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How Valuing Nature Can Transform Agriculture

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In Brief:

Society must increase food production and restore vital ecosystem services or suffer unacceptable consequences. Unfortunately, conventional agriculture may be the single greatest threat to ecosystem function. At the same time, reducing ecologically harmful agricultural inputs or restoring farmlands to native ecosystems threatens food production. We fell into this predicament because we designed agricultural and economic systems that failed to account for ecosystem services, and the path forward requires redesigning both systems. Agroecology—which applies ecological principles to design sustainable farming methods that can increase food production, wean us away from nonrenewable and harmful agricultural inputs, and restore ecosystem services—promises to be an appropriate redesign of agricultural systems. We focus on the example of management-intensive grazing (MIG), which mimics natural grassland-grazer dynamics. Compared to conventional systems, MIG increases pasture growth and cattle production, reduces the use of fertilizers and pesticides, and enhances biodiversity, water quality, nutrient capture, and carbon sequestration. Redesigning economic institutions to reward the provision of ecosystem services and provide the public goods required for the global-scale development and dissemination of agroecology practices still presents a serious challenge. Payments for ecosystem services (PES) are a promising mechanism through which those who benefit from ecosystem services can compensate those who provide them, for mutual gain. Numerous schemes already exist that pay landowners for land uses that sequester carbon, regulate and purify water, and enhance biodiversity, but their effectiveness is debated. We propose a form of PES in which the potential public beneficiaries of ecosystem services at the local, national, and global scales fund the research and development, extension work (i.e., farmer education, usually supported by government agencies), and affordable credit required to scale agroecology up to the level required to provide for a growing global population.

Key Concepts:

- Our conventional food system is the leading cause of habitat, soil, and biodiversity loss and nitrogen and phosphorous pollution. As a result, it is perhaps the single greatest threat to ecosystem function.
- Agroecology—the study, design, and management of agroecosystems based on ecological principles, with particular attention to the needs of small farmers—is capable of increasing the production of both food and ecosystem services while reducing the use of harmful and expensive agricultural inputs.
- Payments for ecosystem services (PES), a policy through which those who benefit from ecosystem services compensate those who adopt land-use decisions that provide them, can potentially provide the resources and incentives required to scale up agroecology.
- The promotion of agroecology demands significant investments in public goods such as R&D, extension services (i.e., farmer education), infrastructure, and affordable, low-risk credit. The returns on investment flow to all farmers adopting the practices, not to private investors alone. Similarly, the returns from ecosystem services flow to all of society. An effective PES scheme for agroecology must account for this.

Ecosystem services are conventionally defined as the human benefits provided by natural ecosystems and include the capacity of those systems to reproduce or replenish themselves. It is useful, however, to distinguish between two types of flows from nature that benefit humans: ecosystem services and throughput.[1,2]

Ecosystems generate services at a given rate over time and are not physically transformed into the services they provide.[3] Roughly speaking, a given forest can filter a certain amount of water per day or sequester a certain amount of CO2, though amounts change depending on the health and age of the forest, and essentially the same forest remains at the end of the day. There is a growing scientific consensus that ecosystem services are essential to human survival and that the potential to create technological substitutes is very limited. At the same time, human activities increasingly threaten their adequate provision, posing a dangerous paradox.[4,5]

Most ecosystem services have public-good characteristics. This means that either they are freely available for use by all and cannot be privately owned, i.e., bought or sold (in economic jargon, they are nonexcludable); or else use by one person does not affect use by another, so that charging for use creates artificial scarcity (in economic jargon, they are nonrival). Many services have both characteristics. For example, it would be impossible to establish private property rights to climate regulation or to the filtration of UV radiation by the ozone layer. My use of the ozone layer does not leave less for others. It is possible, however, to limit activities that degrade ecosystem services and to buy and sell the right to engage in them. This is the mechanism behind cap and trade systems for CO2.

