience and regulating services. We argue for better applications of resilience-based approaches and call for refocusing ecosystem service research on human well-being outcomes articulated in the social targets of the SDGs, in addition to the more traditional biophysical and conservation based outcomes.

Highlights:

- The transition towards the interdisciplinary global Sustainable Development Goals calls for a greater recognition of agriculture's contribution to multiple objectives.
- As the largest ecosystem of the Anthropocene, and the ecosystem most closely tied to human well-being, understanding agricultural ecosystem as complex adaptive socio-ecological systems is a prerequisite to achieving sustainability.
- An ecosystem service and resilience approach facilitates this transition by emphasizing environmental contributions to food security, and human well-being in a time of change.

Introduction

Rising demand for food, fuels and fibers are intensifying pressure on the world's food production systems [1, 2]. Novel approaches that secure the natural resource base upon which

agriculture is founded can relieve these pressures by leveraging agriculture's contribution to multiple global demands including food and nutrition security [3]. Covering 38% of the terrestrial, ice-free surface of the planet, agricultural ecosystems are the largest of the Anthropocene, and are a major force behind breaching multiple planetary boundaries [4-6]. Agriculture contributes to between 19 and 29% of total GHG emissions [7] 69% of freshwater resource use [3], and 31% of wild biodiversity loss [8, 9]. It is also the primary driver for the disruption of phosphorus, and nitrogen cycles [10]. Because agricultural systems are the primary interface between human and environmental interactions [11], they are likely to be our single most important source of solutions for addressing both environmental sustainability and food security as articulated by the Sustainable Development Goals (SDGs). An ecosystem service based approach facilitates this transition in perspectives, emphasizing the multifunctional contribution that agriculture makes to multiple dimensions of human well-being.

Ecosystem Services in Agriculture:

Ecosystem services are the benefits that nature provides to people [12]. Ecosystem service programs and interventions must thus be able to demonstrate causal change in ecosystems and human well-being [11]. While forests and other natural ecosystems are considered, and remain important sources of ecosystem services, the central role of agricultural ecosystems in service delivery merits much greater recognition [13, 14]. Society expects and accepts management of agricultural ecosystems, which offer a greater range of management and intervention options than available in natural ecosystems. These include fundamental advancements in agroecology and organic agriculture, in combination with redesigned high tech systems such as precision agriculture. Innovation and adaptation of agricultural management practices can substantially enhance ecosystem service delivery and capture while safe-guarding and securing food production objectives [15]. All too often, poorly planned or badly managed

agricultural systems negatively impact the flow and provision of ecosystem services due to nutrient runoff, unintentional pesticide poisoning, and habitat loss and degradation [16]. However, existing and novel agricultural management practices can impact and enhance the flow and provision of numerous ecosystem services while reducing agriculture's negative externalities [16-18]. This includes services central to food production including pollination, pest control, soil fertility and soil structure [13]. It also includes services obtained from agriculture such as food, fuel, and fiber production, provisioning and regulating of water supplies, providing security from natural hazards, climate change mitigation, and cultural services such as spiritual and recreational values, and habitat for both wild and functional biodiversity [16, 18-22]. The inclusion of agricultural ecosystems within the ecosystem service concept has generated a much more interdisciplinary and multifunctional view of agricultural systems [2] showing the centrality of agriculture in achieving global sustainability targets, as well as an opportunity for greater convergence between agricultural and conservation objectives [23].

An Ecosystem Service and Resilience Framework for Agriculture

Transitioning toward greater inclusion and operationalization of ecosystem service and resilience based approaches to agricultural development necessitates a re-envisioning of agricultural systems as complex adaptive socio-ecological systems at the vanguard of sustainability challenges [23, 24]. From an operational point of view, transitioning to an ecosystem service and resilience approach requires recognizing several unique features and components of agricultural systems (Figure 1). First, there can be no confusion. While conservation outcomes are important, the imperative outcomes of an ecosystem service and resilience based approach for agriculture must be able to clearly articulate the benefits to people, whether in the form of sustainable diets, employment opportunities, reduced health risks or conserved cultural heritage and recreation. The approach is thus unapologetically

anthropocentric, albeit with intergenerational sustainability underpinning the articulation of benefits to people. Second, the framework recognizes the unique dual role of agricultural systems emphasizing management decisions both determine the extent to which ecosystem are leveraged for food production, and the impacts of agriculture on the environment. Similarly, these management decisions can determine the extent to which agricultural systems contribute to non-food provisioning ecosystem services such as carbon sequestration in agricultural soils for climate mitigation [25]. The recently released UNEP TEEB for Agriculture and Food Interim report [13] captures these well as the “invisible positive” and “invisible negative” flows from agriculture (Figure 2). Third, capturing these multiple contributions requires an integrative and systems based approach. In light of the strong land based impacts of agriculture, landscape based approaches are the most appropriate for facilitating the discovery, and management of interactions between land uses and management across both spatial and temporal scales. Forth, novel governance decisions and structures are needed to improve the biophysical processes that provide ecosystem services flows, and to enable fair access or use of those benefits by beneficiary communities. Fifth, we emphasize the need for agricultural research to adopt on emerging conservation perspectives [23] to recognize agricultural systems as complex adaptive socio-ecological systems constantly subjected to both environmental and socio-cultural change, to which food production functions must remain resilient.

