RESEARCH PROGRAM ON
Water, Land and Ecosystems

LED BY:
IWMI
International Water Management Institute

CGIAR Research Program on Water, Land and Ecosystems (WLE)

Ecosystem Services and Resilience Framework

IN PARTNERSHIP WITH:

CGIAR Research Program on Water, Land and Ecosystems (WLE)

Ecosystem Services and Resilience Framework

CGIAR Research Program on Water, Land and Ecosystems (WLE). 2014. *Ecosystem services and resilience framework*. Colombo, Sri Lanka: International Water Management Institute (IWMI). CGIAR Research Program on Water, Land and Ecosystems (WLE). 46p. doi: 10.5337/2014.229

/ ecosystem services / agriculture / landscape / agroecosystems / productivity / rice / governance / sustainability / communities / rural areas / living standards / poverty / food security / nutrition / public health / income / investment / stakeholders / farmers / soil conservation / planning / impact assessment / monitoring / decision making / case studies / East Africa / Ghana / Peru / Costa Rica /

ISBN 978-92-9090-805-0

Front cover photo: Bioversity International/L.Sebastian

Main contributors (listed alphabetically): Simon Attwood[1], Deborah Bossio[2,7], Evan Girvetz[2], Becky Chaplin-Kramer[3,4], Fabrice DeClerck[1,7,8], Elin Enfors[5], Alexander Fremier[6], Line Gordon[5], Fred Kizito[2], Sarah Jones[1], Isabel Lopez Noriega[1], Nathanial Matthews[7], Matthew McCartney[10], Megan Meacham[5], Marcela Quintero[2], Roseline Remans[1,8], Richard Soppe[12], Louise Willemen[9] and Wei Zhang[11]

Other contributors: Jeremy Bird[10], Jeremy Cherfas[1], Simon Cook[7], Jan De Leeuw[13], J. Carter Ingram[14], Molly Jahn[15], Louise Karlberg[5], Quang Bao Le[16], Victor Mares[17], Jeffrey Milder[9,18], Andrew Noble[7], Silvia Silvestri[19], Emmanuel Torquebiau[20], Martin van Brakel[7], Michael Victor[7], Alain Vidal[21], Suhas Wani[22], Sylvia Wood[1,8] and Camilla Zananaini[1]

[1]Bioversity International, [2]International Center for Tropical Agriculture (CIAT), [3]The Natural Capital Project, [4]Stanford University, [5]Stockholm Resilience Centre, [6]Washington State University, [7]CGIAR Research Program on Water, Land and Ecosystems (WLE), [8]Columbia University, [9]Cornell University, [10]International Water Management Institute (IWMI), [11]International Food Policy Research Institute (IFPRI), [12]International Center for Agricultural Research in the Dry Areas (ICARDA), [13]World Agroforestry Centre (ICRAF), [14]Wildlife Conservation Society, [15]University of Minnesota, [16]Swiss Federal Institute of Technology, Zurich, [17]International Potato Center (CIP), [18]Rainforest Alliance, [19]International Livestock Research Institute (ILRI), [20]Centre de coopération internationale en recherche agronomique pour le développement (CIRAD), [21]CGIAR Challenge Program on Water and Food (CPWF) and [22]International Crops Research Institute for the Semi-Arid Tropics (ICRISAT)

CONTENTS

FOREWORD

WLE's vision is a world in which agriculture thrives alongside vibrant ecosystems, and those engaged in agriculture live in good health, enjoy food and nutritional security, and have access to the inputs and resources they need to continuously improve their livelihoods. Intensifying agriculture and productivity in ways that are sustainable is a huge challenge in the Anthropocene. Humanity is increasingly surpassing important planetary boundaries, including climate change, biodiversity loss, and alteration of nutrient and water cycles (Rockström et al., 2009), while our resource use is not yet meeting the minimum threshold required to obtain just social conditions for humanity, including meeting global food and income needs (Raworth 2012). The prevailing paradigm presents technological approaches to agricultural intensification as the most viable solution to increasing food production, despite its severe and negative impacts on the environment. In our view, an ecosystem service based approach to development and management decisions provide the best opportunity to sustainably and equitably increase food security, and also provide opportunities for income generation for people. It is hoped that this report will shape and drive forward our collective efforts to apply existing, and generate new, research and activities to facilitate the uptake of ecosystem service-based approaches in regions where CGIAR works.

The CGIAR Research Program (CRP) on Water, Land and Ecosystems (WLE) combines the resources of 11 CGIAR centers, the Food and Agriculture Organization of the United Nations (FAO), and numerous national, regional and international partners to provide an integrated approach to natural resource management research. WLE supports an approach to sustainable intensification in which healthy functioning ecosystems are seen as a prerequisite to agricultural development, food security and human well-being. Ecosystem Services and Resilience (ESR) is a **crosscutting core theme** within WLE that focuses on the role of ecosystem service based approaches in building community resilience and helping WLE achieve its development outcomes. This program is led by the International Water Management Institute (IWMI), a member of the CGIAR Consortium and is supported by CGIAR, a global research partnership for a food-secure future.

This ESR Framework outlines how WLE, working closely with its partners, intends to shape and drive forward the integration of ESR concepts into development and resource management decisions in agricultural landscapes. Section 1 provides the rationale for developing an ESR Framework, and section 2 specifies its goals and objectives. Section 3 presents the definitions, concepts and five core principles that combine to form a framework for WLE's ESR work. Section 4 describes the ecosystem services that are central to WLE's activities, providing a basis for the presentation of the theory of change for WLE's ESR work in section 5, where we explain how the ESR approach will contribute to achieving the system-level outcomes (SLOs) of CGIAR and WLE's intermediate development outcomes (IDOs). Section 6 provides details of the tools, methods and approaches that can be used to implement an ESR approach, and discusses their strengths and limitations. In section 7, we present several case studies illustrating ecosystem service concepts that can be used to improve livelihoods and human well-being. Section 8 highlights critical opportunities for strengthening the scientific knowledge on ESR research for development, and is followed in section 9 by some concluding remarks on the potential value of this ESR approach. By presenting this ESR Framework, we aim to provide scientists from WLE and its partners with a launchpad for the integration of the ESR approach into development work across the program.

Gretchen Daily
WLE Steering Committee
Stanford University

Fabrice DeClerck
ESR Core Theme Leader, WLE
Bioversity International

Photo: Neil Palmer

1. RATIONALE FOR THE ESR FRAMEWORK

Rising demand for food and upward trends in resource-intensive consumption are intensifying pressure on the world's food production systems (Garnett et al. 2013; Bommarco et al. 2013). Agriculture now accounts for 38% of the global land area (FAO 2011a) and provides employment for 31% of the world's employed people (World Bank 2014). Yet, an estimated 842 million people worldwide suffered from chronic hunger (FAO 2013), which means that they do not have enough food to lead an active life.

Industrial methods of agriculture have significantly increased crop yields per unit area (Bommarco et al. 2013). This has helped to meet the world's food needs, but has led to severe environmental impacts, including global biodiversity loss, and water and land degradation (Foley et al. 2011). As pressure on land, water and energy increases, the expansion of industrial agriculture becomes a less viable option. At the same time, less-intensive, smallholder agriculture alone cannot produce the yields that are needed to satisfy the world's growing demand for food. In order to feed the growing human population, changes are needed to the way in which we produce, distribute and consume food.

Sustainable intensification of agriculture has emerged as one promising response to these challenges, where discussions focus on increasing food production in ways that do not undermine the natural resource base upon which this production depends. There have been recent attempts to define, more precisely, what sustainable intensification means (see, for example, Garnett et al. 2013) and understand how it might be achieved (Poppy et al. 2014). It is also recognised that increasing production will not, on its own, be sufficient to increase food security (Loos et al. 2014), and must be combined with efforts to achieve more equitable distribution of food and improve consumption patterns. Indeed, as much as one-third of the food produced may be lost or wasted, globally, through inefficient harvesting, storage and processing of food, as well as market and consumer behaviour (FAO 2011b).

“In order to feed the growing human population, changes are needed to the way in which we produce, distribute and consume food.

WLE proposes efforts to intensify agriculture shift to focus on **increasing food and livelihood security through the creation of resilient socio-ecological systems that secure the sustainable provision and equitable distribution of ecosystem services.** Our priority is to increase food and livelihood security for the world's poor by enhancing the sustainability and equity in the provision of ecosystem services – and securing the natural resource base that underpins these services – that flow to and from agriculture and provide monetary, health, and well-being benefits to people. There are potentially substantial benefits to people from the improved management of ecosystem service flows; as an indication, between 1997 and 2011, the losses to ecosystem services due to land-use change are estimated to be between USD 4.3 and USD 20.2 trillion per year (Costanza et al. 2014). WLE seeks to understand how, when and where selected ecosystem services can be sustainably harnessed in agricultural systems and landscapes to unleash their potential and deliver positive outcomes for development. Our rationale for producing this ESR Framework is to specify the ESR core theme's research priorities and to provide a conceptual framework to WLE and its partners for applying ecosystem service and resilience science to achieve development outcomes.

2. GOALS AND OBJECTIVES

The main **goal** of this ESR Framework is to help WLE achieve its Intermediate Development Outcomes (IDOs) and CGIAR's System-Level Outcomes (Table 1) by demonstrating how ecosystem services and resilience serve as key research for development themes.

The central **hypothesis** of this ESR Framework is that ecosystem service stocks and flows in agricultural landscapes can be managed to contribute to these development outcomes, and resilience concepts can help guide this process. While the concept of ecosystem services is in itself a topic of debate (Schröter et al. 2014), in section 3 on *Applying ecosystem services and resilience concepts to achieve development outcomes,* we discuss the mounting evidence indicating that good management

CGIAR SYSTEM-LEVEL OUTCOMES (SLO)	WLE INTERMEDIATE DEVELOPMENT OUTCOMES (IDO)
A. **Reducing rural poverty** B. **Increasing food security** C. **Improving human nutrition and health** D. **Sustainable management of natural resources**	1. **Productivity:** Improve land, water and energy productivity in rainfed and irrigated agroecosystems. 2. **Income:** Generate increased and more equitable income from agricultural and natural resource management, and ecosystem services in rural and peri-urban areas. 3. **Gender and equity:** Enhance the decision-making power of women and marginalized groups, and increase the benefits derived from agricultural and natural resources. 4. **Adaptation:** Increase the ability of low-income communities to adapt to environmental and economic variability, demographic shifts, shocks and long-term changes. 5. **Environment:** Increase the resilience of communities through enhanced ecosystem services in agricultural landscapes.

TABLE 1. CGIAR System-Level Outcomes (SLOs) and WLE Intermediate Development Outcomes (IDO).

of ecosystem service flows to and from agriculture can improve human well-being in agricultural landscapes, increasing food and livelihood security. In this way, we seek to meet our objective of providing a conceptual framework and presenting the existing evidence base for applying ecosystem service and resilience science to achieve development outcomes.

3. APPLYING ECOSYSTEM SERVICE AND RESILIENCE CONCEPTS TO ACHIEVE DEVELOPMENT OUTCOMES

The ESR core theme's vision is for ecosystem service management interventions that deliver multifunctional agricultural landscapes, where communities are supported by the multiple ecosystem services and associated benefits provided by natural and agricultural systems in these landscapes. To achieve this vision, we ask: how, when and where can ecosystem service management be used to create and sustain **resilient socio-ecological systems and deliver positive impacts on food and livelihood security?**

The ESR Framework is centred on the notion that people can manage ecosystem service flows through agricultural systems and landscapes in ways that achieve positive outcomes for human well-being, notably poverty reduction and increased food and livelihood security. WLE suggests that resilience be used as a guide for studying the stability of agricultural systems and the ecosystem services on which communities depend. In this document, we refer to this notion of ecosystem service management guided by resilience thinking as the **ESR approach.**

Ecosystem condition and the stock and flow of ecosystem services impact directly on human well-being. Scientists are working to better understand which factors determine the type and severity of these impacts, such as whether changes to the supply of one ecosystem service – notably food - has more significant impacts on human well-being than changes to another; whether time-lags mask the impact of ecosystem service decline on human well-being; and whether technological and social advances can improve use efficiency and provide substitutes to ecosystem services to the extent that ecosystem degradation and human well-being are decoupled (Raudsepp-Hearne et al. 2010).

To achieve positive impacts on human well-being, WLE scientists research the: (i) ecosystem structures and functions that underpin service provision; (ii) threats and critical thresholds affecting this ecosystem service supply; (iii) type and distribution of and trade-offs between ecosystem services across and between landscapes under different management regimes; (iv) the effect of different governance mechanisms and institutional structures on the availability of ecosystem services and their benefits to different beneficiary groups; (v) indicators and metrics for monitoring the impacts and outcomes of changes to ecosystem service flows on ecosystems and people.

> *“Ecosystem condition and the stock and flow of ecosystem services impact directly on human well-being*

WLE seeks to inform **large-scale intervention decisions** that have cross-scale and cross-level impacts on ecosystem service flows to and from agriculture. This includes large-scale decisions in planning (e.g. development allocations), energy (e.g. design and location of hydropower systems), agriculture (e.g. investment in irrigation infrastructure), conservation (e.g. habitat restoration and protection) and hazard mitigation (e.g. flood control). WLE engages with decision stakeholders to understand their information needs and the constraints to ecosystem service management, where decision-stakeholders typically include national and local governance institutes and their policy advisors, investors, community groups, farmer representatives, and conservation and development NGOs. Engaging these stakeholders is critical for ensuring ESR research is demand-driven and focused on closing knowledge and method gaps in all phases of decision-making.

In the subsequent sections we describe, in more detail, the conceptual framework underpinning the ESR approach.

3.1 CONCEPTUAL BASIS

CBD (1992) defines an **ecosystem** as “a dynamic complex of plant, animal and microorganism communities and their non-living environment interacting as a functional unit.” Biophysical structures and processes in an ecosystem can have functions that provide a service – something that is useful - to people (Haines-Young and Potschin, 2010). We use the definition of **ecosystem services** advanced by Walker and Salt (2006), with our additions shown in parenthesis: “the combined actions of the species [and physical processes] in an ecosystem that perform functions of value to society.” This definition highlights that ecosystem services are about the benefits that ecosystems provide to people, and captures the notion that the biological and physical characteristics of a system underpin the delivery of ecosystem services.

Similar to TEEB (2010), we classify ecosystem services as provisioning, regulating, habitat and cultural services, where:

- **PROVISIONING** services refer mainly to goods that can be directly consumed, and include food, water, raw materials, such as fibre and biofuel, and genetic, medicinal and ornamental resources.
- **REGULATING** services comprise regulation of climate, air quality, nutrient cycles and water flows; moderation of extreme events; treatment of waste – including water purification; preventing erosion; maintaining soil fertility; pollination; and biological controls, such as pests and diseases.
- **HABITAT** services are those that maintain the life cycles of species or maintain genetic diversity, through

quality and quantity of suitable habitat, e.g., natural vegetation that enables the natural selection of species to maintain a diverse gene-pool or which service as a source of pollinator and pest control agents. These types of habitats benefit people primarily by maintaining stocks and flows of biodiversity, which underpin and ensure the resilience of many of the provisioning, regulating and cultural services provided by ecosystems.

- **CULTURAL** services refer to the aesthetic, recreational and tourism, inspirational, spiritual, cognitive development and mental health services provided by ecosystems.

Annex 1 presents WLE's complete ecosystem service typology. Figure 1 illustrates some of the ecosystem services provided by different land-use and management choices in an agricultural landscape.

The complex relationship between ecological processes, functions and ecosystem service delivery is gradually becoming clearer, although research still needs to be carried out to strengthen this understanding (see section 8 on illustrative research questions). For example, soil biota in ecological systems are often disregarded, and yet they play fundamental roles in driving ecological processes that lead to ecosystem goods and services, upon which human civilization totally depends on (Lavelle et al. 2006). The array of ecosystem processes to which soil invertebrates make fundamental contributions include: i) increased soil porosity ⇒ water infiltration ⇒ water availability for agriculture; and ii) decomposition and humification ⇒ nutrient cycling ⇒ nutrient availability for crop and pasture growth (Lavelle et al. 2006; Bottinelli et al. 2014). However, while the linkages between soil biological diversity and ecosystem services are generally accepted, the task of attributing particular ecological functions to particular species, assemblages or even ecosystems remains a difficult one. In light of the ongoing work needed to disentangle the structures, processes and functions underpinning the provision of ecosystem services, mimicking the structure of natural ecosystems in managed agricultural systems seems likely to be the surest route to securing sustainable and resilient systems.

WLE considers **agricultural systems** to include the cultivation of crops and livestock production on land (agriculture) and in water (aquaculture), as well as fisheries and forestry. While the notion of ecosystems may conjure images of pristine natural landscapes, we explicitly include agricultural systems within the ecosystem concept as "novel", or human-modified, ecosystems (Hobbs et al. 2006). There is ample evidence that these managed ecosystems provide

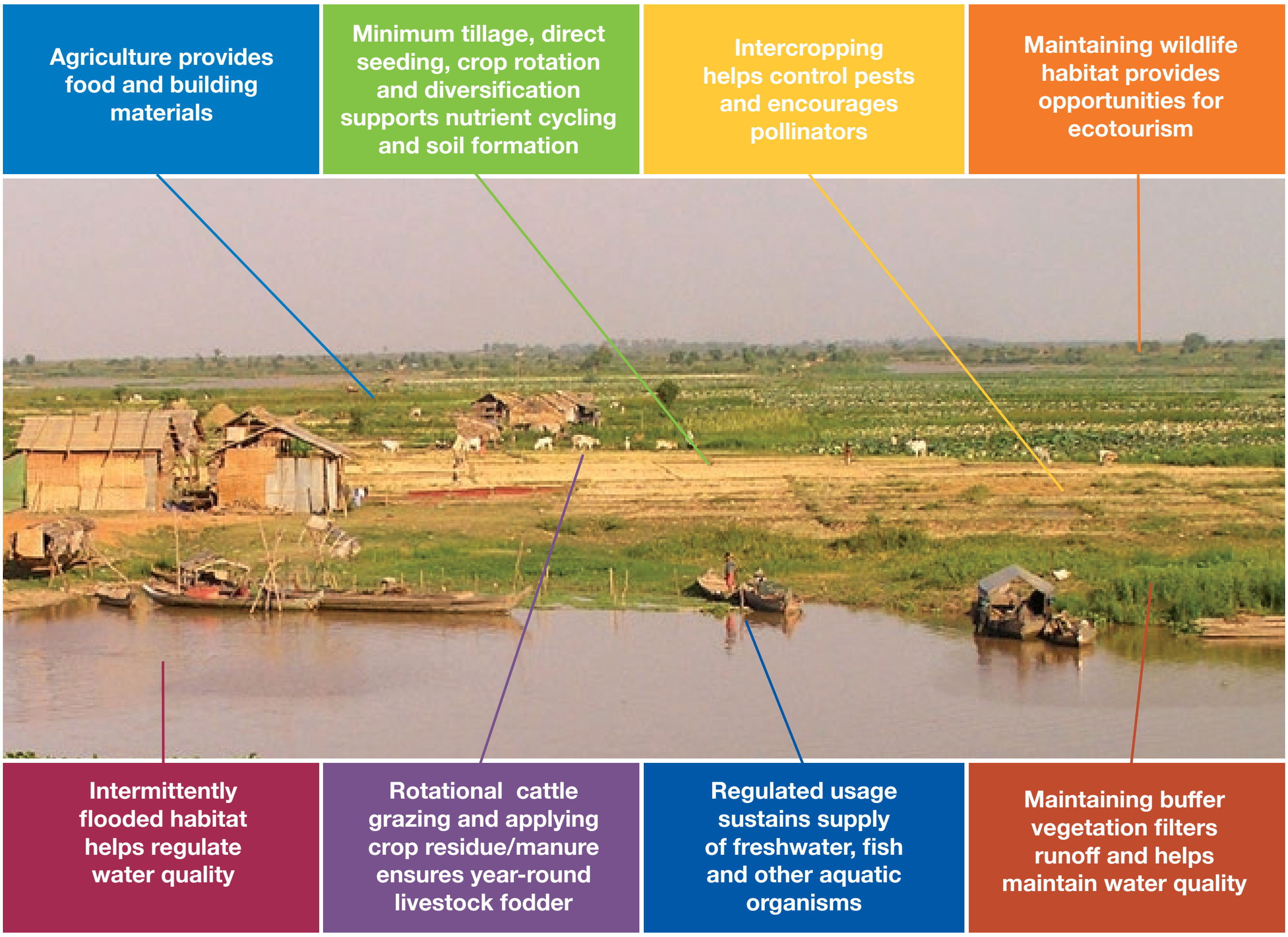

FIGURE 1. Examples of ecosystem services that should be valued and bolstered in an agricultural landscape of Kampong Chhnang, Cambodia. WLE's vision for agricultural intensification include interventions that enhance these services to increase food quantity, quality and accessibility, and improve livelihood security. *Source*: WorldFish/E. Baran.

ecosystem services (Power 2010; Zhang et al. 2007). Indeed, ecosystem services are very important in agricultural landscapes because of their critical role in achieving food security, human health and well-being. Farmers are generally considered 'providers' of provisioning ecosystem services, using inputs and practices to provide a range of goods on which we depend, such as food, fiber and biofuel. However, good agricultural management practices impacts and can enhance the flow and provision of many other ecosystem services, such as pollination, biological pest control, maintenance of soil fertility and structure, supply of habitat for wildlife, sustaining the aesthetic value of a landscape and regulating water supply (Tscharntke et al. 2005, Power 2010; Zhang et al. 2007). Conversely, poorly planned or badly managed agricultural systems can negatively impact the flow and provision of ecosystem services due to nutrient runoff, unintentional pesticide poisoning of some species and habitat loss (Zhang et al. 2007).

> ***"Ecosystem services are the combined actions of the species [and physical processes] in an ecosystem that perform functions of value to society***

This inclusion of agroecosystems within the ecosystem service concept has fuelled discussions around ecosystem service-based approaches to agriculture (Bommarco et al. 2013; Kremen and Miles 2012) and generated a much more interdisciplinary view of agricultural systems. Notably, conservation biologists have given greater consideration to the benefits that humans derive from ecosystems, even though their more traditional focus is on the conservation of species (Kareiva and Marvier 2007); it has also been incorporated into environmental economics, creating a surge in discussions on the externalities involved in the consumption of services, and the complexities in equitably distributing economic costs and benefits of the use and management of ecosystem services. The role of economics in the valuation of ecosystem services has also conjured fierce debate on the commodification of nature (e.g., The Guardian 2012a, 2012b).