In contrast to ecosystem services, throughput is a physical flow of raw materials and stored energy from nature, converted into economic products and then returned to nature as disordered waste. Raw materials are physically transformed into economic products and then waste, and within certain limits we can control the rate at which this occurs. For example, we can clear-cut a given forest in a week or a year and transform it into houses. Throughput unavoidably removes, rearranges, and degrades ecosystem structure, compromising its ability to generate services. Raw material inputs are generally market goods, while markets often ignore the costs imposed by their removal or their return to nature as waste.

Like ecosystem services, throughput is essential to all economic production, since it is impossible to make something from nothing. There is therefore invariably a trade-off between economic production and ecosystem services.[2,3] Both markets and shortsighted political systems typically favor the immediate benefits of converting ecosystems into throughput over the slow but steady supply of ecosystem services provided by conservation or restoration.

There is, however, a very real threat that continued degradation of ecosystems will lead to threshold effects or tipping points that might cause our ecosystems to collapse, often unexpectedly.[6–8] Efforts to increase our food supply using conventional means may lead us across such thresholds, with unacceptable costs. At the same time, the demand for food has never been greater. Nearly one billion people on the planet today are already malnourished, and rising global food prices—already at record highs—threaten them with starvation.[9] While dietary changes, improved distribution, and less waste would clearly help, the United Nations estimates that we need to increase food production by 70 percent by 2050 to meet the growing demand from a burgeoning population.[10] Further complicating the issue, food systems rely heavily on endangered ecosystem services such as climate regulation, water regulation, nutrient cycling, biological pest control, disturbance regulation, and pollination. Sacrificing ecosystem services for food production in the short run could lead to a catastrophic loss of both in the long run.

Scientists and scholars have of course been warning of imminent starvation for hundreds of years,[11,12] yet per capita grain production and average global grain yields per hectare have outpaced population growth. In fact, many of these gains have been driven by our apparent ability to create substitutes for ecosystem services. Nitrogen fertilizer from natural gas and mineral phosphorus seemingly substitute for nutrient cycling, erosion control, and soil formation and allow an end to fallow periods. Petrochemical pesticides substitute for biological pest controls and further increase short-term yields. Increasing production from low-output systems and the use of modern technology to increase production limits could still increase global food production, but it will be extremely challenging to do so without further degrading ecosystem services.[13]

Unfortunately, conventional agriculture's dependence on nonrenewable substitutes for ecosystem services makes it the dominant threat to biodiversity, ecological function, and ecosystem services—paradoxically the very things we need to sustain agriculture.[14,15]

Dwindling supplies of fossil fuels and phosphorous coupled with excessive waste emissions mean we cannot rely indefinitely on nonrenewable inputs to increase food production. In 1940, U.S. food systems converted 1 calorie of energy inputs into 2.3 calories of food on the table, while today they convert some 7.3 calories of fossil fuel inputs into 1 calorie of food.[16] In a reversal of the previous dynamic, efforts to substitute food crops (as biofuels) for fossil fuels now threaten food supplies. The next round of productivity increases in agriculture will have to rely much more extensively on nature's rapidly diminishing renewable services.[17]

A similar dynamic plays out at the local level. In many threatened ecosystems, the amount of restoration required to maintain invaluable ecosystem services decreases food production and drives local farmers into poverty. One example is Brazil's highly biodiverse Atlantic Forest, of which only 7 percent remains. Some two-thirds of Brazil's population depends on it for water purification, flood regulation, nutrient cycling, and other invaluable ecosystem services. Other nations depend on it for global services such as climate regulation and habitat for biodiversity. Failure to restore the system is likely to result in massive extinctions in the near future,[7,18,19] destroying critical ecosystem services, many essential for agriculture. For example, deforestation, fragmentation, and poor management practices in the Atlantic Forest already contribute to higher temperatures, more fires, reduced water quality and supply,[20] landslides, flooding, erosion,[21] and reduced soil quality and nutrient cycling,[22] all of which threaten agricultural output.