This framework is designed to enhance efforts to understand and manage ecosystem services that can build socio-ecological system resilience to stresses and shocks to support food security and poverty alleviation goals. Resilient systems in agricultural landscapes are better able to recover their fundamental structure and functionality in the face of change or to transform into new regimes where this has desirable environmental and social outcomes. Incorporating resilience into an ecosystem service-based approach identifies threats and

thresholds affecting ecosystem service provision, and reduces these threats while increasing the ecological and human capacity to recover and avoid crossing critical thresholds. This should be carried out within the context of improving development outcomes for poor people over long time frames, which means that priority should be given to building resilience in ecosystem services that benefit the poor or disadvantaged when considering trade-offs.

To facilitate the gradual integration of ecosystem service and resilience perspectives into agriculture, we propose five core principles that serve to guide research and interventions (Box 1). We briefly recognize these as follows:

CORE PRINCIPLE 1: Meeting the needs of people is fundamental

Decisions regarding the use and management of ecosystem services should benefit people, particularly the poor or disadvantaged, in ways that are transformative either increasing stable access to sustainable diets, or reducing exposure risk water, air, or vector born diseases for example. While ecosystem service tools and technologies remain strongly rooted in the environmental sciences with approaches that relate changes in ecosystem structure to changes in service provision and flows, we must improve capacity to demonstrate causality and extent of contribution to improved human well-being [26]. To accomplish this, ecosystem service based approaches must move beyond biophysical measures of impacts to better demonstrate the impact of ecosystem change. Such an approach emphasizes not only the inherent value of environmental goals (e.g. SDG 14 Life Below Water; SDG 15, Life on Land), but also their actual contribution to social goals [e.g. SDG 1 No Poverty, SDG 2 Zero Hunger, SDG 3 Good Health and Well-Being; 27].

CORE PRINCIPLE 2: People use, modify, and care for nature which provides material and immaterial benefits to their livelihoods

People and nature are inextricably linked, tightly coupled and function within complex adaptive systems. Human actions and land-use choices affect the processes that provide ecosystem services, their flow and distribution. The presence, recognition and distribution of ecosystem services and their benefits drive societal choices and can create or reduce livelihood options. These feedbacks and complexities highlight that beneficiaries and providers of ecosystem services are intrinsically linked [28]. Both societal and ecological components of agricultural systems and landscapes, and the interactions between them must be understood and incorporated into governance decisions. This requires methods of ecosystem service analysis capable of matching ecosystem service providers to beneficiaries, and elucidating effects of management decisions on both ecosystem functions and processes underpinning service provision and on flow to beneficiary groups.

CORE PRINCIPLE 3: Cross-scale and cross-level interactions of ecosystem services in agricultural landscapes can be managed to positively impact development outcomes

Ecological and societal structures and functions influencing the provision of ecosystem services operate at a wide range of spatial, temporal, ecological and institutional scales, each of which has several levels of resolution. Correctly identifying the ecological and spatial scales at which ecosystem services are provided, and matching these to appropriate jurisdictional extents is critical for sound ecosystem service management [29]. A cross-scale and cross-level approach [30] provides an opportunity for nested management, where ecosystem service management at one level can be integrated with management at coarser levels in ways that might not be identifiable without cross-level analysis.

CORE PRINCIPLE 4: Governance mechanisms are vital tools

Rules, practices and institutions that govern the management and use of natural resources influence the provision and distribution of ecosystem services. Governance operates at multiple levels and includes farmers making choices about agricultural practices at the field, farm and growing season levels; community organizations creating and maintaining forest or landscape management structures, national governments choosing where to direct investments in the water supply chain; and local customary or regulatory laws and policies on natural resource use. Interventions can be made at all levels of governance to improve the long-term sustainability of ecosystem services, and the equitable access to services and their benefits, by encouraging, facilitating or enforcing changes to ecosystem service use and management. To be effective, these interventions must take into consideration the biophysical structures and processes underpinning service provision [31] as well as the existing social context, specifically polycentric governance [32].

