2 Drivers and Challenges for Food Security

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Abstract

At the global scale, humanity is increasingly facing rapid changes, and sometimes shocks, that are affecting the security of our food systems and the agroecosystems that are the ultimate sources of food. To plan and prepare for resilient food production and food security in a sustainable and efficient way, we are challenged to better understand the conditions and likely responses of these diverse agroecosystems under various drivers of change and scenarios of future trends. Among the many direct drivers and indirect pressures that exist or are emerging, the discussion in this chapter focuses on the main themes of drivers of demographic changes, globalization of economic and governance systems (including markets), and climate change. The current state of health of water and land resources, and of ecosystems and their services, are considered alongside these drivers, as these are critical determinants of the pathways with sufficient potential to move food-producing systems towards more sustainable production. Hence, addressing the opportunities, synergies and constraints of multiple drivers will be critical for policy advice to build resilient food systems in the future.

Background

Food security, meaning access to adequate food for all, at all times, requires, inter alia, sustainable and increased production and productivity in the agricultural sectors, as well as more equitable distribution of food. In this chapter the starting point for understanding food security is grounded in the food security framework developed by FAO (EC-FAO Food Security Programme, 2008) to reflect the multifaceted risks and challenges possible along the food supply chain to attain food security. The general framework comprises four dimensions:

- *Food availability:* the availability of sufficient quantities of food of appropriate quality, supplied through domestic production or imports.
- *Food access:* access by individuals or nations to food, including access to

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resources to produce food and the ability to purchase food.

- *Food stability:* to be food secure, a population, household or individual must have access to adequate food at all times. They should not risk losing access to food as a consequence of sudden shocks (e.g. an economic, societal or climatic crisis) or cyclical events (e.g. seasonal food insecurity).
- *Food utilization:* utilization of food through appropriate diet, clean water, sanitation and health care to reach a state of nutritional well-being where all physiological needs are met.

In all these dimensions of food security, water and other ecosystem services play integral parts in both supply and impact. Hence, food security is the product of many variables, including: physical factors such as climate, soil type and water availability; the management of these factors and other natural resources (water, land, aquatic resources, trees and livestock) at the level of fields, landscapes and river basins; and losses and waste along the value chain. It also requires adequate policies and institutions in the many sectors that influence the ability of men and women to produce and purchase food, and the ability of their families to derive adequate nutrition from it. These intricate linkages mean that food security cannot be considered in isolation. The feedbacks among food production, access, reliability and utilization are essential in the context of multiple changes in society and its environment (see Box 2.1).

Drivers, which may be defined as any natural or human-induced factor that directly or indirectly causes a change in an ecosystem (Millennium Ecosystem Assessment, 2005a; Carpenter *et al*., 2009), can be observed at global, regional and local scales, and ultimately put direct or indirect pressure on the management of natural resources. Key global drivers discussed here centre around food and water availability, because these are major influences affecting agricultural water demand and increasing the pressure on ecosystems. A workable framework of drivers and causal links affecting water stress and sustainability, as well as human well-being, is well illustrated in Cosgrove *et al*. (2012).

This chapter is focused around major drivers of change to the food security–water–ecosystems complex as loosely corresponding to those identified in the recent Foresight project 'Global Food and Farming Futures' (Beddington, 2010; Foresight, 2011); the types of drivers are similar to those of various global assessments, such as the Millennium Ecosystem Assessment (2005a,b), the World Water Assessment Programme of the United Nations (WWAP, 2009, 2012) and the Intergovernmental Panel on Climate Change (IPCC, 2012). Thus, this chapter will address the demographic drivers (i.e. population trends and changes in population preferences), the current state and trends in ecosystem services, climate change, and issues on the globalization of economies and governance.