By law, farmers must maintain a permanent, sustainable-use forest reserve on 20 percent of their Atlantic Forest property. In addition, natural forest cover is mandatory for a minimum of 30 meters on either side of waterways, for 50 meters surrounding springs, on slopes over 45 percent, on hilltops, and in other ecologically critical zones,[23] where only small farmers are allowed to implement agroforestry systems. To comply with these laws, most farms would have to return farmland to forest, but few farmers comply. If small farmers restored as much forest as required by law, they would have too little farmland to earn a living and would likely plunge into poverty.[24] Ironically, following major floods in 2009, the governor of Santa Catarina declared that the state had to choose between larger crops and larger slums and would no longer comply with the federal forestry code.[25]

The solution is to design food systems that actively restore ecosystem services and increase food production, along with the economic institutions required for their development and dissemination.[17,26,27]

A Sociotechnological Solution: Agroecology

A suitable food system must replace nonrenewable or ecologically harmful off-farm inputs 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. The system should pay particular attention to the needs and aspirations of poor farmers in marginal environments. The field of agroecology, defined as the "application of ecological science to the study, design and management of sustainable agroecosystems,"[28] fuses agronomy, ecology, and other disciplines in order to achieve these goals.[26,29,30]

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 percent, substantial carbon sequestration, more-efficient water use, reduced pesticide use, and increased ecosystem services.[31] Another metastudy found that agroecology practices enhanced both species richness and abundance in a variety of agricultural landscapes,[32] while research on agroforestry finds that high biodiversity is compatible with high yields.[33] Agroecology can successfully couple agriculture with conservation.[34]

Agroecology may also be one of the best responses to climate change. First, it reduces fossil fuel inputs and greenhouse gas emissions relative to conventional agriculture. Second, increased reliance on trees and other deep-rooted perennials, greater crop diversity, lower tillage, and the physical properties of organic soil make it more resistant to extreme weather events, ranging from hurricanes to drought. Third, higher biodiversity can protect against the spread of pests and weeds that will likely accompany higher temperatures.[26] Finally, agroecology could potentially sequester 1.2–3.1 billion tons per year of atmospheric carbon in soils and in biomass, which in turn could increase grain and root crop yields by 30–42 million tons per year in developing countries alone.[35]

Our own research in Brazil supports similar conclusions. At our study sites in Santa Catarina, cattle pasture is the dominant land use. Soil erosion on denuded pastures, pesticides and fertilizer application, use of rivers and springs as watering holes, and conversion of native forest to pasture all have serious environmental impacts.[36] Economic returns are generally quite low, averaging only $10–$100 per hectare per year.[37]

Management-intensive grazing (MIG), or Voisin grazing, is an agroecological alternative in which pastures are divided with electric fences into numerous paddocks. Riparian zones are fenced out to stabilize banks, avoid erosion and runoff, and improve water quality, which in turn improves herd health and productivity. Water is then pumped to tanks in each plot, eliminating frequent cattle trips to riparian zones. Animals are moved from pasture to pasture, mimicking their movements in nature. High livestock density for short periods allows optimal forage growth and dramatically increases net primary production.[36] Forage biodiversity intensifies, which both increases and stabilizes production.[38] Pasture is never overgrazed, ensuring better ground cover, less erosion, and better nutrient cycling, reducing the need for fertilizers. Moving stock from pasture to pasture interrupts the reproductive cycle of insect pests, reducing the need for pesticides. Meanwhile, healthier, more biodiverse pastures reduce the need for herbicides. More productive pastures store more carbon, improving soil quality and mitigating climate change.[36,39–41]

MIG is suitable for small farmers because it requires less labor and capital compared to feedlot systems and it consumes significantly less hay and produces higher output per area compared to continuous grazing.[36]

In short, MIG increases output while decreasing inputs. The agroecology team at the Federal University of Santa Catarina has implemented Voisin grazing projects on over 600 farms in the region. We surveyed a random sample of 60 farms, 15 from each of four separate watersheds. Some 90 percent of surveyed farmers increased the number of cows per hectare, yield per cow, and total yield; 49 percent of farmers reported decreased labor requirements (27 percent reported an increase); 65 percent claimed that both quantity and quality of pasture improved greatly, while an additional 8 percent claimed that pasture improved in quality and 25 percent that it increased in quantity. Concerning herd health, the vast majority of farmers found that ticks, horn flies (*Haematobia irritans*), worms, and mastitis all decreased, in many cases significantly (no more than 5 percent found that any of these diseases had increased). Increases in milk production, farm revenue, number of cows, and production per cow were highly significant.

