11 Management of Water and Agroecosystems in Landscapes for Sustainable Food Security

Eline Boelee,[1*] Sara J. Scherr,[2] Petina L. Pert,[3] Jennie Barron,[4] Max Finlayson,[5] Katrien Descheemaeker,[6] Jeffrey C. Milder,[2] Renate Fleiner,[7] Sophie Nguyen-Khoa,[8] Stefano Barchiesi,[9] Stuart W. Bunting,[10] Rebecca E. Tharme,[11] Elizabeth Khaka,[12] David Coates,[13] Elaine M. Solowey,[14] Gareth J. Lloyd,[15] David Molden[7] and Simon Cook[16]

[1]*Water Health, Hollandsche Rading, the Netherlands;* [2]*EcoAgriculture Partners, Washington, DC, USA;* [3]*Commonwealth Scientific and Industrial Research Organisation (CSIRO), Cairns, Queensland, Australia;* [4]*Stockholm Environment Institute, University of York, UK and Stockholm Resilience Centre, Stockholm University, Stockholm, Sweden;* [5]*Institute for Land, Water and Society (ILWS), Charles Sturt University, Albury, New South Wales, Australia;* [6]*Plant Production Systems, Wageningen University, Wageningen, the Netherlands;* [7]*International Centre for Integrated Mountain Development (ICIMOD), Kathmandu, Nepal;* [8]*World Water Council (WWC), Marseille, France;* [9]*International Union for Conservation of Nature (IUCN), Global Water Programme, Gland, Switzerland;* [10]*Essex Sustainability Institute, University of Essex, Colchester, UK;* [11]*The Nature Conservancy (TNC), Buxton, UK;* [12]*United Nations Environment Programme (UNEP), Nairobi, Kenya;* [13]*Secretariat of the Convention on Biological Diversity (CBD), Montreal, Canada;* [14]*The Arava Institute for Environmental Studies (AIES), Hevel Eilot, Israel;* [15]*UNEP–DHI Centre for Water and Environment, Hørsholm, Denmark;* [16]*CGIAR Research Program on Water, Land and Ecosystems, Colombo, Sri Lanka*

Abstract

Various food and financial crises have increased the pressure on natural resources while expanding on alternative ways of considering agroecosystems as potential long-term providers of ecosystem services if managed in a sustainable and equitable way. Through the study of interrelations between ecosystems, water and food security, this book has aimed to increase the understanding and knowledge of these interactions for better planning and decision making processes at various levels. This chapter concludes *Managing Water and Agroecosystems for*

* E-mail: e.boelee@waterhealth.nl

Food Security. It discusses the main findings of the preceding chapters, from analyses of drivers of sustainable food security, via agroecosystems with their ecosystem services and challenges for water use and scarcity, to specific challenges for environments such as drylands and wetlands. Using a comprehensive landscape approach, recommendations on water productivity, agroecosystem services and integrated water management are brought together succinctly. In addition, knowledge gaps and issues for further research have been identified that may support further implementation of the agroecological approach in many landscapes around the world.

Background

At the global scale, humanity is increasingly facing rapid changes, and sometimes shocks, that affect the security of our food systems and the agroecosystems that are the ultimate sources of food (Chapter 2). Together, drivers such as demographic changes, globalization of economic and governance systems (including markets), and climate change, all have important implications for the sustainable security of food. These drivers centre around food availability and access to water, as these are the major influences affecting agricultural water demand and increasing the pressure on ecosystems. Addressing the opportunities, synergies and constraints of these multiple drivers will be critical for policy advice to enable the building of resilient food systems for future generations (Chapter 2).

Water is already scarce at various temporal and spatial scales, although these estimates are hampered by uncertainties in data. However, there *is* certainty that improving food security will place further pressure on both water resources and ecosystems. How water is used in agriculture, and over time, depends on a variety of factors, including population growth, economic development, environmental constraints and accessibility, be it through infrastructure and technologies, or through governance and institutions (Chapter 5).

With increasing competition over access to water, finding an equitable way to distribute water among uses and users seems difficult, as many obstacles exist to the effective implementation of integrated water resource management (IWRM) (Chapter 10). If current water management practices continue, it is unlikely that this will solve the many challenges associated with water usage in agriculture – challenges both from poverty and from the environment. When water for ecosystems and water for food are considered separately, the potential for inter-sectoral conflict is heightened and the problem becomes even more challenging. Hence, in order to share a scarce resource and guarantee long-term sustainability, it is imperative to transform governance theories into a practical process providing solutions on the ground that can meet future water demands.

