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Contribution of Forest Ecosystem Services Toward Food Security and Nutrition

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Keywords
Forest ecosystem · Food security · Environmental sustainability · Biodiversity · Trees

Definition

Forest ecosystem services can be explained in three interrelated frameworks i.e. (i) Natural Resource Accounting framework (NRA) and/or Non-timber Forest Products framework, which entail direct use benefits, indirect use benefits and intermediate use services, (ii) Ecosystem Services (ES) which comprises ecosystem processes (supporting services) and ecosystem services (provisioning services, regulating services and cultural services), and (iii) Sustainable Forest Management (SFM) (Dlamini and Samboko 2017).

The working definition of food security for this chapter was adopted from the World Food Summit of 1996. The World Food Summit definition states that: "Food security exists when all people, at all times, have physical and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life" (World Food Summit 1996).

Introduction

This chapter discusses how forest ecosystem services (FES) can contribute toward food security in the context of Sustainable Development Goal 2, which seeks to end hunger, achieve food security and improved nutrition, and promote sustainable agriculture. FAO (2016) states that 1.6 billion people rely on forests.

Current projections indicate that the world's current population of nearly 7.4 billion will continue growing, reaching 8.5 billion in year 2030, 9.7 billion in year 2050, and exceeding 11 billion by 2100 (2017 UN World Population Prospects). Population growth will occur mainly in poor countries, in the developing world, and predominantly in Africa (Dawson et al. 2013). Presently, there is a global decline in agricultural production in contrast to the sporadic rise experienced during the latter part of the twentieth century. This indicates that the demand for food might soon exceed the world's production levels. Therefore, there is an urgent need to seek alternative sources of food hence the consideration of forest and related ecosystems in enhancing food security, which has been a largely unexplored phenomenon (Carrasco et al. 2016; Cruz-Garcia et al. 2016), until recently (Cruz-Garcia et al. 2016).

W. Leal Filho et al. (eds.), *Zero Hunger*,
https://doi.org/10.1007/978-3-319-69626-3_67-1

In most developing countries, forests and related ecosystems are mostly seen as a nuisance that needs to be cleared in order to expand agriculture (Aju 2014). However, the world has become more aware of the need for sustainable development, where forests and related ecosystems have a substantial role to play toward the attainment of the Sustainable Development Goals (Swamy et al. 2018). Thus, concerns over the indiscriminate exploitation of natural resources and its impacts on the environment have led to the concept of natural and environmental resource economics and policy. This culminates in forest accounts, i.e., allows for quantification of the real value of forest ecosystems and their potential contribution to all the pillars of food security at local, national, regional, and global scales (Aju 2014; Turpie et al. 2015; Vira et al. 2015). The contributions of forest ecosystems to food security include their role in environmental protection, being sources of household income and employment for the rural poor (Shackleton et al. 2011; Mulenga et al. 2012; Mofya-Mukuka and Simoloka 2015; Rowland et al. 2015; Vira et al. 2015; Dlamini and Samboko 2017; Delvaux and Paloma 2018). For example, it has been shown that while environmental income contributes 28% of total household income globally, 77% of that proportion comes from natural forests and woodlands. Likewise, non-timber forest products (NTFPs) contribute 45% of rural household income in Burkina Faso (Leßmeister et al. 2018). These benefits and services improve crop and livestock production and enhance food availability or increase the capacity of people to buy sufficient food. Recent studies suggest that contrary to the deep-seated false dichotomy between forestry and agriculture, convergence and cooperation of experts from agriculture and forestry is an imperative to effectively fight persistent hunger and associated malnutrition (Shackleton et al. 2011; Aju 2014; Mofya-Mukuka and Simoloka 2015; Rowland et al. 2015; Vira et al. 2015; Carrasco et al. 2016). Likewise, FES and biodiversity are the center pivot to numerous strategies aimed at enhancing agricultural production and productivity for better food and nutrition security outcomes (Shackleton et al. 2011; Mulenga et al. 2012; Mofya-Mukuka and Simoloka 2015; Vira et al. 2015). This concurs with Ickowitz et al. (2014) who found a positive correlation between tree cover and dietary diversity (a proxy for nutrient diversity of diets in Africa).

The subsequent sections follow up on the introduction and lay the foundation and elaborate on the concepts of FES and food security. This gives a clear perspective of the internationally accepted and widely adopted frameworks for FES and food security, which immediately shows that these concepts are interdependent. Later, the nexus between ecosystem services (ES) and food security is critically interrogated, challenges are highlighted, and options are explored.

Conceptual Framework for FES and Food Security

Forest Ecosystem Services in Perspective

This chapter is based on the understanding and conceptualization of three interrelated theoretical frameworks, namely, (i) the natural resource and environmental accounting framework (NRA) which is similar to the NTFPs framework, (ii) the ecosystem goods and services framework (ES), and (iii) the sustainable forest management framework (SFM). The first two frameworks seek to define the vast array of FES (or simply ecosystem services) in general terms, while the third is about the sustainability of ecosystem functions as well as ecosystem goods and services. A brief discussion of these frameworks follows.

Firstly, as displayed in Table 1, the NRA framework/NTFPs framework values forests and related ecosystems based on three dimensions: (i) direct use benefits, (ii) indirect use benefits, and (iii) intermediate use services (Shackleton et al. 2011; Dlamini 2007; Dlamini and Geldenhuys 2009, 2011; Dlamini 2013; Turpie et al. 2015; Vira et al. 2015; Dlamini and Samboko 2017). Notably, this framework is related to the ES framework in that direct use services could be interpreted as provisioning services, while indirect use benefits could be regulatory services, and intermediate use services are supporting services.