Over 98 percent of farmers said that their initial investment is generating the desired returns or more. Nearly 70 percent of farmers repaid the initial investment in the first year, and over 87 percent did so within two years. Perhaps most important, 85 percent claimed that the project improved their quality of life.

The same surveys also confirmed positive ecological impacts. Prior to adoption of MIG, nearly 74 percent of farmers used pesticides, 28 percent over the entire pasture; after adoption, these numbers fell to 54 percent and 3 percent, respectively. Over 72 percent of farmers claimed that manure decayed faster (i.e., nutrient cycling improved) after adoption of MIG, and over 85 percent reported improved soil quality, organic matter, and water retention. Sixty percent of farmers reported more macroinvertebrates in their pastures, attesting to an increase in biodiversity. Total vegetation coverage increased from under 2 percent of pastures to over 72 percent, while areas with scant coverage decreased from over 73 percent to under 2 percent.

Integrating MIG with silvo-pastoral systems further increases ecological and economic benefits. Trees provide essential shade for the cows, protect pastures from drying, cycle nutrients from deeper soil layers to the surface, provide additional fodder, and can also produce fruits and wood. Improved shade cover alone can increase production by 20 percent.[36,41,42]

However, in spite of the numerous benefits of MIG and other agroecosystems, relatively few farmers in our study region have adopted these practices. Transmission is based on farmer-to-farmer communication facilitated by extension workers (i.e., agricultural educators), which consist entirely of members of our research team, their students, and former students. The implementation process is labor and knowledge intensive, involving field presentations to farmer groups at their request; participatory selection of farms to become pilot projects; detailed farm surveys; field zoning; paddock layout; installation of watering systems; forage planning; an economic summary; an implementation schedule; on-farm project evaluation with the farm family; and ongoing evaluation.[43] Many of the costs are covered by the Federal University of Santa Catarina or by grants. While monetary investments for farmers are relatively modest with a quick payback period, credit costs in Brazil are exceptionally high, around 40 percent for standard bank loans.[44] Subsidized credit for agroecology is available from the federal government in limited quantities but can be difficult and time-consuming to obtain, financing only 5.1 percent of farmers in our survey. Another obstacle is the lack of infrastructure, such as roads and milk-processing plants. Farmers must also dedicate time and land to the process. The farmers receive no additional compensation for the off-site ecosystem services they provide.

Restoration of natural areas, as required by law, is even more challenging. Many farmers in our study site would have to reforest 30–75 percent of their arable land, and 89 percent of farmers from our survey stated that only punitive legal measures could force them to comply. Our goal is to develop agroforestry systems that make forest restoration with native fruit, medicinal, ornamental, and timber tree species at least as profitable as pasture. A promising backbone for these systems is *Euterpe edulis*, a threatened native palm that produces the valuable açai fruit, popular in Brazil with soaring demand abroad.[45] We are also trying to integrate forest patches into MIG to further increase ecosystem services and provide both timber and nontimber forest products.[43] Both efforts require resources for research, development, and dissemination. Compensation for ecosystem services provided by agroecosystems could potentially cover the costs associated with their development and adoption.

Institutional Solutions: Scaling Up Agroecology with Payments for Ecosystem Services

Agroecology is only capable of restoring ecosystem services and feeding the world if scaled up substantially, which will require considerable investments. This will require economic institutions that account for the value of the ecosystem services provided. Many authors have proposed payments for ecosystem services (PES) as a solution.[17,24,35,46,47] While PES schemes have proliferated impressively in recent years, there is little clear evidence of success and abundant concerns over equity impacts, efficiency, and the inappropriate commodification of nature.[47–49]