Natural Resources and Ecosystem Health for Food

Terrestrial and aquatic ecosystems provide food for people, both as ecosytems in their natural state, for instance through forest products and inland capture fisheries, and in the form of intensively or extensively managed landscapes, such as crop and forestry systems, livestock keeping and aquaculture (see Chapter 4). Global estimates on the water needed for meeting the Millennium Development Goal (MDG) target on hunger suggest that the current appropriation of circa 7130 km^3 annually for food needs to increase to at least 12,050–13,500 km^3 by 2030 (Rockström *et al*., 2009a). Some of this additional water may be mobilized through water savings such as improved water productivity, in particular in currently low-yielding agroecosystems (see Chapter 8).

There are fundamental differences in opportunities among, as well as within, countries, depending on their available resources of both water and investment capacity (Rockström *et al*., 2009a). Access and control over land, water and produced capitals (e.g. financial capital, technologies) are also key factors to achieve the MDGs and increase water productivity in a way that will benefit the poor – notably women (UNEP, 2009). These different opportunities for the

Box 2.1. Hunger and food security.

The latest FAO estimates indicate that global agricultural production needs to grow by 70% between 2009 and 2050 to feed the population. The increase is due to a shift in demand towards higher value products of lower calorific content, and an increased use of crop output as feed for the rising meat demand (FAO, 2009a). At the same time, the adaptation of the agriculture sector to climate change will be a necessity for food security, poverty reduction and the maintenance of ecosystem services. In such a context, sustainable use and management of water and biodiversity resources in agroecosystems play a decisive role in providing food and income for a growing population (Nellemann *et al.*, 2009; FAO and PAR, 2011).

Despite 10 years of global commitment to reduce hunger, the number of hungry people (as measured through Millennium Development Goal (MDG) target 1A) remains more or less the same as estimated during the base year of 1990 (Fig. 2.1). Significant gains have been achieved in the past 20 years, as the relative share of hungry people has decreased from around 20% of developing country populations in 1990 to a current value of 12.5% (FAO, WFP and IFAD, 2012). Still, about 870 million people do not have sufficient food and 98% of these live in developing countries. Sixty-five per cent of the world's hungry live in India, China, the Democratic Republic of Congo, Bangladesh, Indonesia, Pakistan and Ethiopia. Women are particularly vulnerable and account for about 60% of the global hungry (FAO, 2010).

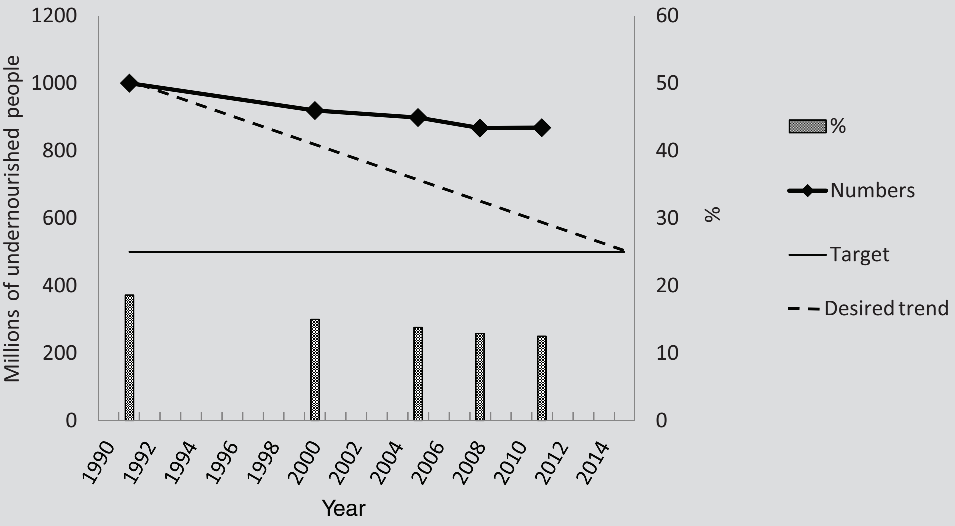

Fig. 2.1. Trends in numbers and percentages of undernourished people in the world for the period from 1990 to 2015 (last point projected), compared with the Millennium Development Goal (MDG) target of halving the number of hungry people (based on FAO, WFP and IFAD, 2012).

development of water for food security may have quite different impacts on water resource appropriation in different countries, in addition to impacts on the downstream flows that ultimately affect various water-related ecosystem services and functions. A comprehensive analysis of the need for water for food, and of the potential impacts on water-dependent ecosystem services in various landscapes, is not yet available on an aggregated global level.