Contribution of Forest Ecosystem Services Toward Food Security and Nutrition, Table 1 Examples of direct use benefits, indirect use benefits, and intermediate use services from forest and related ecosystems

Direct use benefits	Indirect use benefits	Intermediate use services
1. Timber for construction and furniture 2. Wood for crafts and household tools 3. Fire wood/fuel wood 4. Construction poles 5. Wild fruits 6. Wild vegetables 7. Wild herbs 8. Honey 9. Bushmeat 10. Insects for food 11. Bird eggs 12. Medicinal products 13. Thatch 14. Grass hand brushes 15. Twig hand brushes 16. Weaving reeds 17. Sand/clay 18. Plant dyes 19. Plant resins 20. Seeds for rattles and decoration 21. Other benefits	1. Pollination services 2. Livestock grazing 3. Recreation/aesthetic services (ecotourism) 4. Religious functions 5. Cultural functions 6. Other benefits	1. Carbon sequestration 2. Water shed protection 3. Protection against soil erosion 4. Habitat for wild fauna and flora (breeding and nursery functions) 5. Biodiversity reserve 6. Oxygen production 7. Acid rain deposition 8. Roles in the water cycle 9. Runoff reduction (cultivated) 10. Other services

Source: Dlamini 2007; Dlamini and Samboko 2017

Contribution of Forest Ecosystem Services Toward Food Security and Nutrition, Table 2 Categories and examples of Eecosystem processes and ecosystem services

Ecosystem processes	Ecosystem services		
Supporting services	Provisioning services	Regulating services	Cultural services
1. Primary production 2. Provision of habitat 3. Nutrient cycling 4. Soil formation and retention 5. Production of atmospheric oxygen 6. Water cycling	1. Food 2. Medicinal 3. Fiber 4. Fuel 5. Genetic Resources 6. Biochemicals 7. Fresh Water	1. Climate regulation (heat and hydrology) 2. Disease regulation 3. Flood regulation 4. Invasion resistance 5. Herbivory 6. Pollination 7. Seed dispersal 8. Pest regulation 9. Natural hazard protection 10. Erosion regulation 11. Water purification 12. Detoxification	1. Spiritual and religious values 2. Knowledge system 3. Educational 4. Inspirational 5. Recreational 6. Aesthetic 7. Communal 8. Symbolic

Source: Secretariat of the Convention on Biological Diversity 2010

Secondly, as presented in Table 2, the ES approach considers forests and related ecosystems as having four pillars: (i) supporting services, (ii) provisioning services, (iii) regulating services, and (iv) cultural services (Turpie et al. 2015; Vira et al. 2015). Similarly, the ES framework is related to the NRA framework in the sense that supporting services could be interpreted as

Contribution of Forest Ecosystem Services Toward Food Security and Nutrition, Table 3 The seven internally agreed and widely adopted elements of SFM (i.e., criteria)

(i) **Extent of forest resources**: Development, maintenance, and improvement of forest resources including their contribution to Global Carbon cycles
(ii) **Forest biological diversity**: Conservation and enhancement of biodiversity in forest ecosystems
(iii) **Forest health and vitality**: Maintenance and enhancement of forest ecosystem health, vitality, and integrity
(iv) **Productive functions of forest resources**: Maintenance and enhancement of productive functions of forests and other woodlands
(v) **Protective functions of forest resources**: Maintenance and improvement of environmental and conservation functions of forests and other wooded land and combating land degradation and desertification
(vi) **Socioeconomic functions of forests**: Maintenance and enhancement of socioeconomic benefits of forests and other wooded land
(vii) **Legal, policy, and institutional framework**: Adequacy and effectiveness of legal, institutional, and policy frameworks for sustainable forest management

Source: UN 2008, Resolution 62/98 establishing the Non-legally Binding Instrument on All Types of Forests

intermediate use services, while provisioning services could be direct use benefits, and regulatory services are synonymous with indirect use benefits and cultural services fall under indirect use benefits.

Thirdly, the SFM framework is used to inspire pragmatic, realistic, and innovative mechanisms for sustainable use and management of forest products (goods and services). In turn, this would guarantee forest ecosystem functions or processes that ultimately ensure healthy forests and a steady/stable supply of forest ecosystem goods and services (Dlamini 2013; Mulenga et al. 2012; Turpie et al. 2015; Vira et al. 2015; Dlamini and Montouroy 2017). The generally accepted definition of SFM came out of the General Assembly of the United Nations in December 2007. Thus, the most widely, intergovernmental agreed definition of sustainable forest management (SFM) states that: “sustainable forest management as a dynamic and evolving concept aims to maintain and enhance the economic, social and environmental value of all types of forests, for the benefit of present and future generations.” It is characterized by seven elements (Criteria) as listed in Table 3. This definition is clearly inspired by the premise of sustainable development which is basically the convergence of the social, ecological, and economic pillars.

Progress toward attaining SFM is monitored through a set of criteria and indicators (C&I) for SFM. In reality, the full potential of forest ecosystem functions as well as forest services can only be achieved if the principles and criteria and indicators for SFM are fully implemented. Options would include integrating/mainstreaming C&I for SFM into the hierarchy of national environmental policies and strategies, e.g., national forest policies, national forestry strategies, national forestry programs, national action programs for the UN Convention on Biodiversity (national biodiversity strategies) and action plans, national action plans for the UN Framework Convention on Climate Change (national climate change policies and strategies), national action programs for the UN Convention to Combat Desertification, and Land policies. To strengthen the implementation of the C&I for SFM, these could be infused into Forest Law Enforcement, Governance and Trade-related laws such as the Forest Acts and Biodiversity Acts (Dlamini 2015; Dlamini and Montouroy 2017). This would ensure that in addition to directly providing food, forests are able to maintain the biodiversity and ES that support sustainable food production.

Incidentally, the C&I for SFM reflect all the pillars and principles of the NRA framework and ES framework. Thus, the C&I for SFM are crucial for the success of the NRA and ES frameworks in safeguarding ES.

The Concept of Food Security

Perceptions of food security have changed in the last few decades to address changes in official policy direction. The term "food security" was first tossed in the mid-1970s, after the World Food Conference of 1974 when food security was confined to the national, regional, and international levels and defined in the context of food supply – guaranteeing the availability and price stability of basic foodstuffs: "Availability at all times of adequate world food supplies of basic foodstuffs to sustain a steady expansion of food consumption and to offset fluctuations in production and prices." Subsequently, the definition of food security was revisited and henceforth food security analysis reflected the individual and household levels over and above the national and international levels of aggregation. This culminated in the universal and widely accepted World Food Summit (1996) definition of food security that emphasizes that food security is multidimensional and encompasses four pillars, i.e., food access (dependent on finance and physical and social factors), availability (from agriculture production and land use or exchange), utilization/food use (nutritional diversity and food safety issues), and stability of supplies (seasonally and year to year). This paradigm shift in the focus of the concept of food security has triggered a new discourse in policy responses, including the emergence of innovative frameworks, such as the sustainable livelihood approach. The sustainable livelihood framework forms the central plank of development programs at local, national, regional, and international levels. The World Food Summit definition states that: "Food security exists when all people, at all times, have physical and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life" (World Food Summit 1996). In practical terms the concept of food security has become comprehensive and complex. This study has adopted this definition.