However, there are two radically different approaches to PES. One approach calls for voluntary transactions in which at least one buyer purchases a well-defined ecosystem service (or land use expected to provide it) from at least one provider, and payment is conditional upon provision.[50] This approach seeks to force ecosystem services into the market framework. For example, firms whose CO2 emissions are constrained by law can increase their own emissions if they pay landowners to sequester timber in forestry projects. However, this approach targets the specific service of carbon sequestration, often at the expense of water regulation, biodiversity, or other equally important services.[51]

An alternative approach views PES as a transfer of resources (e.g., money, education, infrastructure, as appropriate) between social actors (e.g., individuals, governments, nongovernmental organizations) “designed to create incentives that align individual or collective land use decisions with the social interest in the management of natural resources.”[52] This approach seeks to adapt economic institutions to the particular characteristics of the ecosystem services and the land uses required to provide them.[5] For example, in a policy known as the ecological value-added tax (ICMS ecológico) pioneered by several Brazilian states, state governments return a portion of sales taxes to municipalities in proportion to the municipalities’ protection of watersheds and conservation areas. Public beneficiaries of ecosystem services reward the public sectors that provide them, resulting in an impressive growth of protected areas at low cost and with low overhead.[53,54]

The fact is that markets are inefficient at promoting agroecology among service providers, because the private sector has limited incentives for providing the public goods required for the dissemination of agroecology or for paying for the primarily public-good ecosystem services that agroecology provides. As we show in the following sections, PES for agroecology should focus on collective-action institutions, which typically means cooperatives, nongovernmental organizations, governments, and international institutions.

Promoting Agroecology among Service Providers

Agroecology substitutes ecological knowledge for external inputs. Not only is agroecology knowledge intensive, but it is also specific to individual agroecosystems. Agroecology practices are best developed by local farmers deeply familiar with local ecosystems and agricultural practices in close collaboration with agroecologists and scientists.[29] Appropriate economic institutions are required to help create and disseminate the necessary knowledge.

Two characteristics of R&D for agroecology suggest that it is best supported by public-sector institutions. First, the results of such R&D, ranging from land-management techniques to new plant varieties, are easily copied by others who did not invest in their development (i.e., R&D is relatively nonexcludable). Farmers have always copied the best practices of their neighbors. An individual firm or farmer may be reluctant to shoulder all the costs of expensive R&D when others can share the benefits for free. Patents are designed to create private property rights to information, allowing the inventor to sell it, thus creating more incentives to invent. However, agroecological technologies can be particularly difficult to patent. Knowledge is created in common and used in common. Resulting practices are best spread horizontally from farmer to farmer, facilitated by extension workers, which allows adaptation to changing ecological, social, and economic conditions.[26,55] Research, development, and dissemination therefore demand significant public investment in outreach and extension programs.[17,26,27]

Second, knowledge is not diminished through use. When patent rights can be enforced, they restrict use to those who pay for a technology. If the technology increases food production and ecosystem services—for example, a high-yielding variety of perennial wheat that sequesters carbon, reduces erosion, and is highly drought resistant—society is clearly better served by unrestricted adoption. Patents solve one problem but create another. Paradoxically, the value of knowledge is maximized at a price of zero, but at that price the private sector will not supply it.[56]

For both of these reasons, the public sector has traditionally dominated agricultural R&D and extension work,[57] with an estimated average rate of return on investment of 65 percent,[58] and should continue to do so.

Agroecology also has direct implementation costs for farmers, many of whom are poor, lack the resources to invest in new production techniques, and, due to their poverty and the inherent risks of agriculture, may not have access to affordable private-sector credit. Not all agroecology programs will work, and failure to repay credit—especially at the high interest rates common in developing nations—can force farmers into a debilitating cycle of debt. Most microcredit schemes have interest rates of 25 percent or more. Once seen as a panacea for rural poverty, microcredit is now frequently compared to subprime mortgages because profit-seeking lenders charge exorbitant interest rates to poor villagers unable to pay.[59] Farmers need affordable credit, which is generally supplied only by the public sector. Furthermore, investment in agroecology should be a cooperative endeavor. Farmers assume large risks in changing their traditional practices, so the beneficiaries of the ecosystem services should shoulder financial risks.

