RUFORUM Working Document Series (ISSN 1607-9345), 2019, No. 18 (1): 749 - 758.
Available from http://repository.ruforum.org

Research Application Summary

Trade-offs and synergies between agricultural production and biodiversity conservation in contrasting socio-ecological landscapes of South-western Ethiopia

Dereje, B. J.

Department of Natural Resources Management, College of Agriculture and Veterinary Medicine, Jimma University, P. O. Box 307, Jimma, Ethiopia

Corresponding author: drj_bekele06@yahoo.com

Abstract

According to the global sustainability goals, achieving food security and biodiversity conservation are among the most critical challenges of the 21st century. They are, there tore, central aspects of the US sustainable development goals, and also of the development agenda of the African Union. In addition, the discourse about the need to shift the widely recognized trade-offs between agricultural production and biodiversity conservation to overlaps or synergies is also receiving top attentions by different actors at various levels in recent times. Accordingly, the ambitious growth and transformation plan, and the green development strategy of Ethiopia recognize that the trade-offs between agricultural development expansion and biodiversity conservation interventions should be shifted to synergies so that they would complement each other rather than competing with another. This paper reviews empirical studies on the nexus between agricultural development expansion and biodiversity conservation, and thereby identifies the trade-offs and synergies between them, with special emphasis in the contrasting socio-ecological landscapes of coffee production systems in South-western Ethiopia. The review focuses on the synthesis of trade-offs between provisioning and regulating ecosystem services representing agricultural production and biodiversity conservation, respectively. The review indicates that there are different types and levels of trade-offs between provisioning and regulating ecosystem services that vary according to the multiple factors operating in the multi-functional socio-ecological landscapes. Creating synergies and harmony between these trade-offs, therefore, requires sound landscape governance system designed on the basis of multi-criteria analysis (socio-economic and demographic aspects; ecological aspects; as well as effective policy systems and institutional set-ups). Management interventions, such as natural or organic coffee certification, and promotion of climate-smart agriculture can be used for reconciliation of the competing interests on the ecosystem services.

Key words: Coffee production, Ethiopia, food security, green development, multi-criteria analysis, provisioning services, regulating services, services provision

Résumé

Selon les objectifs mondiaux de développement durable, la sécurité alimentaire et la conservation de la biodiversité comptent parmi les défis les plus critiques du 21e siècle. Elles constituent des aspects centraux des objectifs de développement durable des États-Unis, ainsi que du programme de développement de l'Union africaine. En outre, le discours sur la nécessité de déplacer les compromis largement reconnus entre la production agricole et la conservation de la biodiversité vers des chevauchements ou des synergies fait également l'objet d'une attention particulière de la part de différents acteurs à différents niveaux ces derniers temps. En conséquence, l'ambitieux plan de croissance et de transformation et la stratégie de développement écologique de l'Éthiopie reconnaissent que les compromis entre l'expansion du développement agricole et les interventions de conservation de la biodiversité doivent être déplacés vers des synergies afin qu'ils se complètent plutôt que de se concurrencer. Cet article passe en revue les études empiriques sur le lien entre l'expansion du développement agricole et la conservation de la biodiversité, et identifie ainsi les compromis et les synergies entre eux, avec un accent particulier sur les paysages socio-écologiques contrastés des systèmes de production de café dans le sud-ouest de l'Éthiopie. La revue se concentre sur la synthèse des compromis entre l'approvisionnement et la régulation des services éco systémiques représentant respectivement la production agricole et la conservation de la biodiversité. L'examen indique qu'il existe différents types et niveaux de compromis entre l'approvisionnement et la régulation des services éco systémiques qui varient en fonction des multiples facteurs opérant dans les paysages socio-écologiques multifonctionnels. La création de synergies et d'harmonie entre ces compromis nécessite donc un système de gouvernance solide du paysage conçu sur la base d'une analyse multicritères (aspects socio-économiques et démographiques ; aspects écologiques ; ainsi que des systèmes politiques et des structures institutionnelles efficaces). Les interventions de gestion, telles que la certification du café naturel ou biologique et la promotion de l'agriculture intelligente face au climat peuvent être utilisées pour concilier les intérêts concurrents sur les services éco systémiques.