Scope and Objectives of the Paper

The ultimate purpose of this paper is to interrogate the relationship between various FES and pillars/dimensions of food security or simply the direct and indirect contribution of FES to food security at the local, national, regional, and international/global scales. A framework depicting the direct and indirect roles of forests and tree-based production systems in food provision is presented. The use of the ES framework to understand the role of FES in achieving food security is outlined in various components. In addition, the role of agroforestry in food and nutrition security is interrogated. Further, the framework of drivers directly and indirectly impacting on forests and tree-based systems for food security and nutrition is presented. Consequently, the importance of understanding the major drivers affecting forests and tree-based systems for food security and nutrition is discussed.

Forest Ecosystem Services and Food Security: The Connection

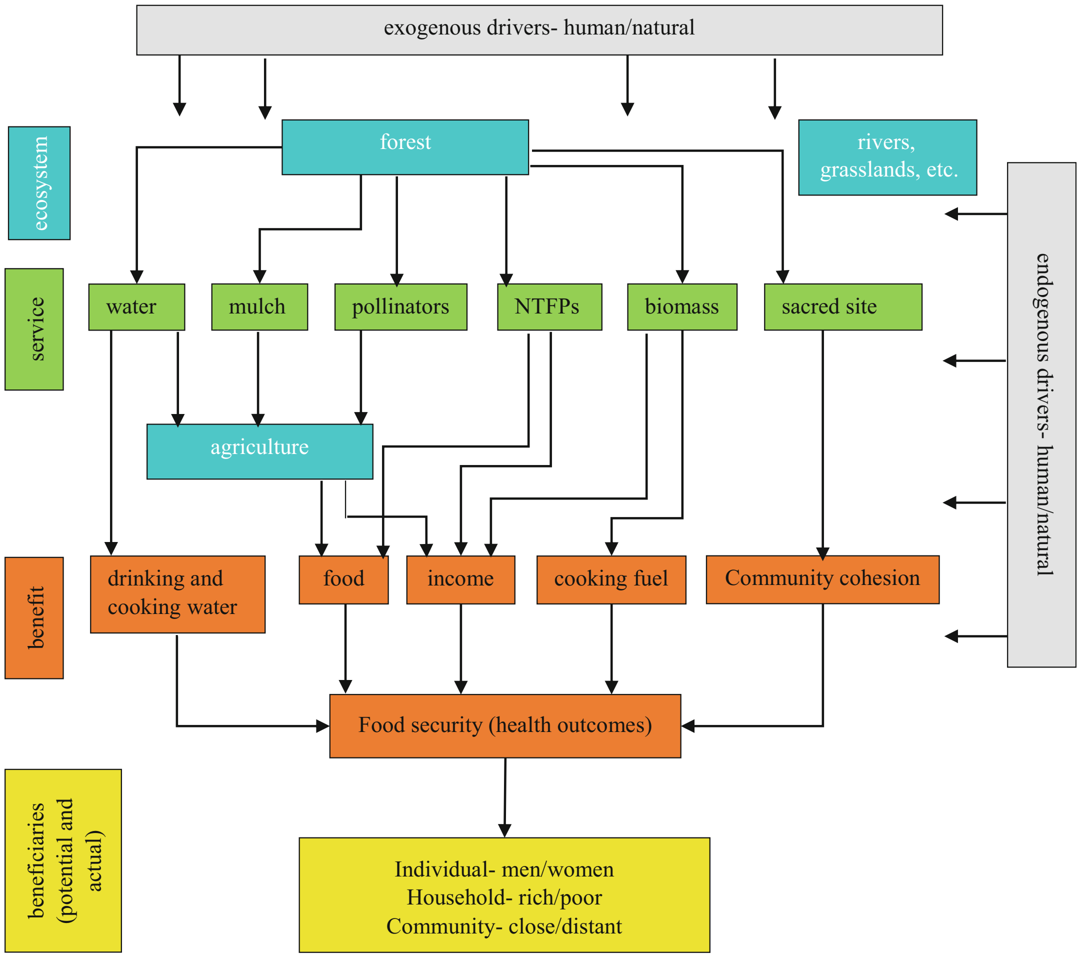
Food security and FES are complex and multidimensional (Poppy et al. 2014; Mofya-Mukuka and Simoloka 2015; Turpie et al. 2015; Cruz-Garcia et al. 2016). For example, food security is not only dependent on forest and related ecosystems, but it is also one of the underlying causes and/or drivers of loss of forests and related ecosystems. In addition, clearing of forests for agricultural development is one of the main causes of loss of ecosystems (e.g., wetland habitats and aquatic ecosystems) and habitats in agricultural societies. In other words, alarming land degradation from landscape transformation is often a consequence of efforts to enhance food security through increased agricultural production (Carrasco et al. 2016). Agricultural production normally comprises land use change, land cover change, change in management practices, and agricultural inputs, which directly or indirectly lead to rapid landscape transformation and land degradation (Poppy et al. 2014; Turpie et al. 2015; Vira et al. 2015; Cruz-Garcia et al. 2016; Dlamini and Samboko 2017). For example, Benıtez-Badillo et al. (2018) reported shrinkage of forest habitats that used to harbor wild edible fruits (which could contribute to the nutritional needs of local communities) as a result of land-use changes driven by agricultural expansion and human settlements in Mexico.

Further, overexploitation or unsustainable utilization and poor management of NTFPs could also result in resource depletion, especially as driven by commercialization and external market forces (Poppy et al. 2014; Turpie et al. 2015; Dlamini and Samboko 2017). Nonetheless, the flow of FES from natural forests and woodlands plays a pivotal role in enhancing food availability in poor rural communities worldwide (Poppy et al. 2014; Benıtez-Badillo et al. 2018). The routes through which forests and related ecosystems contribute to food and nutrition security were illustrated in Poppy et al. (2014), by highlighting the exogenous drivers (human and natural) and stipulating the ecosystems, the associated services, and their direct use benefits, indirect use benefits, and intermediate use services. Further, potential and actual beneficiaries are indicated. In this case ecosystems include forests, rivers, and grasslands, while the multiple services from the forest ecosystems include water, mulch, pollinators (which support agriculture), NTFPs, biomass, and sacred sites. Benefits cover drinking and cooking water, food income, cooking fuel, and community cohesion which culminate in food security (health outcomes). Beneficiaries are communities, households, and individuals.