Other public-sector investments required for scaling up agroecology include “storage facilities, rural infrastructure (roads, electricity, information and communication technologies) and therefore access to regional and local markets, access to … insurance against weather-related risks, … and support to farmer’s organizations and cooperatives.”[26,57]

Though government expenditures on public goods for agriculture generate exceptionally high annual returns,[26,57] many government expenditures in agriculture are used to subsidize private goods (e.g., fertilizers, pesticides), with low or even negative social returns, in part because such subsidies are readily targeted toward politically influential (i.e., wealthy) farmers. Simply shifting existing expenditures from subsidies to public investments could increase agricultural output by more than 40 percent in some Latin American countries, while reducing poverty and the negative environmental impacts of output expansion.[57,60]

Our research in Brazil confirms the importance of extension education and credit. Prior to adopting Voisin grazing, nearly 60 percent of farmers surveyed thought that both implementation and subsequent cattle management would be difficult or very difficult, a significant deterrent to adoption. Post-adoption, these numbers fell to 8.2 percent for implementation and 1.6 percent for management. Over 96 percent of the farmers interviewed would recommend MIG to a friend. This suggests that such agroecological practices are likely to spread much faster from farmer to farmer, especially when extension workers facilitate the process—90 percent of our sample claimed that field days with extension workers and other farmers were very important. Thirty-eight percent of surveyed farmers thought that the investment costs were high or very high, presumably placing Voisin grazing out of reach for the poorest farmers.

In sum, the required expansion of agroecology demands public-sector investment. Those who benefit from the ecosystem services generated should provide the resources required.

Capturing Resources from Service Beneficiaries

Different ecosystem services have different physical characteristics, which should determine whether the private sector or collective institutions should finance the ecosystem services benefits from agroecology and also what scale of collective institution is appropriate.

One relevant characteristic is excludability. Is it possible to create property rights to the ecosystem service in question? Most provisioning services, such as the increased yields from agroecology, directly and exclusively benefit landowners, who have a direct incentive to invest in these services’ provision. Similarly, in many circumstances, the benefits from water filtration and erosion control can be exclusively captured by water utilities, water bottlers, breweries, and hydroelectric plants. Some of the most cited success stories in PES involve projects in which such entities have funded upstream farmers to adopt more environmentally friendly practices.[61–63]

However, many regulating, support, and cultural services—such as climate regulation, flood regulation, the ecological resilience provided by biodiversity, and scenic beauty—cannot be privately owned, so there is little direct incentive for landowners to provide them. Such services should be financed or provided through collective action, because the public as a whole inevitably benefits. Costa Rica is the best-known example of a national government, subsidized by the international Global Environmental Facility, paying private landowners directly for greenhouse gas mitigation, biodiversity, water regulation, and scenic beauty.[64] Though forest cover in Costa Rica has increased dramatically, this began prior to the PES scheme, so the overall effectiveness of the program is difficult to determine.[64,65]

Waste-absorption capacity, another service, has long been treated as an open-access regime, in which actors are free to emit nitrogen, phosphorous, greenhouse gases, and other pollutants into the environment. However, government regulations can restrict access and force polluters to pay; in cap and auction schemes (a variation on the cap and trade mentioned previously), collective institutions impose limits on emissions and then auction off permits to polluters. Revenue should be used to finance agroecology and other activities that restore or protect ecosystem services. For example, the Regional Greenhouse Gas Initiative in the northeastern United States caps greenhouse gas emissions from the power sector, auctions off permits, and then invests the revenue in energy efficiency.[66] Most cap and trade schemes create offset markets, which allow polluters to pay others to reduce or sequester emissions. However, offsets subtract from emissions reductions while investments in agroecology add to them.

Biogenetic information was formerly an open-access resource as well, until the international Convention on Biological Diversity created laws that give nations property rights to endemic biogenetic information. Individuals or businesses wishing to use this information must now pay for the right to do so.