Mots clés : production de café, Éthiopie, sécurité alimentaire, développement écologique, analyse multicritères, services d'approvisionnement, services de régulation, prestation de services

---

Introduction

As per the global Sustainability Development Goals (SDGs), addressing issues of food security and biodiversity conservation are among the most critical challenges of the 21st century (Jan *et al.*, 2017). Despite some improvements in global food production, FAO (2015) report indicated that many people (approximately 800 million people) remain undernourished. On the other hand, efforts made to ensure food security, stich as the expansion and intensification of agriculture, continue to be the major causes of biodiversity losses. As a result, the challenges of achieving food security and conserving biodiversity are believed to involve a trade-oft, especially in farming landscapes of developing countries like Ethiopia. The majority of people in Africa (about 70%), and roughly three-fourths of poor people of the continent live in rural areas. These poor rural people mainly depend on agriculture as a means of their livelihoods. However, they are increasingly unable to meet their basic food needs as population pressure on land resources grows (Shilomboleni, 2017). Agriculture is, therefore, identified as a major contributor to land transformation and hence, in most cases, it is identified as a threat to biodiversity conservation and ecosystem services (EESs), which are vital to human well-being and from which agriculture itself benefits. Deforestation, on the other hand is a major threat to biodiversity and many ecosystem services, and it is closely linked to agricultural expansion. It is evident that the major underlying cause for deforestation (leading to other immediate drivers such as agricultural land expansion, and others), especially in the context of developing countries like Ethiopia, is the rapid and continuous human population growth.

On the other hand, since 1990s, Ethiopian Government has developed a long-term economic development strategy called Agricultural Development Led Industrialization (ADL1) which is the Government's overarching policy response to Ethiopia's food security and agricultural productivity challenges. The strategy focuses primarily on expansion of large-scale commercial farms and improving productivity in smallholdings.

In addition, as per its current Growth and Transformation Plan (GTP II: 2015/ 16-20 19/20), Ethiopia aims to achieve middle-income status by 2025 while developing a green economy is planned to be used as a guiding strategy. It has been well recognized that following the conventional development path would result in many adverse effects, among which a sharp increase in greenhouse gas (GHG) as emissions and unsustainable use of natural resources would be the major ones. The Ethiopian Government has, therefore, developed a Climate Resilient Green Economic (CRGE) development strategy to avoid such negative effects. Implementing the strategy would offer important co-benefits, which include improving public health through better air and water quality, and promoting rural economic development by increasing soil fertility and food security. To realize these benefits, the strategy recognizes the need of maintaining healthier and well functioning natural ecosystems.

Among the important pillars identified and planned to support the implementation of the Ethiopia's CRGE development strategy, agriculture and forestry are the major ones. In connection with the agricultural development sector, improving crop and livestock production practices for ensuring food security and enhancing farmers' income while reducing GHG emissions are being emphasized. On the other hand, the forestry sector is targeting on protecting and re-establishing forests for their contribution in economic development, biodiversity conservation and ecosystem services, including as carbon stocks. This means that the CRGE development strategy of the country requires that the trade-offs between agricultural development expansion and biodiversity conservation activities should be shifted to synergies so that they would complement each other rather than competing with one another. This paper, therefore, reviews research findings from previous studies on the nexus between agricultural development expansion and biodiversity conservation. Subsequently, it identifies the trade-offs and synergies between them, with special emphasis on the contrasting socio-ecological landscapes of coffee production systems in South-western Ethiopia. The review involved an in-depth analysis on the levels of competitions and overlaps among various ecosystem services (such as provisioning and regulating services) under different scenarios of coffee-based production systems.

Methodological approach

Review of various published literatures of empirical studies on the nexus between provisioning ecosystem services (mainly represented by agricultural production) and regulating services (represented by various ecosystem services resulting from biodiversity conservation) was made. The review mainly focused on identifying different kinds of trade-offs and options for synergies between agricultural production and various kinds of regulating ecosystem services. In addition to the review made from general perspective, review of empirical evidences in specific context of contrasting soc io-ecological landscapes in south-western Ethiopia with different gradients of coffee density was undertaken. These coffee production systems were purposively considered because coffee is an important agricultural commodity both for the national economic development and also for smallholder farmers' socio-economic wellbeing. The systems also represent different levels of trade-offs among various ecosystem services depending on the management regimes of the socio-ecological landscapes.