WLE defines an **ecosystem service-based approach** to sustainable intensification as deliberately harnessing or restoring ecosystem services for production goals (e.g., increased yields, higher crop-per-drop ratios) or in ways that support these goals (e.g., pest control, seed dispersal, protection from storm damage), while reducing the negative impacts on the natural resource base that underpins these ecosystem services. In essence, an ecosystem service-based approach aims to facilitate an overall net positive effect on the provision of ecosystem services, both to and from agriculture. In this way, it aims to manage natural resources sustainably while maintaining or increasing food production and other ecosystem services. This might include, for example, the conservation of habitat for predatory arthropods to facilitate natural pest control (Rusch et al. 2013), landscape management of barriers to reduce the flow of agricultural pests (Avelino et al. 2012) or coordinating and incentivizing collective soil conservation in agricultural landscapes to increase the efficiency of hydropower (Estrada-Carmona and DeClerck 2011). We note that an ecosystem service-based approach is not devoid of technology or solely based on biological processes; rather, the development of technologies, tools and management practices that complement and increase the efficiency and impact of ecosystem services remain a critical line of inquiry and development. In our view, human-dominated landscapes present better opportunities for ecosystem service management than natural systems or protected areas because of the greater feasibility to manage landscape composition and configuration in the function of priorities. Agricultural landscapes are particularly amenable to such management due to their tremendous dependence on, and capacity to provide, ecosystem services, as well as the potential to develop industrial approaches to agriculture to achieve desired production, landscape and development goals. For example, Garbach et al. (In Review) found that, amongst five systems of agroecological intensification, precision agriculture showed the strongest potential to increase yields and ecosystem service provision).

Ecosystem services interact with, and are intrinsically linked to, social structures and processes. As described by Levin et al. (2009), humans can be considered an "integral part of the ecosystem, since humans derive a portfolio of services from the ecosystem and also act as a driver influencing ecosystem processes." Consideration of the coupling between social and environmental systems has given rise to the notion of **socio-ecological systems.** There is a wealth of literature on the theory of socio-ecological systems (see, for example, Berkes et al. 2003; Becker and Jahn 2006; Ostrom et al. 1999; Ostrom 2009). WLE's understanding of socio-ecological systems is guided by Walker and Salt (2006), who highlight that: (1) social systems are embedded in and interlocked with ecological systems (dynamics in one system affect the other); (2) socio-ecological systems can change in unpredictable, non-linear and transformative ways; (3) they are complex adaptive systems; (4) socioecological systems have varying degrees of 'resilience', and biological, physical and social factors can enhance (or reduce) this resilience.

Resilience, as we apply it here, means the ability of a socioecological system to undergo change and retain sufficient functionality to continue to support livelihoods through, for example, the sustained provision of ecosystem services, including the quantity, quality, access and utilization of food supply (sensu Park et al. 2010). Resilience is emerging as an important concept for understanding the stability and trajectory of the complex socio-ecological systems where ecosystem services are provided and consumed (Gordon et al. 2008, Scheffer et al. 2001). Resilience is not a static notion, rather it is focused on temporal change and on the role of internal and external drivers in transforming societies for better or for worse. These include drivers such as extreme weather events, spread of invasive species, shifts or failure in economic markets, or the introduction of new governance structures. Within development and, specifically, the WLE context, the focus is on positive transformative change - improved conditions for the poor - when shocks occur.

Resilience is not necessarily an inherent component of ecosystem service-based approaches; optimizing the delivery of a bundle of ecosystem services for a selected management goal may increase the vulnerability of other ecosystem service flows to changes in the future with potentially negative outcomes on system resilience. Consideration of resilience in the design of ecosystem service-based approaches adds another dimension to the consideration of trade-offs, whereby some amount of redundancy in service delivery and access is desirable (LaLiberte et al. 2010). Principles of socioecological resilience (Biggs et al. 2012) are largely derived from the natural sciences. However, we hypothesize that the complex adaptive nature of ecosystems and the services they provide inherently includes greater resilience than static technological fixes. This is a critical line of inquiry for WLE. The challenge lies in designing ecosystem service management approaches that build system resilience and prevent crossing undesirable change thresholds (TEEB 2010).

> ***"Resilience, as we apply it here, means the ability of a socioecological system to undergo change and retain sufficient functionality to continue to support livelihoods through, for example, the sustained provision of ecosystem services, including the quantity, quality, access and utilization of food supply (sensu Park et al. 2010).***

The next section presents the principles that we identify as being critical to the effective use of our approach for achieving development outcomes, and explains how these shape our approach.

BOX 1. FIVE CORE PRINCIPLES UNDERPINNING WLE'S ESR FRAMEWORK.

1. **People:** Meeting the needs of poor people is fundamental.
2. **People and nature:** People use, modify, and care for nature which provides material and immaterial benefits to their livelihoods.
3. **Scale:** Cross-scale and cross-level interactions of ecosystem services in agricultural landscapes can be managed to positively impact development outcomes.
4. **Governance:** Governance mechanisms are vital tools for achieving equitable access to, and provision of, ecosystem services.
5. **Resilience:** Building resilience is about enhancing the capacity of communities to sustainably develop in an uncertain world.

Five core principles

The ESR Framework is grounded in five core principles (see Box 1) that we identify as being vital for the effective use of ecosystem service-based approaches and resilience thinking in the development context.

These principles guide our ESR work in agricultural landscapes to help achieve development goals, including WLE's Intermediate Development Outcomes (IDOs).

WLE's ESR Framework

WLE's conceptual framework for using ecosystem service management to achieve development outcomes is presented in Figure 2.

WLE's work on ecosystem services and resilience is grounded in the idea that ecosystem services provide benefits to people that support livelihoods and human well-being, such as by generating income or providing nutritional diversity in diets (see *Core principle 1*). The quality and type of benefits received from ecosystem services depend on biological processes, creating tightly coupled socioecological systems (see *Core principle 2*), but also on whether the services and their benefits are equitably accessible and available for use.

As illustrated in Figure 2, we think about ecosystem services in agricultural landscapes in terms of:

- services from agricultural systems, such as food (caloric, nutritional and cultural dimensions), water, fiber, biofuel and medicinal resources that flow directly to people;
- services to agricultural systems that support production, such as pollination, regulation of water supplies and genetic resources; and
- services that flow through, and are mediated by, agricultural systems to people in other ways, such as by moderating extreme climatic events, erosion control, regulation of air and water quality, and providing opportunities for recreation and ecotourism.

These service categories necessitate a matrix view of agricultural landscapes as including farmed fields, field margins, embedded semi-natural land uses, such as agro-forests, and natural land uses, such as wetlands and forests. Agriculture is frequently discussed in terms of its negative impacts on the environment, contributing to biodiversity loss, land degradation, water pollution and climate change (Foley et al. 2011). Indeed, agricultural systems often negatively impact ecosystem service flows (and ultimately food production) in agricultural landscapes, for example, by polluting water and soil with nutrient runoff or by degrading natural habitat (Zhang et al. 2007), increasing sedimentation in rivers and streams, and increasing greenhouse gas emissions (Power 2010). One of the important insights that arises from studying ecosystem services is the understanding that agricultural systems can be better managed across and within scales to lessen, reduce and

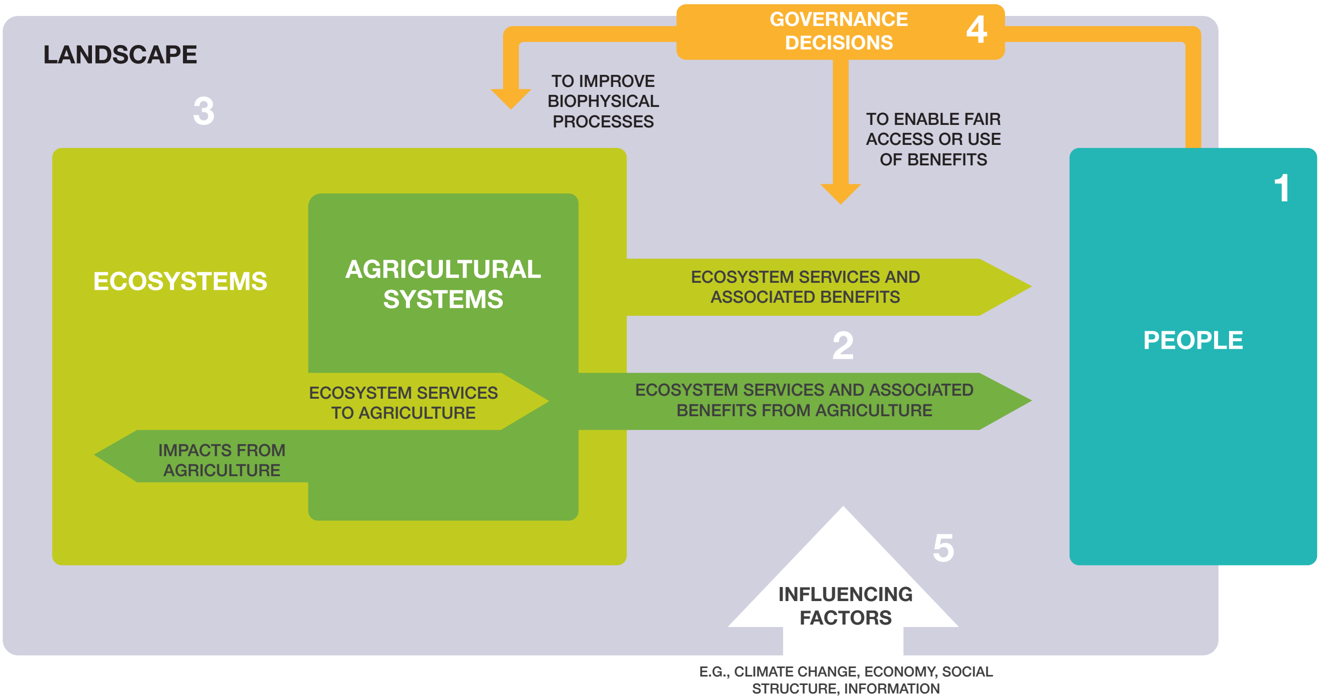

FIGURE 2. WLE's ESR Framework for how the management of ecosystem service flows through an agricultural landscape can improve the health, security and economic benefits to people.

even produce positive impacts on the environment, and improve the flow of ecosystem services to people (*Core principle 3*). For example, production is one component of agricultural systems, and is dependent on a plethora of regulating and supporting ecosystem services that are provided to agricultural systems and benefit people in other ways (Zhang et al. 2007). Many of the ecosystem services that are critical to agricultural production can be enhanced on agricultural lands themselves, through in-field management and are included in agroecological fields of study. Others are best suited to landscape-level interventions, which consider the management, composition and configuration of agricultural, semi-natural and natural land uses within agricultural landscapes. However, it is vital to understanding the trade-offs at multiple management levels involved in increasing agricultural productivity (Fremier et al. 2013); if increased yield is achieved at the expense of clean drinking water, productive fisheries or renewable energy generation then increasing agricultural productivity is unlikely to ultimately improve human well-being or alleviate poverty.

People (e.g., individuals, farmers, communities, institutions) can make conscious choices to improve the flow of ecosystem services and maximize benefits through better governance of ecosystem service flows (see *Core principle 4*). Our hypothesis is that selective ecosystem service use and management enhances the biophysical structures and processes that produce these services. These decisions can enable more equitable access to and use of benefits from these ecosystem services.

Ecosystem service flows are influenced, and constrained by, internal and external drivers, such as climate characteristics, social structures, including societal demand for different services (underpinned by social needs, norms, perceptions and values [Cowling et al. 2008]), status of knowledge and information availability, and economic conditions. These factors can constrain governance options and create shocks that impact the flow of ecosystem services. Resilience thinking provides a foundation for securing resilience in socioecological systems and resilience of ecosystem service flows – providing increased security for livelihoods that depend on the benefits from ecosystem services and potentially increasing the capacity of communities to develop (*Core principle 5*).

3.2 THE ESR APPROACH

In this section, we describe how ecosystem service management might be applied in practice within this conceptual framework, to achieve positive development outcomes. We pivot the discussion on the five core principles that guide our approach.

CORE PRINCIPLE 1: Meeting the needs of poor people is fundamental

This principle highlights that WLE's ESR approach is centered on the needs of poor people; our view is that decisions about the use and management of ecosystem services should benefit the poor, specifically by increasing food and livelihood security.

We identify three ways in which poor people can benefit from good ecosystem service management in agricultural landscapes in line with development goals, namely, through the provision of: (1) a sustainable and equitably distributed supply of provisioning ecosystem services that are of direct importance to human health and well-being, notably food, fiber, biofuel and water-related services; (2) reduced risk and severity of impacts from some system shocks on lives and livelihoods; and (3) opening up new and alternative opportunities for income generation.

The first benefit is particularly important for agrarian communities or those that are dependent on natural resources. WLE advocates that ecosystem service management goals should seek to sustainably and equitably provide food and other essential ecosystem services from agricultural landscapes.

These provisioning services are supported by a plethora of regulating and habitat ecosystem services. For example, agricultural productivity is dependent on soil nutrient cycling, regulation of water flows, carbon sequestration, pollination and pest control (Zhang et al. 2007).

The second benefit is derived from ecosystem service management decisions that build the resilience of ecosystem service flows to and from agriculture. This includes ecosystem services that reduce the risk and severity of impacts to people and livelihoods from shocks to a socioecological system. For example, the risk and impact of natural hazards can be reduced by ecosystem services that moderate extreme climatic events, such as heat waves, regulate climate, including through carbon sequestration and maintenance of air temperatures, regulate water supply and quality, and sustain genetic diversity (TEEB 2010). Resource use and management decisions should support these ecosystem services and enhance the related benefits, for example, by providing water storage and retention areas that enable drainage to reduce flood potential in flood-risk areas, and using vegetation and open spaces to provide shade and encourage air-flow in areas prone to heat waves and high temperatures. These decisions help increase food security, for example, by ensuring long-term supplies of fodder for livestock in the form of above- and below-ground biomass, or by reducing or eliminating soil and water pollution from nutrient runoff.

The third benefit refers to income for poor people that is enabled by ecosystem services. This includes increasing income through productivity rises, creating new employment options, or financial remuneration received in return for selective natural resource use and management. For example, ecosystem service-based benefits can be delivered through the selling and certification of agricultural commodities, such as coffee and cacao (Tscharntke et al. 2014), or payments for specific services, such as water-related services in the Cañete River Basin in Peru (see Case Study C) and the nationalized payments for ecosystem services (PES) program in Costa Rica (see Case Study D and Estrada-Carmona and DeClerck 2011). Ecosystem services can also generate income for poor people through ecotourism, for example, where high wildlife diversity or charismatic species are maintained in a landscape; or in the form of cost savings, generally comprising the avoided costs of importing services or treating degraded services to make them suitable for consumption through harnessing ecosystem services. For example, the cost of supplying clean freshwater to Greater Mumbai could be reduced by retaining forest cover within and around the agricultural systems in the watershed, which is rapidly being deforested, with cost savings estimated at USD 1.32 per hectare (ha) of retained forest cover per year (Singh and Mishra 2014).

CORE PRINCIPLE 2: People use, modify, and care for nature which provides material and immaterial benefits to their livelihoods

As much as we are increasingly under the impression that we live in a digital world, the concept of socio-ecological systems highlights that people and nature are inextricably linked, tightly coupled and function within complex adaptive systems. For instance, close linkages have been found between biological and cultural (as represented by language) diversity and endangerment (Sutherland 2003; Loh and Harmon 2014), and between exposure to nature and psychological functioning (Bratman et al. 2012), which contribute to our understanding of cultural ecosystem services. The presence, recognition and distribution of ecosystem services and their benefits drive societal choices and can create or reduce livelihood options. Conversely, human actions and land-use choices affect the processes that provide ecosystem services, and their flow and distribution. These feedbacks and complexities highlight that beneficiaries (people) and providers (ecosystems) of ecosystem services are intrinsically linked (Luck et al. 2009).

> ***“The concept of socio-ecological systems highlights that people and nature are inextricably linked, tightly coupled and function within complex adaptive systems.***

WLE's ESR approach seeks to ensure both societal and ecological components of a system, and the interactions between them are understood and incorporated into governance decisions. This requires a method of ecosystem service analysis that seeks to match ecosystem service provision to ecosystem service beneficiaries, and to model the effect of different ecosystem service management decisions on both ecosystem functions and processes that underpin service provision and on the flow to different beneficiary groups.

CORE PRINCIPLE 3: Cross-scale and cross-level interactions of ecosystem services in agricultural landscapes can be managed to positively impact development outcomes

Adequately addressing scale is central to ecosystem service-based strategies for poverty alleviation and increased food security. Following Cash et al. (2006), we define ***scale*** as the dimension used to study a phenomenon, and *level* as units of analysis situated along each scale. The ecological and societal structures and functions influencing the provision of ecosystem services operate at a very wide range of spatial, temporal, ecological and institutional scales, each of which has several levels of resolution (see Table 2).

While ecologists may understand the importance of ecological functions and processes in sustaining ecosystem services in a system (e.g., functional traits [characteristics] of different organisms, populations and communities, and their heterogeneity across an agricultural landscape), this may be less clear to social scientists. Conversely, ecologists may overlook the presence and influence of **socioeconomic heterogeneity** in a landscape (Fremier et al. 2013), and the resultant unequal value attributed to, and dependence on, ecosystem services across disparate communities. Correctly identifying the ecological and spatial scales through which these ecosystem services are provided, and matching these to appropriate jurisdictional extents is critical for sound PES management (Fremier et al. 2013). WLE proposes a **cross-scale and cross-level approach** (*sensu* Cash et al. 2006) that focuses on identifying ecological functions and structures providing services, and societal values, needs, use and management of these services, across and within scales in an agricultural landscape. To do this in practice, we advocate that a single scale is selected as the base unit of analysis and compared to at least one finer and one coarser level (*sensu* Walker and Salt 2006). This information can then be used to identify cross-scale and cross-level service management options that will positively impact service flows for development goals. For example, better targeting of anthropogenic inputs and resource-intensive land uses across time and space can help enhance ecosystem service flows through a reduction in the negative environmental effects, such as the selective use of pesticides to reduce unintentional harm or mortality of non-target species (Cunningham et al. 2013), or targeted planning of irrigation and dryland farming across a landscape to increase water availability and reduce the risk of salinization (Crossman et al. 2010).

In general, WLE suggests the use of the **landscape** as the base spatial unit of analysis (and the basin as the maximum extent) for studying ecosystem services. There is growing recognition of the role of landscape composition and configuration in assuring, or eroding, the delivery of ecosystem services (Sayer et al. 2013; Tscharntke et al. 2005). Landscapes provide a sufficiently large area to encompass most ecological processes that drive and interact with ecosystem service provision, and capture a wide range of stakeholders involved in service use and natural resource management decisions.

> ***"WLE proposes a cross-scale and cross-level approach (sensu Cash et al. 2006) that focuses on identifying ecological functions and structures providing services, and societal values, needs, use and management of these services, across and within scales in an agricultural landscape.***

A cross-scale and cross-level approach also provides an opportunity for nested management, which means that ecosystem service management at fine level can be integrated with management at coarser level in ways that might not be identifiable without cross-level analysis. An example of where this is useful is in land sharing and sparing strategies which, although hotly contested, are fundamentally about scale and abruptness of land use contrast (Fischer et al. 2008; Cunningham et al. 2013). In particular, much debate has revolved around the notion of **sparing or sharing** agricultural and conservation functions of landscapes. The notion of sparing suggests that agriculture and conservation functions can be disaggregated by identifying areas or regions that are best suited for agricultural production, concentrating agricultural activities in these areas and retaining marginal agricultural lands for conservation. In contrast, the notion of land sharing argues that agricultural and conservation functions should be mixed with integrated approaches to landscape management, which highlights the multi-functional nature of agricultural landscapes. Taking a cross-scale and cross-level approach focuses on matching scale and level to both ecological and social processes (Fremier et al. 2013), enabling easier identification of whether a landscape or its nested components are best managed using a land-sparing or land-sharing approach (Fischer et al. 2008).

Studying cross-level interactions helps identify which ecosystem services can be managed to increase benefits over small spatial extents, and short temporal and spatial time frames. These are, typically, the result of a management intervention from a single land user who implements a change in service management and is the primary beneficiary of the outcome. For example, a farmer planting nitrogen-fixing legumes on their field is the manager and beneficiary of the soil-based services provided by that intervention. In contrast, other services, such as the maintenance of water quality and flow, may be the result of coordinated management decisions over larger land areas. The providers and consumers of these services are frequently disaggregated in

	SCALE			
LEVEL	**SPATIAL**	**TEMPORAL**	**ECOLOGICAL**	**INSTITUTIONAL**
Fine	Field	Minutes-hours	Individual	Individual
↓	Farm	Days-months	Population	Family
	Community	Years	Community	Community
	Landscape	Decades	Ecosystem	National
Coarse	Region	Centuries	Biome	International

TABLE 2. Four scales and levels within and across which ecosystem services interact.

space and time. An example is collective action by land users across upland regions of a watershed to maintain water flow and quality, thereby benefiting downstream water users. Incentives or regulations are generally needed to effectively manage services that produce benefits over long spatial and temporal lags. Policies and actions that seek to balance ecosystem service trade-offs will need to address the potential for an increase in some of these services (e.g., provisioning services such as crop yield) that lead to a reduction in some other services (e.g., see Figure 1B, Benayas et al. 2009).

In essence, a cross-scale and cross-level approach facilitates the identification and analysis of inter- and intra-scale **synergies and trade-offs**, such as those between increasing food and housing security, increasing benefits to female and male, or young and old, farmers, and meeting the water flow requirements of flood-control managers and irrigation farmers. The approach, therefore, strives to bring together stakeholders from different sectors and levels to work together and achieve integrated governance, coordinated by existing institutions wherever possible, which is a product of multi-stakeholder decision-making.

CORE PRINCIPLE 4: Governance mechanisms are vital tools

The provision of ecosystem services and the benefits that people derive from them are influenced very much by the rules, practices and institutions that govern the management and use of natural resources. Governance, in this sense, operates at multiple levels and includes, for example, farmers making choices about agricultural practices at the field, farm and growing season levels; community organizations creating and maintaining forest management structures; national government choosing where to direct investments in the water supply chain; and local customary or regulatory laws and policies on natural resource use. The large geographic extents at which WLE operates mean that many of the ecosystem services the program focuses on can often be classified as **common pool**. These are services where one person's use diminishes the availability of the service for use by others (Lant et al. 2008), and where excluding access to some users may be desirable in principle but very difficult in practice (sensu Ostrom 1990), e.g., fish, freshwater and forest resources. Common pool services necessitate significant innovation and creativity in governance structures to ensure their equitable availability in perpetuity.