This last example leads us to a second important characteristic of ecosystem services, which cannot be affected by institutions: rivalry. Does use by one person leave less for others? It only makes sense to ration access to a service when this is true. For example, global ecosystems have a finite capacity to absorb greenhouse gas emissions. Use by one nation leaves less for others, so access should be rationed, which requires collective action. Those who use the service should compensate society for the right to do so. Cap and auction is an appropriate market-like policy. However, many services are not depleted through use. For example, no matter how many farmers benefit from a particular genetic trait in a crop, that trait remains available to others. Forcing farmers to pay for the genetic traits suitable to a specific agroecosystem hinders adoption. As explained above, using prices to ration access to information, biogenetic or otherwise, is simply inefficient. Society as a whole should finance the provision and protection of biodiversity, while the information it contains should be open access for all.[67]

An important point to bear in mind is that agroecosystems generate numerous services simultaneously. Payment for any single benefit may be inadequate to fund the required scaling-up of agroecology, but payments for all benefits together will likely be sufficient. Private beneficiaries of ecosystem services from agroecology projects, such as downstream hydroelectric plants or water bottlers, could free ride on public provision, further reducing the potential for market-like solutions.

A third characteristic is the spatial distribution of the ecosystem services in question, which determines who is responsible for financing their provision. Landowners or tenants should invest in site-specific services, such as the increased yields from agroecology. Local governments should invest in regional services, such as microclimate regulation, pollination, flood regulation, and disturbance regulation, though ecosystem services of course ignore political boundaries. Cooperative global efforts should finance climate regulation and ecological resilience provided by biodiversity.[68] Developing a global cap and trade scheme for greenhouse gases, with a substantial share of the revenue dedicated to agroecology, is particularly urgent.

Transferring Resources from Beneficiaries to Providers

The remaining challenge for PES is to identify appropriate mechanisms for transferring resources from beneficiaries at multiple scales to the providers of ecosystem services. There should be four separate components.

One priority is to fund the development of appropriate agroecology technologies. The proper approach is to build on existing research centers, including small-scale nonprofit centers such as the Land Institute, which seeks to develop perennial polyculture over coming decades;[69] national centers such as Brazil’s agricultural research corporation Embrapa, a global leader in R&D for tropical agriculture; and international centers such as the Consultative Group on International Agricultural Research (CGIAR), which seeks to increase crop productivity, protect the natural resource base on which agriculture depends, and improve institutions and policy in developing nations.[70] To be eligible for public funding, centers’ missions should focus explicitly on the joint production of ecosystem services and food while minimizing external inputs—a truly green revolution, requiring transdisciplinary science—and resulting technologies should be open access. Diverting funding from the estimated one trillion dollars of perverse subsidies that degrade ecosystem services[71] or using revenue from new greenhouse gas cap and auction schemes would have a double impact on ecosystem services.

A second priority is to fund the dissemination of these technologies through extension education and outreach. Funding for such extension and outreach could come from national, state, and local governments, using revenues collected from activities that affect national ecosystem services under both the polluter pays principle (e.g., payments for waste-absorption capacity) and the beneficiary pays principle (e.g., payments by hydroelectric plants and water utilities for improved water quality and reduced sediment loads). Governments should also directly subsidize public-good services such as flood regulation, pollination, and disease regulation. Some of the poorest countries will require international assistance, justified by the global public goods provided.

A third priority is financing for farmers to adopt agroecology. Because both farmers and financers benefit, a low- or zero-interest credit program with shared risks is promising. National and international beneficiaries of the services provided could establish the initial credit fund, while farmers could contribute their land, knowledge, and labor in a cooperative effort. Farmers would repay loans only if agroecology generates profits, with larger profits meriting higher interest rates to increase the funding pool. Large improvements in ecosystem services would merit increased funding from the beneficiaries.

Finally, additional incentives may be required to scale up agroecology to the level required to provide food and ecosystem services for growing populations. For example, the Brazilian ecological value-added tax (ICMS ecológico) approach, described above, could be adapted to the international level: a share of the revenue from Kyoto carbon auctions could be distributed among countries in proportion to their carbon sequestration and biodiversity enhancements,[67] perhaps using low-cost indicators of forest cover, no-till agriculture, and perennial polyculture as proxies.

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