Trade-offs among Provisioning and Regulating Ecosystem services. I t has been widely reported that major ecosystem degradations and simultaneous failures in multiple ecosystem services are highly connected to each other (Carpenter *et al*., 2006). For example, the dry lands of sub-Saharan Africa provide one of the clearest cases where these multiple failures of ecosystem services have resulted in many consequences: failing crops and grazing, declining quality and quantity of fresh water, and loss of tree cover. On the other hand, a synthesis of over 200 cases of investments in organic agriculture showed that the implementation of various novel agricultural techniques and practices could result in a reduction of ecosystem service trade-offs in many developing countries around the world (both dry lands and non-dry lands), even as crop yields increased (Pretty *et al.* , 2006, cited in Elmqvist *et al.*, 2011). This implies that, with the appropriate knowledge, incentives and institutions at hand, multiple failures can be avoided and synergies can be created.

Figure. 1 below, for example, illustrates a range of possible trade-offs between provisioning and regulating ecosystem services (Elmqvist *et al.*, 2011). As it can be seen from the graph (Fig. 1), there is a steep decline in regulating services even with a moderate increase in provisioning services production in type 'A' response; while in type ' B' response, there is a linear relationship and in type 'C', levels of provisioning services may increase to very high levels before there is a decline in regulating services. Therefore, the supply of regulating ecosystem services can be low, intermediate or high for a similar level of provisioning services depending on the type of response.

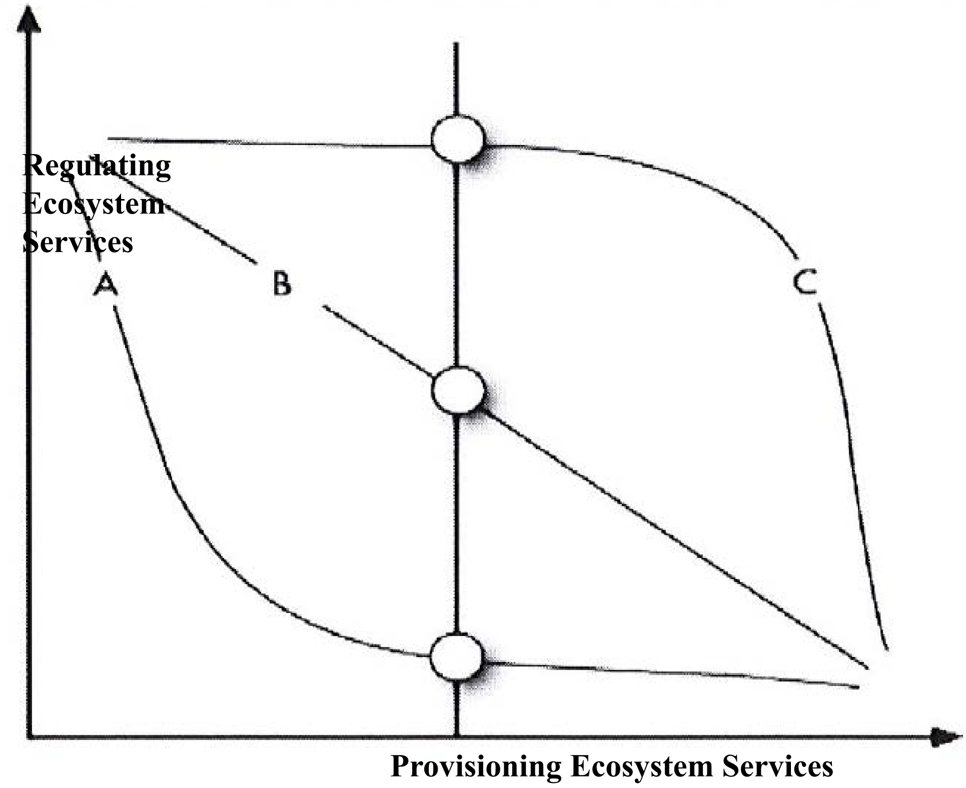

Figure 1. The potential trade-offs between provisioning services (e.g. food, timber) and regulating services (e.g. soil quality maintenance, pollination, biological control and water regulation, etc

The major task for the researchers in the contemporary disciplines of forestry and agriculture is, therefore, to design and undertake studies which can generate information on how the existing production system with often strong negative effects on regulating services - type 'A' response, can be transformed into type 'B' or even type 'C'.