Interventions can be made at all levels of governance to improve the long-term sustainability of ecosystem services, and the equitable access to services and their benefits, by encouraging, facilitating or enforcing changes to ecosystem service use and management. To be effective, these interventions must take into consideration the biophysical structures and processes underpinning service provision as well as the existing social context, specifically the **polycentricity of governance -** referring to the diverse and multiple institutions that influence policy, existing governance outcomes, socioeconomic conditions and constraints, and cultural values, beliefs or traditions that result in preferences for certain management models (for example, centralized versus decentralized; individual versus. collective). Managing ecosystem services as **common pool resources** through polycentric governance systems requires an understanding of stakeholder (i.e., local and national government, community organizations, nongovernmental organizations (NGOs), private actors, research institutes) interests and agency at each governance level, and interactions between these stakeholders (Nagendra and Ostrom 2012). These interventions should facilitate polycentric governance of natural resources and, specifically, should not rely solely on single-level (e.g., national) government action, oversimplifying the complexity of natural resource management (McGinnis 1999; Nagendra and Ostrom 2012). As such, WLE advocates that interventions should be made as part of a participatory process where a wide range of stakeholders are engaged from the start.

CORE PRINCIPLE 5: Building resilience is about enhancing the capacity for communities to sustainably develop in an uncertain world

Building resilience in socio-ecological systems to enhance capacity and create opportunities for sustainable development in local communities is a fundamental component of system-based thinking in the development context. We currently live in a period where a lot of social and biophysical changes are taking place, globally. This is increasingly referred to as the Anthropocene (Barnosky et al. 2014), which poses new and often unpredictable challenges for managing ecosystem services for food security and poverty alleviation. There is a tendency to think that the poor are primarily operating at a very local level, since a substantial proportion of their livelihoods come from either the direct benefits of local ecosystem services or from local markets. However, connectivity between ecosystems and other systems at larger spatial extents, such as regional and global climate, hydrological and economic systems, can significantly influence local ecological and social structures, and their functionality.

Global drivers such as climate change can alter local resource availability and dynamics, and can increase the risk of extreme climatic events, such as droughts and dry-spells, in some parts of the world and flooding in others. These events affect the start and length of the growing seasons, making it more difficult to predict planting and harvesting times, and can change the range of different types of pests that can potentially have large impacts on crop yields and livestock health. Increased dynamism in global financial markets can also affect local realities, as new markets suddenly open up or collapse, and as prices fluctuate, and can potentially have large impacts on access to, and use of, ecosystem services upon which local livelihoods depend. Another important component that reduces the predictability of processes in ecological systems is environmental degradation, which can create system **tipping points** or thresholds beyond which functions in a system change significantly, are difficult to reverse, and trigger shifts to new system regimes (i.e., fundamentally different conditions), causing a rapid decline in the system's ecological and financial resources that are typically very costly and challenging to recover (Scheffer et al. 2001; Gordon et al. 2008). Sometimes this affects agricultural production capacity, e.g., environmental degradation is estimated to have caused losses of 5.7 million metric tonnes of grain per year in China during the late 1980s (Rozelle et al. 2008). These examples illustrate that a) local communities are increasingly dependent on, and connected to, larger scale processes; and b) the increasingly unpredictable nature of processes in a socio-ecological system impacts livelihoods.

This calls for enhanced efforts to build socio-ecological system **resilience** to stresses and shocks to support food security and poverty alleviation goals. Resilient systems in agricultural landscapes are able to recover their fundamental structure and functionality in the face of change or to transform into new regimes where this has desirable environmental and social outcomes. WLE suggests incorporating resilience into an ecosystem service-based approach, which means seeking to identify threats and thresholds affecting ecosystem service provision, and aiming to reduce these threats while increasing the ecological capacity to recover from these threats and avoid crossing critical thresholds. This should be carried out within the context of **improving development outcomes for poor people over long time frames**, which means that priority should be given to building resilience in ecosystem services which benefit the poor (Core principle 1) when considering trade-offs. Walker and Salt (2006) suggested using hierarchy theory to understand and build resilience, a theory which seeks to understand and manage cross-scale connections by choosing a focus level (e.g., landscape), and then looking at the drivers and changes that are happening in at least one larger level (e.g., basin or subcontinent) and searching for mechanisms to address these drivers at finer levels (e.g., fields), linking the approach outlined in Core principle 3. In particular, there is a need to monitor both the 'fast variables' (i.e., those with a short temporal lag between intervention and response) in agricultural systems, such as crop yields, as well as changes to 'slower' variables (i.e., those with medium or long temporal lags) that undermine long-term resilience, such as phosphorus levels in soils and lake sediments, aquifer levels and soil formation rates (Benayas et al. 2009).

> ***"Resilient systems in agricultural landscapes are able to recover their fundamental structure and functionality in the face of change or to transform into new regimes where this has desirable environmental and social outcomes.***

Several frameworks exist to help assess and build socio-ecological system resilience (e.g., Walker and Salt 2006), the resilience of ecosystem services in a system (e.g., Biggs et al. 2012) or the resilience of an agroecosystem (e.g., Cabell and Oelosfe 2012). In particular, Biggs et al. (2012) suggested seven principles for building the resilience of ecosystem services:

- maintain diversity and redundancy;
- manage connectivity;
- manage slow variables and feedbacks;
- foster understanding of socio-ecological systems as complex adaptive systems;
- encourage learning and experimentation;
- broaden participation; and
- promote polycentric governance.

WLE proposes these principles as forming the basis for operationalizing resilience in the context of food security and poverty alleviation goals. For instance, the first principle - to maintain diversity and redundancy - indicates that it is not only the general diversity of each system component (e.g., species, livelihoods, freshwater sources, land uses and institutions) that matters for resilience; it is also the abundance of each component, and their combined functional diversity and the level of diversity across these three elements determines the range of potential responses to failures/ surprises. Many poor communities show a high dependency on local ecosystem services as a safety net in times of failing on-farm yields (e.g., gathering of wild growing fruits and vegetables, bush meat, charcoal) (Enfors and Gordon 2008). The management of ecosystem services should seek to maintain these 'safety net' ecosystem services to help build resilient communities, for example, by identifying the level beyond which the depletion or enhancement of one or a bundle of ecosystem services threatens the provision of those services, on which poor communities depend highly for their food and livelihood security.

Farmers also safeguard food security and incomes by spreading risk through the planting of many different kinds of crops and varieties along with home gardens. This diversity serves as a base and insurance for livelihoods, and interventions to manage ecosystem service flows should seek to maintain these risk reduction strategies. Indeed, although land-use management is often focused only on a few species or local processes, only a diversity of species may guarantee resilience in dynamic agricultural landscapes (Tscharntke et al. 2005). Sometimes it is argued that a more general livelihood diversification, where smallholder farmers increasingly engage in other types of small-scale businesses, labor activities, seasonal migration and internalize remittances in their local economies, is one way of reducing vulnerability to local risks. However, ecosystem services remain a very important foundation for their livelihoods, which means that diversity affecting these services still matters (Nielsen et al. 2012). In general, a high diversity in the provision of ecosystem services mitigates the negative impacts of shocks, and makes it easier to adapt diets and livelihoods when these shocks cause yield failures (Enfors and Gordon 2008).

4. WLE'S TARGET ECOSYSTEM SERVICES

WLE classifies ecosystem services into four main categories (see Annex 1). The program considers many, if not all, of these categories, but focuses on the emergent impact of land-use change on the provision of ecosystem services as a result of collective action or large-scale investment decisions. Achieving WLE's vision within CGIAR requires system-level work in unison with targeted collaborations both internal to the CRP (flagships) and external (CRPs) to deliver impact at scale.

WLE's focus is on the horizontal flow of the ESR framework, emphasizing the impact of the biophysical structure and processes, their translation into ecosystem services and manifestation as improvements to livelihoods (Core principles 1 and 2). This horizontal relationship is straddled by two of WLE's crosscutting themes: Ecosystem Services and Resilience (ESR), and Gender, Poverty and Institutions (GPI). The three system CRPs (i.e., CGIAR Research Programs on Dryland Systems, Integrated Systems for the Humid Tropics ["Humidtropics"], and Aquatic Agricultural Systems) and WLE share some focus on ecosystem services, although this is typically characterized as Agroecological Intensification (AEI) (see Table 3) and farm/farming or community-level interventions in the system CRPs. WLE focuses on ecosystem services as common pool resources emphasizing the impacts of collective action or large-scale interventions. The scalability of individual farm interventions to landscape-level impacts will be a focus of WLE's contribution to CGIAR's program of work, complementing work in farming systems. There is a need for a strong collaborative partnership with the CGIAR Research Program on Policies, Institutions and Markets (PIM) in conducting the research, and development of institutions, markets and governance systems for restoring and securing ecosystem services. ESR has recognized the importance of both internal and external drivers impacting theories of change in WLE focal regions. Climate change is one such driver where close collaboration between the CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS) and WLE will be fundamental.

WLE recognizes several other critical drivers, particularly population growth, growing economies, increased resource consumption and changing diets (Bonhommeau et al 2013), operating in unison and being critical in regional foresight analyses. WLE's crosscutting theme on Gender, Poverty and Institutions is fundamental for strengthening research and impact on the relationship between services and human well-being (Core principles 1 and 2). The Strengthening Decision Analysis and Information Systems (DAI) flagship provides the link between biophysical research on ecosystem services and

ECOSYSTEM SERVICE CATEGORIES	EXAMPLES OF ECOSYSTEM SERVICES STUDIED BY WLE	PLOT, FARM AND SMALL-CATCHMENT SCALE APPROACHES	WLE (LANDSCAPE SCALE) APPROACHES	EXAMPLES OF WLE-TYPE APPROACHES[1]	FLAGSHIP AND CRP
Provisioning services					
Food	Crops cultivated, fish from fisheries, livestock, wild fauna, wild fruit	Field-level yield and crop diversity increases from agroecological intensification	Capacity of landscape to produce food (calories and dietary/nutritional diversity) with mixed land-use composition and configuration.	Khumairoh et al. 2012	LWP, RDE
Water	Water used for drinking, irrigation, cooling	Water-use efficiency of specific crops and cropping systems	Total budgets of watershed/basins to produce water for growing urban areas or for new irrigation structures. Impacts such as loss of natural vegetation or change in crop selection/ configuration on water consumption	Brauman et al. 2013*	LWP, RDE
Raw materials	Timber for construction, fuelwood, fodder, fertilizer	Total yield as a measure of intercropped systems at the field/farm scale.	Productive capacity of the landscape system as a measure of energetic (fuelwood), caloric and nutritional balances; fecal sludge as a raw material for agriculture	Cofie et al. 2009* Lydecker and Drechsel 2010* Murray et al. 2011* Scheierling et al. 2011	LWP, RDE, RRR
Genetic resources	Crop improvement	Within field varietal mixtures for increasing productivity and reducing crop loss	Among field varietal diversity and impacts on increasing productivity, reducing loss as a result of pests and diseases; mobilizing genetic resources between agroecologies to close yield gaps; connectivity and gene flow in socio-ecosystems	Jarvis et al. 2011* Krishna et al. 2013*	MRV

[1] * Indicates ISI peer-reviewed research in which a current WLE scientist has contributed as a primary author.

ECOSYSTEM SERVICE CATEGORIES	EXAMPLES OF ECOSYSTEM SERVICES STUDIED BY WLE	PLOT, FARM AND SMALL-CATCHMENT SCALE APPROACHES	WLE (LANDSCAPE SCALE) APPROACHES	EXAMPLES OF WLE-TYPE APPROACHES[1]	FLAGSHIP AND CRP
Regulating services					
Air quality regulation	Capturing fine dust, chemicals, etc.		No-till systems (e.g., managing water levels and aquatic biodiversity for rice straw decomposition in lieu of burning) Retaining permanent vegetative soil cover to avoid loss of topsoil Tree-based hedgerows to capture fine dust near human settlements	Palm et al. 2014*	RDE
Climate regulation	Carbon sequestration, influence of vegetation on infiltration and rainfall	Greenhouse gas (GHG) sequestration of cropping systems	GHG sequestration of alternate land-use compositions and configurations	Palm et al. 2014*	MRV CCAFS
Moderation of extreme events	Storm protection and flood control	Crop selection to regulate environmental variability (e.g., multi-strata advanced farming systems (AFS) to reduce variability in temperature and humidity at plot level)	Selection of landscape-level land-use (composition and configuration) to regulate climate (e.g., use of wetlands to absorb flood energy)	McCartney et al. 2011* McCartney 2013* Wood et al. 2013*	MRV FTA rainbow water
Regulation of water flows	Natural drainage irrigation and drought prevention	Infiltration and storage capacity of cropping systems and field management practices	Impacts of groundwater regulation, wetland systems (e.g., Tonle Sap, Inner Niger Delta), riparian forests, protected forest areas on flow regulation; impact of landscape-level adoption of AFS on water quality (nitrogen [N] and phosphorous [P]), including salinization, e.g., extent of riparian forest and field margin management needed to capture and store excessive nutrient loads/ensure water quality	Fremier et al. 2013*	RDE, LWP, MRV FTA rainbow water
Waste treatment	Water purification as it passes through soil and natural vegetation	Capacity of cropping systems to retain and process waste materials; impacts on net primary productivity; process resources recovered from waste; the use of safe water in irrigation	Closed-loop nutrient cycling; use of waste from humans and animals as fertilizers; resource flows from source to sink. Composting of vegetative matter of waste	Ntow et al. 2008* Abiadoo et al. 2010 Wichelns and Drechsel 2011*	RRR
Erosion prevention	No-till, contour planting, conservation agriculture	AFS, cover crops, no-till, etc., and other field-level soil conservation management	Landscape-level targeting of erosion conservation in basins to reduce sediment flow to reservoirs; PES for soil conservation	Saravia et al. 2009* Estrada-Carmona and DeClerck 2011* Palm et al. 2014*	MRV/RDE
Maintenance of soil fertility	Soil formation	Field-level soil conservation interventions	Collective action for soil conservation, including relationships with water quality; landscape soil fertility balance and targeting of regions for restoration of soil fertility; managing irrigation landscapes to reduce salinization risk or restoration of salinized soils	Crossman et al. 2013	RDE

ECOSYSTEM SERVICE CATEGORIES	EXAMPLES OF ECOSYSTEM SERVICES STUDIED BY WLE	PLOT, FARM AND SMALL-CATCHMENT SCALE APPROACHES	WLE (LANDSCAPE SCALE) APPROACHES	EXAMPLES OF WLE-TYPE APPROACHES[1]	FLAGSHIP AND CRP
Pollination	Retaining semi-natural habitat, or reducing disturbance frequencies to support pollinator populations	Composition of species and low disturbance management interventions to maintain pollinator diversity	Landscape-level calculation of pollination demand and vulnerability; Composition and configuration of landscape configuration to maintain pollinator abundance, and dispersal via landscape connectivity and permeability	Ricketts et al. 2008* Steffan-Dewenter et al. 2002 Hajjar et al. 2008* Kremen et al. 2007* Lebuhn et al. 2013*	MRV
Biological control	Seed dispersal, pest and disease control	Push-pull systems, impact of agricultural food systems on the suitability of habitats for pests and diseases, Integrated Pest Management.	Impacts of the composition and configuration of the landscape on pests and diseases (barrier), and movement of the control agent (bridge) Gene flow and services from in situ conservation	Avelino et al. 2012* Zhang et al. 2007 Hajjar et al. 2008* Zhou et al. 2014*	MRV
Habitat services					
Maintenance of the life cycles of species	Reproductive and nursery habitat	Management of cropping systems as habitat for species contributing to on-farm services	Landscape-level connectivity/ permeability for biodiversity; conservation of wetlands, spatial/ temporal management of agricultural waters to increase the availability of habitat for species; impact of biodiversity species on biocontrol, nutrient cycling and cultural services (e.g., Tonle Sap Biosphere Reserve)	DeClerck et al 2010* Martinez-Salinas and DeClerck 2010 DeClerck et al. In Review* Wright et al. 2012	MRV
Maintenance of genetic diversity	Especially in gene pool protection	Farmers' access to genetic resources; seed quality	Gene flow between farms and evolutionary services from in situ conservation; prioritization and conservation of global centers of agricultural biodiversity	Pereira et al. 2013*	RDE MRV
Cultural					
Aesthetic information **Opportunities for recreation** **Inspiration for culture, art and design** **Spiritual experience** **Information of cognitive development**	Recognition of the long-term role in human/ environment interaction in shaping culture and identity, and inclusion of mental well-being as a critical element of human well-being.	N/A	Improving the benefits of protected areas to livelihoods in life raft ecosystems (e.g., Tonle Sap, Inner Niger Delta, East Africa), in collaboration with conservation organizations (The Nature Conservancy, Conservation International, Wildlife Conservation Society) Inclusion of multiple knowledge forms – including indigenous knowledge - in ecosystem service assessment, and collaboration with FAO on globally Important agricultural heritage sites in WLE focal regions Participatory mapping of ecosystem services to identify cultural values that require conservation and restoration	Eyzaguirre et al. 2007* Carpenter et al. 2012* Johns et al. 2013*	ESR GPI
Mental health benefits	Stress reduction, enhanced concentration, improved moods			Bratman et al. 2012*	

TABLE 3. Ecosystem services included in WLE's program of work. The "Plot, farm and small-catchment scale approaches" column highlights approaches used by the system CRPs (the CGIAR Research Programs on Dryland Systems, Integrated Systems for the Humid Tropics ["Humidtropics"], and Aquatic Agricultural Systems) to study these ecosystem services, while the "WLE (landscape scale) approaches" indicates approaches typical of WLE. Plot, farm and small-catchment scale studies feature a greater focus on the role of ecosystem services in agroecological intensification while landscape approaches explore the interactions between collective action by many individual farmers and landscape-level ecosystem services. The "Flagship and CRP" column identifies to which WLE flagship and CGIAR CRP research on these services primarily pertain. The "Examples of WLE-type approaches" column provides references to literature where WLE-type approaches are used to study ecosystem service stocks and flows (see also section 7, Case studies).

the social, political and economic dimensions of decision science. The Managing Resource Variability and Competing Uses (MRV), Recovering and Reusing Resources in Urbanizing Ecosystems (RRR), Regenerating Degraded Agricultural Ecosystems (RDE) and Sustainably Increasing Land and Water Productivity (LWP) flagships provide the thematic research underpinning the crosscutting themes and decision science. The Integrating Ecosystem Solutions into Policies and Investments (IES) flagship, based on WLE's four focal regions, provides the contextual basis for the program's research on ecosystem services and resilience, and provides an indication of which services need to be prioritized to achieve its intermediate development outcomes in each geographical region. It is through this flagship that WLE's thematic research will be channelled.

5. THEORY OF CHANGE

The **theory of change** for the ESR crosscutting theme for achieving CGIAR's system-level outcomes and WLE's intermediate development outcomes is the integration of the ESR approach into decision-making across all sectors involved in the management of ecosystem services in poor agricultural regions. In the WLE context, decision making ranges from collective action at local scales, and incentive systems for individual farmers to implement ecosystem service-based management options, to regional solutions (e.g., work carried out in the program's focal regions). We place particular emphasis on matching ecological and governance scale levels for the management of ecosystem services (Fremier et al. 2013; see Core Principle 3).

Many guidelines exist for using ecosystem service research to impact decision making. For example, Ruckelshaus et al. (2013) proposed pathways along which outputs of biodiversity and ecosystem service assessments can flow to impact on decision-making and generate positive outcomes. These pathways capture the importance of ecosystem service research in building knowledge among stakeholders and decision makers, so that they might make better-informed choices, design appropriate implementation mechanisms, and implement these mechanisms to produce improvements in human well-being through ecosystem services. Another example is Cowling et al. (2008), who proposed a three-tiered process for safeguarding ecosystem services, arranged around assessment, planning and management phases. This model places particular emphasis on the importance of undertaking a social and political assessment alongside biophysical and valuation assessments of ecosystem services, in order to generate 'user-inspired and user-useful' research. Each of these frameworks emphasizes the importance of ensuring that decisions about changes to land use and management are made as part of a **participatory and iterative** process, where outcomes are **monitored and adapted** to increase benefits and are demand-driven rather than researcher-driven.

The four columns of the ESR impact pathway diagram (Figure 3), modified from Ruckelshaus et al. (2013), represent different pathways that constitute a level of success in integrating ecosystem service and resilience research into decision-making to achieve development outcomes. Deeper impact is achieved as

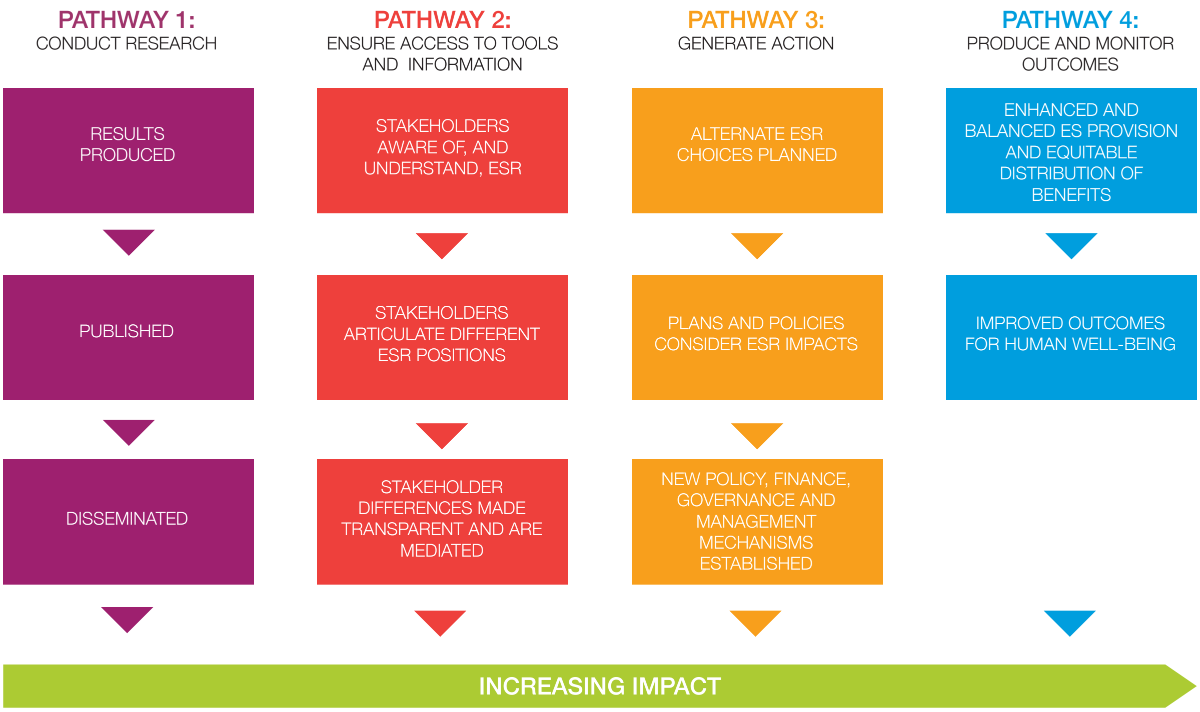

FIGURE 3. Pathways for achieving impact from ecosystem services and resilience research on human well-being (*source*: Modified from Ruckelshaus et al. 2013). Note: ES - ecosystem services.

the process proceeds from top to bottom down each pathway, and left to right across the four pathways. Pathway 1 represents research and communication to generate and disseminate new knowledge and improve understanding of how, when and where ecosystem services and resilience can be used to improve human well-being in agricultural landscapes. Pathway 2 represents the impacts that this research and knowledge

> ***The theory of change for the ESR crosscutting theme for achieving CGIAR's system-level outcomes and WLE's intermediate development outcomes is the integration of the ESR approach into decision-making across all sectors involved in the management of ecosystem services in poor agricultural regions.***

on the attitudes, beliefs, awareness and understanding of stakeholders and decision makers. Pathway 3 represents the influence that ecosystem service and resilience research has on specific actions which may constitute commitments, procedural change or a specific decision about funding or continuing/amending a program or policy. Pathway 4 represents specific outcomes of developing new management structures, collective action, policy or finance mechanisms, and making measurable improvements in ecosystem service provision, biodiversity and human well-being.