Thus, forest and related ecosystems and associated ecosystem goods and services, therefore, become an invaluable livelihood strategy to poor rural communities in developing countries (Shackleton et al. 2011; Dlamini 2013; Turpie et al. 2015; Benıtez-Badillo et al. 2018). This validates the need for sustainable ecosystem management (SEM). A diagrammatical representation of the indirect and direct routes through which forest and related ecosystems and their services contribute to food and nutrition security is given in Fig. 1.

Similarly, according to Poppy et al. (2014), the forest-tree-landscape continuum is a framework that comprises several factors, i.e., managed forests, shifting cultivation, agroforestry, and single-species crop production (monoculture). Direct roles from these factors include dietary diversity, i.e., food provisioning, e.g., fruits, vegetables, mushrooms, fodder and forage, bushmeat, fish, and insects. Over and above that, there are livelihood safety nets (Dlamini 2007; Poppy et al. 2014: Delvaux and Paloma 2018). While indirect roles encompass tree products for income generations such as tree crops, wood production, and NTFPs. In addition, indirect roles entail ES, i.e., provisioning of genetic resources, habit provisioning, water provisioning, pollination, microclimate amelioration, soil formation, erosion, nutrient recycling, and pest regulation (Poppy et al. 2014; Binam et al. 2017; Dlamini and Samboko 2017). The sum total of the direct roles and indirect roles translates into the food system which is based on food security and nutrition inspired by six pillars (access, stability and seasonality, availability, sustainability, dietary choice and use, and health and disease). The role of forests and related ecosystems in food and nutrition security is clearly outlined in this framework as supported by the works of Dlamini (2012, 2013), Vira et al. (2015), and Turpie et al. (2015). A schematic flow diagram of the forest-tree-landscape continuum is presented in Appendix 1.

To illustrate this further, sections "Forest Ecosystem Services in Perspective" and "The Concept of Food Security" above imply that forest ecosystem services, being a broad concept, may contribute directly or indirectly to food security in many ways. For example, in Cameroon according to Ingram et al. (2012) in practical terms, some direct use benefits, such as forest foods (e.g., bush mango, *Irvingia* spp.), directly contribute to food security, while others (provisioning services), indirect use benefits (regulating services), and intermediate use services (supporting services) also enhance availability of food, access to food, utilization of food, and stability of food supply (Dlamini 2013; Mofya-Mukuka and Simoloka 2015; Dlamini and Samboko 2017). Another perspective would be that utilization of forest and forest-related resources and ES that support the access and utilization dimensions of food security may undermine the ecosystem functions that support food availability. This phenomenon, therefore, underlines the importance for the



Contribution of Forest Ecosystem Services Toward Food Security and Nutrition, Fig. 1 Schematic diagram of the direct and indirect routes by which ES and benefits contribute to food and nutritional outcomes. (Source: Poppy et al. 2014)

integration of ES into food security plans and poverty reduction strategies in developing countries, in particular (Vira et al. 2015).

Furthermore, there are four ways in which forests and related ecosystems contribute to the four pillars of food security (Cruz-Garcia et al. 2016). Firstly, under the pillar of utilization, regular and direct consumption of wild foods, for example, accounts for over 20% of the diet of children in selected countries in Southern Africa and, in particular, in vulnerable households (Poppy et al. 2014; Mofya-Mukuka and Simoloka 2015; Turpie et al. 2015). In addition, food utilization may depend on the availability of fuelwood and clean water in order to enable households to prepare safe and healthy food. Thus, poor access to fuelwood and clean water could compromise food and nutrition security and health. Secondly, for the pillar of stability, wild foods are crucial safety nets for farmers in adverse conditions when crops fail or food reserves run low (Mulenga et al. 2012; Poppy et al. 2014; Mofya-Mukuka and Simoloka 2015; Turpie et al. 2015; Benıtez-Badillo et al. 2018; Delvaux and Paloma 2018). Thirdly, under the pillar of availability, food availability is assured by forest and related ES' role in agriculture; these include water (i.e., intermediate use services/provisioning services), timber for fencing and implements (which are direct use benefits/provisioning services), as well as pollination services (i.e., indirect use benefits/regulating services) (Turpie et al. 2015; Vira et al. 2015). Fourthly, in terms of the access pillar, income generated from trade on forest ecosystem goods (i.e., direct use benefits/provisioning services) such as fruits, nuts, fibers, resins, and other NTFPs plays a critical indirect role in food access by enabling poor households to purchase nutritious food (Poppy et al. 2014; Vira et al. 2015). NTFPs play a pivotal role in sustainable livelihoods throughout the world, in particular toward household income. The contribution of NTFPs to household income, particularly for the rural poor ranges from 20% to 80%, and this justifies why national governments have a moral obligation of promoting SEM and domestication and commercialization of NTFPs. Past case studies on NTFPs by Vedeld et al. (2004), Appiah et al. (2007), Babulo et al. (2009), Shackleton et al. (2007), Kamanga et al. (2009), Adam and Pretzsch (2010), Yemiru et al. (2010), FAO (2011), Heubach et al. (2011), Mulenga et al. (2011), Ingram et al. (2012), Kar and Jacobson (2012), Pouliot (2012), Bwalya (2013), Pouliot and Treue (2013), Cruz-Garcia et al. (2016), and Delvaux and Paloma (2018) show that the scale of the contribution varies widely, depending on context and wealth group, with often higher proportional contributions to poorer households.

As mentioned above, the relationship between forest and related ecosystems and food and nutrition security can be affected by a wide range of internal and external drivers of variable certainty and intensity (Poppy et al. 2014; Vira et al. 2015). Local communities normally acclimatize and/or change the utilization patterns of forest and related ES in response to gradual trends, such as changes in the structure of the demography and deteriorating soil fertility. However, with the abrupt volatile shocks such as insistent droughts, floods, landslides, earthquakes, commodity price collapses, pests and disease outbreaks, conflict, etc. and the unusual combinations and their temporal and spatial interactions, there is high likelihood for extreme pressure on ecosystems that in turn exacerbates degradation. Consequently, food security is negatively impacted, and poor rural communities turn to coping strategies (such as excessive deforestation) that continue to destabilize forest ecosystem functions and diminish FES such as unsustainable forest utilization (Poppy et al. 2014; Vira et al. 2015; Dlamini and Samboko 2017; Ingram et al. 2012).