Major Regulating Ecosystem Services considered in the trade-offs. According to the classification by 'The Economics of Ecosystems and Biodiversity, TEEB (2009, reported in Elmqvist *et al.*, 2011)', regulating ecosystem services include: cl innate regulation, water regulation, biological control, pollination, maintenance of soil quality and erosion prevention and hazard control. These services may exhibit different thresholds in response to e.g. land cover change; and the capacities of ecosystems to provide the services are based on complex processes and interactions taking place within the ecosystems. A short review of current knowledge about the dynamics of these services is summarized below (based on TEEB, 2009):

Climate regulation. Different ecosystems have a climate regulation role to widely varying extents. Forests, for example, are the only major ecosystems where the amount of carbon stored in biomass of the plants exceeds that in the soil implying that deforestation can substantially affect climate regulation role of the forest ecosystem. As a results of the intensive production methods, agricultural ecosystems currently have low soil carbon stores, and there is scope for enhancing those stores depending up on the agricultural practices being used.

Water regulation. Water regulation roles of ecosystems also vary with their types and qualities. Accordingly, a very good vegetation cover is a major determinant of water flows and quality. For regulating water flow and improving water quality, ecosystems such as forest and wetlands with intact groundcover and root systems are considered very effective. There are a variety of routes through which water reaches freshwater stores (lakes, rivers, aquifers). These routes include direct precipitation, surface and subsurface flows and human intervention. In almost all cases, the water quality is altered by the addition and removal of organisms and substances.

Biological control. Even though the relationship between densities of natural enemies and the biological control services they provide is unlikely to be linear, certain levels of their diversities and distributions are important. This means that the biological control functions of ecosystems may decline disproportionately when a certain tipping point in natural enemy diversity is passed.

Pollination. Pollination services of ecosystems can become too scarce or too unstable if the pollinator species/functional diversity is below a certain threshold level. At a landscape context, such a tipping point might occur when sufficient habitat is destroyed that the next marginal change causes a population crash in multiple pollinators. The other possible alternative is that a threshold in habitat loss may lead to the collapse of particularly important pollinators, leading to a broader collapse in pollination services of the ecosystems.

Maintenance of soil quality. There are different factors that can govern the process of soil formation. These factors include: the nature of the parent materials, biological processes, topography and climate. The major characteristic of the development of most soils is the progressive accumulation of Organic materials, which in turn depends on the activity of a wide range of microbes, plants and associated organisms. Nutrient cycling, which occurs in all ecosystems and is strongly linked to productivity is the major determinant of soil quality. A key element in the nutrient cycling is nitrogen, which occurs in enormous quantities in the atmosphere and is convened to a biologically useable form by bacteria.

On the other hand, nitrogen fertilizer is becoming ever more expensive with about 90% of the cost directly related to use of energy (typically from gas) and supplies are therefore not sustainable, especially to the smallholder poor farmers. Therefore, nitrogen fixation by organisms, which accounts for around half of all nitrogen fixation worldwide, has to be considered for sustainable agricultural systems increasingly in the future.

Erosion prevention. Vegetation cover contributes to soil erosion prevention through different mechanisms, such as interception of the rain drops by the canopies and through their root system. Forests, in steep terrains, for example, protect against landslides by modifying the soil moisture regime. The ecosystem service for erosion prevention is generally not species specific or dependent on biodiversity in general, though in areas of high rainfall or extreme runoff events, forests may be more effective than grassland or herb-dominated communities.

It may generally be concluded from the above review that, despite the high uncertainty, to varying degrees these regulating services may respond along the A, B or C response curves in Figure 1 above as provisioning services increase (corresponding to a specific land use/cover change) depending on the specific spatial and temporal context. The important question to be asked here is, therefore. are there strategies in designing production of provisioning services and the socio-ecological landscape management that can reduce the likelihood of type A response and increase the likelihood of type B or even type C responses? In the section below, the potential of such management is illustrated with an example of one important provisioning service, coffee, considering its different production system in South-western Ethiopia.