Moving Towards an Agroecological Landscape Approach

Chapter 6 discusses several approaches that are capable of preserving water and increasing the use of low quality water for dryland agriculture. Drylands are highly vulnerable, making ecosystem management a priority for reversing land degradation and making optimum use of the – often limited – available natural resources. Options such as the introduction of appropriate plant species for specific landscapes can be successful only when the entire ecosystem and its users are taken into account. Similarly, the exploitation of wetlands by people is a reality that has already led to rapid degradation. Wetlands sustain a wide range of ecosystem services that contribute to water and food security, but their exploitation should be embedded in a systematic approach that incorporates the many functions of these ecosystems, or more will be lost and further degraded (Chapter 7).

Management of water in agriculture typically targets the provisioning ecosystem services of biomass for the harvesting of food, fodder, fibre or other valued goods, often at the expense of other supporting or regulatory services (Chapter 3). Reduced access to and quality of water, combined with increased demand for water, are among the reasons for the rapid growth of aquaculture, which has its own water management requirements and impacts on water and food security. At the same time, water availability is one of the limiting factors to biomass production, which explains why agricultural management is often focused primarily around the supply of water, in combination with other inputs such as manure, fertilizer, improved seeds and pest control (Chapter 5). If agricultural activities are viewed in isolation and receive disproportionately more water, landscapes will lose the capacity to provide the full range of ecosystem functions and services that they currently do – or formerly did (FAO/Netherlands, 2005). However, as long as many of these ecosystem services do not have a market value, they are not included in conventional agricultural management approaches. At the same time, conservation strategies usually target specific (semi-natural) ecosystems or threatened species, while treating agriculture as a threat to be contained and mitigated. In Chapter 4, it was shown that it is possible to go beyond making trade-offs between agricultural production and environmental quality by improving the quality of agroecosystems and reversing degradation that has an impact on productivity.

Ecosystem services are directly important for many people (Chapter 3). This is particularly the case in agriculture-based basins in low income countries, where many livelihoods depend on natural ecosystems such as wetlands and forests for survival (Kemp-Benedict *et al.*, 2011). Pro-poor policy responses to environmental problems can enhance multiple objectives such as human health, socio-economic growth and aquatic environmental sustainability (Millennium Ecosystem Assessment, 2005). Healthy agroecosystems have the potential to provide a high diversity of nutritious food, which is based on their functioning biodiversity (Kaplan *et al.*, 2009). Sustainable management of agroecosystems is, therefore, critical to addressing food security issues (FAO/Netherlands, 2005).

To ensure food security, it is important that decision makers support the management of ecosystem services by taking appropriate policy measures that encourage sustainable land management, integrated water resources management and more sustainable agricultural practices by farmers. Solutions include not only minimizing the negative impact of agriculture on ecosystems, but also better management of agroecosystems and non-agricultural ecosystems to support improved water security for agriculture. These approaches include, among others, equitable access rights, better soil and water conservation, management of water quality and quantity, improved livestock and fish management, and sustaining biodiversity (Chapter 9).

This calls for a refining in the management of water from what is termed in IWRM 'water for food' to 'water for agroecosystems', in which the whole ecosystem base of provisioning, regulatory, cultural and supporting services are considered (Chapter 10). Recognizing and accounting for these multiple ecosystem services of agroecosystems, coupled with elements of IWRM at the basin scale, including consideration of all water resources above and below ground, can be a powerful and sustainable response to freshwater scarcity. Identifying the most promising options to increase water productivity is complex and has to take into account environmental, financial, social and health-related factors. In general, improving agricultural water productivity can be achieved by creating synergies across scales and between various agricultural sectors and ecosystems, thereby enabling multiple uses of water and equitable access to water resources for different groups in society (Chapter 8).

Lessons Learned: Principles and Recommendations

Many of the recommendations in the previous chapters may prove most effective if they are applied in combination with other measures in an integrated approach, as has been shown for wetlands (Chapter 7). Increased water productivity in agroecosystems enhances the value of water within those systems and helps in the reallocation of water to a variety of uses and ecosystems (Chapter 8). In multifunctional agroecosystems, water is thus managed more productively for provisioning services (crops, trees, livestock, fish) and, in addition, sustains regulating, supporting and cultural ecosystem services (Chapter 5). In an IWRM approach, this can be managed at the basin level for agroecosystems, cities, industry, nature and other functions (Chapter 10). In many cases, active management of the landscape and various elements in it is required to help sustain the various ecosystem functions and services (Molden *et al*., 2007).

In an agroecological landscape approach, ecosystems are linked, and natural resources, such as water and land, are managed specifically to enhance ecosystem services. In this way, synergies can be exploited and productivity improved, while obtaining added value from improved carbon storage, erosion control, water retention, waste treatment and cultural values such as recreation (Chapter 4). As pointed out in the previous chapters, most of these added services do not conflict with agricultural production and, in many cases, they improve both its productivity and sustainability, so that the integrated management of agroecosystems for multiple services and benefits can be considered to be the key for addressing food security issues (FAO/Netherlands, 2005). The challenge is then to manage agroecosystems and landscape ecosystem services so that that improved water management and increased water productivity lead to both food security and synergies within the landscape, instead of to mutual degradation (Keys *et al*., 2012).