Water is one of the main factors limiting future food production, particularly in the poorest areas of the world, where access to water, and its timely availability, are especially challenging. Over 1.6 billion people currently live in areas of physical water scarcity, and 1 in 10 continues to lack water for drinking and sanitation (UN, 2011). For 'business as usual' in agricultural practices, increased urbanization and changed diets, the amount of water required for agriculture to feed the world population would need to increase by 70–90% (Molden, 2007; Rockström *et al*., 2009a). Yet humans and ecosystems already face water stress from over-abstraction and from pollution (e.g. Rijsberman, 2006; see Chapter 5). Groundwater depletion is an under-examined issue of special concern, given its critical link in sustaining irrigation and people in highly densely populated areas (e.g. Giordano and Villholth, 2007). Close to 80% of the world's population is exposed to high levels of incident threat to water availability, according to a first global synthesis that jointly considers both human water security and biodiversity perspectives (Vörösmarty *et al*., 2010). The challenge is, therefore, to improve water productivity at the landscape or river basin level, thus accounting for a wider set of goods and services beyond agricultural produce (Ong *et al*., 2006; Molden, 2007; see Chapter 8).

The Millennium Ecosystem Assessment sought to catalogue the state of the environment and assess the consequences of ecosystem change on human well-being, including its effects on (and the effects of) food production (Millennium Ecosystem Assessment, 2005a). It showed that the significant increases in provisioning services (largely the goods used by people) that has been achieved in recent times, in particular food production through agriculture, have, to a large extent, been achieved at the expense of reductions in other ecosystem services, such as cultural aspects or services supporting or regulating other items that people need to sustain their well-being, societies and economies. These regulating and supporting services include, among other functions, drinking water supply, flood and drought protection, nutrient recycling, regulation of pests and diseases, and the provision of habitats for flora and fauna (for more on ecosystem services see Chapter 3).

The rural poor and marginal groups continue to have direct reliance on the ecosystem services of healthy natural ecosystems. In times of natural or anthropogenic shocks, such as droughts, floods, fires or market price volatility, there are few, if any, safety nets for ensuring that even their most basic nutritional needs are met. These groups of people also have less capacity to cope with the situation, or to find substitutes, when ecosystems and their services begin to degrade, and therefore are increasingly and more immediately vulnerable to such degradation (WRI, 2005).

Ecosystem deterioration, and the resultant loss of integrity, biodiversity and valued ecosystem services, along with the risk of reduced system resiliency to future shocks, must be more adequately factored into our understanding of drivers and the complex system feedbacks that their trends induce to safeguard food security in the future (Keys *et al*., 2012). Environmental degradation generates multiple negative feedbacks on food production systems, and on the livelihoods and human well-being they support. Depleted, fragmented and polluted river systems, lakes and aquifers already bear testament to these interrelationships. For instance, some 65% of global river discharge, and the aquatic habitat that water supports, are under moderate to high threat (Nilsson *et al*., 2005; Dudgeon *et al*., 2006). Such documented alterations to ecosystem health expose the currently untenable situation of accelerated degradation of natural and agroecosystems, especially wetlands (Millennium Ecosystem Assessment, 2005b), and the resultant declines in and unintended consequences for human ecosystem benefits (for further discussion pertaining to wetlands see Chapter 7).

