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Editorial

Agroforestry-Based Ecosystem Services

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1. Introduction

Agroforestry, land use at the agriculture-forestry interface that implies the presence of trees on farms and/or farmers in forests, has a history that may be as old as agriculture, but as an overarching label and topic of formal scientific analysis, it is in its fifth decade. The trees as such, and the agroforestry system they are part of, provide direct benefits to the farmer (land manager), often through a combination of marketable goods, subsistence needs of the farm household, buffering climate variability, and protecting soil and water resources. However, it also provides benefits to those sharing the same landscape, the same watershed, biome, or even planet Earth, the latter especially as part of the global climate and biodiversity conservation discourses. These external benefits are generally discussed under the heading 'ecosystem services' (Figure 1), and are the topic of the collection of papers in this Special Issue.

Figure 1. Agroforestry-based ecosystem services are human benefits achieved beyond the farm scale from the way trees on farm interact with soil and water, carbon storage, and biodiversity and of the cultural/relational aspects of landscapes with partial tree cover.

For this Special Issue, we invited case studies or synthesis papers that achieve the following:

1. Quantify change in ecosystem services in forest–agriculture interface landscapes and relate such to stakeholder concerns and farmer/manager decisions;
2. Analyze efforts to increase the feedback from external stakeholders to land use decisions (including 'agroforestry') within landscapes; and/or
3. Describe and analyze efforts to transcend an existing forestry versus agriculture dichotomy in land use policies.

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2. Quantifying Ecosystem Services

Of the twelve papers in the first category (Table 1), seven have a biophysical/ecological focus and five a social one. For the current discussion, four groups of ecosystem services are important and distinct: provisioning and economic services, soil and water conservation, carbon-related roles in the global climate discourse, and biodiversity-related services. Many papers discuss more than one type of service.

Table 1. Papers quantifying change in ecosystem services related to farmer/manager decisions.

	Biodiversity-Related			
Title and Reference	**Provisioning, Economic**	**Soil & Water**	**Carbon-Related**	**Biodiversity-Related**
Biophysical focus:				
Traditional pollarding practices for dimorphic ash tree (*Fraxinus dimorpha*) support soil fertility in the Moroccan High Atlas [1]	Traditional tree management	Mycorrhiza		Local tree species
Soil organic matter, and mitigation of and adaptation to climate change in cocoa–based agroforestry systems [2]		Corg, water holding capacity	Carbon stocks	Comparing land use systems
Earthworm diversity, forest conversion, and agro-forestry in Quang Nam province, Viet Nam [3]		LU impacts on 'soil engineers'		Earthworm diversity
Assessing context-specific factors to increase tree survival for scaling ecosystem restoration efforts in East Africa [4]	Farmer's technology tested	Tree seedling management		
Tree roots anchoring and binding soil: reducing landslide risk in Indonesian agroforestry [5]		Slope stabilization		Functional tree diversity
Infiltration-friendly agroforestry land uses on volcanic slopes in the Rejoso watershed, East Java, Indonesia. [6]		Infiltration and erosion control		Comparing land use systems
Groundwater-extracting rice production in the Rejoso watershed (Indonesia) reducing urban water availability: characterization and intervention priorities [7]	Rice production using ground-water from AF hillslopes	Water balance effects of lowland water use		
Focus on farmers/managers:				
Fruit tree-based agroforestry systems for smallholder farmers in northwest Vietnam—a quantitative and qualitative assessment [8]	Farmer knowledge, economic analysis			
Local knowledge about ecosystem services provided by trees in coffee agroforestry practices in Northwest Vietnam [9]	Farmer knowledge, preferences	Soil & water protection		Functional tree diversity
Gendered species preferences link tree diversity and carbon stocks in cacao agroforest in Southeast Sulawesi, Indonesia [10]	Gendered tree preferences		Carbon stocks	Functional tree diversity
Agroforestry innovation through planned farmer behavior: trimming in pine–coffee system [11]	Constraints to farmer tree management			
Gendered migration and agroforestry in Indonesia: livelihoods, labor, know-how, networks [12]	Human migration~ AF knowledge			