Based on the findings reported in this book for drylands (Chapter 6), wetlands (Chapter 7), increased water productivity (Chapter 8), the management of ecosystem services (Chapter 9) and integrated water management (Chapter 10), and supplemented with references from the international literature, we have summarized a set of recommendations below on how to manage water and other natural resources in agroecological landscapes. While basins are the ideal management unit from a hydrological or IWRM perspective, in reality, administrative boundaries play an important role and a more flexible definition of the landscape has to be used.

- *Prioritize development issues*
  Each landscape or basin, depending on the context, has its own issues. Long-term problems may be quite similar, but short-term priorities need to be determined locally. The analyses by Cook *et al*. (2011) and Kemp-Benedict *et al*. (2011) provide a useful starting point by considering the level of economic development within a particular locality or region (discussed in Chapter 5). The process of formulating priorities can further be facilitated by using some of the guiding questions suggested by Cook *et al*. (2011). For instance: how much water is there in the basin and who uses the water; how productively is water used by agriculture; and who has the power to change this? Finally, interventions can be developed, for instance, by looking at how sensitive the system is to change (see Cumming, 2011).
- *Promote diversity within the production systems*
  Multifunctional agriculture can help to increase the productivity of natural resources and reduce risk for farmers (OECD, 2001; Groenfeldt, 2006). Optimizing the diversity of the above and below ground biotic components within the production system (crops, animals, soil and pollinators) can increase the adaptive capacity of the production system. This would help to buffer it against fluctuations in water availability, temperature, and pests and diseases, thereby enhancing the resilience of the system as well as rural livelihoods (Hajjar *et al*., 2008; Chapter 9). Synergies between livestock and aquaculture (van der Zijpp *et al*., 2007) can be explored for increasing resource recovery and productivity (Chapter 8). The same holds true for other integrated systems, such as crop–livestock systems, rice–fish culture, tree–crop systems (Zomer *et al*., 2009), aquaculture in reservoirs, forest pastures or wastewater-fed aquaculture (Chapter 7). The integration of trees can help to fix nitrogen, tighten nutrient, water and carbon cycles, and produce

additional goods, e.g. year-round available fodder, and biomass for use as organic fertilizer and fuel (Garrity *et al*., 2010).

- *Promote diversity in landscapes*
  Landscapes with high levels of land use diversity, as well as biodiversity, are more resilient and better able to mitigate adverse environmental conditions (Folke *et al*., 2004). Large monocropped areas can be developed into landscapes that have higher levels of biodiversity by identifying and linking natural habitat patches, including aquatic ecosystems. Habitat integrity and connectivity can be maintained by incorporating hedgerows, multipurpose trees and, where spatially feasible, corridors of natural vegetation interconnecting parcels of agricultural land and natural ecosystems (such as wetlands and forests, which may need to be specifically developed where these natural systems are remote). In large irrigated areas, canals and roads can be lined with perennial vegetation, such as trees, thus also serving as important passages and habitats for animals. Canals and other waterways that connect aquatic ecosystems, and so maintain the connectivity of migratory routes for aquatic fauna, provide the variety in habitats required for subsequent life cycle stages, for example spawning (Chapter 7). Landscape-scale planning of strategic tree cover interventions can reduce flow accumulation by providing sites for water infiltration and penetration. For instance, contour hedgerows can reduce runoff and soil erosion on slopes, and buffer strips may protect watercourses (Chapter 9). By incorporating both fodder production and grazing land, livestock can be managed at the landscape level too, so that animals are enabled to reach otherwise inaccessible feed sources and the overgrazing and trampling of vulnerable areas is avoided.
- *Increase water productivity*
  Water productivity is defined as the amount of output per unit of water. Crop water productivity can be improved by selecting well-adapted crop types, reducing unproductive water losses and optimizing the joint management of water, nutrients and plants. However, it is crucial to go beyond crops, and to include livestock, trees and fish in water productivity assessments (Chapter 8). Livestock water productivity can be increased through improved feed and animal management, reducing animal mortality, appropriate livestock watering and sustainable grazing management. In agroforestry systems, the right combination of trees and crops can exploit spatial and temporal complementarities in resource use. In aquaculture systems, most water is depleted for feed production, via seepage and evaporation, and through polluted water discharge. Hence, efforts to minimize those losses would improve overall water productivity.
- *Choose the right infrastructure and operation*
  Smart infrastructure planning, and selecting appropriate, multifunctional constructs at the right location that can be operated with a large degree of flexibility, can widen the focus, from simply delivering water to field crops, to providing water for multiple uses by different members of society. This would explicitly include water for bathing, laundry, animal drinking, home gardens, fish ponds and many other domestic and productive uses. Current access to water has to be taken into account and, where necessary, expanded with appropriate structures for the harvesting of rain or runoff water, site-specific water storage (McCartney and Smakhtin, 2010) and distribution infrastructure, as well as by using unconventional sources of water (such as urban wastewater, which can be a valuable resource if managed properly). This approach would need to take into account property rights and their gendered nature, including the rights to the use and management of shared water resources.
- *Mobilize social organization and collective action*
  Engaging communities in water resource management and ownership is critical to ensuring that the various proposed practices meet the needs of the people and are carried on into the future for meeting food and environmental needs. This includes management of other natural resources, such as land and common forest, and