While the impact pathway diagram suggests a linear path to increasing impact, it is important to stress it has an iterative nature, consistent with adaptive management as the current school of practice in natural resource research, management and implementation. For example, use of tools by decision-makers in pathway 2 may reveal shortcomings in these tools that drive forward new research to improve these tools, returning us to pathway 1; or findings from monitoring and evaluation activities undertaken in pathway 4 may provide new insights on the impacts of ecosystem service management on human well-being adjusting the information available to stakeholders in pathway 2.

WLE achieves impact primarily through pathway 1, working in collaboration with its partners and with ecosystem service stakeholders involved in pathways 2 to 4 to ensure our research is responding to user needs throughout the decision-making process and results are translated into action. WLE researchers have been highly successful in generating research, with the program ranked first in the field-weighted citation index of all CRPs (CGIAR 2014, and see Table 3). Much of this research produced by WLE scientists and its partners stems from the program's focal regions, although it draws on a much broader range of experiences. This diversity and range make important contributions to increasing the options considered in the focal regions. For example, Latin America's experience with PES is unparalleled, globally; WLE's PES experience in this region (see case studies C and D in section 7, *Case studies*) represents an important opportunity for south-south learning. WLE's launch of the IES flagship and partnerships in the four focal regions therefore facilitates transforming the science outputs from pathway 1 to impacts achieved through pathways 2 to 4.

WLE therefore aims to **conduct demand-driven research** that generates the usable, accurate and comparable information, tools, and monitoring and evaluation systems that decision-makers need to make informed decisions on the management of ecosystem services. To ensure this research has an impact on development, WLE also seeks to **build and maintain strong partnerships** with ecosystem service managers and their advisors (e.g. farmers, planners, hydrologists, forest managers, national governments, policy advisors, investors) and leading scientists to ensure knowledge exchange, identify windows of opportunity for change, and support institutions in creating enabling environments in which to implement decisions and generate action. We suggest three priority tasks for WLE scientists building these partnerships, to ensure ESR research flows along pathways 1 to 4 and the ESR core theme, along with WLE, achieve its theory of change:

1. **interact** with world-class research organizations at the cutting edge of ecosystem service research and implementation;
2. **engage** in WLE's focal regions and with its partners on high impact research for development to operationalize the benefits of ecosystem services to the world's poorest; and
3. **influence** the global dialogue and processes (Convention on Biological Diversity [CBD], Global Environment Facility [GEF], Intergovernmental Platform on Biodiversity and Ecosystem Services [IPBES], United Nations Sustainable Development Goals [SDGs]) on ecosystem services and poverty alleviation through the program's research and practices.

6. TOOLS, METHODS AND APPROACHES

In this section, we describe the tools, methods and approaches that can be used to support decision makers in the assessment, planning, implementation and monitoring phases of decision-making (see Figure 4).

Assessment

An important first step in integrating ecosystem service thinking into decision making is to define landscape **goals** in consultation with local, landscape and regional stakeholders (see Figure 5). Stakeholder values, perspectives, needs and cultural norms underpin the decision-making process, and these need to be understood early on (Cleveland 2014; Cowling et al. 2008; Ruckelshaus et al. 2013). WLE supports the notion that research activities on ecosystem services should be designed, interpreted and adapted in discussion with all stakeholders with an interest in ecosystem services as part of an iterative process (Cowling et al. 2008; Fish et al. 2011; Ruckelshaus et al. 2013). This holistic process helps to strengthen

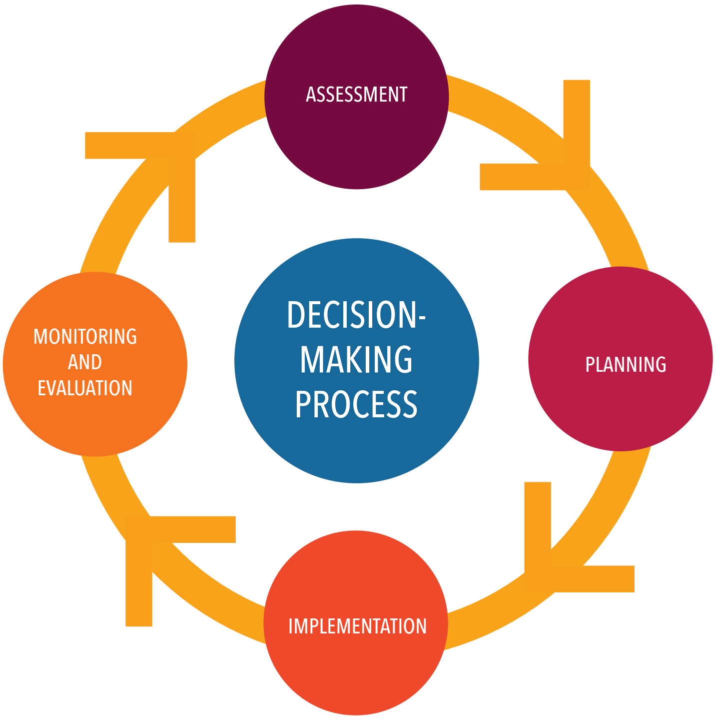

FIGURE 4. Decision-making for ecosystem service management.

the relationship between researchers and ecosystem service beneficiary groups and managers (Ruckelshaus et al. 2013), and to also ensure that the research outcomes and new landscape identity are accepted and legitimized by stakeholders (Cowling et al. 2008). To identify appropriate and effective options for ecosystem service management that benefit the poor (*Core principle 1*), two important factors that need to be understood early in the process are: (i) **stakeholder interests** (including farmers, communities, local businesses, large and multinational companies, local authorities, national government, nongovernmental organizations), and (ii) **power relations** between these stakeholders. An analysis of these factors should seek to understand who influences decision making and who benefits from the range of options under consideration. WLE's priority is on making decisions that benefit the poor where multiple stakeholder interests are at stake.

We discuss specific methods for assessing and engaging stakeholders in section 6, *Implementing ecosystem service management*.

Once the landscape objectives are agreed, a wide range of approaches and methods need to be used to examine the many facets of the ecological function and ecosystem service provision relevant to communities in agricultural landscapes, ideally within a multi-disciplinary and multi-stakeholder framework (Sayer et al. 2013; Bommarco et al. 2013). Identifying the presence and value of an ecosystem service is not straightforward. Aside from the complex relationships between biophysical processes and ecosystem service supply, social context plays an important role in this process because ecosystem services are essentially an anthropocentric perspective (Luck et al. 2012) on the biological, physical and chemical realities of ecosystems and ecological function. Therefore, the identification of ecosystem services, their distribution, flow, value and beneficiaries may be relatively transparent in some instances (Brown and MacLeod 2011), but highly subjective in others. For example, the identification and value of ecosystem services is driven by, among other things, livelihood, education, culture, gender, ethnicity, affluence, land tenure, and social, economic and policy context. The recognition and prioritizing of ecosystem services in landscapes influence how their benefits are perceived, utilized and distributed (Corbera et al. 2007; Patten et al. 2010).

Ecosystem service assessments generally seek to understand the relationship between ecosystems, the services they provide, and the users and managers of the service (*Core principle 2*). When an ecosystem changes, a whole suite of services may change with it, and simultaneously considering as many of these services as possible helps to elucidate the trade-offs of different land-use and management decisions across scales (Goldstein et al. 2012, Willemen et al. 2012). It is useful to understand how a change to a small number of services affects a whole range of other services. Therefore, ecosystem service assessments need to include identification of sources of services, movement/flow of services, threats to both sources of services and services themselves, and the beneficiaries of those services across the landscape and at selected levels nested within the landscape (*Core principle 3*). Management decisions to enhance the benefits that people obtain from one ecosystem service may impact the provision and distribution of other ecosystem services and related benefits, creating trade-offs between development outcomes across and within multiple scales, e.g., increasing native vegetation cover to encourage natural pollinators will reduce the area of land available for other uses, such as cropland. These include temporal, spatial, beneficiary group and ecosystem service trade-offs (Elmqvist et al. 2010, p. 46). Each of these trade-offs need to be understood to enable decision makers to make informed decisions on how management approaches can be changed to promote fair and equitable access to ecosystem services and their benefits (Daw et al. 2011; *Core principle 4*).

There are many existing methods and tools to assist ecosystem service assessments. ValuES[2] provide a fairly comprehensive list of existing tools and methods available for ecosystem service assessment and provide useful advice, aimed at decision-makers, on which approach is most suitable for different decision contexts. Bagstad et al. (2013) reviewed 17 ecosystem service decision-making tools and assessed

[2] ValuES; Method Navigator; http://www.aboutvalues.net/method_navigator/; last accessed 23 September 2014.

the performance of each tool against a range of evaluation criteria to determine their appropriateness for widespread use in the public and private sectors. Figure 6 shows how this study categorizes ecosystem service decision-making tools in terms of their use for impact screening, site-level and landscape-level assessment, and monetary or non-monetary valuation.

As shown in Figure 6, several methods exist for analyzing ecosystem services and their resulting benefits to people at the **landscape level**. These tools seek to understand the functional processes occurring within the ecosystems themselves, track how a change in ecosystem structure could thus lead to a change in the function, services and benefits, and consider where people are on the landscape and to what extent such change will impact them (Tallis and Polasky 2009; Willemen et al. 2013). For example, the ARtificial Intelligence for Ecosystem Services (ARIES)[3] or Integrated Valuation of Environmental Services and Tradeoffs (InVEST)[4] (see Figure 7) tools include a suite of modelling software that enables users to compare ecosystem services, and map the flows to beneficiaries for different investment and intervention decisions. A key distinction between these two tools is the modelling platform upon which they are based; InVEST featuring process-based models derived from the literature and ARIES building new models from Bayesian belief networks informed by user data.

To screen the impact of different scenarios on ecosystem services, Co$ting Nature is a user-accessible tool that is useful for high-level mapping of ecosystem services across landscapes, and hosts all the data necessary to run its models[5]. However, it can be difficult to tailor these models to specific systems (e.g., vegetation in water models is treated as tree and herb, rather than differentiating among different types of agriculture or herbaceous vegetation). The processes represented for any particular service may vary quite dramatically in each of these tools (e.g., whether 'water quality' is estimated by a total human footprint upstream or quantified by the universal soil loss equation and routed across landscapes), so it is important that the users fully understand the limitations and assumptions of each model before applying them to their system.

FIGURE 5. Early engagement in the assessment phase of ecosystem service-based management entails engaging with stakeholders to identify priority ecosystem services. Here, community members work with WLE scientists to identify ecosystem service stocks and flows, as a first step in developing an ecosystem service-based landscape management plan (*Photo*: Trinidad del Río).

> *"When an ecosystem changes, a whole suite of services may change with it, and simultaneously considering as many of these services as possible helps to elucidate the trade-offs of different land-use and management decisions across scales.*

Several tools exist for **site-level** assessments. In addition to those shown in Figure 6, BirdLife International recently developed a Toolkit for Ecosystem Service Site-based Assessment (TESSA), which provides a set of methodologies for measuring and monitoring ecosystem services at the site level with a high degree of community and stakeholder participation throughout its assessment process (Peh et al. 2013). The framework can guide the user through services that are of interest and methodologies that are most appropriate, providing a useful process for stakeholders to step through prior to initiating work with one of the mapping tools described above.

Valuation tools are used to help users understand the monetary and non-monetary values of ecosystem services, an important guide for development-orientated decisions on land-use change and investment. Economic **valuation of ecosystem services** can be based on direct (e.g., market value, cost of replacement/restoration, avoided costs, contingent values) or indirect (e.g., protection expenditure, travel cost, modelling and comparisons) calculations derived from revealed or stated preferences (UNEP-WCMC and IEEP 2013, p. 78). One common approach to economic valuation is benefits-transfer, which applies economic value estimates from one location to a similar site in another location, treating all units of a particular landscape type as identical. Benefits-transfer has been useful in Total Economic Valuation (TEV) studies that aim to take a global or national view of the standing stock of ecosystem services (e.g., Costanza et al. 1997; Costanza et

[3] The ARIES Consortium; ARIES suite of applications; Available at http://www.ariesonline.org/ (accessed on April 17, 2014).
[4] The Natural Capital Project; InVEST software; Available at http://www.naturalcapitalproject.org/InVEST.html (accessed on April 17, 2014).
[5] Policy support systems at King's College, London; Co$ting Nature; Available at http://www.policysupport.org/costingnature (accessed on May 12, 2014).

ECOSYSTEM SERVICES IMPACT SCREENING	LANDSCAPE-SCALE MODELLING AND MAPPING	SITE-SCALE MODELLING	NONMONETARY VALUATION	MONETARY VALUATION
ESR (aspatial) Co$ting Nature (spatial)	ARIES EcoAIM EcoServe Envision EPM ESValue InFOREST InVEST LUCI MIMES SolVES	EcoMetrix LUCI	EcoAIM ESValue SolVES	NAIS Ecosystem Valuation Toolkit Benefit Transfer and Use Estimation Model Toolkit

POTENTIAL STEPS IN ECOSYSTEM SERVICES ASSESSMENT PROCESS

FIGURE 6. Decision-making tools used during assessment and planning of ecosystem service management (*Source*: modified from Bagstad et al. 2013).

al. 2014), but applying these approaches at a landscape or finer levels makes resolving the specificity of the landscape type and deciding what constitutes 'similar enough' particularly important and challenging (Plummer 2009). Moreover, ecosystem services have important sociocultural and ecological values, which mean that estimates of service values based solely on economic valuation will inevitably exclude part of the total service value (TEEB 2010). Non-monetary methods for valuing ecosystem services include livelihood assessments, vulnerability assessments and capability approaches. These alternatives help integrate measures of human well-being that are not amenable to monetary valuation, such as human rights and cultural values (TEEB 2010).

Despite the significant progress made through the development and application of ecosystem service assessment and valuation tools (Ruckelshaus et al. 2013; Bagstad et al. 2013; Vigerstol and Aukema 2011; Nemec and Raudsepp-Hearne 2012), researchers are struggling to translate the latest science in measuring ecosystem services into outputs that have practical applications for managers and decision makers. This is where CGIAR and its partners can help; by working more closely with ecosystem service managers and users to understand and close the research-policy gap, for example, by strengthening tools that can be used to guide the decision-making process.

One major problem with existing assessment tools is that they have not been fully developed to represent functional differences in agricultural best management practices, which limits their ability to identify optimal ecosystem-based management approaches in agricultural landscapes. However, in many cases, this functionality can be added with additional data or inputs on the part of the user. For example, InVEST has biophysical attribute tables that accompany many of the spatial data inputs and characterize the pollutant retention capacity, carbon storage or other functions provided by different land-cover classes. Agricultural land uses could be broken down into more categories based on their management practices, and different biophysical values applied according to the scientific literature. ARIES models can be modified by the user to reflect local conditions and specific physical processes using local data, and if such data exist then this can help to differentiate between different agricultural management practices.

> ***"This is where CGIAR and its partners can help; by working more closely with ecosystem service managers and users to understand and close the research-policy gap, for example, by strengthening tools that can be used to guide the decision-making process***

Another limitation with existing assessment methods is that they are based on the best available science and, therefore, limited by the science itself and by the accuracy and availability of data. As stated by Box and Draper (1987, p. 74), "Remember that all models are wrong: the practical question is how wrong do they have to be to not be useful."

In many cases where local data are scarce, on-the-ground measurements will be essential to improve the modeling of ecosystem services in agricultural landscapes. However, **Big Data** is emerging as one high potential data collection technique. Big Data refers to the vast quantities of data that are being created every day through various mediums, including computers, mobile phones, and global positioning system (GPS) and remote sensing devices. This includes the wealth of data exchanged by mobile phone users in developing countries, where knowledge and information has previously been hard to access remotely or over large scales. The complexities and numerous trade-offs associated with ecosystem service-based assessments highlight the need for linked information systems, where data is available and accessible for rapid assessment of ecosystem service stocks and flows.

The most exciting aspect of this data revolution is that much of the information obtained is provided voluntarily by end users or through everyday processes (for example, regional precipitation maps being developed by measuring signal strength between cell phone towers), when individuals and groups are galvanized to collect and send data to online or mobile sources, notably through crowdsourcing initiatives. An example of successful crowdsourcing is the growing volume of freely accessible data on bird species compiled online by smartphone users, e.g., via iBird, which is subsequently used by rice farmers in the Central Valley of California to manage water levels to provide habitat for migrating waterfowl, and to increase the soil and pest control services they provide.

Making these data **accessible, usable and useful** is the challenge that scientists, governments and industry working in international development are now seeking to overcome (World Economic Forum 2012; Sachs et al. 2010). Vital Signs is leading the way in channelling Big Data on ecosystems for agricultural management, by seeking to provide open access data - including data on ecosystem services - "at all scales that are relevant for agricultural decision making" (Vital Signs 2014). Vital Signs was launched in 2012 and is operational in three countries (Tanzania, Ghana and Uganda), with plans to further expand their service globally. WLE's work on ESR aims to help by working closely with ecosystem service managers to ensure that data the research community collects on ecosystem services is accessible to these stakeholders, and provides the type of high-value information they find helpful. These efforts are facilitated by CGIAR's Open Access and Data Management Policy, which regards research outputs as 'international public goods' that should be widely distributed to promote knowledge sharing and transfer.

Planning

Improving ecosystem service flows in agricultural landscapes typically requires a combination of multi-level approaches and interventions. Indeed, ecosystem service-based and conventional interventions and management options are not mutually exclusive; on many occasions, these approaches are complementary and can be used together sustainably. For example, sustainably maximizing benefits to people may require a mix of ecosystem service-inspired approaches and anthropogenic inputs; at the farm level, this could mean mixing nitrogen-fixing legumes with manure and limited chemical fertilizers to increase soil fertility, rather than phasing out fertilizer altogether. At the landscape level, it could translate into using the knowledge of ecosystem service flows to inform investment decisions on grey infrastructure – such as dams – to manage water supply. The type and combination of interventions that will be most effective and appropriate will depend on the specific objective (the service or service bundle to be managed), but is influenced and constrained by economic, technical and political context, societal structure and needs, cultural preferences, and the availability of, and access to, knowledge and information. These factors vary across and within scales requiring **joined-up and adaptive governance**, whereby institutions and groups from different sectors and scales, influencing ecosystem service governance, work together to share knowledge and learning, align goals and strategies, and agree on implementation mechanisms, continually reviewing and modifying these approaches to improve outcomes (Nagendra and Ostrom 2012).

> ***"The complexities and numerous trade-offs associated with ecosystem service-based assessments highlight the need for linked information systems, where data is available and accessible for rapid assessment of ecosystem service stocks and flows.***

There are many approaches to **multi-stakeholder assessment and engagement** to support decision making. Fish et al. (2011) provided clear guidance on ensuring that decision making for an ecosystems approach is part of a participatory process, and proposed a three-step process: (i) identify the type of engagement required (learn from, inform, collaborate with); (ii) assess the stakeholder landscape and understand who is important and why; and (iii) select appropriate stakeholder analysis techniques. This work highlights that there is no accepted standard for systematically mapping stakeholders in decision making, but stakeholder analysis is emerging as a promising method for categorizing different stakeholders and assessing relationships between them. Reed et al. (2009) reviewed methods for stakeholder analysis and presented a schematic diagram for possible rationales, typologies and methods for using this approach in natural resource management (Figure 8). For example, in this work, identifying stakeholders (service beneficiaries, managers and decision

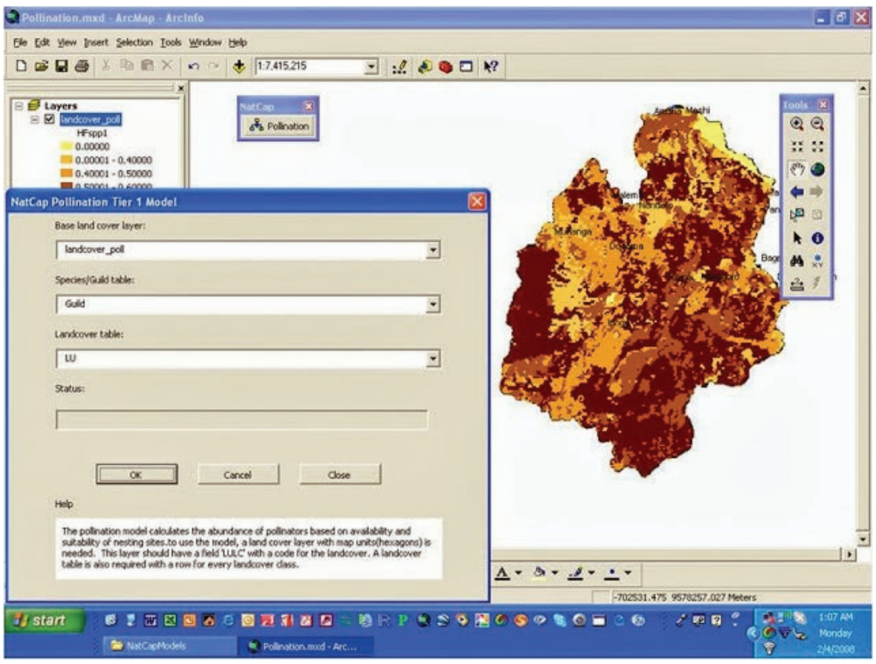

FIGURE 7. Ecosystem service mapping using InVEST (*Source*: The Natural Capital Project).