Biodiversity is a central indicator for the state of the global environment and ecosystem services (see also Chapter 9). It has been suggested that the current rates of species extinction are far beyond what is considered a 'safe operating space for humanity' (Steffen *et al*., 2011). Indeed, an assessment of 31 different indicators of the status of global biodiversity in relation to the Convention on Biological Diversity (CBD; initiated in 1992) target of achieving a significant reduction in the rate of biodiversity loss by 2010 was unequivocal in demonstrating that the rate of biodiversity loss is not lessening at a global scale (Butchart *et al*., 2010). In this study, state-of-biodiversity indicators pointed to declines in biodiversity without a significant reduction in its rate of decline (Fig. 2.2, dotted line 'State'). This was coupled with an acceleration in the risk of species' extinction, with only freshwater quality and trophic integrity in the marine ecosystem showing marginal improvement. In direct contrast, various indicators of the pressures (or indirect drivers) on our ecological assets, such as the ecological footprint, which reflects aggregate resource consumption, nitrogen pollution and climatic impact, showed increases (Fig. 2.2, solid line 'Pressure'). Practice and policy responses (among these, the extent of protected areas and official development assistance for biodiversity), while encouraging in their increases and, in a few cases, in their local success, presently remain inadequate to check the trend of deterioration (Fig. 2.2, dashed line 'Response'). Perhaps unsurprisingly in this context, though based on a poor information base, the benefits that humans have derived from their natural capital were also found to be in accelerated decline; this is perhaps most significant for the more than 100 million poor people inhabiting remote areas within threatened ecosystems (Butchart *et al.*, 2010) who are likely to be particularly dependent upon the ecosystem services of healthy ecosystems with high biodiversity. There is an urgent need to identify new and improved local and global governance models that can ensure sustainable food production, while managing ecosystem services and biodiversity in synergy.

Alongside water resources, the present state of land, soils and their biodiversity may present the fundamental challenge for the future of food security (Bossio and Geheb, 2008), with some 11.7% of global land cover already converted to cropland (for which Steffen *et al.* (2011) propose a planetary boundary of 15%). Moreover, a recent report by FAO (2011) entitled *The State of the World's Land and Water Resources for Food and Agriculture (SOLAW)* concluded that growth in food production must take place on existing land. That is, current low-producing agricultural land

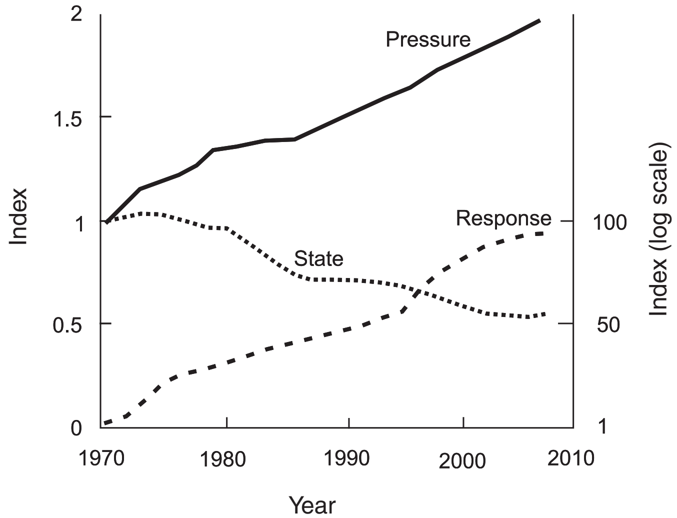

Fig. 2.2. Aggregated indices of the state of and pressure on biodiversity (left-hand *y*-axis), and the responses of biodiversity to protection, policy and aid measures (right-hand y-axis) over the period 1970–2010. The state of biodiversity (dotted line 'State') is based on nine indicators that cover species' population trends, habitat extent and condition, and community composition; pressure on biodiversity (solid line 'Pressure') is based on five indicators of ecological footprint, nitrogen deposition, numbers of alien species, over-exploitation and climatic impacts. The response (dashed line 'Response') of biodiversity to various measures is based on six indicators that cover protected area extent and biodiversity coverage, policy responses to invasive alien species, sustainable forest management and biodiversity-related aid (after Butchart *et al.* 2010). Values in 1970 were set to 1 for 'State' and 'Pressure', and to 0 for 'Response'.

will need substantial investments to become productive as well as to avoid taking new land under cultivation. According to the *SOLAW* report, more than one third of agricultural land is already severely or moderately affected by land degradation. Moreover, there is a mismatch between resource availability for increasing production, i.e. access to relatively arable land and reasonable quality water resources, and expected needs from the places where food-insecure and poverty-affected people live and will live in the near future. This outset provides a fundamental challenge on how to ensure food security, because the current state of resources is already degraded; particular regions at risk for soil and water resources have been identified in the highlands of East Africa, and in South and East Asia. Under current agricultural practices, this would result in an increasing demand for land of up to an additional 200 million ha by 2030 (Bindraban *et al.*, 2010) for food and feed only. This does not even consider the potential impact of people's needs for fibre, timber and fuel, which also require land.