grazing lands (Bossio and Geheb, 2008). Alternative grazing management practices can have a substantial impact only when compliance is high, and sufficient spatial coverage of the interventions is ensured. Efforts also need to be made to make sure that management and ownership involve equitable access across diverse and sometimes marginalized groups within local communities. The devolution of responsibilities has to be matched with the devolution of rights or power. Raising awareness among community groups about the implications of alternative types of water use and the associated trade-offs will greatly enhance the capacity of the groups to conserve biodiversity and manage water efficiently.

- *Apply refined IWRM*
  In IWRM, all sources of water throughout the basin, including rain and surface water, as well as water held in soil and aquifers, are considered in a comprehensive manner and managed for the benefit of a broad range of uses. As stated in Chapter 10, water is no longer supplied to crops, trees, livestock or fish, but to multifunctional agroecosystems linked and managed together, at the river basin or landscape level. With effective institutional and policy support, water use can be optimized by increasing its efficiency, for example by using water more effectively in rainfed agriculture, improving water storage and reusing wastewater, as well as limiting the further expansion of water withdrawal from water sources and minimizing the impacts of climate change. IWRM can be further developed by recognizing and incorporating the need to safeguard environmental water flows for other ecosystems in order to enhance long-term ecosystem health and resiliency. The concept of environmental flows provides a basis for calculating the amount of water (quantity, quality and timing) required to sustain ecosystems and safeguard their services to people (Keys *et al.*, 2012; Chapters 5 and 10).
- *Develop institutions for integrated natural resources management*
  Up until now, relatively more effort has been placed on building institutions to manage irrigation delivery than on overall water and natural resource management. However, institutions must be developed, changed and supported at various levels to maintain healthy multifunctional agroecosystems and to ensure equity of access, use and control over resources. This means that specialized line agencies from various ministries have to collaborate much more closely than before, both with each other and with the end users. For example, joint management of water, land, crop and livestock is required to adequately address erosion problems.
- *Foster supportive policies*
  National and landscape level policies can support not only the development and management of early warning and response systems for climate change, but also improved markets, buffers of food and fodder, and insurance schemes to cover loss of yields or livestock (World Bank, 2009). Multifunctional agroecological landscapes need supporting services in all sectors, ranging from the monitoring of water distribution and soil fertility to veterinary centres and public health facilities. Incentive systems such as payments for ecosystem services (PES) and payments for watershed services can support the transition to more sustainable farming systems and enhance resilience (Swallow and Meinzen-Dick, 2009; Mulligan *et al.*, 2010; Cumming, 2011; Chapter 9). Such policies may enable farmers to adopt practices that lead to long-term benefits, but with lower returns in the short term.
- *Inter-sectoral collaboration*
  The application of an integrated approach to water resources management, and the strengthening of institutions and policies for an ecological landscape approach, require an enlightened collaboration across different relevant sectors (Chapter 5), e.g. between the various ministries, both at a national and a local level, depending on the level of decentralization in a country. Ministries of the Environment may be in the best position to promote an ecosystem services approach to food security at the landscape level, because of their expertise, but, in reality, this is a huge challenge. In

many countries Ministries of the Environment, if they exist at all, often have a small budget and little power. In contrast, Ministries of Agriculture are often in a better position, especially in countries where agriculture delivers a large proportion of the gross domestic product (GDP). Also, the mandate, policies and practices in the agriculture sector probably have the greatest potential to help shape agroecological landscapes. Therefore, if all the various ministries work together, with the water, health, energy and planning sectors, there would be greater potential leverage for promoting the management of agroecosystem services.

The Integrated Landscape Approach in Practice

Landscape approaches can improve food security and nutrition by diversifying food sources and increasing the sustainability of production systems at multiple scales. It takes the concept of multifunctionality in agriculture (Nguyen-Khoa and Smith, 2008) to a higher scale. For example, multifunctional rice fields in Vietnam are used to grow rice (thus increasing food security), reduce erosion and buffer water quantities (both regulatory services), retain nutrients (supporting services) and, at the same time, diversify production by allowing fish and ducks into the rice fields, as well as grazing animals after harvest. Landscape elements can be added to enhance more regulatory and supporting ecosystem services, e.g. ponds interspersed with the fields, which can be used for aquaculture and livestock drinking, while also regulating water flows. Similarly, multipurpose trees can help to increase infiltration and reduce runoff (regulatory services), and can be used in agricultural landscapes to connect forest habitats (biodiversity), bring insects for pollination and soil organisms closer to fields (supporting services), cycle nutrients and carbon (supporting services), and also diversify provisioning services by supplying fuel wood and timber in addition to fodder and fruit.