Integration of Food Security and Environmental Sustainability in a Forest Ecosystem Services Framework

According to Smith and Maltby (2003) and Poppy et al. (2014), the three elements of the ES framework that are critical/key to achieving food security are:

(i) Multiple scales of analysis
(ii) Disaggregation of beneficiaries
(iii) Consideration of trade-offs in policy and decision-making

Recent studies have reported the existence of features in multiple scales of analysis and disaggregation of beneficiaries that have similar attributes to the five operational guidelines of the Convention on Biodiversity (Poppy et al. 2014). Although the third element (i.e., iii) is similar to the provisions of the CBD's ecosystem approach, it goes a step further to include the trade-offs decision-makers ought to consider in order to achieve complex/multiple outcomes (i.e., delivering both environmental sustainability and food security) (Franks and Hou-Jones 2016).

Scale of Analysis

The level of detail (scale and extent) to which ecosystems and habitats may be studied or analyzed determines how the system is viewed and/or perceived. For example, single-scale analysis could obscure critically important processes at finer and/or broader scales (Poppy et al. 2014). Therefore, it may be imperative with FES analysis to consider both biophysical processes, which influence forest ecosystem functions, and the associated institutional processes, which shape the governance, at various scales. An orthodox example is that of transboundary or transfrontier wetland habitats and aquatic ecosystems (e.g., water catchments) which often require unique models of joint decision-making involving all key stakeholders. To reconcile ecosystem sustainability (i.e., the multiple goals of ecosystem integrity and resilience) and food security (food production in this case), it is important to integrate across all pertinent spatial and temporal scales (Poppy et al. 2014). See Box 1 for more details.

Box 1 The Basis of a Sustainability Model for FES and Food Security

The vital components of a sustainability model for FES and food security are twofold, i.e., at the spatial scale and at the temporal scale. On the spatial scale, it is crucial to focus at the local and national levels following two logical steps: (i) analysis which entails identifying, profiling, and understanding internal and external drivers of certain situations, e.g., the forest-agriculture interface which comprises a mosaic of *more* and *less* intensively managed habitats and ecosystems and (ii) adopting the integrated landscape approach to understand how the dynamic interactions between various components (patches) affect forest ecosystem functions and ultimately the delivery of FES. While the temporal scale focuses on two issues: (i) dynamism of FES flow (on a temporal scale, the flow of forest and related ecosystem services is ever changing and dynamic) and (ii) analytical approaches toward sustainable harvesting benchmarks (modern analytical approaches should adopt a wide range and/or broad spectrum of temporal scales, fostering reflections and learning from past events while giving a true impression of the carrying capacity of forest ecosystems (biophysical limits) of what can be termed sustainable harvesting/extraction thresholds in a forest ecosystem over time). Challenges: It is difficult to establish

(continued)

Box 1 The Basis of a Sustainability Model for FES and Food Security (continued)

institutional frameworks (structures) that would deal with the varying temporal scales at which many biophysical processes operate. This is compounded by our lack of understanding of interconnectivity and feedback across overlapping scales within social-ecological systems.

Source: Adopted from: Poppy et al. (2014)

Disaggregation of the Beneficiaries

The phenomenon of disaggregating beneficiaries is relatively new; however, in a short space of time, it has become universally accepted as a crucial element in managing forests and related ecosystems (Poppy et al. 2014). Local-, national-, regional-, and global-scale beneficiaries are mapped and analyzed, as well as the flow of FES. In addition, the governance systems are studied. This provides the full picture of the dynamics surrounding FES. A detailed account is presented in Box 2.

Box 2 Key Components in the Disaggregation of Beneficiaries for Equitable Management of Forest Ecosystems

The disaggregation of beneficiaries for equitable management of forest ecosystems is based on two components, i.e., beneficiaries and governance. The beneficiary's component is inspired by three interrelated elements (i.e., who are the beneficiaries, value of household–/community-based studies, and ecosystems of global concern). On the other hand, the governance component is divided into three elements including the decision-making processes, stakeholder consultations, and impacts of governance. ***Decision-making process***: It is critical to understand who takes decisions about different ES (in terms of management of

(continued)

Box 2 Key Components in the Disaggregation of Beneficiaries for Equitable Management of Forest Ecosystems
(continued)
source ecosystems and the management of flow of service) and whether other users or stakeholders respect their authority to do so. ***Stakeholder consultation***: Participatory engagement is the key to understanding this at the local level, but this has to be combined with the district- and national-level analysis to consolidate the official governance perspective on management activities with what is happening de facto on the ground. ***Impacts of governance***: Further, it is extremely important to consider the impacts of governance at the international level and/or global scale.

Source: Adopted from: Poppy et al. (2014)

Consideration of Trade-offs in Policy and Decision-Making

Sections "Scale of Analysis" and "Disaggregation of the Beneficiaries" lead to a clear understanding that there are trade-offs between which ES are prioritized from which ecosystems and for whom. The greater the human demands on a landscape, and the less transparent or legitimate local governance or authority systems are, the more intractable the trade-offs (e.g., between provisioning, regulating, and cultural ecosystem services) become (Poppy et al. 2014; Franks and Hou-Jones 2016).

Scientists argue that taking an ecosystem approach leads to:

(i) Greater opportunity for integration, resulting in a reduced need for trade-offs between social and ecological needs (Poppy et al. 2014; Franks and Hou-Jones 2016).
(ii) Trade-off decisions are made more transparently, and more equitable compromises can be reached that recognize the needs of current stakeholders and future generations in different locations.

It is important to recognize, however, that the trade-off analysis is inevitably a risk-based process, especially where the lives of poor local communities are concerned. While top priority should be given to those ES that can alleviate poverty and hunger in the short term, this should not lead to a reduced capacity in other critical ES on a sustainable basis. Therefore, achieving an integrated approach is supported by the widespread recent recognition in the ES literature of the importance of managing "bundles" of ES rather than individual services (Poppy et al. 2014; Franks and Hou-Jones 2016). Ecosystem "bundles" are defined as sets of ES that repeatedly appear together across space or time (Poppy et al. 2014; Franks and Hou-Jones 2016).

Focusing on bundles rather than on individual ES provides a way to consider the trade-off analysis in diverse landscapes shaped by both social and ecological forces and could be a more powerful way of looking at forest ecosystems and associated agroecosystems (Poppy et al. 2014; Franks and Hou-Jones 2016). This approach contrasts with many payments for ecosystem services (PES) schemes which, by promoting maximization of a single marketed ES (e.g., carbon sequestration or biodiversity), can reduce the flows of other ES (Poppy et al. 2014; Franks and Hou-Jones 2016), thus constituting a potential risk to the achievement of food, energy, or water for certain beneficiaries. Achieving food security sustainably, therefore, requires examining bundle-based trade-offs between provisioning and other ES (i.e., supporting services, regulating services, and cultural services) for multiple beneficiaries (Poppy et al. 2014; Franks and Hou-Jones 2016).