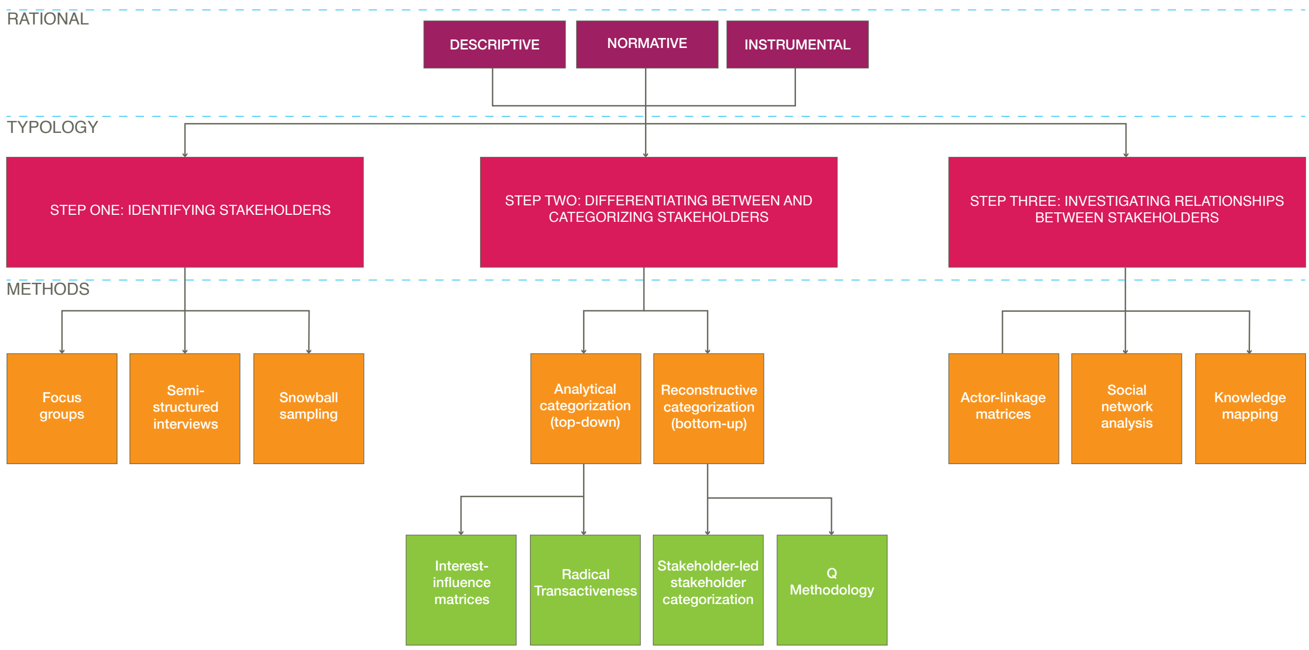

FIGURE 8. Illustration of possible rationale for typology of approaches to, and specific methods used during, stakeholder analysis (*Source*: Reed et al. 2009).

makers) is recognized as one essential component that may be approached by holding focus group discussions, undertaking semi-structured interviews or snowball sampling.

WLE's approach is in line with Reed (2008), who argues that, in order to ensure high-quality decision making, stakeholder participation must be approached in a way that empowers participants, encourages equity, builds trust and furthers learning. Furthermore, stakeholder knowledge – such as farmer knowledge - should be integrated with scientific knowledge to enable a holistic understanding of socio-ecological systems in agricultural contexts (Reed 2008).

Stakeholder engagement should be ongoing throughout the decision-making process and include all sectors of society, including those that are typically underrepresented. However, the time-consuming nature of iterative stakeholder engagement can create challenges for scientists and policymakers, who may need results within relatively short time frames to demonstrate progress or fit within windows of policy development (Ruckelshaus et al. 2013).

The selection of adequate ecosystem service management approaches and interventions to achieve landscape goals should take into account trade-offs and synergies in management outcomes at different spatial scales, times and for different beneficiary groups. An example of a tool that can help guide the decision-making process is a decision tree that identifies optimal management solutions for different priorities (such as improving water quality). Crossman et al. (2010) developed a decision tree to help managers make spatially targeted investment decisions that optimizes water supply and related environmental flows. This research shows that targeted investments in irrigation infrastructure has the potential to significantly increase agricultural productivity and net economic returns (Figure 9).

> ***"Stakeholder engagement should be ongoing throughout the decision-making process and include all sectors of society, including those that are typically underrepresented***

One factor that needs to be considered during the decision-making process is that sustainable intensification of agriculture through ecosystem service-based approaches is a relatively new concept and the terminology – specifically, use of the word 'intensification' - may not be well understood or accepted by decision makers both in a policy development context and on the ground (for a lively discussion on this, visit the WLE Agriculture and Ecosystems Blog (wle.cgiar.org/blogs). There is a danger that the concept is misinterpreted or that the terminology is inadvertently or intentionally applied to approaches that are not distinctly different from business-as-usual intensification. To sidestep this risk, initiatives based on the enhancement of ecosystem services need to be clearly differentiated from conventional ideas about agricultural intensification in policy parlance and documentation.

Implementation

Governance mechanisms can create an **enabling environment** for implementing ecosystem service management and securing the equitable distribution of service benefits (*Core principle 4*). When designing strategies for sustainable and equitable management of ecosystem services, the following aspects of governance are crucial: (i) public policies and laws; (ii) customary laws and traditions; (iii) incentive mechanisms; and (iv) institutions, and capacity development and empowerment. We discuss here how these aspects can be incorporated into ecosystem service based-approaches with a view to understanding where CGIAR and its partners can help to create an enabling environment.

(i) Public policies and laws

Local, national and international law delineate the rights and obligations of people in relation to the utilization of natural resources. The increased attention being given to environmental problems in the last century, primarily at the international level, has resulted in the proliferation of national statutory laws that seek to protect or re-establish the quality of natural and human environments, and the basic elements of such environments: air, water, land and life. The extent to which these laws contribute to the provision of ecosystem services and the equitable management of these services very much depends on: i) whether they are based on scientifically sound principles; ii) the capacities of resource users to follow the rules (i.e., the feasibility of the rules themselves); and iii) the enforcement capacities of the agencies in charge of implementing the laws. In many developing countries, the sustainability of ecosystem services very much depends on the joint improvement of these three aspects of environmental law.

The management of ecosystem services in agricultural landscapes is also very much influenced by statutory laws that do not directly pertain to environmental protection, including property laws (particularly on land, water, forests), market laws (such as that used for food price regulation, import and export control of agricultural products, and food quality and safety standards), finance laws (especially in relation to agricultural credit and insurance) and labor laws (for example, laws that regulate the rights and obligations of farm workers). Often, the content of these laws reflect government preferences in relation to agricultural development trajectories and, in many cases, they are not well aligned with the same government's intentions in relation to environmental sustainability and biodiversity conservation. For example, agricultural policies and laws that promote, through different means, large extensions of mono-cropping systems, the continuing trend towards large farms rather than sustainable small farms, or a heavy reliance on and use of pesticides and fertilizers, are likely to put the sustainability of ecosystem services in agricultural landscapes at risk. Introducing sustainability objectives and biodiversity values in national policies, and laws and regulations is an important step towards a more coherent governance system.

Command and control rules and incentive-based mechanisms can be used to stimulate and sustain action. For example, payments for selective management of ecosystem services can be used to benefit service users and managers (e.g., see case study C in section 7, *Case studies*), helping to improve ecosystem service flows and achieve more equitable distribution of benefits. UNEP-WCMC and IEEP (2013) presented a guidance document for policymakers seeking to integrate ecosystem services into national governance systems through National Biodiversity Strategy Action Plans. This document is a useful reference for researchers seeking to support national partners in, for example, the use of valuation tools and incorporating ecosystem services into national accounting.

(ii) Customary laws and traditions

Together with statutory law, the management of ecosystem services is subject to customary laws and traditions. Land tenure, water use and forest exploitation are some of the issues that

FIGURE 9. Decision tree for targeting investment for reconfiguring irrigation investments in the Torrumbarry Irrigation Area in northern Victoria, Australia, in line with different investment priorities and ecosystem services (indicated by the yellow, red and green colored boxes) (*Source*: Crossman et al. 2010).

are commonly subject to widely accepted undocumented rules at the community level. For example, in Ghana, and several countries of the Sahel, access to land and water is regulated by customary law where local chiefs and priests play a central role. In the twentieth century, the effective implementation of customary law in large parts of these countries was affected by colonization, migration and people's conversion to Christianity and Islam, but customary rules and rights continued and continue to be very much respected in certain rural areas. In the last decades, statutory laws on land and water tenure and use, coupled with the creation of an official decentralized system of land and water management, have created a parallel structure which often does not recognize the existence of customary law and the role of local chiefs and priests (Opoku-Ankomah et al. 2006). Similarly, in these countries, development projects and initiatives instigated by international organizations have sometimes focused on formalizing land and water rights without paying sufficient attention to existing traditional, non-written rules, which can not only provide more legal certainty than the statutory laws but are more effective in ensuring the provision and maintenance of ecosystem services. A coherent and effective governance system of natural resources and ecosystem services should include a balanced mixture, where statutory and customary laws or traditional components reinforce each other.

It is generally recognized that secure **property rights**, in particular, to the land and natural resources found on a given piece of land, provide the incentives required for individuals (e.g. farmers) and/or groups to undertake the investments in ecosystem management activities that enhance ecosystem services and resilience (Mwangi and Markelova 2009). Property rights do not necessarily imply the sole authority to use and dispose of a resource (or to claim full ownership). The claim to a benefit stream can refer to a number of different bundles of rights, which do not require complete control over a resource. Schaleger and Ostrom (1992) distinguished between use rights, which include access and withdrawal, and control rights, including management, exclusion and alienation.

To be effective, property rights need recognition and legitimacy. This, in turn, implies the need for governance structures that enforce rights and the corresponding duties of others to respect those rights (Di Gregorio et al. 2008). Only clearly established property rights give the necessary authorization and control over the resource to farmers to, first, invest in ecosystem services and, then, negotiate possible revenues that can be gained from such services (Greiber 2009). Property rights can be recognized in statutory as well as customary laws, and these may differ. Creating or changing property rights in national laws without taking into consideration the bundles of rights and multiple claims recognized by the customary law of villages and communities, will lead to only more confusion (Meinzen-Dick and Pradhan 2002; Greiber 2009).

WLE recognize that engaging farmers in the provision of ecosystem services may require a balanced and flexible approach to property rights, taking into consideration that conferring exclusive rights on a user or group of users of an ecosystem will restrict the use rights of others and weaken secondary rights such as access options (Meinzen-Dick and Pradhan 2002). The use aspect of property acquires a particular relevance in this regard. Common pooling and management of resources such as forests, fisheries and rangelands, which may all be held under different property arrangements such as state, common property or private, may provide the necessary incentives for users to exploit them in a sustainable manner.

(iii) Incentive mechanisms

Many public policies created for the protection of ecosystems and ecosystem services have taken the form of command and control rules, which mandate that actors undertake specific actions and apply sanctions if they do not comply. In contrast, incentive-based mechanisms seek to increase economic benefits for actors, if they change their behavior and formally recognize the multiple services that can be provided by alternate production modalities. Incentive-based mechanisms are either put in place by public policies or are privately negotiated. These include charges such as taxes and user fees, subsidies, tradable permits and premiums associated with quality marks and certificates. In the last few decades, payments for ecosystem services (PES) have proliferated around the world as another incentive-based mechanism, i.e., the Reducing Emissions from Deforestation and forest Degradation (REDD) program. Costa Rica, Mexico and China, among other countries, have initiated large-scale programs that give direct payments to landowners or land users for undertaking specific land-use practices that could increase the provision of hydrological services, biodiversity conservation, erosion prevention, carbon sequestration or scenic beauty. WLE recommends that incentive-based mechanisms are given a prominent place in the governance of ecosystem services, as they can be very effective when combined with command and control approaches.

(iv) Institutions, and capacity development and empowerment

The organizations in charge of defining and implementing the rules are an important part of governance systems. Local and national governments play an vital role in creating a strong institutional setting that does not necessarily need to rely exclusively on public organizations. The provision of ecosystem services across different scales normally requires that private institutions are also involved in the definition of the management principles, rules and incentives, besides the management of natural resources. Decentralization and delegation from public authorities to private entities may result in better and more equitable management of ecosystem services.

The management of ecosystems often requires collective action to address the complexities arising from the existence of multiple users and users of ecosystem services, and from their own nature as commons. The commons have two features: (i) their use by one person makes them less available for use by another; and (ii) it is typically very difficult to limit public access to them (through laws or physical barriers). Examples from many parts of the world demonstrate that, at the local level, collective action can lead to the sustainable exploitation of natural resource commons such as forests, watersheds and rangelands. The management of other commons such as marine fisheries and transboundary watersheds imply collective action problems that require coordinated measures at the international level. The emergence of collective action initiatives for the management of ecosystem services can be instigated from exogenous interventions, but it will always depend on endogenous capacities and, in particular, the presence of a strong social capital. Public and private initiatives that seek to promote the sustainability of agricultural landscapes must invest in social capital and in the capacities of farming communities to first define their own development trajectories and make their collective voice heard. When designing management institutions for common resources, the first step to a successful cooperative management approach is ensuring communication and access to information. Possessing multiple ways to communicate about the resources or services being managed has proven to be an essential element in the successful co-management of shared resources.

The actual creation of rules and incentive mechanisms relies on the capacities of, and communication among, the different stakeholders involved in ecosystem service management, from local and national authorities to public and private firms, and farmer organizations and individual users of natural resources. Based on this, WLE initiatives must dedicate enough resources to invest in **capacity building** at different levels. Building institutional capacity may involve, for example, strengthening the knowledge of different authorities about ecosystem service-based approaches, and of the substantial benefits these can have on agriculture, other livelihoods and human well-being, and for improving their ability to enforce new regulations on natural resource management and put in place the necessary incentives for people to contribute to the sustainable management of ecosystem services.

Implementing ecosystem service-based approaches and interventions are also facilitated by actions that invest in social capital and increase people's willingness to commonly pool and manage natural resources. In view of the nature of ecosystem services as commons, understanding when and how collective action can be promoted and investing in collective action for the co-management of such services and the natural resources behind them need to form an intrinsic part of WLE projects.

Monitoring and evaluation

Monitoring and evaluation (M&E) is key to adaptive ecosystem service management, in order to verify whether or not interventions to change land-use and management deliver the desired social and environmental benefits, especially for the poor. Interventions and management approaches need to be reviewed and revised as social and ecological conditions change or when these result in undesirable or inadequate outcomes. M&E is vital for accounting to donors and when presenting evidence to the science policy arena.

For WLE to monitor and evaluate outcomes from work on ecosystem services and resilience, the program needs to ascertain the impact of research, its use by, and influence on, development partners (NGOs, national agricultural research systems (NARS), private sector, government representatives) and on development outcomes. Cleveland (2014, 73) place a high value on social inclusion early on in the M&E process (i.e., when goals are defined), and stress that actions should only be implemented after identifying indicators that can be used to measure progress towards meeting these goals. This approach can be adapted as needed and helps to increase the sustainability of complex agricultural systems.

However, outcomes of ecosystem service-based management are not readily amenable to aggregate indicators – as with human health, no single metric is capable of providing a holistic indication of health, rather combined metrics are needed to provide a composite diagnostic. Furthermore, the often long spatial and temporal lags between ecosystem service providers and beneficiaries (Fremier et al. 2013), and the flow of ecosystem services across interconnected systems, means that the outcomes of specific management approaches on ecosystem service flows may not be easily identifiable or measurable, especially over short time frames. This presents a challenge, since WLE's monitoring and evaluation system seeks to identify outcomes within the time frames of the WLE research cycle.

> ***"Monitoring and evaluation (M&E) is key to adaptive ecosystem service management, in order to verify whether or not interventions to change land-use and management deliver the desired social and environmental benefits, especially for the poor***

CGIAR is at the forefront of the challenge of M&E thinking and practices, and is in the process of directly linking its institutional goals to the new Sustainable Development Goals (SDGs), in order to better align its research activities with the needs of the SDG partner countries and stakeholders. These outcomes are met through the collaborative efforts of CGIAR's 15 global research programs and hundreds of partner organizations, including national and regional research institutes, civil society organizations, academia and the private sector. For the purpose of implementation, these outcomes must be mapped to observable and measureable variables that can guide prioritization, and against which progress towards resolving some of the world's most pressing issues can be monitored (Rockström et al. 2009).

Ruckelshaus et al. (2013) proposed indicators to monitor progress in achieving positive outcomes using information generated from (biodiversity and) ecosystem service assessments. This research suggested that the impact of interventions on development outcomes can be measured using standard biodiversity and ecosystem service metrics (e.g., crop yield, stability, connectivity for biocontrol agents and pollinators, soil nutrient mineralization, and freshwater quality and quantity, as per Cardinale et al. 2012), and measures of human health, livelihoods, income and other dimensions of well-being (e.g., Dasgupta 2001; UNDP 2013), which refer back to core principles 1 and 2 underpinning the ESR Framework.

> ***"An early task for our ESR work will be to develop a meaningful set of metrics and indicators for integration of research on ecosystem services and resilience into decision making, and the effect of ecosystem service management changes, in supporting WLE's IDOs.***

An early task for our ESR work will be to develop a meaningful set of metrics and indicators for integration of research on ecosystem services and resilience into decision making, and the effect of ecosystem service management changes, in supporting WLE's IDOs. These indicator sets will be developed in collaboration with the CGIAR system CRPs and the CGIAR Research Program on Policies, Institutions and Markets, and will aim to be consistent with global efforts on highlighting the role of healthy environments in achieving the SDGs (e.g., work in IPBES and CBD).

POTENTIAL PITFALLS AND KEYS TO SUCCESS

Successfully implementing an ESR approach at the landscape level means overcoming several key challenges.

One pitfall is **flawed conception,** due to, for example, mis-identification of links between ecosystem functions and services, focusing on single level or singular mechanisms for service provision, or weak definitions of ecosystem services and the ecological processes that drive them (Estrada-Carmona et al. 2014). Similarly, deciding to enhance a selection of services that do not provide critical benefits to the poor in a landscape may result in further marginalization. There is ample evidence of these errors as the ecosystem service concept has gained interest and attention globally. For all the success achieved by the Costa Rican PES (see Case study D in the section, *Case studies*), the payment is fundamentally about paying for reforestation or forest conservation rather than for any of the four services presented: biodiversity conservation, carbon sequestration, hydrological flows and scenic value. Basing conclusions on robust scientific evidence, accounting for the spatial context of the landscape and the people in it, and ensuring participatory, multi-stakeholder involvement, particularly in the assessment and planning stages, are the surest routes to avoiding this pitfall. Effective monitoring of outcomes, conducted within an adaptive management framework, will be central to ensuring that an optimum range of services has been selected, the components of the landscape delivering the services are successfully identified, and management actions associated with this can be incrementally improved and communicated more broadly.

A harder, but critical, challenge to overcome is the **lack of capacity** arising from the inequitable distribution of financial resources, knowledge and information, and power. Taking the latter as an example, distribution of power is very influential in the public policy decision-making process (Transnational Institute 2014) and, therefore, in determining the appropriateness and effectiveness of policy mechanisms for implementing an ESR approach. Distribution of power, however, is often met with resistance by the powerful. Powerful stakeholders, such as some multinational companies, government officials or wealthy landowners, whose interests may be aligned with conventional approaches to agricultural intensification (and who stand to lose revenue or power from changes to these approaches), may stall, derail or weaken policies advocating sustainable intensification (Rodriguez et al. 2009; Clapp and Fuchs 2009). All approaches to sustainable intensification must be mindful of who stands to win and lose from any proposed changes to the status quo.

Specific **social contexts** can also create significant challenges in the form of existing policies, cultural norms (e.g., informal agreements on land tenure, exclusion of women or other stakeholders from the decision-making procedure) and conflicts (e.g., conflicts between users of ecosystem services; poor political relations between decision makers) or war.

The limitations mentioned here show that ecosystem services are not a panacea (Ostrom 2007). The drivers of food insecurity and poverty go far beyond those that can be addressed by the judicious utilization of ecosystem services, and as such an ecosystem service-based approach to agricultural production needs to be one of a suite of approaches to tackling poverty and food insecurity. However, ecosystem service-based approaches (and notably PES schemes) have been successful in achieving positive outcomes in poor rural areas (see case studies C and D in section 7, *Case studies*), and WLE believes that there remains a huge untapped capacity for this approach to be used where it is not yet being operationalized. One major challenge lies in increasing the institutional understanding of the benefits, which are linked to the fact there are still substantial knowledge gaps around how best to manage ecosystem services for food security and poverty alleviation goals. This is where WLE, through CGIAR, can make a real difference, by both increasing the evidence base and the institutional capacity.

7. CASE STUDIES

The case studies presented in this section describe existing approaches and opportunities for the better use and management of ecosystem services in agricultural landscapes towards achieving agriculture and development goals. We draw on examples from Africa, Asia and South America.

Case Study A: Agricultural Growth Corridors in East Africa

Agricultural growth corridors are being supported by governments and development organizations in eastern Africa as a way of bringing in major investments to the agriculture sector. The most notable of these is the Southern Agricultural Growth Corridor of Tanzania (SAGCOT), with other corridors being developed in Mozambique and Kenya (see Figure 10). The corridors have objectives of fostering inclusive and commercially successful agribusinesses that benefit small-scale farmers, while improving food security, reducing rural poverty and ensuring environmental sustainability. Public-private partnerships form the institutional foundation of the corridors. Catalytic funding is provided by the donor community to spur investment and help engage smallholders through economic opportunities.

Large investments in these corridors will undoubtedly change the trajectory of development, economics, natural resource use, ecosystem configurations and bundles of ecosystem services generated in the landscape. Commercial farming will be expanded, which will bring opportunities but also poses significant risks for the livelihoods of smallholder farmers and the sustainability of natural resources. On the one hand, this could provide new market opportunities and improved livelihoods for smallholder farmers. On the other hand, it could result in adverse impacts through the loss of diversity in productive services and essential regulating services, land degradation, biodiversity and habitat loss, water scarcity, land tenure concentration, and the displacement of relatively diverse production systems by large-scale agriculture. Smallholder farmers are central to the issues in the SAGCOT (Core principle 1), and all investments—both in large commercial farming and in smallholder activities—are closely linked to nature through the exchange of ecosystem services and the need for the sustainable use of natural resources (Core principle 2).

For these corridors to sustainably intensify agricultural productivity, they must improve stakeholder-engaged land-use planning, governance structures and stakeholder capacity across spatial levels. Land tenure and community planning are major issues at the local level up to National Agricultural Investment Plans (NAIPs), government ministries and policies at the national level (Core principle 3). Governance is provided by the SAGCOT Centre, public-private partnership, facilitating investments, while promoting socially inclusive green growth (Core principle 4). Farmers' organizations and cooperatives also provide an important role at the local to regional levels to help build community capacity and help to increase their resilience to climate change, global economic market influences, land degradation and other factors (Core principle 5).