In aquatic ecosystems, recognition of the full range of provisioning ecosystem services, i.e. not only fish, is vital if the true value of such 'aqua-ecosystems' is to be accounted for and safeguarded in the livelihoods of people and in local and national economies. Beyond capture fisheries, well-managed aquatic ecosystems also provide biodiversity, cultural services and aesthetic values. By providing environmental flows at the basin level, aquatic ecosystem services may benefit many people and make significant contributions to their well-being and resilience (Brummett *et al*., 2010).

When managing agroecosystems as part of landscape approaches, the upstream areas merit special attention, as these are often degraded and need to be rehabilitated. In practice, many of the examples, particularly those relating to action in wetlands or changing agricultural practices, are about ecosystem restoration (e.g. Box 11.1). In most cases, this means restoring or enhancing the services provided by the ecosystem. This also holds true for the transformation of conventionally managed agroecosystems into multifunctional agroecological landscapes that provide the widest range of ecosystem services. Rehabilitation implies the regrowth of grass and trees, which ultimately requires water. Hence, in these areas, the water for agroecosystems will not immediately result in many provisioning services, except possibly for some fodder as part of cut and carry systems. During this rehabilitation phase then, there may be higher water requirements for regulatory and supporting services (including carbon capture), with less water to contribute to downstream river flows. In the long term, there will be compensation for this phase through a reduction in erosion levels (and in the siltation of downstream infrastructure), and increased infiltration and higher downstream river flows.

Several organizations are promoting landscape approaches and contribute to a knowledge base on the impacts and constraints. The 'Landscapes for People, Food and Nature Initiative' (2012) identified 109 active or recent landscape initiatives in Latin America, 150 in Africa and 21 in Asia and the Middle East. In these landscape management systems, people have developed integrated strategies and multistakeholder processes for maintaining agricultural productivity, as well as rich natural ecosystems. Many of these are projects in

Box 11.1. River restoration in Jordan. Example based on IdRC (2006), IUCN (2009), and updated by Stefano Barchiesi (IUCN) in April 2012.

The Zarqa River is the second tributary to the Jordan River. It rises in springs near Amman and flows through a deep and broad valley into the Jordan River. Around 65% of the Jordanian total population and more than 90% of the small–medium industries of Jordan are concentrated in the Zarqa River Basin, and the demands for water are very high. This has led to the over-pumping of groundwater for agriculture, drinking and industrial uses, which, together, have reduced the natural base flow of the river. The flow characteristics have been further modified by the discharge of treated domestic and industrial wastewater into the river; these discharges comprise nearly all of the summer flow of the river and substantially degrade the water quality.

In a heavily populated and industrialized region, it is a challenge to establish a solid waste management strategy to stop the contamination of the river. Since 2006, the REWARD (Regional Water Resources and Drylands) Programme of the IUCN (International Union for the Conservation of Nature) Regional Office for West Asia (ROWA) has worked in close consultation with the Jordan Ministry of Environment on a long-term strategy for the restoration of the basin. 'The Restoration and Economic Development of Zarqa River Basin' Project was one of the demonstration projects initiated by the DGCS (Italian Ministry of Foreign Affairs)/WESCANA (West, Central Asia and North Africa) Project and supported by the IUCN Water and Nature Initiative (WANI), with funding from DGIS (Netherlands' Directorate-General for International Cooperation).

The Jordanian Ministry of Environment placed the rehabilitation and integrated environmental management of the Zarqa River Basin at the top of its priorities in 2006. With the support of IUCN, the Ministry conducted a sustainability review of the institutional arrangements within the Ministry of Environment, including the Zarqa River Basin Rehabilitation Unit (ZRRU), and formed a Committee with representatives of governmental institutions, research organizations, universities and local NGOs (non-governmental organizations) to develop a national strategy for the restoration of the Zarqa River. The strategy for action was completed in 2009 with funding from the Spanish Agency for International Cooperation and UNDP (United Nations Development Programme). The strategy builds on the principles of integrated water resources management (IWRM) in combining the development of effective governance, the application of economic tools, knowledge management and capacity building, the engagement of civil society and the implementation of restoration and sustainable management.

The restoration strategy has three phases. In the first 3 year phase, urgent pilot restoration activities demonstrated to people how progress can be achieved, and what the benefits of a healthy river are to society. At the same time, planning took place for cleaning up the rubbish in the river, re-establishing riverside vegetation and managing water resources sustainably. This was backed by the participation of river users and communities in decision making and action for rehabilitation. The economic benefits from restoration will grow over time, together with the regulatory, provisioning (agriculture) and cultural (recreation and tourism) ecosystem services. In the second and third phases, the whole river ecosystem will be restored to health over a period of 10–15 years.