Demographic and Social Drivers

Understanding trends in population size and associated demographics will be critical to estimating the future demand for food. A review of how reliable population projections are showed that by 2050 there will be between 8 and 10 million people, with most growth in developing countries (Lutz and Samir, 2010). Hence, there are two aspects to the driver relating to food security and demographic change at the global scale[1]. First, in order to feed approximately 9 billion people by 2050, food production has to increase (probably double, according to Molden, 2007). Secondly, as the global population increases its wealth, in terms of more income per capita, food composition will increase and change (Fig. 2.3). Higher incomes result in choices of food that appropriate more water per produced energy unit (Fig. 2.4; Lundqvist, 2006), although this depends on whether the diet is vegetarian or mixed. The change of water appropriation for various diets is well

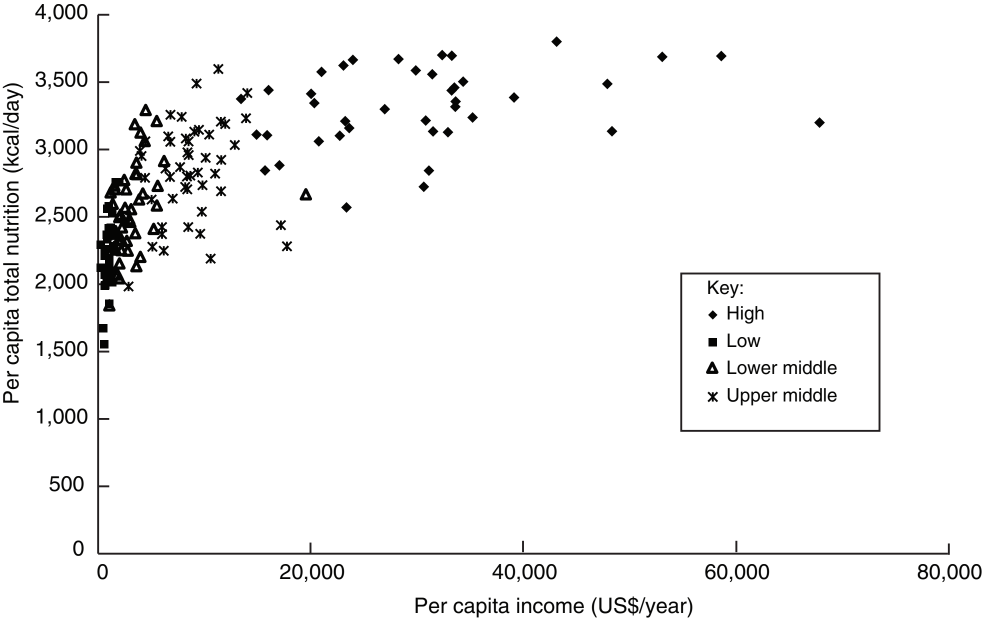

Fig. 2.3. Per capita dietary consumption (kcal/day) versus per capita income for various countries according to the World Bank classification (based on data from FAOSTATS, 2012 and World Bank, 2012).