These corridors provide an impact pathway for research and development, with decision-making processes, large private investors, governance institutions and farmers' organizations providing a wide array of entry points. Many NGOs and development institutions are very active in the SAGCOT, providing strong partnerships for research and capacity building. The institutionalized framework of development in these areas make them ideal for the monitoring of the social and environmental conditions needed to provide feedback and impact of the development trajectory over time. With large investments being promoted in such focused areas, the SAGCOT and other agricultural growth corridors provide real-world laboratories to research how green growth, management of ecosystem services and

FIGURE 10: East Africa Transport and Agricultural Growth Corridors.

sustainable agricultural intensification can be accomplished at large scales, while promoting the livelihood and economic opportunities for smallholder farmers.

Case Study B: Dealing with pressures on ecosystem services in the Volta River Basin

The Volta River Basin is located in West Africa and covers an estimated area of 400,000 km^2. The basin is spread over six West African countries (43% in Burkina Faso, 42% in Ghana, and 15% in Togo, Benin, Cote d'Ivoire and Mali) (Boubacar et al. 2005). The Volta River Basin is dynamic and diverse with high terrestrial and aquatic diversity, and a remarkable reliance on the Volta River's environmental services: fishing, farming and grazing for people's livelihoods. It also has a variety of natural resources (soils, vegetation, water, wildlife, etc.), which constitute the natural capital assets that have been harnessed to different degrees to enhance social, human and financial capital in order to alleviate poverty. However, over the recent decades, pressure on the natural resource base, particularly water resources, has increased and resulted in new patterns of development within the six riparian countries, an aspect that further emphasizes Core principle 3 on cross-scale and cross-level interactions in agricultural landscapes. There are numerous dams in the basin, which include the Akosombo, Kpong and Bui dams in Ghana, and Kompienga and Bagre dams in Burkina Faso. Water from these reservoirs is primarily used for hydropower production, with other significant uses being transportation, fishery, water supply (commercial and domestic purposes), tourism and irrigation.

The pressures on water resources and other ecosystem services are affecting agricultural productivity across the region for irrigated and rainfed systems. Based on Core principle 2, people and nature are intrinsically linked, and both are required to enhance the flow of ecosystem services to and from agricultural landscapes; if not managed judiciously, the reverse occurs, resulting in degradation of the natural resource base. Some context-specific examples include poor upstream catchment management with practices such as 'sand winning' and bricklaying, which increase siltation and sedimentation, and in turn reduce the storage capacity of reservoirs, thus impacting optimal irrigation potential in the dry season and an abundance of fish in the reservoir. Alongside these challenges, the region is experiencing a demographic shift from the poorer North to the richer South, with strong rural-urban migration patterns (including the younger male generation of rural farmers). The unscrupulous disposal of rubbish in riparian zones due to urban sprawls impairs the water quality for domestic purposes and compromises longevity for aquatic life.

FIGURE 11. Banana plantation in the Kumasi region near Bobiri Forest Reserve in Ghana, depicting interspersed oil palm and cocoa trees, and other evergreen trees. At the field level, this level of diversification offers a buffer against climate- and market-related shocks, and provides extra income and offers numerous other provisioning and regulating ecosystem services. WLE scales up these field-level impacts by asking where in the landscape these types of systems would have the greatest impact, and the extent to which they have impact on ecosystem service provision. (*Photo:* Bioversity International/C. Zanzanaini).

There are region-specific opportunities that can help address the aforementioned challenges. For example, targeted planning might be used to enhance ecosystem service flows, enabled through building human and institutional capacity (Core principle 4). Strengthening institutions and governance mechanisms is particularly important in the Volta region, where existing structures lack the capacity or means to support rural communities or to ensure a sustainable approach to urban development to accommodate rural-urban migration trends. This would also help address landownership and tenure constraints, without which people would not have the incentive to embark on potential interventions for riparian restoration on land they do not own. For example, planting 'economic' trees, such as fruit trees, that incentivize communities to care for them, provides livelihood options for surrounding communities while also promoting ecosystem integrity, as exemplified in Figure 11. The aforementioned interventions directly relate to WLE's IDOs on income, adaption and the environment. The approach outlined in this framework could be used to help scientists and policymakers identify opportunities for better investments and interventions in agriculture, water and forest management in the Volta River Basin, in conjunction with identifying more effective impact pathways to help increase agricultural production and improve the livelihoods of poor farmers in these agricultural landscapes.

Case Study C: Rewarding for water-related ecosystem services in the Cañete River Basin (Peru)

The Cañete River is in the high Andes at an altitude of 4,429 m and marks the start of a 235-km long river that flows into the Pacific Ocean. The Cañete River Basin extends across 6,017 km^2 and is characterized by high levels of poverty. The low-lying, drier parts of the basin, where mean annual precipitation is below 20 mm per year, is home to 86% of the basin population who, along with the remaining 14% of the population living in the upland areas, rely on the upper reaches of the basin for their water supply, where the mean annual precipitation is between 736 and 1,169 mm.

The ecosystems found in the Upper Cañete Basin (see Figure 12) are critical for the provision of water-related ecosystem services, such as total water yield and availability throughout the year, helping to meet the water demands of users. The ecosystems that provide these services are native grasslands, wetlands, Andean forests, relicts and shrubs that are typical of the high Andes. These ecosystems ensure permanent streamflow in the downstream areas of the Cañete River. From June to November, there is a surplus of 3 m^3/s or more water basin-wide; while over the January to April period, the surplus is much larger at about 132.87 m^3/s. Thus, in contrast to other similar basins in the country, the Cañete River Basin provides users with an adequate supply of water throughout the year, removing the need for grey infrastructure to store water for use during the drier months.

Agricultural area located in the lower drylands of the basin (see Figure 13) is the largest water user, accounting for nearly 76% of the total available water resources, followed by the urban population and mining. According to Pareja (2012), if the levels of water available during the months of low streamflow is further reduced, the agricultural area will perceive economic losses due to a decrease in crop production of about USD 718,341 to USD 17,713,649 per year, depending on the severity of the reduction in the amount of water available.

Although agriculture is the biggest water user in this basin, the water-related ecosystem services are very important to users in other sectors as well. For example, Tapasco (2013) found that 80% of urban water users in the lower part of the basin would be willing to contribute to a pool fund for financing the recuperation and conservation of the upstream ecosystems to the sum of USD 1.94/month/user, which would mean a potential total contribution of approximately USD 460,000/year. For the hydropower company located in the middle basin, the maximum additional revenue to the company arising as a result of improved water flows during drier months would be approximately USD 15 million based on the company's optimal production capacity (Tapasco 2013), although the actual cost savings will depend on the level at which flows in the drier months can be improved through recuperation and better management of the upland ecosystems.

In spite of the high value of highland ecosystems in maintaining the water balance in the basin, which directly benefits lives and livelihoods (Core principle 1) in interconnected systems across the basin (Core principle 2), the

FIGURE 12. Upland section of the Cañete River watershed, Peru. (*Photo:* CIAT/Neil Palmer).

FIGURE 13. Farmer in the lowland reaches of the Cañete River Basin, Peru. (*Photo:* CIAT/Neil Palmer).

water-related ecosystem services they provide are threatened by inadequate management of pasturelands in the upper part of the basin and results in overgrazing and frequent human-induced fires. This results in soil compaction and reduced water infiltration, with a subsequent reduction in the soil's capacity to store water that is vital for regulating water flows in the basin. The clear causal relationship between the functions that maintain the highland ecosystems and the downstream beneficiaries of the service, the need to recuperate and conserve those ecosystems, and the interest of beneficiaries in ensuring the provision of water-related ecosystem services led the Ministry of the Environment (MINAM) to decide to implement a scheme that rewards upstream communities that cooperate in the recuperation and conservation of highland ecosystems (Core principles 3 and 4). The growing interest of donors in testing, assessing and promoting PES schemes or similar ones, as a mechanism to conserve ecosystems and their services, enabled MINAM, with support from the International Fund for Agricultural Development (IFAD), to initiate early conservation and restoration activities as well as to create a trust fund to support a PES-type scheme in this basin. Efforts to design and implement the PES initiative are supported by various organizations and notably the International Center for Tropical Agriculture (CIAT), who has worked to identify the economic value of the basin's ecosystem services and the priority areas in the basin where investments should be targeted to ensure the provision of these services. CIAT also facilitated the design of the PES scheme to ensure consistency and relevance of the support and contributions provided by IFAD to the MINAM-led PES initiative. This scheme is set to start operating in 2014.

The purpose of this scheme is to allow beneficiaries of water-related ecosystem services to continue to benefit from maintaining or improving water levels in quantity, quality and regularity, while reciprocating these benefits to people that manage lands where the services are provided. It is expected that this reciprocity, in the form of an economic retribution, will promote the sustainable use of these ecosystem service providing areas (and the biodiversity that they contain) and thereby increase the resilience of the socio-ecological systems dependent on these services (Core principle 5). The actual definite value to be transferred from beneficiaries to providers of ecosystem services has not been agreed on yet, and it is expected that this will be determined through negotiation. For this, MINAM will provide reference values, generated by CIAT, for water-related ecosystem services for different sectors as well as the opportunity costs for providers of ecosystem services (as available). Stakeholder engagement and capacity building will take place prior to implementation of the financial component of the MINAM-IFAD PES scheme, and is likely to include: (i) a communication strategy for negotiation of PES, (ii) verification of land tenure and control, (iii) creation of the trust fund, (iv) stakeholder agreements, and (v) creation of ad hoc watershed committee. The resultant PES is expected to incorporate at least two sectors benefiting from the provision of water-related ecosystem services.

Case Study D: Costa Rica

Costa Rica has long been hailed as an international leader in ecosystem service-based management because of its nationalized PES program, which provides farmers and landowners with cash payments for forest restoration and conservation (see Figure 14). The PES program which was launched in 1997 recognizes the role that forests play in regulating hydrological flows and improving water quality, carbon sequestration, adding significant aesthetic value to a country whose primary source of income is tourism, and in providing habitat for wild biodiversity. While there has been numerous critiques of the program's approach, metrics and definition of ecosystem services, the program managed by Fondo Nacional de Financiamiento Forestal (FONAFIFO) points to a reversal of deforestation rates in the country and an increase in forest cover from 25% in the 1980s to over 50% today. The program, a global pioneer, has also demonstrated significant adaptability; originally serving to counter the loss of livelihoods associated with the 1997 forest decree, largely banning timber harvesting on private and public lands, to a more holistic approach that is gradually using targeting and valuation tools to better match farm-level interventions to landscape-level ecological processes and services. The Costa Rican PES program provides a highly effective, transparent scheme, grounded on a solid legal and financial basis with clear rules and a capacity to evolve based on feedback.

WLE, through Bioversity International, Centre de coopération internationale en recherche agronomique pour le développement (CIRAD) and Centro Agronómico Tropical de Investigación y Enseñanza (CATIE), have long engaged in research on PES in Costa Rica, focusing on several of the nationally recognized biological corridors. Here, we focus on the Volcanica Central Talamanca Biological Corridor (VCTBC). The 114,000-ha VCTBC is an initiative dating back to 2000, when the first proposal to increase biological connectivity in the corridor was launched. This proposal was initially designed to maintain altitudinal connectivity in the face of increasing agricultural pressure for resident species of conservation concern that annually migrate up and down the slopes of the Cordillera Central in response to annual changes in the wet and dry seasons. The concept has evolved, however, to focus on an ecosystem service-based approach that matched conservation objectives with multi-stakeholder priorities. Since 2003, the VCTBC has been managed by a small, but effective participatory regional steering committee, and five local steering committees comprised of community and institutional representatives in the sub-corridors. The management of the VCTBC is driven and financed by the various institutions and organizations that comprise the steering committee, as well as by the local communities involved. While the initial focus of the group was on maintaining biological connectivity, ecosystem services have become the primary driver of change in the landscape (see Figure 14). Early rapid assessment identified several key stakeholder groups in the corridor: (i) coffee, cattle, and sugarcane farms, which comprise 30% of the landscape; (ii) urban residents of the city of Turrialba and adjacent communities; (iii) the Costa Rican Institute of Electricity; (iv) the ecotourism sector, largely comprised of 12 rafting companies; and (v) national ministries of the environment and protected areas. Several of these groups had historically contentious relationships, particularly the Costa Rican Electricity Institute (ICE), whose damming of the Reventazón River eliminated nearly all rafting opportunities on the Reventazón (classified as one of the top 10 best rivers, globally), but generated more than 2,400 GWh of electricity (25% of the country's consumption) – a key for Costa Rica's goal of becoming the first carbon-neutral country, globally.

The steering committee of the VCTBC created a 'safe space' for stakeholder interactions, which has largely consisted of developing a shared vision of the corridor by identifying regions of conflict and cooperation. This dialogue space currently focuses on ecosystem services that are valued in the corridor, and the portfolio of

FIGURE 14: This Costa Rican cattle farmer receives an annual payment from the Costa Rica Institute of Electricity for soil conservation practices aimed at reducing sedimentation rates in the Angostura reservoir. The sign in the back reads, "My farm participates in the Management of the Reventazón River Watershed (ICE)." While the individual action of single farmers is important for increasing farm productivity and stability, their collective action can yield landscape-level functions which require novel incentive mechanisms (*Photo:* Bioversity International/F. DeClerck).

institutions and mechanisms available to support achieving the shared vision of the VCTBC. The strongest case supporting this approach has been ICE making direct payments to FONAFIFO for payments to farmers in the corridor for forest protection, forest restoration and agroforestry for soil conservation ecosystem services. Research conducted by Bioversity International, CATIE and CIRAD together with ICE has used the Revised Soil Loss Equation (Estrada and Declerck 2011) to target the farms that should be prioritized (see Figure 15). Newer research using the Natural Capital Project's InVEST and Rios model platforms indicate that targeting efforts to implement soil conservation on areas with erosive crops on steep slopes is the most cost-effective strategy for reducing reservoir sedimentation rates. Likewise, using PES to encourage soil conservation though agroforestry practices and forest conservation is cheaper than the USD 10 million avoided cost of dredging sediment from reservoirs. An investment of USD 34.5 million would provide a sufficient incentive for converting 78% of the corridor's area to soil conservation practices (assuming complete adoption by farmers). However, half this investment (USD 16.4 million) would produce the same outcome in terms of the reduction of the exported soil and expansion of the life span of the dam. Overlaying the soil conservation priorities with conservation priorities has permitted regional conservation groups to plan intervention actions with ICE in creating a dialogue space where traditionally conflictive stakeholder dynamics become cooperative. We use this example to demonstrate the importance of understanding cross-level processes – particularly how collective action within numerous small farms can lead to landscape-level results.

Other research in the same region is focusing on pest control (see Figure 16), as an ecosystem service highlights the role of landscape composition and configuration as a pest control mechanism. While the primary driver of reducing coffee borer beetle outbreaks in coffee plantations remains the farm-level removal off all coffee grains during harvesting (disrupting pest population dynamics), landscape-level barriers to the movement of the female beetle (the primary vector unit) also impacts the pest's abundance at field levels and is critical to reducing re-infestations rates. Farmers recognize that field-level interventions are ineffective, if they are not practiced by their neighbors. Avelino et al. (2012) showed that coffee plantations surrounded by forest elements have reduced infestation rates. Field- level work has also shown that dispersal across sugarcane fields and pastures is possible, but is negligible across forests adjacent to coffee plantations. Current WLE work is studying the synergies and trade-offs between using landscape-level arrangement of forests, agroforests and other land uses as barriers to pest movement, while creating corridors for wild biodiversity. This work is being complemented by a project of Bioversity International, CATIE, CIRAD and the University of Idaho, which quantifies the effects of avian communities on the coffee berry borer. Field trials of this study have found a 50% increase in borer infestation rates when birds are excluded from the coffee plants. These results are similar to that found in northern Costa Rica by Karp et al. (2013).

Key elements of this work have included prioritizing the values of ecosystem services by stakeholders in the community (ICE: sedimentation rates; Coffee farmers: pest outbreaks; Ecotourism: maintaining wild biodiversity; Community: maintaining water quality and hazard mitigation). Each service is dependent on the scaling of field-level interventions to landscape-level effects, thus requiring a portfolio of intervention mechanisms such as PES for reducing sedimentation rates, agricultural extension to limit pest movement services, and farm certification by Rainforest Alliance and Starbucks for ensuring biological connectivity. Major challenges remain, such as quantifying the impacts of the interventions on specific services, and transcending private property management with ecosystem service management, which transcends private property boundaries. However, the research support provided in the quantifying and targeting of services has been fundamental in identifying intervention opportunities, ecosystem service providers and the beneficiaries willing to pay for specific services.

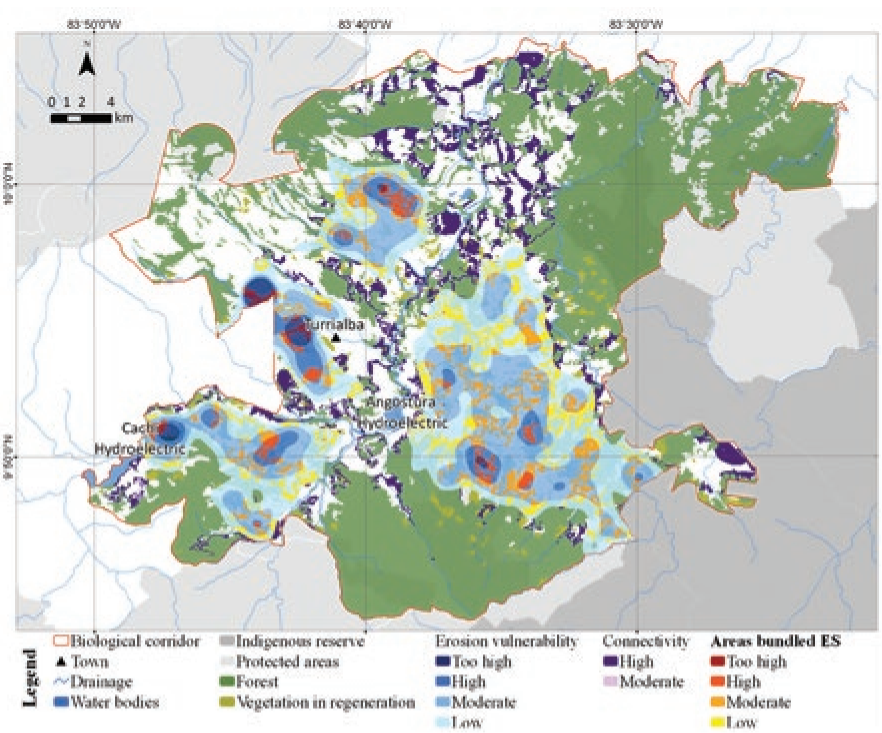

FIGURE 15: Map showing ecosystem services, targeting farms that should be prioritized for conservation of soil services, overlain on critical biological corridors. The overlain region identifies regions where biodiversity conservation and sediment reduction are complementary (*Source*: Estrada-Carmona and DeClerck 2011).

FIGURE 16. WLE research with CATIE, CIRAD, Bioversity International and the University of Idaho is quantifying the landscape-scale effects of pest control ecosystem services. Research has demonstrated that forests and agroforests serve as effective barriers to pest movement, with corridors for pest control agents complementing field-level interventions. Early results indicate that excluding avian diversity from individual coffee plants increases pest outbreaks by approximately 50% (*Photo:* Bioversity International/Fabrice DeClerck).

Case Study E: Rice Production in the Greater Mekong Subregion

The Greater Mekong Subregion (GMS) has many endowments. It is rich in natural resources, especially water, fish and forests that provide important sources of income and nutrition for large proportions of the region's population. It is characterized as being dynamic and fast-changing, with rapid economic development fuelled by direct investment in land, hydropower and transport infrastructure. The move toward the Association of Southeast Asian Nations (ASEAN) Economic Cooperation in 2015 will facilitate greater transboundary migration and economic integration.

Despite there being positive indicators, significant segments of the total population, especially those living in rural areas, suffer from poverty and food insecurity. More than 40% of the population of Vietnam and more than 50% of the population of Cambodia, Lao PDR and Myanmar continue to live on less than USD 2/day. The number of malnourished infants continues to be unacceptably high. Economic development has come at the cost of degradation of land and water resources, declining biodiversity and a reduction in ecosystem services. Agricultural intensification, driven by both 'land grabs' and national agricultural policies, add further pressure on the natural resources of the region. Water resources development, particularly for hydropower and large-scale irrigation, is transforming the natural flow regime with complex impacts on the world's largest inland freshwater fishery (Matthews 2012).

The prevailing high levels of poverty, household food insecurity and the huge environmental pressures that the present growth patterns are creating, suggest that current economic growth is neither sufficiently inclusive nor sustainable in the long term. Ultimately, the future of countries in the region depend in large measure on the stewardship of natural resources and greater inclusiveness in the benefits from resource exploitation. Experience from other fast-growing Asian economies indicates that economic growth alone is neither fast nor inclusive enough to lift the majority of poor farmers out of poverty. More focused interventions in favor of the poorest and most vulnerable are necessary and should be part of overall development strategies (*Core principle 1*).

Since many of the rural poor are farmers, interventions in agriculture have a key role to play. If the countries of the Mekong are to reach their potential, they need to better plan investments through analysis of the costs and benefits, and trade-offs that rapid agricultural and economic development entail; in essence, decision makers in the GMS need to implement approaches that secure ecosystem services both from and for agriculture over the short and long term, which is one of the fundamental components of the ESR Framework.

One such challenge which exemplifies the key principles of the ESR Framework is increasing rice production (see Figure 17). Rice production in Asia is closely intertwined with politics, and ideas of nationalism and food security.

FIGURE 17. Rice fields in Laos (*Photo:* IWMI/Matthew McCartney).

Currently, rice is the mainstay of most people's diets, and notwithstanding the already noted food insecurity at household level, all the countries of the GMS produce more than enough food to feed their growing populations. Throughout the region, current food insecurity relates more to access to food for the poorest, and the lack of nutrition in rice, rather than total production.

The concern is that rice ecosystems are not only important for rice throughout the region, but they often harbor a highly diverse set of organisms that provide multiple benefits, including pest control and maintenance of soil fertility, as well as being an important food source in their own right. Some rice-based ecosystems contain more than 100 useful species from an ecosystem services perspective. In relation to food, the 'catch' from rice fields is usually modest and only sufficient for a single day. Consequently, it often goes un-noticed in official statistics, yet this 'invisible' fishery can be vitally important for livelihoods and people's well-being. In Laos, fish and other aquatic organisms caught in rice fields and associated irrigation channels, including amphibians, molluscs, crustaceans and insects, have been identified as a vital source of food for local people. They account for a large share of many people's intake of protein, micronutrients and essential fatty acids. In some places, traditional governance systems have enabled rice fields to be cultivated and a range of ecosystem benefits to be derived sustainably for many hundreds of years. In many cases, arrangements have been made to ensure that the landless and the poorest have access to the 'invisible fishery' (Core principle 4).