The significant obstacles that remain to improving water management in the Zarqa River Basin are the lack of clear governance of the water basin, which has resulted in more difficult enforcement of water legislations and policies, and also the lack of inter-stakeholder agreements, knowledge of socio-economic consequences, information on various aspects of the basin (e.g. environmental flows and surface–groundwater interactions), awareness of water conservation and management, and experience of systematic approaches relevant to water resources management.

places where high levels of poverty coincide with critical conservation priorities (Landscapes for People, Food and Nature Initiative, 2012). This confirms the dependency of many poor people on ecosystems for their livelihoods (Chapter 3). In other areas of the world, whole landscape approaches are being developed particularly to address issues of water quality, water conflicts over natural resources and cultural heritage (Landscapes for People, Food and Nature Initiative, 2012). Other initiatives operate at a somewhat smaller scale but have important landscape components, such as the global initiative to identify and safeguard Globally Important Agricultural Heritage Systems and their associated landscapes, agricultural biodiversity, knowledge systems and cultures, which was started by FAO (Food and Agriculture Organization of the United Nations) in 2002 (http://www.giahs.org).

Research is now underway to track and analyse impacts on production, ecosystem services and human well-being of the landscape approach in many locations. Though methodologies are still under development, it has become clear that in many places the approach has not yet moved, beyond a vision of leaders, into practical implementation. This highlights a particular risk in adopting a landscape approach, as the notion of what a landscape should sustain and how it should be managed will vary between stakeholders. Consequently, policy makers and natural resource managers will need integrated landscape assessment and participatory planning approaches to reconcile multiple demands, including the need for environmental protection and biodiversity conservation. Concerns that landscape approaches might be dominated or corrupted by powerful or more influential groups should also be acknowledged, and appropriate safeguards and measures are needed to ensure transparency and accountability. On the optimistic side, the available case studies demonstrate that there have been ample positive results in vulnerable regions, where earlier conventional approaches did not work (see Landscapes for People, Food and Nature Initiative, 2012; Landscapes for People, Food and Nature Initiative Blog, 2012). The results that have been obtained suggest that 'landscape approaches can increase the "total bottom line" outcomes of rural landscapes while improving the sustainability of livelihoods and resilience of rural communities' (Landscapes for People, Food and Nature Initiative, 2012).

Related initiatives

Another concept that is gaining worldwide momentum is that of Green Economy. Although this is criticized for its practical implications, several recommendations on water management echo the recommendations outlined above (UNEP, 2011; MLTM *et al*., 2012). Investment in water-dependent ecosystems, infrastructure and management is seen as a way to expedite the transition to a green economy and to help achieve all water-related Millennium Development Goals (MDGs) at the same time as keeping global water use within sustainable limits. This would require an investment of US$198 billion/year until 2050. Institutional arrangements, such as PES, could help to reduce this amount. The improvement of agricultural water use is crucial to achieving these goals (UNEP, 2011).

The British programme 'Ecosystem Services for Poverty Alleviation' (ESPA, 2009–2016; see NERC, 2012) strives to 'improve ecosystems management policies to help alleviate poverty in the developing world'. Even though it is not directly focused on food security, ESPA may help to bridge some of the knowledge gaps identified in this book by supporting 'high quality and cutting-edge research that will deliver improved understanding of how ecosystems function, the services they provide, the full value of these services, and their potential role in achieving sustainable poverty reduction'. The evidence and tools generated in ESPA should enable farmers and decision makers to manage ecosystems sustainably and in a way that contributes to reducing poverty, hunger and disease. The programme seeks to provide evidence on the values of ecosystem services, drivers and trends, processes that influence ecosystem services, the importance of these services in alleviating poverty and enhancing sustainable growth, and ways to overcome constraints for the provision of those critical ecosystem services. ESPA works in South Asia, China, sub-Saharan Africa and Amazonia, and addresses various research themes, including water, health and biodiversity.

The CGIAR Research Program on Water, Land and Ecosystems was launched in March 2012 and aims to address some of the world's most pressing problems related to boosting food production and improving livelihoods, as well as simultaneously protecting the environment. This 10 year Program capitalizes on available knowledge and solutions in natural resource management, and aims to bring these together under an umbrella of ecosystem management (WLE, 2012).

Finally, trans-disciplinary thinking is also a key component of two integrative approaches to public health: EcoHealth (Lebel, 2003) and One Health (Kaplan *et al.*, 2009). Both of these require scientists from very different disciplines to work together, and emphasize the role of a healthy environment in determining the health of people and animals (see also Chapter 5). The link with natural resource management for food security in agroecological landscapes is apparent from the many pandemics in recent years, such as H1N1 flu and avian flu, which were related to livestock and poultry management.