CORE PRINCIPLE 5: Building resilience is about enhancing the capacity for communities to sustainably develop in an uncertain world

The fifth principle is both one of the most complex, but most important. Management options for agricultural systems are subject to, and must be responsive to, constantly changing environmental and social conditions. In the absence of perfect information on complex systems, resilience approaches are needed and emphasize the need to manage agricultural systems as complex adaptive socio-ecological systems with attention played to component diversity and redundancy, connectivity, and slow variables and feedbacks [33, 34]. Resilience is maintained by securing capacity to learn and experiment, ensuring participation, and supporting polycentric governance options. More than ensuring the specific resilience of agricultural systems to these externalities, resilience thinking provides an embedded capacity to adapt core production

functions of agriculture in the face of change. This is particularly important at a time when increased global dynamics, can have profound effects on local realities [35].

Contributions to Sustainable Development

Two of the important distinctions of the 2015 SDG's from the 2000 MDG's include the global nature of the compact – addressing changes that need to be taken by developed as well as developing countries, and the greater attention given to interactions between goals. This interdisciplinary focus has generated numerous reviews articulating the contributions of various disciplines to the SDG's such as from environmental sciences [36], and nutrition [37]. What is evident from these analyses, and particularly from the environmental sciences, is that there exists an organizational hierarchy to these goals with the environmental goals serving as both the foundation of their attainment, and the broader context for their achievement (Folke et al. in Review). This is also evident in the planetary boundaries [4, 5] and their modification by Dearing et al. [38] into a “planetary donut” which depicts environmental boundaries as limits to be maintained (outer circle), and social foundations to be raised (inner circle) to secure a “safe and just” operating space for humanity. Ecosystem services bridge these two domains by providing a means of managing environmental processes for human well-being and emphasizes environmental goals as a means to sustainably attaining social goals.

Our emphasis on the multifunctional role of agricultural systems, and utilization of the TEEBAgriFood framework calls into question the oversimplification of provisioning services. Agricultural yields are all too often simply quantified as evidence of increased provisioning ecosystem services [39], whereas much of this yield is attained through the replacement of regulating ecosystem services with external inputs [Figure 2,13]. This replacement drives many of agriculture's negative externalities or invisible costs [13] and ignores most recommendations for managing resilience [33]. Using an ecosystem service and resilience approach in agriculture

maintains human well-being through the provision food and nutritional security as the principle system outcome, but emphasizes the contribution and conservation of regulating and cultural services to this outcome.

Finally, our framework provides important nuance to the land-sharing/land-sparing debate. There is no doubt in our minds that critical conservation space must be spared from the plow. Calls and actions for ensuring wilderness spaces [40, 41] independent of any physical services these places might play are a necessary part our path towards sustainability and are articulated in the land conversion planetary boundary [4, 42]. Evidence suggests that providing a global sustainable diet is possible, while maintaining or reducing space allocated to food production [43]. We doubt however, that agricultural lands can be spared while meeting sustainability goals in light of agriculture's dependence on biodiversity and ecosystems for regulating services, and in light of its contribution to conservation objectives [13]. Shared agricultural lands must be managed to secure the genetic and species diversity and traits that underpin food production [20], and dietary diversity [44-46]. Similarly, conservation objectives cannot be met without a shared agricultural space that provides both a space for wild biodiversity, and connectivity between spared protected areas [47].

As with conservation [23], agriculture must undergo an important transformation that retains core foundations in improved varieties and agricultural management technologies to secure production functions, but it must urgently embrace new ideas and practices inclusive of environmental change, resilience, adaptability, and socio-ecological systems. Doing so is facilitated by an ecosystem service and resilience approach to agricultural systems allowing for convergence between agricultural and conservation sciences. This convergence is a necessary pre-requisite for achieving sustainability targets.

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Table and Figure Headings:

Figure 1: An ecosystems services framework for agricultural landscapes which highlights the need for better articulate of impacts and benefits to people (1); the capacity of agricultural management to provide services complementing food production services (2); but necessitating landscape based approaches to describe and quantify interactions between system components and levels (3); that must be supported with governance decisions that improve the contributions of biophysical processes contributing to service provision, and to enable fair access and use of benefits (4); while facilitating learning and adaptive capacity to external influencing factors, whether social or environmental in their construct (5).

Figure 2: The Economics of Ecosystems and Biodiversity (TEEBAgriFood) framework for capturing the visible and invisible costs and benefits of agricultural and food systems on both ecosystems, and human systems (TEEB 2015).

Box 1: Five core principles underpinning research and application of ecosystem services in agricultural ecosystems and landscapes.

Figure 1:

Figure 2:

Box 1:

Principle	Description
People	Meeting the needs of poor people is fundamental.
People and Nature	People use, modify, and care for nature which provides material and immaterial benefits to their livelihoods.
Scale	Cross-scale and cross-level interactions of ecosystem services in agricultural landscapes can be managed to positively impact development outcomes.
Governance	Governance mechanisms are vital for achieving equitable access to, and provision of, ecosystem services.
Resilience	Building resilience is about enhancing the capacity of communities to sustainably develop in an uncertain world.

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