Trade-offs between Coffee production as a Provisioning service and other Regulating services. lt is evident that the high forests of South-western Ethiopia are the centre of origin of Arabica coffee, Coffea Arabica; and still, more or less wild coffee populations are found throughout these forests (Woldemariam, 2003 ; Schmit, 2006, cited in Elmqvist *et al*., 2011). People living in agricultural landscapes surrounding these forests and forest fragments utilize this coffee by picking the berries from scattered shrubs in the natural ecosystems, and also by managing certain areas within the forests to increase coffee productivity. Clearing some forest understory and increasing coffee density below the canopy of indigenous trees through planting or by allowing natural regeneration are commonly practiced activities in the area. There is thus a gradient in coffee density within the forest ecosystem from true forest coffee to semi-forest coffee systems where most small trees and shrubs have been removed in favour of coffee. In addition to these systems with continuous canopy cover, smallholder farmers also cultivate coffee in home gardens below selected shade trees.

These various land-uses with coffee production vary in terms of both provisioning ecosystem services and regulating ecosystem services ranging from low yield/ ha in forested landscapes to very high yields in areas of intense inputs of fertilizers and pesticides and with regulating services showing responses from type A to type C (Fig. 2).

A s shown in the Figure 2, forest coffee represents more or less wild-harvested coffee with rather low yield per ha, but where regulating ecosystem services are largely maintained in the landscape. On the other hand, sun coffee is high-yielding under intense input of pesticides and fertilizers but with much reduced biodiversity and other regulating services in the landscape. An intermediate kind of trade-off, where different management interventions may result in the same yield per ha but with very different impacts on regulating services (type A, B and C-responses) is represented by the shade grown coffee. In this specific case, levels of regulating services are determined by density and diversity of trees maintained for provision of coffee shade. Therefore, different management interventions can be designed for achieving type-C response through enhancing the economic value of coffee (e.g. through coffee certification as organic product) without further degrading the other ecosystem services.

Synthesis and Discussion on Nexus between Food production and Biodiversity conservation According to the Millennium Ecosystem Assessment (2005), the existing perception about the role of biodiversity in food security has been influenced. As a result, the four pillars of food security, health, and nutrition (food availability; access to food; utilization of food; and, stability of food supply) are believed to inextricably linked" with the health of natural ecosystems and the biodiversity they contain. A landscape, consisting of a mosaic of various ecosystem types (forests, croplands, water bodies, infrastructure, etc.) in which ecosystem functions are optimized to meet social, ecological, and economic demands, is the foundation for the delivery of various Ecosystem Services (ESSs). I n such multi-functional landscapes, biodiversity is a critical component of the ecological functioning resulting in the various Ecosystem Services that are vital for human welfare.

Biodiversity conservation and food security are now increasingly perceived as complementing to each other despite the fact that they were considered to be in usually exclusive in the past (Tscharntke *et al.* , 2005; Brussaard *et al.* , 2010, cited in Paul *et al.*, 2017). With food security high on the current development agenda, it is necessary to understand how biodiversity can contribute to a food and nutrition-secutre future. The narrow focus by many ecologists and conservation biologists, where biodiversity conservation is emphasized only in non-agricultural ecosystems, fails to recognize the role that biodiversity plays in agricultural production system. The majority of the world's biodiversity, particularly in the tropics, resides outside of the protected areas, often in complex, multi-functional landscapes, which are managed by farmers and recognized to have their role the food production system.