In agropastoral parklands of the Moroccan High Atlas, traditional practices of managing the local dimorphic ash tree (*Fraxinus dimorpha*), endemic to North Africa, involve pollarding [1]. Compared to soil without trees, the soil under trees was shown to be enriched with phosphorus, nitrogen, carbon, and mycorrhizal spore density, suggesting soil fertility benefits generated by sound agroforest management. Belowground roles of agroforestry in climate change mitigation (C storage) and adaptation (reduced vulnerability to drought) are less obvious than easy-to-measure aspects aboveground. Comparisons between cocoa agroforestry systems, intermediate in properties between remnant forest, and cocoa monocultures [2] showed that increased soil organic matter content can support about a week's worth of evapotranspiration without rain, assisting in climate change adaptation. Agroforestry systems in Viet Nam were also found to be intermediate between natural forest and cropland in terms of earthworm diversity [3]. Out of a total of 25 different earthworm species, 21 were found in natural forests, 15 in agroforestry, 14 in planted forests, and 7 in annual croplands and home gardens. A cosmopolitan species, *Pontoscolex corethrurus*, dominated habitats with intensive anthropogenic activities but was rare in natural forests. The study concluded that protection of the remaining natural forests is urgent, while the promotion of a tree-based farming system such as agroforestry can reconcile earthworm conservation and local livelihoods.

Especially in drylands, tree planting is not enough to get trees growing, and survival rates depend on management. A survey in Kenya and Ethiopia [4] showed low tree survival especially for tree species preferred by local communities, but also local knowledge on options to increase seedling survival in local context. Soil quality ranking was positively correlated with tree survival in Ethiopia, regardless of species assessed, while in Kenya the presence of soil erosion on a farm had a negative effect on seedling survival. The need for watering, manuring, and protection from grazing varied with context and tree species.

Biophysical properties at the plot level influence ecological relationships at the landscape scale. Once established, tree root systems can stabilize hillslopes and riverbanks, reducing landslide risk, but comparisons across a wide range of tree species are rare as research methods are laborious. Observing proximal (close to the tree stem) woody roots and applying fractal allometry hypotheses, a comparison [5] of 55 tree species in Indonesia found differences in the ratio of stem to root cross-sectional area (relative amount of roots) as well as relative distribution in topsoil ('Soil-Root Binding') and subsoil ('Root Anchoring') that both contribute to soil stabilization. The study concluded that a mix of tree species with deep roots and grasses with intense fine roots provides the highest hillslope and riverbank stability.

Rapid infiltration of rainfall into soils is important to reduce surface runoff and erosion on mountain slopes exposed to high-intensity rainfall. The degree of tree cover that is needed to achieve a desirable level of infiltration, however, depends on further characteristics of soil, tree species, and zone-dependent rainfall properties. A study in Indonesia [6] found that for midstream conditions only a tree canopy cover of >80% qualified as "infiltration-friendly" land use, but erosion rates were relatively low for a tree canopy cover in the range of 20–80%. In the upstream watershed, a tree canopy cover > 55% was associated with the infiltration rates needed, as soil erosion per unit overland flow was high. The tree canopy characteristics required for infiltration-friendly land use clearly varied over short distances with soil type and rainfall intensity showing that generic rules, such as a 30% forest cover requirement, cannot be the basis for local resource management using agroforestry concepts. A study of the water balance and the impacts of lowland water use in the same watershed through uncontrolled flow of Artesian wells found that equal attention is needed for the upstream and downstream parts of the watershed if urban water supply is to be secured [7].

The second group of papers described in Table 1 has farmer knowledge, choices, and preferences as their primary focus. Agroforestry practices with fruit trees can be more profitable than sole-crop cultivation within a few years, as data for Viet Nam and two local fruit tree species show [8]. After seven years agroforestry systems with longan

(*Dimocarpus longan*) and son tra (*Docynia indica*) had generated 2.4-times higher average annual income than sole maize, the main comparator in the area. Farmers also reported that agroforestry enhanced ecosystem services by controlling surface runoff and erosion, increasing soil fertility and improving resilience to extreme weather, indicating a win-win in economic and environmental terms, if the initial investment hurdle can be overcome.

Farmer knowledge of ecosystem services provided by trees in coffee agroforestry practices in Northwest Vietnam was found to differ between three indigenous groups surveyed [9]. Most farmers were aware of the benefits of trees for soil improvement, shelter (from wind and frost), and the provision of shade and mulch. In contrast, farmers had limited knowledge of the impact of trees on coffee quality and other interactions amongst trees and coffee. The farmers' selection of tree species to combine with coffee was highly influenced by economic benefits provided, especially by intercropped fruit trees, which was influenced by market access, determined by the proximity of farms to a main road.

Surveys in Southeast Sulawesi of tree diversity on cocoa agroforestry systems [10] showed that gendered preferences for trees partly diverge and may contribute to overall diversity. Male farmers selected timber and fruit tree species with economic benefits as shade trees, while female farmers preferred production for household needs (fruit trees and vegetables). Tree portfolios reflected the preferences of both genders. In agroforestry, tree diversity was found to be proportional to differences in carbon stock, with an intermediate position between the concave relationship in forest decline and the convex one in reforestation responses.

In a specific form of agroforestry in which forest authorities own the land and trees and farmers are allowed to intercrop, ecological management choices reflect the social relations of power. In a setting where farmers have contracts permitting coffee cultivation under pine trees, experiments tested canopy trimming to improve light for coffee production while maintaining tree density [11]. Exploring planned farmer behavior brought 'path dependency' and 'lack of trust' to the forefront as issues to be understood before agroforestry innovation can contribute in the triangle of farmers, forest authorities, and empirical science.

A wider policy perspective is needed to understand the gendered decisions to migrate into or away from areas where agroforestry is practiced in Indonesia [12]. Most of the decision making that the research revealed was linked to perceived poverty, natural resource and land competition, and emergencies, such as natural disasters or increased human conflicts. Movements of a temporary labor force and/or migrants who might still return to their landscape of origin, do contribute to the spread of agroforestry knowledge (and germplasm) between areas of higher and lower human population density, contributing to ecosystem service awareness.

3. Co-Investment in Ecosystem Service Provision by External Stakeholders

Five papers considered the logical next step after recognizing that ecosystem services depend on farmers' land management: co-investment (Table 2).

Table 2. Papers addressing efforts to increase the feedback from external stakeholders to land use decisions (including 'agroforestry') within landscapes.

Title and Reference	**Ecosystem Services**			
	Provisioning, Economic	**Soil & Water-Related**	**Carbon-Related**	**Biodiversity-Related**
Effects of agroforestry and other sustainable practices in the Kenya Agricultural Carbon Project (KACP) [13]	Project impact study		Co-investment in carbon stocks	
Discounted cash flow and capital budgeting analysis of silvopastoral systems in the Amazonas region of Peru [14]	Farm economic analysis			

Table 2. *Cont.*

Title and Reference	Ecosystem Services			
	Provisioning, Economic	**Soil & Water-Related**	**Carbon-Related**	**Biodiversity-Related**
Carbon storage potential of silvopastoral systems of Colombia [15]	Options for national climate policy		Potential increase in silvopastoral tree density	
Enhancing Vietnam's nationally determined contribution with mitigation targets for agroforestry: a technical and economic estimate [16]	Options for national climate policy		Potential increase in various AF systems	

Support for sustainable agricultural land management can also be motivated by global climate change concerns, with externally funded advisory services. An evaluation of the Kenya Agricultural Carbon Project (KACP) [13] concluded that farmers benefitted from increased maize yields after participation in the program that supported terraces and agroforestry practices. Study results, showing that the KACP farms had higher food self-sufficiency and tended to have higher monetary savings than control farms, suggest that, apart from the carbon stock gains that generated the co-investment by external stakeholders, local benefits were clear.

A study of the economic consequences of silvopastoral systems in the Peruvian Amazon [14] found that these were above those for either planted forests or conventional cattle-pasture systems. Benefits could be substantially higher—at least for the farmers pioneering such activities—where farmers generated added-value through on-site retail stands and direct links to customers.

Nine Latin American countries plan to use silvopastoral practices—incorporating trees into grazing lands—to mitigate climate change, but the cumulative potential of scaling up silvopastoral systems at national levels is not well quantified [15]. The range, 5 to 122 Mg ha^{-1}, of carbon stock values in Colombian grasslands in 2017 based on ecofloristic zones, suggests a potential for further increase. If all existing grasslands could be brought to the tree density of the current median or 75th percentile, silvopastoral systems could be a substantive part of nationally determined contributions (NDCs) and nationally appropriate mitigation actions (NAMAs) in Colombia and other Latin American countries with similar contexts.

The Nationally Determined Contributions (NDCs) of several non-Annex I countries already mention agroforestry but mostly without associated mitigation targets. The absence of reliable data, including on existing agroforestry practices and their carbon storage, partially constrains the target setting. A study for Viet Nam [16] tried to fill this gap by synthesizing above- and belowground vegetation and soil carbon for the close to 0.8 M ha of existing agroforestry systems identified. Estimates are that expansion to 0.9–2.4 M ha of agroforestry is technically and economically feasible, to offset the greenhouse gas emissions of the agriculture sector by 2015.

4. Addressing the Agricultural-Forestry Policy Interface

A final group of five papers (Table 3) considered the agricultural-forestry interface, in policy and institutional terms, as essential to the further development of agroforestry.

Table 3. Papers analyzing efforts to transcend the existing forestry versus agriculture dichotomy in land use.