Emerging Threats to Food Security and Environmental Sustainability

Population growth, significant land use change, and climate change have emerged as very serious setbacks to any meaningful efforts toward attaining food and nutrition security in developing countries lately (Poppy et al. 2014). Further, the threat of climate change to food security and environmental sustainability cannot be over-emphasized. For example, according IUCN (2007) climate change is characterized by the hazards and impacts outlined in Box 3.

Box 3 Categories of Food Security-Related Climate Change Hazards and Their Associated Impacts

Category 1: ***Drought*** whose associated impacts include crop damage/loss, leading to food scarcity and hunger, water shortages, reduced fish stocks, income loss (reduced access to livelihood capitals), reduced charcoal business, increase in diseases (affecting humans and animals), ecohealth issues, decreased water quality, increased soil erosion (increased runoff), decreased soil fertility, and increased honey production (if drought is not too severe).

Category 2: ***Floods*** which result in crop damage/loss, leading to food scarcity and hunger, loss of crop land and grazing ground, decline in fish catches, increase in diseases (malaria, dysentery, cholera, etc.), destruction of infrastructures (houses, roads), and life loss (humans and livestock).

Category 3: ***Extreme heat*** that may cause increase in diseases affecting animals, crops and humans (especially malaria), decreased human capacity to do work, loss of life (animals and humans), crop damage/loss, reduced fish stocks (due to rising water temperatures, physical and ecosystem changes), decreased livestock feed, and reduced water quality.

Category 4: ***Shorter rainy*** *season* that leads to decreased crop yields, crop damage/loss, decreased income from crop selling, crop seeds do not reach maturity (which negatively affects the next crop generation), and reduced charcoal production and business (forests face deforestation, degradation, and increase in forest fires).

Source: Modified from IUCN (2007).

The response to climate change cuts across all scales: from local to national to regional to global scales. Globally the UN Framework Convention on Climate Change (UNFCCC) is the international policy framework responsible for climate change mitigation and adaptation. Several regional climate change scale mechanisms are in place, as well as national mechanisms including climate change policies and strategies. Numerous international processes are ongoing to help influence the behavior at national and local levels. It is important to consider some of the unintended outcomes of adaptation.

Agroforestry, Food, and Nutritional Security

Definition, Conceptualization, and Challenges and Options

The concept of agroforestry has emerged as another viable option to supply of a wide range of ES to complement natural forests and other related life-supporting ecosystems (Dawson, 2013; Binam et al. 2017). By definition, agroforestry refers to the integration of woody species (trees and shrubs) with annual crop cultivation, livestock production, and other farm activities (Binam et al. 2017). Further, agroforestry is a series of land management approaches practiced by more than 1.2 billion people worldwide (Dawson et al. 2013). Varied ecological and socio-economic conditions have given rise to specific forms of agroforestry in different parts of the world. Immediate benefits of agroforestry include runoff reduction; soil erosion control; accumulation of soil organic matter; improvement of soil fertility; watershed protection; carbon sequestration; supply of fuelwood, fodder, food, and nutrition; biodiversity conservation and enhancement of climate change adaptation and mitigation; etc. Challenges for agroforestry in food and nutrition security generally include policy constraints, constraints in delivering tree products to markets, underinvestment in research, and others. Options entail policy opportunities and planning for climate change mitigation and adaptation.

In Barak Valley, Assam, India, 87 tree species identified in agroforestry home gardens were reported by Das and Das (2005). Farmers indicated a mean of eight species used as edible fruit per home garden, many of which were indigenous. Fruit trees were more dominant in smaller gardens, approximately five species per garden used for timber and two for wood fuel. In Los Santos and Rio Hato, Panama, Garen et al. (2011) revealed 99 tree species of which 3/4 indigenous, utilized, planted, and/or protected on farmers' land. Approximately 1/3 of species were valued for human food, 27 mostly exotic fruits mentioned as planted, and about 1/3 of species each valued for their wood or as living fences. In addition, >60% of species were assigned multiple uses. Surrounding Mount Kenya, Kenya, 424 woody plant species, of which 306 indigenous, were revealed in farm plots. Further, farmers indicated many species used for food. Seven of the ten most common exotic species were planted, mainly for edible fruits/nuts. The most common indigenous species were used primarily for timber/firewood (Kehlenbeck et al. 2011). Farmers indicated that >20% of species yield fruits/nuts for human consumption. The most common exotic was coffee and then timber trees in east of Mount Kenya, Kenya (Lengkeek et al. 2003). In addition, 297 tree species, approximately 2/3 indigenous, were revealed in smallholder farms. In two areas of West Kalimantan, Indonesia, >120 tree species were identified in forest gardens, and most species are not planted. Farmers indicated that about 30% of species were used for edible fruit and latex and in other nondestructive ways and approximately 50% used for timber and in other destructive ways. Seedlings of unused trees are removed around naturally regenerating and intentionally planted fruit/other useful trees (Marjokorpi and Ruokolainen 2003). Between 92 and 90 trees species are identified in coffee farm plots outside and inside the park, respectively, in Bukit Barisan Selatan Park, Lampung province, Sumatra, Indonesia Philpott et al. (2008). Over and above that, >50% of farmers grew a total of 17 other products in addition to coffee, including spices, timber, and, most commonly, indigenous and exotic fruits. Farmers planting outside the park grew alternative tree products more often. Sambuichi and Haridasan (2007) reported 293 tree species, 97% indigenous, revealed in cacao plantation plots in forest understory in Southern Bahia, Brazil. Many indigenous trees used for food. Seedlings favored for retention during weeding were those providing edible fruit or good wood. The most abundant exotics were fruit species. In Yaoundé, Mbalmayo, and Ebolowa subregions, Cameroon, Sonwa et al. (2007) reported 206 mostly indigenous tree species are revealed in cacao agroforestry plots. Farmers indicated 17% of tree species are used primarily for food, 2/3 of which were indigenous, 22% of tree species primarily for timber, and 8% for medicine. Excluding cacao, the three most common species (two indigenous) were used for food. Close to urban Yaoundé, the density of food trees was higher.