Implications and Priorities for Research

The gap between theory and practice highlighted in the previous section shows that there are many challenges to the effective implementation of integrated landscape approaches. Some of these are institutional constraints, as pointed out in the recommendations that we have listed, but there are also important knowledge gaps, as laid out in the preceding chapters. Briefly, while understanding and recognizing the principles, do we really know *exactly how* water and agroecosystems must be managed to achieve food security, now, in 2050 and beyond?

Knowing the various agroecosystem functions and services that water can provide, how can water management enhance these functions and services? How do we decide how much water should be used for crop irrigation and energy production, and how much should be used for nature conservation? Can we really manage our agroecosystems differently so that we reduce trade-offs, as well as maximize the provision of ecosystem services, and at the same time use the same amount of natural resources, especially of land and water? Will this indeed lead to long-term sustainability and increased well-being for more people? How can recommendations for improvements from field to landscape or basin level be translated into policy actions? Questions like these can help identify knowledge gaps, along the lines of the guiding questions formulated by Herrero *et al.* (2009) on livestock, ecosystems and livelihoods.

Knowledge gaps from preceding chapters

To ensure that we have enough water for food and for a healthy planet, we must go beyond implementing the known improved techniques, incentives and institutions, and invest in understanding the various ecosystem functions and services, as well as their interactions, in agroecosystems (Chapter 3). Much is known about the global drivers of food security (Chapter 2), but we know less about how these drivers – either directly or indirectly – affect ecosystem services. A more in-depth analysis of one of these drivers, e.g. climate change, on productivity, ecosystem services and livelihoods in nine basins led to general recommendations, but was hampered by the usual uncertainties in the predictions (Mulligan *et al.*, 2011). Even at local level, there is not always sufficient information on the value of ecosystem services, especially when these go beyond the provision of food and fuel, which makes them less suitable for monetization (Chapter 4). Recent inventories of the global values of ecosystem services, such as those by the global initiative Economics of Ecosystems and Biodiversity (TEEB, 2010), have demonstrated the huge knowledge gap that there is of the value of the agroecosystems (van der Ploeg *et al.*, 2010) that cover so much of the earth's surface, compared with other ecosystems.

Our knowledge on water use in agroecosystems is more detailed, although this may not be true for a broader range of ecosystem services (Chapters 5 and 8). More research is needed on tools to analyse the potential for improvement at various spatial and temporal scales in order to focus and tune an appropriate and practical management approach year after year. Some major areas where attention needs to be given are: the role of agroecosystems in water storage and supply, particularly the renewable recharge of groundwater and improved soil moisture storage, and the role of water transpiration by agricultural crops in sustaining local and regional water cycles (Chapter 5). Insights are limited on water quality at basin level, and its influences from and impacts on agricultural development, though this is likely to become an increasingly more important topic.

The discussion of drylands (Chapter 6) and wetlands (Chapter 7) have provided concrete examples of how complex the issues in these ecosystems can be. As the specific interventions are, by definition, site specific, general knowledge gaps here are mainly on which institutional arrangements would best support integrated ecosystem management approaches. The application of various interventions is not obvious either. For instance, many studies have suggested there is substantial potential in semi-arid rangelands for carbon sequestration as well as for increases in water productivity, but much less is known about the way these would have to be managed in order to tap in to this potential (Chapter 6). In arid and saline areas, sustainable agriculture is only possible by combining specific crop selection and crop development, soil management, integrated livestock management, conservation and agroforestry, and mobilizing underutilized water sources.

The synergy of such a combined strategy may increase the efficient use of the resource base, but it requires local and generic knowledge to be applied, with attention given to the many marginal groups that live in these areas. In wetland agroecosystems, approaches to the multiple use of water resources show great promise for increased productivity, but rely on the preservation of traditional knowledge on integrated systems and the constraints of these systems (Chapter 7). Opportunities to further develop integrated systems could be explored, though assessments are required to determine the impact on ecosystem services within and outside these systems, and the potential for new risks to farmers. Such studies will also help to identify the needs for capacity building of water and land managers on ecosystem services.

There have been many recent innovations in the field of increasing water productivity (Chapter 8), but less is known about the impacts on overall basin water efficiencies if several measures are applied at a large scale. Scenario analysis can help in understanding the effects of different options on future water demands from agriculture, but the inclusion of other sectors, such as livestock, fisheries, aquaculture and trees, as well as non-provisioning ecosystem services, is much more complicated. Hence, further research is needed on the implications of various (integrated) interventions and of improved agricultural water productivity on poverty, food security, economic growth and landscape functioning, in addition to cost–benefit analyses of water requirements for ecosystem services. At the same time, not enough is known about how innovations change our systems and the resulting outputs and impacts of the agroecosystems, but this type of research is rare. Therefore, predictions on which innovations to develop how, when and where can hardly be made. Similarly, while payment for (environmental or) ecosystems services (PES) is being applied more widely, knowledge is still lacking on the proper institutional arrangements to ensure that farmers receive sufficient incentives for their changed practices (Chapter 9).