Title and Reference	**Ecosystem Services**			
	Provisioning, Economic	**Soil & Water-Related**	**Carbon-Related**	**Biodiversity-Related**
Agroforestry as policy option for forest-zone oil palm (OP) production in Indonesia [17]	Smallholder OP as AF option	Concerns over OP disturbing hydrology	Concerns over C emissions	Concerns over OP causing deforestation
People-centric nature-based land restoration through agroforestry: a typology [18]	Range of restoration intensities	Subsoil recovery slow	Realistic expectations of tradeoffs	Realistic expectations of tradeoffs
Cost-benefit analysis of landscape restoration: a stocktake [19]	Efficient use of scarce public funds	Realistic expectations of benefits	Realistic expectations of tradeoffs	
Sustainable agroforestry landscape management: changing the game [20]	Social-ecological systems perspective	Need for shared understanding		
Agroforestry-based eco-system services: reconciling values of humans and nature in sustainable development [21]				Relational values (both + and −) of biodiversity are under-studied

With 15–20% of Indonesian oil palms located, without a legal basis and permits, within the forest zone (‘Kawasan hutan’), international concerns regarding deforestation affect the totality of Indonesian palm oil exports [17]. Data analysis showed that ‘Forest zone oil palm’ (FZ-OP) is a substantive issue with substantial geographic variation in intensity within Indonesia that requires analysis and policy change. Responses will need to take the legal basis of the forest zone and its conversion into account, as well as the existing social stratification in oil palm production (large-scale, plasma and independent growers), and the various environmental consequences of forest conversion to FZ-OP depending on the location. Conditional acceptance of diversified smallholder plantings in ‘agroforestry concessions’ is one of the policy options to be considered.

In the decade of ecological restoration, just started, agroforestry can be a major ‘people-centric nature-based’ solution, if contextualized appropriately [18]. Restoration entails innovation to halt ongoing and reverse past degradation. Four intensities of land restoration can be distinguished in their interaction: R.I. Ecological intensification within a land use system, R.II. Recovery/regeneration, within a local social-ecological system, R.III. Reparation/recuperation, requiring a national policy context, and R.IV. Remediation, requiring international support and investment. Relevant interventions start from core values of human identity while addressing five potential bottlenecks: Rights, Know-how, Markets (inputs, outputs, credit), Local Ecosystem Services (including water, agrobiodiversity, micro/mesoclimate) and Teleconnections (global climate change, biodiversity).

With the increase in demand for landscape restoration and the limited resources available, there is need for economic analysis of landscape restoration to help prioritize investment of the resources [19]. However, cost-benefit analysis (CBA) seems limited and varied in its application as a commonly applied tool in the economic analysis of landscape restoration. Of the 2056 studies identified in a literature search, only 31 met the predefined criteria of rigor and relevance. About 60% of those focused on agroforestry, afforestation, reforestation, and assisted natural regeneration practices, but only 16% covered all cost categories, with opportunity costs being the least covered. Eighty-four percent apply direct use values, while only 16% captured the non-use values. The study thus suggests a strong need for improvements in both the quantity and quality of CBA to better inform planning, policies, and investments in landscape restoration.

While location-specific forms of agroforestry management can probably reduce problems in the forest–water–people nexus by balancing upstream and downstream interests, social and ecological finetuning is needed and requires a shared understanding of the underlying relations. ‘Serious games’ have been shown to contribute to such understanding but they so far (1) appear to be ad hoc and case-dependent, with poorly defined extrapolation domains, (2) require heavy research investment, (3) have untested cultural limitations, and (4) lack clarity on where and how they can be used in policy making. The final contribution to this special issue in this section [20] addresses ways to overcome these four challenges through a more systematic approach to game prototypes linked to a typology of forest–water–people nexus issues, in which agroforestry-based ecosystem services can be appreciated.

5. Re-Imagining Agroforestry-Based Ecosystem Services

Beyond directly responding to the three questions raised in the call for papers for the special issue, the concept of agroforestry-based ecosystem services itself evolved [21] as part of the broader debates on Sustainable Development Goals and the multifunctionality of land use, understood as a mosaic of forests, agroforestry, agriculture, and urban areas, at coarse or finely grained mosaic of interacting components. New perspectives that were introduced in [20] but elaborated in [21] include the balance between relational (two-way, reciprocal relations) and instrumental (goal-oriented, substitutable) value articulation on ecosystem functions relevant for human well-being at local, national, and global scales. Whereas the 'ecosystem services' language emphasized human benefits, part of which can also be substituted by technical means (potentially at higher cost) and are thus nice to have but not essential. The tone of the debate is changing, with the realization that tinkering with all non-human life on this planet is a huge risk to humanity. The recent "making peace with nature" report [22] urges for a coherent approach to climate change, loss of biodiversity, and pollution as part of reimagining and transforming the ways in which the values of humans and nature are reconciled. An ambitious vision of the way agroforestry can be part of the solution needs to connect local to global scales and vice versa.

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