Meanwhile, Dawson et al. (2013) reported the number of selected tree species that are utilized for food and nutrition security to smallholders in Africa, South America, and Southeast Asia. Tree functions included human food, animal fodder, soil improvement, and fuel. Africa utilized the highest number of tree species and had the highest number of indigenous species, while Southeast Asia was second with South America coming last, although with the highest proportion of indigenous species overall (see Table 4 for a detailed breakdown).

Drivers of Forests and Tree-Based Systems for Food Security and Nutrition

Drivers Directly and Indirectly Impacting on Forests and Tree-Based Systems for Food Security and Nutrition

According to Vira et al. (2015) and Basnett et al. (2015), drivers of forests and tree-based systems for food security and nutrition can be separated, for analytical reasons, into the following four interconnected categories: (i) environmental drivers (e.g., climate change, deforestation and forest transition, invasive species), (ii) social drivers (e.g., conflicts in and about forests, relative poverty and inequality, and demographic change, including migration, urbanization, and

Contribution of Forest Ecosystem Services Toward Food Security and Nutrition, Table 4 Selected tree species providing tree functions important for food and nutrition security to smallholders in various regions

Function	Region			
	Africa	South America	Southeast Asia	Total (regions)
Human food	295 (54)	119 (43)	225 (49)	639 (50)
Animal fodder	295 (55)	96 (45)	191 (47)	582 (50)
Soil improvement	194 (51)	73 (45)	154 (45)	421 (48)
Fuel	357 (53)	126 (42)	249 (47)	732 (49)
Total (Functions)	1,141 (53	414 (43)	819 (47)	2,374 (49)

Note: The percentage of references to indigenous species is given in brackets
Source: Dawson et al. (2013)

agrarian transformation), (iii) economic drivers (i.e., income per capita, absolute and relative food prices, market and policies, and production system changes), and (iv) governance, (i.e. state-focused governance, and governance beyond the state: markets and non-state actors). These drivers interact constantly and affect environmental sustainability and food security outcomes and can be illustrated through the framework of drivers directly and indirectly impacting on forests and tree-based systems for food security and nutrition. A flow diagram of the drivers directly and indirectly impacting on forests and tree-based systems for food security and nutrition is shown in Appendix 2.

Major Drivers Affecting Forests and Tree-Based Systems for Food Security and Nutrition

Vira et al. (2015) and Basnett et al. (2015) reported that the major drivers affecting forests and tree-based systems for food security and nutrition may be clearly shown in a framework that comprises three major components, i.e., multiple effects (with associated four sub-components: population growth, urbanization, governance shifts, and climate change), land use and management (with associated four sub-components: commercialization of agriculture, industrialization of forest resources, gender imbalances, and armed conflicts), and consumption, income, and livelihoods (with associated three sub-components: raising food prices, increasing per capita income, and formalization of tenure rights). Refer to Appendix 3 for a schematic presentation of the compartmentalization of major drivers.