Fundamental research questions emerge on how to operationalize the various recommendations made, e.g. how to ensure that water in IWRM is allocated to a broad range of agroecosystem services, and not just to food production (Chapter 10). Ecoagricultural research from an IWRM perspective would help to identify feasible options that, in turn, need policy efforts to be realized. Although the political will may not always be available, this could change, once countries consider the full social, economic and environmental costs of not conserving existing water resources, as well as the costs of failure to develop new water sources. Multi-stakeholder dialogues would help to generate support at all levels, but need to be based on specific knowledge, packaged and communicated in a way that is understandable to the broader population.

Other scientists have also pointed out the many knowledge gaps on how local solutions should be combined into an overall integrated landscape approach, in which issues such as competition between multiple functions and the earlier mentioned methodological issues in the valuation of ecosystem services for current and future generations are important components (Hermann *et al.*, 2011). However, it is not always clear what policies are best, especially when evaluating decisions about ecosystems for water and food production, as these different systems operate on different timescales, but also underlie each other. Specific social science research is needed to include a better understanding of adaptive management institutions, but also of the role of women and youth and resilient livelihoods in implementing landscape approaches.

As climate variability increases across agroecological zones (Chapter 2), farmers need a reliable water supply, supported by adequate storage systems, to secure sustainable food production (Chapter 5). Assessments of freshwater scarcity continue to be refined from previous annual estimates to reflect the actual monthly consumptive use of groundwater and surface water. Still more rigorous and realistic accounting of the flows is needed to sustain the ecological integrity and essential services of those agroecosystems being managed for long-term food security, which will help to add a long-term environmental understanding to these water use patterns. Timely provision of good quality inputs is no longer sufficient, and early warning systems need to be developed to help address the vulnerability of farmers in variable climates and enhance efficiency in the use of water and nutrients (Chapter 8). The timescale needs to take into account the potential impacts of climate change, especially for vulnerable populations with low adaptive capacity, in order to ensure that food security targets are met.

Need for action research

The next step is to put these guidelines into practice and monitor the process long term and closely, to see how it works in reality and where adaptations are required in the approach. Baseline valuation assessments of ecosystem services in agricultural production systems can then be compared with those in real life agroecological landscapes, providing an evidence base on what works and what does not in the application of an ecosystem services approach to water and food security. In many places, such evaluations are hampered by an almost total lack of baseline data (see above), e.g. on streamflows and water quality, and sometimes even on rainfall. This makes it very hard to run models and obtain a good understanding of the current situation, let alone monitor and evaluate change.

The Landscapes for People, Food and Nature Initiative (2012) has started supporting the large scale application of landscape approaches, including improving key aspects of the enabling environment. This and other initiatives (e.g. Vital Signs, 2012) are also working to improve monitoring and impact assessment of landscape level initiatives and processes, but much remains to be done. The end users need support in managing their landscapes with the natural resources in it, for a wide range of ecosystem services, with proper valuation and monitoring to determine impact, identify obstacles and successes, and develop recommendations for further practical application of the approach. This is only possible with long-term collaborative commitments and agreements between universities, research centres, landscape initiatives, planners and practitioners. While increased environmental sustainability and productivity can be expected when managing for a broad range of ecosystem services, targeted interventions are needed to safeguard food security and equity. Hence, we end this book with an appeal to collaborative action research, in which planners and implementers from the agricultural, environmental and other sectors collaborate with scientists to create and scientifically monitor agroecological landscapes over the long term.

Conclusions

This book has shown the importance of ecosystem services in agriculture and how water and ecosystems can contribute to food security. The capacity and productivity of agroecosystems will be enhanced when the water quantity and quality are adequate for the whole range of ecosystem services, which will lead to greater environmental sustainability. Summarized in this chapter are the main elements required for an integrated management approach to water and agroecosystems at the landscape level. The resulting landscapes look like a mosaic of various healthy agroecosystems, natural ecosystems and other landscape elements, in which institutions and policy effectively facilitate the supporting role of water. Thus, agroecosystems can remain productive in the long term, resulting in higher economic returns for farmers. With more ecosystem services and, therefore, greater productivity at basin or landscape level, the health of the ecosystems comprising the resource base would be enhanced, and contribute to long-term sustainable food security.

In the previous chapters, various knowledge gaps were shown, particularly in the understanding of ecosystem services in agriculture and the implementation of the ecosystem approach. More insights can be gained through in-depth analysis of scientific as well as indigenous and practical evidence in various disciplines, which are, as yet, hardly ever combined.

By focusing on the benefits that we can derive from integrated landscape approaches for managing agroecosystems, we can shift the focus from production activities in isolation of other ecosystem services to a focus that treats our productive landscapes as settings for human well-being – settings that are maintained through integration of the benefits that we derive from our water, food and environment.

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