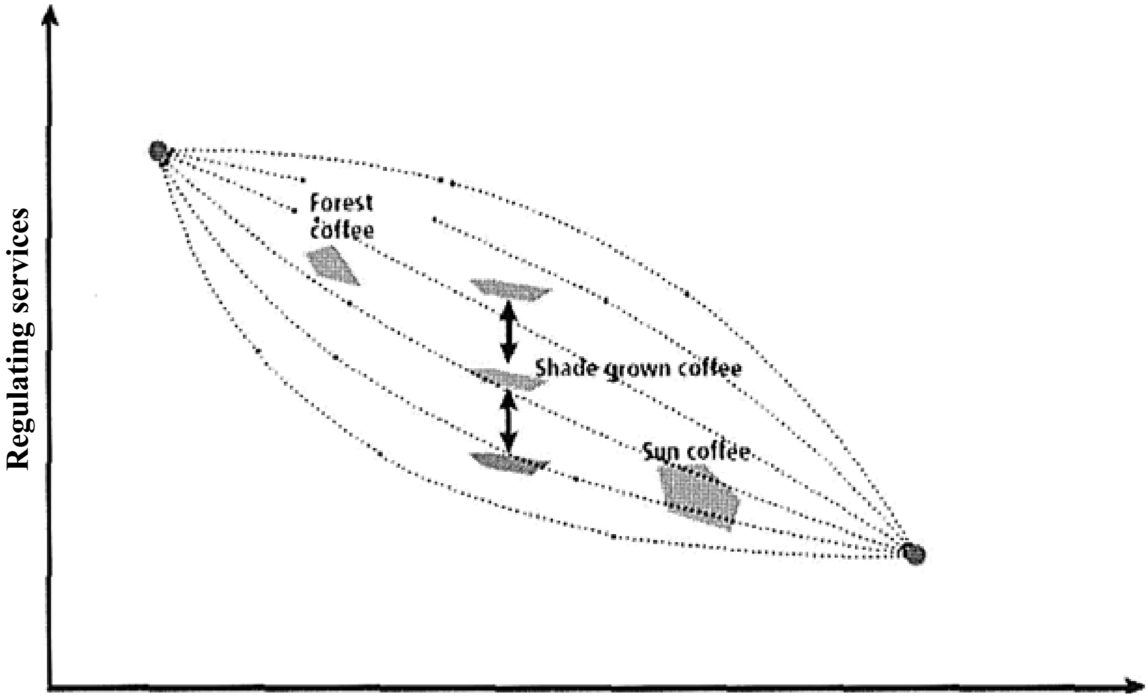

Figure 2. Different kinds oT Irade-ois in coHee prod ucfion sysfems où !South-western E thiopia

According to Paul *et al.* (2017), despite the reported huge number of biodiversity species (approximately 7000 plant species and several thousand animal species) that have been used in human history for food and medicine, only 12 plant crops and 14 animal species provide 98% of the human requirements for food. Among these, three crops alone- wheat, rice, and maize account for more than half of global energy consumption. This situation of increasing uniformity of agricultural production has resulted in the elimination of many wild relatives of crop and livestock species. Moreover, the majority of crop genetic diversity (about three-quarters) has been lost in the past century. This genetic erosion compromises food security, nutrition, and health, because relying on a narrow genetic base makes agricultural production vulnerable to biotic and environmental stresses, and, consequently, yield failures.

The increasing trade-off between food production and biodiversity is known to be the outcome of the inherent conflict between an ever-growing human population and finite natural resources. By raising production efficiency through intensification to meet the growing food demand, for example, biodiversity is being reduced, and this, in turn, reduces the degree of Ecosystem Services that support the food production system itself (Myers *et al.*, 20 13). This can also have other dramatic consequences in addition to affecting the sustainable food production. Pollination, for example, is just one Ecosystem Ser vice that is provided by biodiversity and the role of which is consistently underestimated. Pollination services can be replaced by human activity only at a very high cost. lt is reported that the global economic value of pollination of the main food crops by insects such as bees was estimated at 153 billion in 2005, which is about 9.5% of the value of global agricultural food production of that year (Gallai *et al*., 2008, reported in Paul *et al*., 2017). Despite their such huge economic importance, worldwide decline of pollinators is observed due to various threats such as diseases, climate change, invasive species, habitat loss, and large-scale agro-industries based on the high input of chemicals (FAO, 2008).