It is clear that, in these systems, people and nature are intrinsically linked (Core principle 2). However, these close relationships are under threat by the push to intensify rice production, particularly the use of agrochemicals and unsustainable irrigation practices. Rice intensification may make political sense, but the costs and benefits at community and household level must be evaluated carefully before deciding to follow the path of intensification. Cross-level interactions need careful consideration in order secure successful development outcomes (Core principle 3). It is important that the development opportunities are realized without undermining the living aquatic resources on which so many people currently depend, and which make a significant contribution to the resilience of the rice systems, particularly in the face of climate change (Core principle 5).

8. TARGETED RESEARCH TO CLOSE KNOWLEDGE GAPS

In this section, we provide some illustrative research questions within the WLE flagship projects (research focus areas). The answers to these questions could help fill the gaps in current knowledge on how to use and implement an ESR approach to achieve food security and poverty alleviation goals.

The flagship projects aim to guide multi-disciplinary, cross-CGIAR science

FLAGSHIP OR CORE THEME	ILLUSTRATIVE RESEARCH QUESTIONS
LWP, MRV, RRR and RDE	▪ How do combinations of above- and below-ground biological and physical processes enhance or reduce ecosystem services? ▪ How does diversity in agricultural systems affect ecosystem service stocks and flows? ▪ Where and what are the thresholds within socio-ecosystems beyond which service provision reduces or ceases? How can these thresholds be monitored and managed across different scales and levels? ▪ How can ecosystem service-based approaches be used to build resilience (of ecosystem services and socio-ecological systems) in an agricultural landscape? How can we identify (and potentially measure) this resilience? ▪ How does landscape composition affect the provision of ecosystem services to and from agriculture? ▪ How can a circular economy and an ecosystem-based approach work together to leverage change within policy? ▪ What are the market-based opportunities for enhancing ecosystem service flows, such as through restoring degraded land and reducing water pollution? ▪ How can watershed management be improved using ecosystem service-based approaches to secure freshwater quality, and supply for people and agriculture? ▪ Which types of management approaches (in terms of mechanism and scale of intervention) support the ecological communities that are needed to generate critical ecosystem services? ▪ How can ecosystem service-based management strategies be used in conjunction with other approaches to deliver multiple benefits? ▪ How can ecosystem services and benefits from land and water use be shared equitably across sectors to improve the livelihoods of the poor, foster gender equity and minimize detrimental environmental impacts?
DAI	▪ How can social, biophysical and valuation assessments be better integrated to generate more useful outcomes for decision makers? ▪ What metrics can be used to measure and monitor outcomes from ecosystem service-based approaches? ▪ How can information systems be designed and used to facilitate knowledge collection and exchange? ▪ What is the high-value information that decision makers need when selecting service use and management approaches? ▪ What are the costs and benefits of ecosystem service-based approaches in comparison to conventional/other approaches to land use and management? ▪ What are the economic costs and benefits of different management options? ▪ Where are the 'windows of opportunity' for integrating ecosystem service-based approaches and how can these be identified? ▪ How can knowledge and information about the ESR approach be better communicated to decision makers? ▪ How do power relations affect the decision-making process? How can these be identified and addressed to ensure decisions positively impact poor and marginalized groups?
IES	▪ What are the social needs, values, understanding, perceptions and cultural norms regarding ecosystem services in the four focal regions? ▪ Who are the beneficiaries of ecosystem services provided in each landscape? Who makes decisions about the use and management of these services? ▪ What are the threats to ecosystem service stocks and flows that are critical for agricultural production? How can these threats be reduced using policy and incentive mechanisms? ▪ What are the development priorities in the focal regions? What are the trade-offs and synergies in ecosystem service management choices in terms of delivering development outcomes? ▪ How can we strengthen and unite management strategies across different levels?
GPI	▪ What are the different ways in which women and men depend on ecosystem services for their livelihoods? ▪ How can decisions about ecosystem service management create more equitable access to benefits across gender groups? Who are the winners and losers of these decisions and why? ▪ Are ecosystem services valued differently by women and men, and how can these differences be incorporated into management strategies to address the needs of both groups? ▪ What is the role of gender in improving environmental quality and ecosystem services, including the relationship between women's reproductive rights, population growth and conservation, and the types of institutions (markets, community organizations, cooperatives, networks) that women interact with? ▪ How do social/gender relations (e.g., norms, perceptions, attitudes and behaviors) and gender roles determine women's and men's participation in incentive systems for environmental services, such as the certification for social, environmental or nutritional benefits of commodity systems, payments for ecosystem services, and command and control?

TABLE 4. Initial and illustrative research questions linked to WLE flagship areas.

and partnerships on water, land and ecosystems, with the overarching aim of contributing to CGIAR's System-Level Outcomes and helping to achieve WLE's Intermediate Development Outcomes (see Table 1). *Ecosystem services and resilience* is one of two crosscutting **core themes** (along with *gender and equity in agricultural development*) that WLE is working to integrate across all of the flagship projects. The ESR Framework seeks to guide this process and, as part of this, Table 4 provides some initial and illustrative research questions on ecosystem services and resilience in the agricultural development context (see also Bommarco et al. 2012; Kremen and Miles 2012).

9. CONCLUSION

This ecosystem services and resilience framework presents an approach to agricultural intensification that we believe can contribute substantially to the challenge of meeting the food requirements of the world's growing population without irreversibly damaging the ecosystems on which this production depends. We have sought to demonstrate how ecosystem services and resilience, and their integration into an agricultural intensification model, have the potential to increase various metrics of production (e.g., yield, nutritional diversity) and contribute to food and livelihood security, while simultaneously leading to environmental improvements and a greater 'valuing' of the environment by various stakeholders.

We hope this framework highlights the importance of ecosystem service and resilience concepts, why it is necessary and imperative that CGIAR and its partners work together with ecosystem service stakeholders in agricultural landscapes to find and enact ways to better manage the services that ecosystems provide to people. In this way, we can contribute to delivering the much-needed food security and poverty reduction to poor agricultural communities, while also ensuring the long-term sustainability of the natural resource base on which these communities depend.

REFERENCES

Abaidoo, R.C.; Keraita, B.; Drechsel, P.; Dissanayake, P.; Maxwell, A.S. 2010. Soil and crop contamination through wastewater irrigation and options for risk reduction in developing countries. In: *Soil biology and agriculture in the tropics*, ed., Dion, P. Pp. 275-297.

Avelino, J.; Romero-Gurdián, A.; Cruz-Cuellar, H.F.; DeClerck, F.A.J. 2012. Landscape context and scale differentially impact coffee leaf rust, coffee berry borer, and coffee root-knot nematodes. *Ecological Applications* 22: 584-596.

Bagstad, K.J.; Semmens, D.J.; Waage, S.; Winthrop, R. 2013. A comparative assessment of decision-support tools for ecosystem services quantification and valuation. *Ecosystem Services* 5: 27-39.

Barnosky, A.D.; Brown, J.H.; Daily, G.C.; Dirzo, R.; Ehrlich, A.H.; Ehrlich, P.R.; Eronen, J.T.; Fortelius, M.; Hadly, E.A.; Leopold, E.B.; Mooney, H.A.; Myers, J.P.; Naylor, R.L.; Palumbi, S.; Stenseth, N.C.; Wake, M.H. 2014. Introducing the scientific consensus on maintaining humanity's life support systems in the 21st century: Information for policy makers. *The Anthropocene Review* 1(1): 78-109.

Becker, E.; Jahn, T. (eds.) 2006. *Soziale Ökologie. Grundzüge einer Wissenschaft von den gesellschaftlichen Naturverhältnissen.* Frankfurt/New York: Campus.

Benayas, J.M.R.; Newton, A.C.; Diaz, A.; Bullock, J.M. 2009. Enhancement of biodiversity and ecosystem services by ecological restoration: A meta-analysis. *Science* 325(5944): 1121-1124.

Berkes, F.; Colding, J.; Folke, C. 2003. *Navigating social-ecological systems: Building resilience for complexity and change.* Cambridge, UK: Cambridge University Press.

Biggs, R.; Schlüter, M.; Biggs, D.; Bohensky, E.L.; BurnSilver, S.; Cundill, G.; Dakos, V.; Daw, T.M.; Evans, L.S.; Kotschy, K.; Leitch, A.M.; Meek, C.; Quinlan, A.; Raudsepp-Hearne, C.; Robards, M.D.; Schoon, M.L.; Schultz, L.; West, P.C. 2012. Toward principles for enhancing the resilience of ecosystem services. *Annual Review of Environment and Resources* 37: 421-448.

Bommarco, R.; Kleijn, D.; Potts, S.G. 2013. Ecological intensification: Harnessing ecosystem services for food security. *Trends in Ecology & Evolution* 28(4): 230-238.

Bonhommeau, S.; Dubroca, L.; Le Pape, O.; Barde, J.; Kaplan, D.M.; Chassot, E.; Nieblas, A.E. 2013. Eating up the world's food web and the human trophic level. *Proceedings of the National Academy of Sciences of the United States of America* 110: 20617-20620.

Bottinelli, N.; Jouquet, P.; Capowiez, Y.; Podwojewski, P.; Grimaldi, M.; Peng, X. 2014. Why is the influence of soil macrofauna on soil structure only considered by soil ecologists? *Soil and Tillage Research.* DoI: 10.1016/j.still.2014.01.007

Boubacar, B.; Obuobie, E.; Andreini, M.; Andah, W.; Pluquet, M. 2005. *Volta River Basin synthesis: Comprehensive Assessment of Water Management in Agriculture*. Colombo, Sri Lanka: International Water Management Institute (IWMI)/Comprehensive Assessment of Water Management in Agriculture.

Box, G.E.P.; Draper, N.R. 1987. *Empirical model building and response surfaces*. New York: John Wiley & Sons.

Bratman, G.N.; Hamilton, P.; Daily, G.C. 2012. The impacts of nature experience on human cognitive function and mental health. *Annals of the New York Academy of Sciences* 1249: 118-136.

Brauman, K.A.; Siebert, S.; Foley, F.A. 2013. Improvements in crop water productivity increase water sustainability and food security—a global analysis. *Environmental Research Letters* 8.

Brown, J.; MacLeod, N. 2011. A site-based approach to delivering rangeland ecosystem services. *The Rangeland Journal* 33(2): 99-108.

Cabell, J.F.; Oelosfe, M. 2012. An indicator framework for assessing agroecosystem resilience. *Ecology and Society* 17(1): 18.

Cardinale, B.J.; Duffy, J.E.; Gonzalez, A.; Hooper, D.U.; Perrings, C.; Venail, P.; Narwani, A.; Mace, G.M.; Tilman, D.; Wardle, D.A.; Kinzig, A.P.; Daily, G.C.; Loreau, M.; Grace, J.B.; Larigauderie, A.; Srivastava, D.S.; Naeem, S. 2012. Biodiversity loss and its impact on humanity. *Nature* 486: 59-67.

Carpenter, S.R.; Folke, C.; Norstrom, A.; Olsson, O.; Schultz, L.; Agarwal, B.; Balvanera, P.; Campbell, B.; Castilla, J.C.; Cramer, W.; DeFries, R.; Eyzaguirre, P.; Hughes, T.P.; Polasky, S.; Sanusi, Z.; Scholes, R.; Spierenburg, M. 2012. Program on ecosystem change and society: An international research strategy for integrated social-ecological systems. *Current Opinion in Environmental Sustainability* 4(1): 134-138.

Cash, D.W.; Adger, W.; Berkes, F.; Garden, P.; Lebel, L.; Olsson, P.; Pritchard, L.; Young, O. 2006. Scale and cross-scale dynamics: Governance and information in a multilevel world. *Ecology and Society* 11(2): 8.

CBD (Convention on Biological Diversity). 1992. *Convention on Biological Diversity.* United Nations.

Clapp, J.; Fuchs, D.A. (eds.). 2009. *Corporate power in global agrifood governance*. London, UK: MIT Press.

Cleveland, D.A. 2014. *Balancing on a planet: The future of food and agriculture.* Berkeley: University of California Press.

Cofie, O.O.; Drechsel, P.; Agbottah, S.; van Veenhuizen, R. 2009. Resource recovery from urban waste: Options and challenges for community-based composting in sub-Saharan Africa. *Desalination* 248: 256-261.

Corbera, E.; Brown, K.; Adger, W.N. 2007. The equity and legitimacy of markets for ecosystem services. *Development and Change* 38(4): 587-613.

Costanza, R.; D'Arge, R.; de Groot, R.; Farber, S.; Grasso, M.; Hannon, B.; Limburg, K.; Naeem, S.; O'Neill, R.V.; Paruelo, J.; Raskin, R.G.; Sutton, P.; van den Belt, M. 1997. The value of the world's ecosystem services and natural capital. *Nature* 387: 253-260.

Costanza, R.; de Groot, R.; Sutton, P.; van der Ploeg, S.; Anderson, S.J.; Kubiszewski, I.; Farber, S.; Turner, R.K. 2014. Changes in the global value of ecosystem services. *Global Environmental Change* 26: 152-158.

Cowling, R.M.; Egoh, B.; Knight, A.T.; O'Farrell, P.J.; Reyers, B.; Rouget, M.; Roux, D.J.; Welz, A.; Wilhelm-Rechman, A. 2008. An operational model for mainstreaming ecosystem services for implementation. *Proceedings of the National Academy of Sciences of the United States of America* 105(28): 9483-9488.

Crossman, N.D.; Connor, J.D.; Bryan, B.A.; Summers, D.M.; Ginnivan, J. 2010. Reconfiguring an irrigation landscape to improve provision of ecosystem services. *Ecological Economics* 69: 1031-1042.

Crossman, N.D.; Burkhard, B.; Nedkov, S.; Willemen, L.; Petz, K.; Palomo, I.; Drakou, E.G.; Martín-Lopez, B.; McPhearson, T.; Boyanova, K.; Alkemade, R.; Egoh, B.; Dunbar, M.B.; Maes, J. 2013. A blueprint for mapping and modelling ecosystem services. *Ecosystem Services* 4: 4-14.

Cunningham, S.A.; Attwood, S.J.; Bawa, K.S.; Benton, T.G.; Broadhurst, L.M.; Didham, R.K.; McIntyre, S.; Perfecto, I.; Samways, M.J.; Tscharntke, T.; Vandermeer, J.; Villard, M.; Young, A.G.; Lindenmayer, D.B. 2013. To close the yield-gap while saving biodiversity will require multiple locally relevant strategies. *Agriculture, Ecosystems and Environment* 173: 20-27.

Dasgupta, P. 2001. *Human well-being and the natural environment.* UK: Oxford University Press.

Daw, T.; Brown, K.; Rosendo, S.; Pomeroy, R. 2011. Applying the ecosystem services concept to poverty alleviation: The need to disaggregate human well-being. *Environmental Conservation* 38: 370-379.

DeClerck, F.; Estrada-Carmona, N.; Garbach, K.; Martinez-Salinas, A. In Review. Beyond borders: Managing farmscapes for connectivity increases conservation value for forest dependent birds. *Agriculture, Ecosystems and Environment.*

DeClerck, F.A.J.; Chazdon, R.; Holl, K.D.; Milder, J.C.; Finegan, B.; Martinez-Salinas, A.; Imbach, P.; Canet, L.; Ramos, Z. 2010. Biodiversity conservation in human-modified landscapes of Mesoamerica: Past, present and future. *Biological Conservation* 143: 2301-2313.

Di Gregorio, M.; Hagedorn, K.; Kirk, M.; Korf, B.; McCarthy, N.; Meinzen-Dick, R.; Swallow, B. 2008. *Property rights, collective action, and poverty: The role of institutions for poverty reduction.* CAPRi Working Paper No. 81. Washington, DC: CGIAR Systemwide Program on Collective Action and Property Rights (CAPRi).

Elmqvist, T.; Tuvendal, M.; Krishnaswamy, J.; Hylander, K. 2010. *Ecosystem services: Managing trade-offs between provisioning and regulating services.* UK: Routledge.

CGIAR. 2014. Research performance of CGIAR Research Programs. Elsevier.

Enfors, E.I.; Gordon, L.J. 2008. Dealing with drought: The challenge of using water system technologies to break dryland poverty traps. *Global Environmental Change* 18(4): 607-616.

Estrada-Carmona, N.; DeClerck, F.A.J. 2011. Payment for ecosystem services for energy, biodiversity conservation and poverty alleviation. In: *Integrating ecology and poverty alleviation and international development efforts: A practical guide,* eds., Ingram, J.C.; DeClerck, F.A.J.; Rumbaitis del Rio, C. New York: Springer.

Estrada-Carmona, N.; Hart, A.K.; DeClerck, F.A.J.; Harvey, C.A.; Milder, J.C. 2014. Integrated landscape management for agriculture, rural livelihoods, and ecosystem conservation: An assessment of experience from Latin America and the Caribbean. *Landscape and Urban Planning* 129: 1-11.

Eyzaguirre, P.B.; Dennis, E.M. 2007. The impacts of collective action and property rights on plant genetic resources. *World Development* 35: 1489-1498.

FAO (Food and Agriculture Organization of the United Nations). 2011a. FAOSTAT database. Available at http://faostat3.fao.org/faostat-gateway/go/to/download/R/RL/E; Last accessed 17 July 2014 (accessed on September 3, 2014).

FAO. 2011b. *Global food losses and food waste: Extent, causes and prevention*. Rome: Food and Agriculture Organization of the United Nations (FAO).

FAO. 2013. *The state of food security in the world*. Rome, Italy: Food and Agriculture Organization of the United Nations (FAO).

Fischer, J.; Brosi, B.; Daily, G.C.; Ehrlich, P.R.; Goldman, R.; Goldstein, J.; Tallis, H. 2008. Should agricultural policies encourage land sparing or wildlife-friendly farming? *Frontiers in Ecology and the Environment* 6(7): 380-385.

Fish, R.; Burgess, J.; Chilvers, J.; Footitt, A.; Haines-Young, R.; Russel, D.; Winter, D.M. 2011. *Participatory and deliberative techniques to embed an ecosystems approach into decision making: An introductory guide.* Defra (project code: NR0124).

Foley, J.A.; Ramankutty, N.; Brauman, K.; Cassidy, E.S.; Gerber, J.S.; Johnston, M.; Mueller, N.D.; O'Connell, C.; Ray, D.K.; West, P.C.; Balzer, C.; Bennett, E.M.; Carpenter, S.R.; Hill, J.; Monfreda, C.; Polasky, S.; Rockström, J.; Shehan, J.; Siebert, S.; Tilman, D.; Zaks, D.P.M. 2011. Solutions for a cultivated planet. *Nature* 478: 337-342.

Fremier, A.K.; DeClerck F.A.J.; Bosque-Pérez, N.A.; Estrada-Carmona, N.; Hill, R.; Joyal, T.; Keesecker, L.; Zion Klos, P.; Martínez-Salinas, A.; Niemeyer, A.S.; Welsh, K.; Wulfhorst, J.D. 2013. Understanding spatiotemporal lags in ecosystem services to improve incentives. *BioScience* 63(6): 472-482.

Garbach, K.; Milder, J.C.; DeClerck, F.A.J.; Driscoll, L.; Montenegro, M.; Herren, B. In Review. *Close yield and nature gaps: Multi-functionality in five systems of agroecological intensification.*

Garnett, T.; Appleby, M.C.; Balmford, A.; Bateman, I.J.; Benton, T.G.; Bloomer, P.; Burlingame, B.; Dawkins, M.; Dolan, L.; Fraser, D.; Herrero, M.; Hoffmann, I.; Smith, P.; Thornton, P.K.; Toulmin, C.; Vermeulen, S.J.; Godfray, H.C.J. 2013. Sustainable Intensification in Agriculture: Premises and Policies. *Science* 341: 33-34.

Goldstein, J.J.H.; Caldarone, G.; Duarte, T.K.T.; Ennaanay, D.; Hannahs, N.; Mendoza, G.; Polasky, S.; Wolny, S.; Daily, G.C.G. 2012. Integrating ecosystem service tradeoffs into land-use decisions. *Proceedings of the National Academy of Sciences of the United States of America* 109: 7565-7570.

Gordon, L.; Peterson, G.D.; Bennett, E.M. 2008. Agricultural modifications of hydrological flows create ecological surprises. *Trends in Ecology & Evolution* 23(4): 211-219.

Greiber, T. (ed.) 2009. *Payments for ecosystem services: Legal and institutional frameworks.* IUCN Environmental Policy and Law Paper No. 78. Gland: International Union for Conservation of Nature (IUCN).

Haines-Young, R.; Potschin, M. 2010. The links between biodiversity, ecosystem services and human well-being. In: *Ecosystem ecology: A new synthesis*, eds., Raffaelli, D.G.; Frid, C.L.J. Cambridge, UK: Cambridge University Press.

Hajjar, R.; Jarvis, D.I.; Gemmill-Herren, B.; 2008. The utility of crop genetic diversity in maintaining ecosystem services. *Agriculture, Ecosystems & Environment* 123: 261-270.

Hobbs, R. J.; Arico, S.; Aronson, J.; Baron, J.S.; Bridgewater, P.; Cramer, V.A.; Epstein, P.R.; Ewel, J.J.; Klink, C.A.; Lugo, A.E.; Norton, D.; Ojima, D.; Richardson, D.M.; Sanderson, E.W.; Valladares, F.; Vilà, M.; Zamora, R.; Zobel, M. 2006. Novel ecosystems: Theoretical and management aspects of the new ecological world order. *Global Ecology and Biogeography* 15: 1-7.

Jarvis, D.I.; Hodgkin, T.; Sthapit, B.R.; Fadda, C.; Lopez-Noriega, I. 2011. An Heuristic Framework for Identifying Multiple Ways of Supporting the Conservation and Use of Traditional Crop Varieties within the Agricultural Production System. *Critical Reviews in Plant Sciences* 30: 125-176.

Johns, T.; Powell, B.; Maundu, P.; Eyzaguirre, P.B. 2013. Agricultural biodiversity as a link between traditional food systems and contemporary development, social integrity and ecological health. *Journal of the Science of Food and Agriculture* 93: 3433-3442.

Kareiva, P. and Marvier, M. 2007. Conservation for the People. *Scientific American* 50-57.

Karp, D.S.; Mendenhall, C.D.; Sandi, R.F.; Chaumont, N.; Ehrlich, P.R.; Hadly, E.A.; Daily, G.C. 2013. Forest bolsters bird abundance, pest control and coffee yield. *Ecology Letters* 16(11): 1339-1347.

Khumairoh, U.; Groot, J.C.J.; Lantinga, E.A. 2012. Complex agro-ecosystems for food security in a changing climate. *Ecology and Evolution* 2(7): 1696-1704.

Kremen, C.; Williams, N.M.; Aizen, M.A.; Gemmill-Herren, B.; LeBuhn, G.; Minckley, R. Packer, L.; Potts, S.G.; Roulston, T.; Steffan-Dewenter, I.; Vazquez, D.P.; Winfree, R.; Adams, L.; Crone, E.E.; Greenleaf, S.S.; Keitt, T.H.; Klein, A.M.; Regetz, J.; Ricketts, T.H. 2007. Pollination and other ecosystem services produced by mobile organisms: A conceptual framework for the effects of land-use change. *Ecology Letters* 10: 299-314.