Conclusion

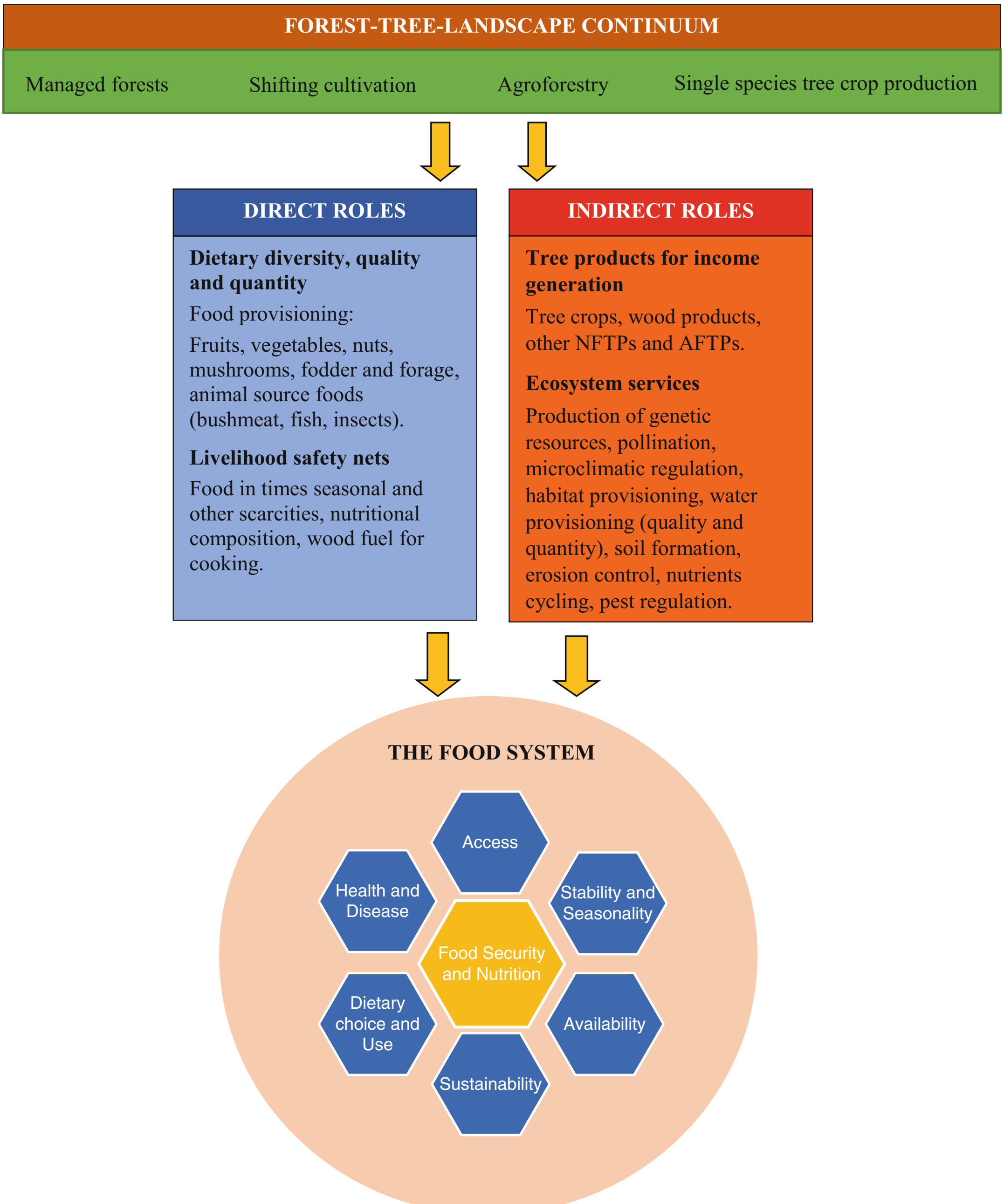
Conclusion

Forest ecosystem services play a crucial role in sustainable livelihoods and in particular in environmental protection and food and nutrition security worldwide. However, there is lack of integration of food security and environmental sustainability within an ES framework. Thus, in most cases food security policies do not recognize and/or promote ecosystem health and vitality. These mainly focus on three issues, i.e., agricultural productivity, trade, and microeconomic policies. The emphasis is more on economic sustainability (as driven by markets) as opposed to ecological sustainability (as determined by ecosystem integrity). Yet in order to reconcile environmental sustainability and food security, both ecological sustainability and economic sustainability are important. The likely outcomes of disregarding the former include alarming ecosystem degradation and persistent food insecurity. Consequently, this makes the achievability of SDG 2 impractical or unattainable.

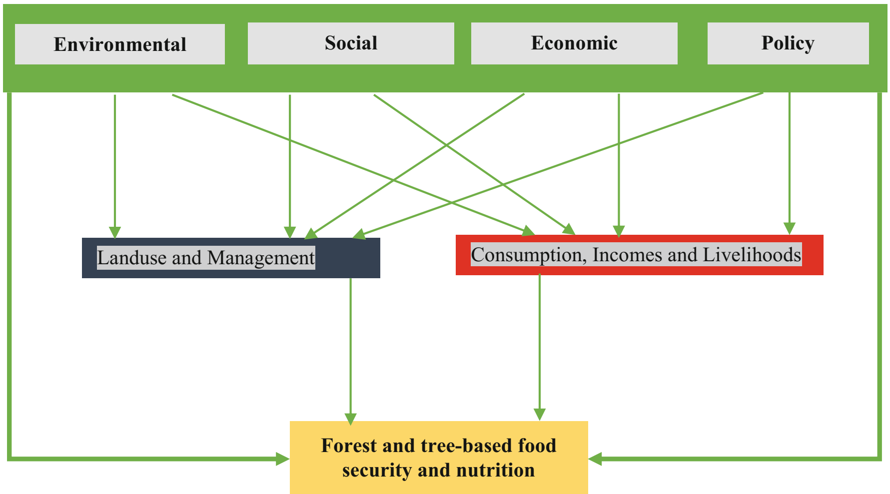
Further, drivers that directly and indirectly impact and/or affect forests and tree-based systems for food security and nutrition are known, and they are of a complex nature. These are environmental, social, economic, and policy oriented.

Appendices

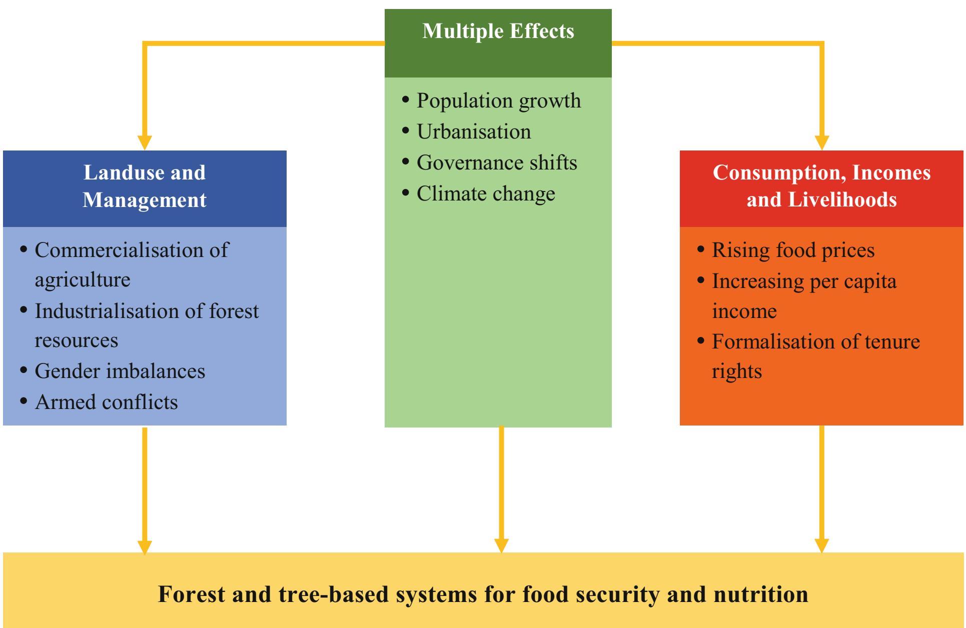
Appendix 1: A Framework Depicting the Direct and Indirect Roles of Forests and Tree-Based Production Systems in Food Provision. Source: Poppy et al. (2014)



Appendix 2: Framework of Drivers Directly and Indirectly Impacting on Forests and Tree-Based Systems for Food Security and Nutrition. Source: Vira et al. (2015)



Appendix 3: Major Drivers Affecting Forests and Tree-Based Systems for Food Security and Nutrition. Source: Vira et al. (2015)



Key Recommendations

There is a need for a shift from business as usual (BAU) to SEM.

National governments should adopt and promote ecosystem-based policies which are the foundation of greater agricultural productivity in the long term. These result in ecosystem rehabilitation/preservation and enhanced food security. In this case, an equilibrium is found between ecological sustainability and economic sustainability. Consequently, environmental sustainability and food security outcomes are achieved. Further, governments should adopt and implement the 12 CBD principles of ecosystem management of 2013. This can be achieved through integration of food security and environmental sustainability within an ES framework. This entails scales of analysis, disaggregation of the beneficiaries, and consideration of trade-offs in policy- and decision-making. Alternatively, this can be achieved through applying the ES framework to food security predictions, in this case, linking national-scale predictions of undernourishment to the local level, disaggregating ES beneficiaries in terms of their food security needs, and recognizing trade-offs between ES services for food security. Alternatively, a targeted scenario analysis (TSA) approach could be adopted to inform decision-making regarding forest ecosystems and food security.

Strategies to deal with the effects and impacts of drivers that directly or indirectly affect and/or impact forests and tree-based systems for food security and nutrition must be formulated, developed, and implemented at the local, national, regional, and global scale.

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