Loss of biodiversity in different kinds of ecosystems (both within and beyond agricultural ecosystems) can generally affect food availability and choices, as well as income and wealth creation as a result of diminishing provisioning ESSs. Hence, biodiversity is not only a feature of food security (as provisioning Ecosystem Service), it also affects the ability of cropland to rely on regulating Ecosystem Services from adjacent land that act to provide water and pest control, among other services. Therefore, a balance has to be found among the various Ecosystem Services in multi-functional landscapes (Cardinale *et al*., 2012). Application of the principles of Climate-smart Agricutitre (CSA), for example, offers a variety of options that address the whole food production system, including ecosystem-based agricultural management (conservation agriculture, agroforestry, crop residue management, water harvesting, and crop diversification). Increased productivity gains within such improved systems may benefit from the feedback effects by which biodiversity raises productivity; and such effects have to be identified and quantified across a variety of landscapes and ecosystems.

In support of making rational decisions, Millennium Ecosystem Assessment (2005) indicated that there were some studies that coin pared the total economic value of sustainable management of ecosystems with other management regimes involving conversion of the natural ecosystems into other land uses or unsustainable practices. These studies indicated that the benefit of managing the ecosystem more sustainably exceeded that of the converted ecosystem (Fig. 3), even though the private benefits, that is, the actual monetary benefits captured from the services entering the market would favour conversion or unsustainable management. These studies are consistent with the understanding that market failures associated with ecosystem services least of greater conversion ot ecosystems than is economically justified. Therefore, designing effective marketing system has to be an integral part of the overall management strategies required for balancing the conflicting interests on ecosystem services.

Conclusion

The extent of trade-offs between agricultural production and biodiversity conservation can generally vary depending up on the various socio-economic and ecological settings, as well as the existing governance system within the scope of a broader socio-ecological landscapes. Therefore, achieving desired levels of synergies and harmony among the var ions ecosystem services in general and between provisioning and regulating services in particular require due consideration of multi-criteria analysis in the specific context of multi-functional socio-ecological landscape. Accordingly, ensuring the best balance between coffee production as a provisioning service and other ecosystem services in coffee producing landscapes of south -western Ethiopia requires sound landscape governance that takes into account multiple dimensions, such as socio-economic and demographic aspects; ecological aspects; as well as effective policy systems and institutional set-ups (including effective market systems).

Acknowledgement

This paper is a contribution to the Fifteenth RUFORUM Annual General Meeting held 2-6 December 2019 in Cape Coast, Ghana.

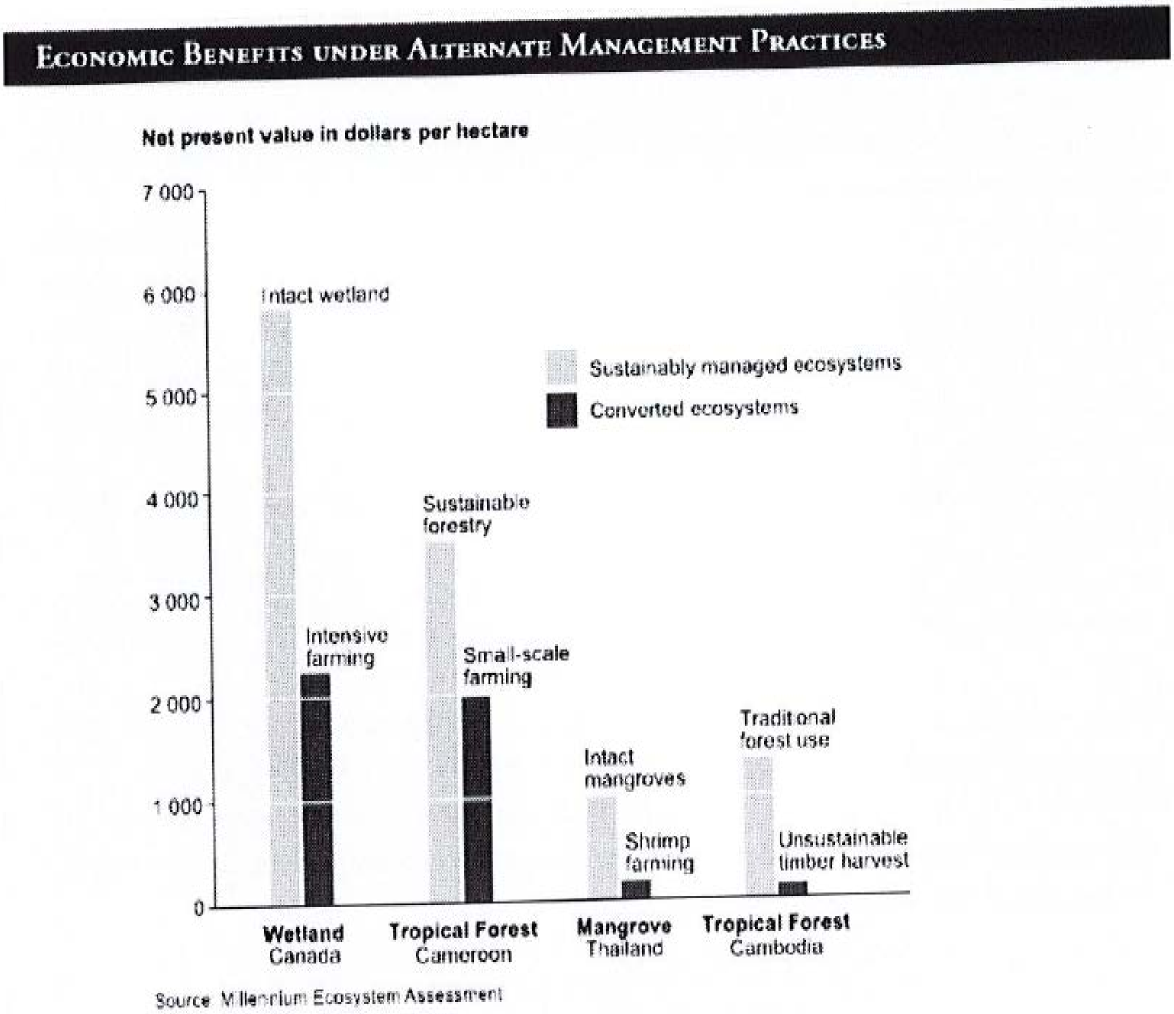

Figure 3. Economie Benehts of Ecosystems under Alternative Management Practices

References

Cardinale, B.J.. Duffy, J.E., G onzalez, A., Hooper, D. U., Perrings. C. and Venail, P.N. 2012. A. Biodiversity loss and its impact on humanity. *Nature* 486: 59 - 67.

Carpenter, S.R.. DeFries, R., Dietz. T., Mooney, H.A., Polasky, S., Reid, W.V, and Scholes, R.J. 2006. Millennium Ecosystem Assessment: Research needs. *Science* 314: 257-258.

Elinqvist, T., Tuvendal, M., Krishnaswamy, J. and Hylander K. 20 1 1. Managing Trade-offs in Ecosystem Services. UN Environment Program.

Food and Agriculture Organisation (FAO). 2008. Biodiversity to Curb World's Food 1 nsecurity; Food and Agriculture Organisation: Rome, Italy.

Food and Agriculture Organization (FAO). United Nations Convention to Combat Desertification UNCCD, 20 15. Global Mechanism. Sustainable Financing for Forest and landscape Restoration: OppoHunities, Challenges and the Way Forward; Discussion Paper. FAO: Rome, Italy.

Hanspach, J., A bson, D. J., French, Collier, N., Dorresteijn, I., Schultner, J. and Fischer, J. 20 l7. From trade-offs to synergies in food security and biodiversity conservation. *Frontiers in Ecology and the Environment* 15 (9): 489-494.

Millennium Ecosystem Assessment (MEA). 2005. Ecosystems and Human Well-Being: Synthesis; Millennium Ecosystem Assessment: Washington, DC, USA.

Myers, S., Gaffikin, L,, Golden, C., Ostfeld, R., Redford, K., Ricketts, T., Turner, W. and Osofsky,

S. 20 13. Human health impacts of ecosy stew alteration. *Proc. Natl. Acad. Sci. USA* 110: 18753-18760.

Shilomboleni, H. 20 17. The African Green Revolution and the Food Sovereignty lvlovement. Contri biitions to Food securitVlek, P. L., Khamzina, A., Azadi, H., Bhaduri, A., Bhafati, L., Braimoh, A. and Taheri, F. 20 17.Trade-offs in multi-purpose land use nuder land degradation. *Sustainability* 9 (12): 2196.