Kremen, C.; Miles, A. 2012. Ecosystem services in biologically diversified versus conventional farming systems: Benefits, externalities and trade-offs. *Ecology and Society* 17(4): 40.

Krishna, V.V.; Drucker, A.G.; Pascual, U.; Raghu, P.T.; King, E. 2013. Estimating compensation payments for on-farm conservation of agricultural biodiversity in developing countries. *Ecological Economics* 87: 110-123.

Laliberté, E.; Wells, J.; DeClerck, F.; Metcalfe, D.; Catterall, C.; Queiroz, C.; Aubin, I.; Bonser, S.; Ding, Y.; Fraterrigo, J.; McNamara, S.; Morgan, J.; Sánchez Merlos, D.; Vesk, F.; Mayfield, M. 2010. Land use intensification reduces functional redundancy and response diversity in plant communities. *Ecology Letters* 13: 76-86.

Lant, C.L.; Ruhl, J.B.; Kraft, S.E. 2008. The tragedy of ecosystem services. *BioScience* 58(10): 969-974.

Lavelle, P.; Decaens, T.; Aubert, M.; Barot, S.; Blouin, M.; Bureau, F.; Margerie, P.; Mora, P.; Rossi, J.P. 2006. Soil invertebrates and ecosystem services. *European Journal of Soil Biology* 42: 3-15.

Lebuhn, G.; Droege, S.; Connor, E.F.; Gemmill-Herren, B.; Potts, S.G.; Minckley, R.L.; Griswold, T.; Jean, R.; Kula, E.; Roubik, D.W.; Cane, J.; Wright, K.W.; Frankie, G.; Parker, F. 2013. Detecting insect pollinator declines on regional and global scales. *Conservation Biology* 27: 113-120.

Levin P.S.; Fogarty, M.J.; Murawski, S.A.; Fluharty, D. 2009. Integrated ecosystem assessments: Developing the scientific basis for ecosystem-based management of the ocean. *PLoS Biol* 7(1): e1000014.

Loh, J.; Harmon, D. 2014. *Biocultural diversity: Threatened species, endangered languages.* Zeist, the Netherlands: World Wide Fund for Nature (WWF).

Luck, G.W.; Harrington, R.; Harrison, P.A.; Kremen, C.; Berry, P.M.; Bugter, R.; Dawson, T.; de Bello, F.; Díaz, S.; Feld, C.K.; Haslett, J.R.; Hering, D.; Kontogianni, A.; Lavorel, S.; Rounsevell, M.; Samways, M.J.; Sandin, L.; Settele, J.; Sykes, M.T.; van den Hove, S.; Vandewalle, M.; Zobel, M. 2009. Quantifying the contribution of organisms to the provision of ecosystem services. *Bioscience* 59(3): 223-235.

Luck, G.W.; Lavorel, S.; McIntyre, S.; Lumb, K. 2012. Improving the application of vertebrate trait-based frameworks to the study of ecosystem services. *Journal of Animal Ecology* 81(5): 1065-1076.

Lydecker, M.; Drechsel, P. 2010. Urban agriculture and sanitation services in Accra, Ghana: The overlooked contribution. *International Journal of Agricultural Sustainability* 8: 94-103.

Martinez-Salinas, A.; DeClerck, F. 2010. The role of agroecoystems and forests in the conservation of birds within biological corridors. *Mesoamericana* 14: 35-50.

Matthews, N. 2012. Water grabbing in the Mekong basin - An analysis of the winners and losers of Thailand's hydropower development in Lao PDR. *Water Alternatives* 5(2): 392-411.

McCartney, M., Morardet, S., Rebelo, L.M., Finlayson, C.M., Masiyandima, M., 2011. A study of wetland hydrology and ecosystem service provision: GaMampa wetland, South Africa. Hydrological Sciences Journal-Journal Des Sciences Hydrologiques 56, 1452-1466.

McCartney, M., 2013. The value of wetlands for livelihood support in Tanzania and Zambia.

McGinnis, M.D. 1999. Polycentric governance and development: Readings from the workshop in political theory and policy analysis. Ann Arbor: University of Michigan Press (cited in Nagendra and Ostrom [2012]).

Meinzen-Dick, R.S.; Pradhan, R. 2002. *Legal pluralism and dynamic property rights.* CGIAR System-Wide Program on Property Rights and Collective Action Working Paper 22. Washington, DC: International Food Policy Research Institute (IFPRI).

Murray, A.; Cofie, O.; Drechsel, P.; 2011. Efficiency indicators for waste-based business models: Fostering private-sector participation in wastewater and faecal-sludge management. *Water International* 36: 505-521.

Mwangi, E.; Markelova, H. 2009. Collective action and property rights for poverty reduction: A review of methods and approaches. *Development Policy Review* 27(3): 307-331.

Nagendra, H.; Ostrom, E. 2012. Polycentric governance of multifunctional forested landscapes. *International Journal of the Commons* 6(2): 104-133.

Nemec, K.T.; Raudsepp-Hearne, C. 2012. The use of geographic information systems to map and assess ecosystem services. *Biodiversity and Conservation* 22: 1-15.

Nielsen, M.R.; Pouliot, M.; Bakkegaard, R.K. 2012. Combining income and assets measures to include the transitory nature of poverty assessments of forest dependence: evidence from the Democratic Republic of Congo. *Ecological Economics* 78: 37-46.

Ntow, W.J.; Drechsel, P.; Botwe, B.O.; Kelderman, P.; Gijzen, H.J. 2008. The impact of agricultural runoff on the quality of two streams in vegetable farm areas in Ghana. *Journal of Environmental Quality* 37: 696-703.

Opoku-Ankomah, Y.; Dembélé, Y.; Ampomah, B.Y.; Somé, L. 2006. Hydro-political assessment of water governance from the top-down and review of literature on local level institutions and practices in the Volta Basin. Colombo, Sri Lanka: International Water Management Institute (IWMI). 36p. (IWMI Working Paper 111).

Ostrom, E. 1990. *Governing the commons: the evolution of institutions for collective action.* Cambridge University Press.

Ostrom, E. 1999. Coping with tragedies of the commons. *Annual Review of Political Science* 2: 493-535.

Ostrom, E. 2007. A diagnostic approach for going beyond panaceas. *Proceedings of the National Academy of Sciences of the United States of America* 104: 15181–15187.

Ostrom, E. 2009. A general framework for analyzing sustainability of social-ecological systems. *Science* 325: 419-422.

Ostrom, E.; Burger, J.; Field, C.B.; Norgaard, R.B.; Policansky, D. 1999. Revisiting the commons: Local lessons, global challenges. *Science* 284(5412): 278-282.

Palm, C.; Blanco-Canqui, H.; DeClerck, F.; Gatere, S.; Grace, P. 2014. Conservation agriculture and ecosystem services: An overview. *Agriculture, Ecosystems and Environment* 187: 87-105.

Pareja, P. 2012. *Valoración económica del agua superficial para uso agrícola en el valle de Cañete.* Thesis. Environmental Engineering. National Agrarian University, Lima, Peru.

Park, S.E.; Howden, S.M.; Crimp, S.J.; Gaydon, D.S.; Attwood, S.J.; Kokic P.N. 2010. More than eco-efficiency is required to improve food security. *Crop science* 50(1): 132-141.

Patten, B.C. 2010. Natural ecosystem design and control imperatives for sustainable ecosystem services. *Ecological Complexity* 7: 282-291.

Peh, K.S.H.; Balmford, A.; Bradbury, R.B.; Brown, C.; Butchart, S.H.M.; Hughes, F.M.R.; Stattersfield, A.; Thomas, D.H.L.; Walpole, M.; Bayliss, J.; Gowing, D.; Jones, J.P.G.; Lewis, S.L.; Mulligan, M.; Pandeya, B.; Stratford, C.; Thompson, J.R.; Turner, K.; Vira, B.; Willcock, S.; Birch, J.C. 2013. TESSA: A toolkit for rapid assessment of ecosystem services at sites of biodiversity conservation importance. *Ecosystem Services* 5: 51-57.

Pereira, H.M.; Ferrier, S.; Walters, M.; Geller, G.N.; Jongman, R.H.G.; Scholes, R.J.; Bruford, M.W.; Brummitt, N.; Butchart, S.H.M.; Cardoso, A.C.; Coops, N.C.; Dulloo, E.; Faith, D.P.; Freyhof, J.; Gregory, R.D.; Heip, C.; Hoft, R.; Hurtt, G.; Jetz, W.; Karp, D.S.; McGeoch, M.A.; Obura, D.; Onoda, Y.; Pettorelli, N.; Reyers, B.; Sayre, R.; Scharlemann, J.P.W.; Stuart, S.N.; Turak, E.; Walpole, M.; Wegmann, M. 2013. Essential biodiversity variables. *Science* 339: 277-278.

Plummer, M.L. 2009. Assessing benefit transfer for the valuation of ecosystem services. *Frontiers in Ecology and the Environment* 7: 38-45.

Poppy, G.M.; Jepson, P.C.; Pickett, J.A.; Birkett, M.A. 2014. Achieving food and environmental security: New approaches to close the gap. *Philosophical Transactions of the Royal Society B* 369(1639): 20120272.

Power, A. 2010. Ecosystem services and agriculture: Trade-offs and synergies. *Philosophical Transactions of the Royal Society B* 365: 2959-2971.

Raudsepp-Hearne, C.; Peterson, G.D.; Tengo, M.; Bennett, E.M.; Holland, T.; Benessaiah, K.; MacDonald, G.K.; Pfeifer, L. 2010. Untangling the environmentalist's paradox: Why is human well-being increasing as ecosystem services degrade? *BioScience* 60(8): 576-589.

Raworth, K. 2012. A safe and just space for humanity. Can we live within the doughnut? Oxford, UK: Oxfam. Available at http://www.oxfam.org/sites/www.oxfam.org/files/dp-a-safe-and-just-space-for-humanity-130212-en.pdf (accessed on June 2, 2014).

Reed, M. 2008. Stakeholder participation for environmental management: A literature review. *Biological Conservation* 141: 2417-2431.

Reed, M.; Graves, A.; Dandy, N.; Posthumus, H.; Hubacek, K.; Morris, J.; Prell, C.; Quinn, C.H.; Stringer, L.C. 2009. Who's in and why? Stakeholder analysis as a prerequisite for sustainable natural resource management. *Journal of Environmental Management* 90: 1933-1949.

Ricketts, T.H.; Regetz, J.; Steffan-Dewenter, I.; Cunningham, S.A.; Kremen, C.; Bogdanski, A.; Gemmill-Herren, B.; Greenleaf, S.S.; Klein, A.M.; Mayfield, M.M.; Morandin, L.A.; Ochieng, A.; Potts, S.G.; Viana, B.F. 2008. Landscape effects on crop pollination services: Are there general patterns? *Ecology Letters* 11(5): 499-515.

Rockström, J.; Steffan, W.L.; Noone, K.; Persson, A.; Chapin, F.S.III; Lambin, E.; Lenton, T.M.; Scheffer, M.; Folke, C.; Schellnhuber, H.; Nykvist, B.; de Wit, C.A.; Hughes, T.; van der Leeuw, S.; Rodhe, H.; Sorlin, S.; Snyder, P.K.; Costanza, R.; Svedin, U.; Falkenmark, M.; Karlberg, L.; Corell, R.W.; Fabry, V.J.; Hansen, J.; Walker, B.; Liverman, D.; Richardson, K.; Crutzen, P.; Foley, J. 2009. Planetary boundaries: Exploring the safe operating space for humanity. *Ecology and Society* 14(2): 32.

Rodriguez, J.M.; Molnar, J.J.; Fazio, R.A.; Sydnor, E.; Lowe, M.J. 2009. Barriers to adoption of sustainable agriculture practices: Change agent perspectives. *Renewable Agriculture and Food Systems* 24(1): 60-71.

Rozelle, S.; Veeck, G.; Huang, J. 2008. The impact of environmental degradation on grain production in China, 1975-1990. *Economic Geography* 73(1): 44-66.

Rubiano, J.; Quintero, M.; Estrada, R.D.; Moreno, A. 2006. Multiscale analysis for promoting integrated watershed management. *Water International* 31: 398-411.

Ruckelshaus, M.; McKenzie, E.; Tallis, H.; Guerry, A.; Daily, G.; Kareiva, P.; Polasky, S.; Ricketts, T.; Bhagabati, N.; Wood, S.A.; Bernhardt, J. 2013. Notes from the field: Lessons learned from using ecosystem service approaches to inform real-world decisions. *Ecological Economics.* doi: 10.1016/j.ecolecon.2013.07.009.

Rusch, A.; Bommarco, R.; Jonsson, M.; Smith, H.G.; Ekbom, B. 2013. Flow and stability of natural pest control services depend on complexity and crop rotation at the landscape scale. *Journal of Applied Ecology* 50(2): 345-354.

Sachs, J.; Remans, R.; Smukler, S.; Winowiecki, L.; Andelman, S.J.; Cassman, K.G.; Castle, D.; DeFries, R.; Denning, G.; Fanzo, J.; Jackson, L.E.; Leemans, R.; Lehmann, J.; Milder, J.C.; Naeem, S.; Nziguheba, G.; Palm, C.A.; Pingali, P.L.; Reganold, J.P.; Richter, D.D.; Scherr, S.J.; Sircely, J.; Sullivan, C.; Tomich, T.P.; Sanchez, P.A. 2010. Monitoring the world's agriculture. *Nature* 466(7306): 558-560.

Saravia, M.; Quintero, M. 2009. CONDESAN: An innovative and multi-institutional Andean platform in continuing evolution. *Mountain Research and Development* 29: 356-358.

Sayer, J.; Sunderland, T.; Ghazoul, J.; Pfund, J.; Sheil, D.; Meijaard, E.; Venter, M.; Boedhihartono, A.K.; Day, M.; Garcia, C.; van Oosten, C.; Buck, L.E. 2013. Ten principles for a landscape approach to reconciling agriculture, conservation, and other competing land uses. *Proceedings of the National Academy of Sciences of the United States of America* 110: 8349-8356.

Schaleger, E.; Ostrom, E. 1992. Property-rights regimes and natural resources: A conceptual analysis. *Land Economics* 68(3): 249-262.

Scheffer, M.; Carpenter, S.; Foley, J.A.; Folke, C.; Walker, B. 2001. Catastrophic shifts in ecosystems. *Nature* 413(11): 591-596.

Scheierling, S.M.; Bartone, C.R.; Mara, D.D.; Drechsel, P. 2011. Towards an agenda for improving wastewater use in agriculture. *Water International* 36: 420-440.

Schröter, M.; van der Zanden, E.H.; van Oudenhoven, A.P.E.; Remme, R.P.; Serna-Chavez, H.M.; de Groot, R.S.; Opdam, P. 2014. Ecosystem services as a contested concept: A synthesis of critique and counter-arguments. *Conservation Letters.* doi: 10.1111/conl.12091.

Singh, S.; Mishra, A. 2014. Deforestation-induced costs on the drinking water supplies of the Mumbai metropolitan, India. *Global Environmental Change* 27: 73-83.

Steffan-Dewenter, I.; Munzenberg, U.; Burger, C.; Thies, C.; Tscharntke, T. 2002. Scale-dependent effects of landscape context on three pollinator guilds. *Ecology* 83: 1142-1432.

Sutherland, W.J. 2003. Parallel extinction risk and global distribution of languages and species. *Nature* 423(6937): 276-279.

Tallis, H.; Polasky, S. 2009. Mapping and valuing ecosystem services as an approach for conservation and natural-resource management. *Annals of the New York Academy of Sciences* 1162: 265-283.

Tapasco, J. 2013. *Disponibilidad de los consumidores de agua potable a aportar en un fondo para la conservación de la parte alta de la cuenca del Río Cañete.* Internal report. Cali, Colombia: International Center for Tropical Agriculture (CIAT).

TEEB (The Economics of Ecosystems and Biodiversity). 2010. *Ecological and economic foundations.* London, UK: Earthscan.

The Guardian. 2012a. *Putting a price on the rivers and rain diminishes us all: Payments for 'ecosystem services' look like the prelude to the greatest privatisation since enclosure*. Available at http://www.theguardian.com/commentisfree/2012/aug/06/price-rivers-rain-greatest-privatisation?guni=Article:in%20body%20link (accessed on June 18, 2014).

The Guardian. 2012b. *We must put a price on nature if we are going to save it: Campaigning against economic valuations could inadvertently strengthen the hand of those who believe nature has little or no worth.* Available at http://www.theguardian.com/environment/2012/aug/10/nature-economic-value-campaign (accessed on June 18, 2014).

Transnational Institute. 2014. *State of power* 2014. Available at http://www.tni.org/stateofpower2014 (accessed on July 28, 2014).

Tscharntke, T.; Klein, A.M.; Kruess, A.; Steffan-Dewenter, I.; Thies, C. 2005. Landscape perspectives on agricultural intensification and biodiversity: Ecosystem service management. *Ecology Letters* 8: 857-874.

Tscharntke, T.; Milder, J.C.; Schroth, G.; Clough, Y.; DeClerck, F.; Waldron, A.; Rice, R.; Ghazoul, J. 2014. Conserving biodiversity through certification of tropical agroforestry crops at local and landscape scales. *Conservation Letters.* doi: 10.1111/conl.12110

UNDP (United Nations Development Programme). 2013. Human development report 2013: *The rise of the South. Human progress in a diverse world.* New York: United Nations Development Programme (UNDP).

UNEP (United Nations Environment Programme)-WCMC (World Conservation Monitoring Centre); IEEP (Institute for European Environmental Policy). 2013. *Incorporating biodiversity and ecosystem service values into NBSAPs. Guidance to support NBPSAP practitioners.*

Vigerstol, K.L.; Aukema, J.E. 2011. A comparison of tools for modeling freshwater ecosystem services. *Journal of Environmental Management* 92: 2403-2409.

Vital Signs. 2014. Vital signs fact sheet. Available at http://vitalsigns.org/files/Vital-Signs-Fact-Sheet-2014.pdf (accessed on April 14, 2014).

Walker, B.; Salt, D. 2006. *Resilience thinking: Sustaining ecosystems and people in a changing world.* Washington, DC: Island Press.

Wichelns, D.; Drechsel, P. 2011. Meeting the challenge of wastewater irrigation: Economics, finance, business opportunities and methodological constraints. *Water International* 36: 415-419.

Willemen, L.; Veldkamp, A.; Verburg, P.H.; Hein, L.; Leemans, R. 2012. A multi-scale modelling approach for analysing landscape service dynamics. *Journal of environmental management* 100: 86-95.

Willemen, L.; Drakou, E.G.; Dunbar, M.B.; Mayaux, P.; Egoh, B.N. 2013. Safeguarding ecosystem services and livelihoods: Understanding the impact of conservation strategies on benefit flows to society. *Ecosystem Services* 4: 95-103.

Wright, H.L.; Lake, I.R.; Dolman, P.M. 2012. Agriculture—a key element for conservation in the developing world. *Conservation Letters* 5(1): 11-19.

Wood, A., Dixon, A., McCartney, M., 2013. People-centred wetland management.

World Bank. 2014. *World Development Indicators: Agricultural inputs.* Available at http://wdi.worldbank.org/table/3.2 (accessed on June 10, 2014).

World Economic Forum. 2012. *Big data, big impact: New possibilities for international development.* Switzerland: World Economic Forum.

Zhang, W.; Ricketts, T.H.; Kremen, C.; Carney, K.M.; Swinton, S.M. 2007. Ecosystem services and dis-services to agriculture. *Ecological Economics* 64(2): 253-260.

Zhou, K.; Huang, J.K.; Deng, X.Z.; van der Werf, W.; Zhang, W.; Lu, Y.H.; Wu, K.M.; Wu, F. 2014. Effects of land use and insecticides on natural enemies of aphids in cotton: First evidence from smallholder agriculture in the North China Plain. *Agriculture, Ecosystems and Environment* 183: 176-184.

ANNEX 1. TYPOLOGY OF ECOSYSTEM SERVICES USED BY WLE.

This section presents the full ecosystem service typology used by WLE. The typology is a modified version of that proposed by TEEB (2010).

	MAIN SERVICE TYPES
	PROVISIONING
1	**Food** (e.g., fish, game, fruit)
2	**Water** (e.g., drinking, irrigation, cooling)
3	**Raw materials** (e.g., fiber, timber, fuelwood, fodder, fertilizer)
4	**Genetic resources** (e.g., crop-improvement and medicinal purposes)
5	**Medicinal resources** (e.g., biochemical products, models and test-organisms)
6	**Ornamental resources** (e.g., artisan work, decorative plants, pet animals, fashion)
	REGULATING
7	**Air quality regulation** (e.g., capturing (fine)dust, chemicals, etc.)
8	**Climate regulation** (including carbon sequestration, influence of vegetation on rainfall, etc.)
9	**Moderation of extreme events** (e.g., storm protection and flood prevention)
10	**Regulation of water flows** (e.g., natural drainage, irrigation and drought prevention)
11	**Waste treatment** (especially water purification)
12	**Erosion prevention**
13	**Maintenance of soil fertility** (including soil formation and nutrient cycling)
14	**Pollination**
15	**Biological control** (e.g., seed dispersal, pest and disease control)
	HABITAT
16	**Maintenance of the life cycles of species through provision of suitable habitats** (e.g., reproduction and nursery habitats)
17	**Maintenance of genetic diversity** (e.g., gene pool protection)
	CULTURAL
18	**Aesthetic information**
19	**Opportunities for recreation and tourism**
20	**Inspiration for culture, art and design**
21	**Spiritual experience**
22	**Information for cognitive development**
23	**Mental health benefits (e.g., stress reduction)**

Photo: CIAT.

CGIAR Research Program on Water, Land and Ecosystems

The **CGIAR Research Program on Water, Land and Ecosystems (WLE)** combines the resources of 11 CGIAR centers, the Food and Agriculture Organization of the United Nations (FAO) and numerous national, regional and international partners to provide an integrated approach to natural resource management research. WLE promotes a new approach to sustainable intensification in which a healthy functioning ecosystem is seen as a prerequisite to agricultural development, resilience of food systems and human well-being. This program is led by the International Water Management Institute (IWMI) and is supported by CGIAR, a global research partnership for a food-secure future.

CGIAR Research Program on Water, Land and Ecosystems
International Water Management Institute (IWMI)
127 Sunil Mawatha, Pelawatta
Battaramulla, Sri Lanka
Email: wle@cgiar.org
Website: wle.cgiar.org
Agriculture and Ecosystems Blog: wle.cgiar.org/blogs

ISBN 978-92-9090-805-0

IN PARTNERSHIP WITH: