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# Ecosystem Services, Agriculture, and Economic Institutions

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## An unsolvable dilemma?

There is little doubt that human activities threaten irreversible damage to our planet's ecosystems and the life sustaining services they generate. Plants, animals, water and soil are fundamental building blocks of ecosystems. When we extract living resources faster than then they can regenerate, divert an ever-greater share of freshwater to human uses, accelerate erosion, or convert natural ecosystems to human uses, we leave our ecosystems physically diminished. When we spew greenhouse gases, ozone depleting compounds and toxic wastes into our environment faster than they can be absorbed, they can only accumulate, further sickening our ecosystems. Unfortunately, the rate at which human society extracts raw materials from nature and returns harmful waste is accelerating, not diminishing. We run the serious risk of crossing critical thresholds beyond which planetary ecosystems can no longer recover, such as runaway climate change or a massive global extinction episode [1].

Humans, like all other species, depend for survival on stable, healthy ecosystems and the services they provide. For example, the current population of seven billion clearly could not survive without agriculture. Weakened ecosystems may become incapable of ensuring the stable climate and water flows, erosion control, pollinator populations, genetic diversity and other ecosystem services essential to agriculture, and the loss of these services on a broad scale could spell the collapse of civilization. The impact of our activities are masked by frequently significant lags between the time they occur and the time their negative impacts on ecosystems unfold. For example, habitat loss already suffered may feed a wave of extinctions lasting decades or even centuries [2], and existing atmospheric carbon stocks may continue to warm the earth for decades [3]. This means that simply halting ecological degradation is inadequate. We must actively restore global ecosystems in order to sustain the essential services they provide. While time lags between human activities and ecological impacts afford us a window of opportunity to achieve this, they also mask the need for action until it may be too late.

Agricultural expansion is currently the greatest global threat to ecosystem services [4]. It is the leading cause of land use change, biodiversity loss, nitrogen and phosphorous emissions, and freshwater use, and a major contributor to climate change and chemical pollution, all of which have been defined as planetary boundaries that cannot be transgressed without causing unacceptable environmental change [5]. This leads to a paradox: converting more natural ecosystems to agriculture increases the land area available for food production, but can actually decrease food production per hectare by eroding the services on which agriculture itself depends. There is empirical evidence that this has already come to pass in some countries [6, 7].

Unfortunately, there are nearly one billion malnourished people already on the planet, and the global population is expected to increase by an additional two billion by 2050. Economic growth coupled with growing inequality means that a growing share of the global food budget will be dedicated to animal protein for the middle class and wealthy, leaving the poor with an even smaller slice of the pie. In light of these trends, the Food and Agriculture Organization (FAO) estimates that failure to increase food production by at least 70% by 2050 could have unacceptable humanitarian costs [8]. No economic activity is more important than food production.

We therefore face a seemingly irresolvable dilemma. Failure to increase food production threatens widespread famine or worse. Conversely, ensuring the continued provision of vital ecosystem services requires extensive ecosystem restoration, which in many regions can only come at the expense of farmland. Restoration will also require reductions in nitrogen, phosphorous, greenhouse gasses, toxic chemicals and freshwater use, all of which are critical inputs to modern agriculture. Restoring ecosystem services in the short run could therefore lead to reductions in food production. However, failure to restore these ecosystem services will likely lead to serious reductions in food production in the future [9]. We apparently face the unpleasant choice between misery now or worse misery in the future.

Admittedly, pessimists since Malthus have been warning that food production cannot keep pace with population growth, and have so far been proven wrong. But previous productivity increases have been primarily driven in one form or another by fossil fuels. It now takes some ten calories of hydrocarbons to put one calorie of food on our dinner plates. From an energy perspective, agricultural efficiency has plunged. Again we face a frightening dilemma: continued use of fossil fuels appears necessary to sustain our food production, but agriculture conservatively accounts for 14% of global greenhouse gas emissions [8], and agriculture is the sector most likely to suffer from climate change. Furthermore, fossil fuels are a finite resource, and there is increasing evidence that we are approaching peak production [10]. The next round of productivity increases in agriculture will have to rely primarily on nature's renewable services at the same time that past productivity increases have driven these services to historical lows [11].

## The Roots of the Crisis

We have ended up in this situation because both our agricultural technologies and our economic institutions ignore the importance of ecosystem services.

Agriculture treats artificial inputs made from non-renewable resources as substitutes for self-replenishing ecosystem services essential to agriculture: chemical fertilizers as substitutes for nutrient cycling and erosion control, chemical pesticides for natural pest predators, tiling for water regulation, fossil energy for solar powered biomass. Unfortunately, these substitutes often reduce the production of the very services they replace: chemical fertilizers and erosion damage the delicate soil ecosystems essential to nutrient cycling, pesticides kill natural pest predators, and tractors compact soils, depleting their capacity to sustain primary production. The result is increasing reliance on artificial inputs, setting us up for potential catastrophe as they are inevitably depleted.

The market economy only functions for resources that can be privately owned, hence bought and sold on markets, which is true only for a minority of ecosystem services [12]. Markets reward farmers for converting ecosystems to agriculture, but not for conserving them to provide life sustaining ecosystem services. Markets reward farmers for output gains from toxic chemical inputs or fossil fuels, but not for the damage these inputs cause to non-marketed services. Both agriculture and ecosystem services are immeasurably valuable, but markets account only for the value of the former. Markets also focus primarily on the short run, neglecting benefits to future generations. Soil erosion far in excess of soil creation is probably the most serious example of this problem. Furthermore, markets are inefficient for resources that are not depleted through use, such as the genetic information that will be required to breed new crops that are more productive and better adapted to changing climates, pests and disease. Genetic information can now be patented, allowing patent owners to ration access via the price mechanism, earning monopoly profits while creating artificial scarcity. Charging farmers royalties on plant varieties that can feed more people on less land will reduce adoption and hence reduce their value [13].

The solution to our dilemma requires fundamental changes in both agricultural systems and in economic institutions.

## Agroecology

Our next generation of agricultural technology must be capable of increasing the provision of ecosystem services from farmland and the provision of food, fiber and fuel from ecological restoration while reducing the use of non-renewable and toxic inputs. A suitable food system must replace non-renewable or ecologically harmful off-farm inputs and the mining of soil and water with their renewable but dwindling ecosystem service counterparts while simultaneously increasing output. It must help mitigate climate change and adapt to its impacts. It must not only maintain the natural resource base, but also actively restore critical ecosystem services. To ensure food actually flows to those who need it most, the system should pay particular attention to the needs and aspirations of poor farmers in marginal environments. Such a system must be based on ecological principles while simultaneously accounting for social and economical capabilities. The transdisciplinary field of agroecology, defined as the "application of ecological science to the study, design and management of sustainable agroecosystems" [14, p.18] is built precisely on these principles to achieve these goals [15-17].

Despite minimal investments in agroecology relative to conventional agriculture, numerous studies suggest that it can simultaneously increase agricultural yields and farmer incomes, ecosystem services, and resilience in the face of extreme weather events. One recent study of nearly 300 model resource-conserving agriculture projects covering 37 million hectares in poor countries documented an average yield increase of 79%, substantial carbon sequestration, more efficient water use, reduced pesticide use and increased ecosystem services [11]. Another meta-study found that agroecology practices enhanced both species richness and abundance in a variety of agricultural landscapes [18], while research on agroforestry finds that high biodiversity is compatible with high yields [19]. Agroecology can successfully couple agriculture with conservation [20].

Agroecology may also be one of the best responses to climate change. It reduces fossil fuel inputs and greenhouse gas emissions relative to conventional agriculture. Increased reliance on trees and other deep-rooted perennials, greater crop diversity, lower tillage, physical properties of organic soil, and numerous other agroecological practices make it more resistant to extreme weather events, ranging from hurricanes to drought. Higher biodiversity can help protect against the likely spread of pests and weeds with higher temperatures [17]. Agrecology can even help capture carbon in soils and in biomass, which could potentially sequester 1.2–3.1 billion tons per year of atmospheric carbon. Restoring carbon to depleted soils can increase grain and root crop yields by 30-42 million tons per year in developing countries alone [21].

## Economic Institutions

The challenge is to design economic institutions capable of incentivizing the dissemination of agroecology at a global scale. Market forces provide incentives to individual farmers for the increased agricultural yields associated with agroecology, but fail to reward the provision of public good ecosystem services, leading to sub-optimal investment. Furthermore, the initial costs of implementation often exceed the investment capacity of poor farmers in marginal environments. Such farmers typically have limited access to credit, and are frequently charged exorbitant interest rates, even by the much-touted micro-credit schemes that are now proliferating around the world.

Economists have suggested payments to individual farmers for the ecosystem services generated by agroecology [22], but transaction costs can be prohibitively high when working with small farmers [23]. Even if farmers were compensated for the full societal benefits, agroecology demands intensive knowledge of local ecosystems, cultures and markets. It is therefore best spread from farmer to farmer, catalyzed and facilitated by agricultural extension workers. The major requirements for the spread of agroecology are investments in R&D, agricultural extension, infrastructure required to bring products to market and low risk, low interest financing mechanisms. Payments to individual farmers do little to provide these services. In contrast, public sector investments in agricultural R&D and other rural sector public goods frequently generate rates of return 40% or more [20, 24, 25].

Public sectors conventionally pay for public goods that benefit their constituents, but the spatial distribution of ecosystem services fail to respect political boundaries. Local or state governments are unlikely to pay for ecosystem services that benefit the nation, and nations are unlikely to pay for global services [26]. We must therefore develop a new type of public-sector payments for ecosystem services, in which wealthy countries and national governments that benefit from the ecosystem services agroecology provides transfer resources to less wealthy countries and local governments otherwise unable to fully finance the necessary public sector investments. This is known as an intergovernmental fiscal transfer [27, 28], and was originally proposed for investments in cross-boundary public goods within a specific nation [29]. Such payments should not be contingent upon the provision of ecosystem services, but rather treated as a type public-sector venture capital. Since both sides of the transaction benefit if the effort succeeds, the initial risk must be shared. Given the unacceptable costs of failure and urgent need for action, we must move forward with such policies as rapidly as possible, learning from our mistakes as we go.

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