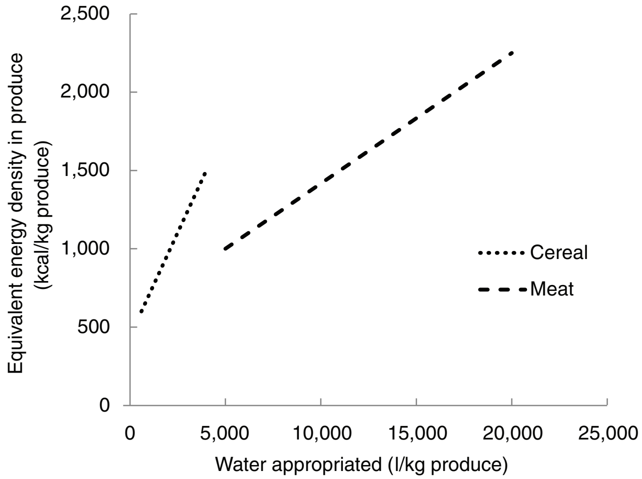

Fig. 2.4. Principal relations between water appropriated for cereal and meat energy content in food (adapted from Lundqvist *et al.,* 2007).

established (e.g. Molden, 2007; Hoekstra and Mekonnen, 2012). As increased energy is derived from animal protein, the amount of water needed to produce that energy increases. In terms of grain equivalents (GE), daily consumption generally varies from 1 to 1.5 kg GE/person for a vegetarian diet (using 1000–1500 l water) and 4 to 5 kg GE/person in wealthy societies (meat rich diet; using 4000–5000 l). Demand for aquaculture products such as fish and shrimp also continues to rise, which means further demand for freshwater resources (Bostock *et al.,* 2010; Hoanh *et al.*, 2010; FAO, 2012b). Thus, more water will be needed as populations increase wealth and consume more animal protein (Fig. 2.4). Near future changes in income for large populations in emerging (upper and lower middle income and low income) countries will have substantial impacts on the current demand for food production and food security, and the water used to produce this food (Box 2.2; see also Tilman *et al.*, 2011).

Parallel to the specific drivers of livestock production, drivers for fisheries that further push these into aquaculture have been identified by Bunting (2013). In addition to threats to freshwater habitat, there are drivers on the demand side in access to resources and in risks margins for the people whose livelihoods depend on fish. Integrated approaches at various levels are required to sustain critical ecosystem services that support fish production (UNEP, 2010).

One of the traditional and adaptive responses to environmental stress has been human migration, often undertaken in an attempt to diversify sources of income, another important demographic driver. While earlier reports suggested that climate change would be a main driver of migration, in reality, socio-economic circumstances are the key determinants (Tacoli, 2011). However, it is clear that most migration takes place south to south, rather than south to north (Tacoli, 2011). Thus, the countries and locations currently dealing with immigration and new settlements are areas that are already pressured to attain food security (Sharma, 2012).

In 2008, the world's population was split evenly between urban and rural dwellers. By 2030, there will be 1.8 billion more urban dwellers and 100 million fewer rural inhabitants (WWAP, 2009). Urbanization, projected to continue at an accelerating pace, is expected to account for 70% of the world population in 2050. As people move to cities and alter their lifestyles, urban upper and middle classes

Box 2.2. Focus: drivers of livestock systems.

Livestock production is the single largest land user globally, with grassland covering 25% of the earth's land area, and land dedicated to feed crops making up one third of the global cropped area (Herrero *et al.*, 2010). In developing countries, however, livestock feed is mainly derived from crop residues and from rangeland with low potential for cropping. Livestock production contributes 53% and 33% of the agricultural gross production in industrial and developing countries, respectively. Developing countries produce 50% of the beef, 41% of the milk, 72% of the lamb, 59% of the pork and 53% of the poultry globally. Livestock is an integral part of mixed crop–livestock systems, and these produce close to 50% of the global cereals. The importance of the livestock sector is also clear from the value of production, as milk has the highest value of production of all commodities globally, followed by rice (second) and by meat from cattle, pigs and poultry (third) (Herrero *et al.*, 2010).

Many animal food products from livestock and poultry will depend on grain as the limits to production on grazing land are reached (Peden *et al.*, 2007). Moreover, growth in the industrial pig and poultry sectors in South America and Asia will create the need for additional grain for feed: by 2050, more than 40% of global cereal use will be for feed purposes (Herrero *et al.*, 2009). Because rich countries already consume high amounts of livestock products, the growth in demand is predominantly a developing country phenomenon (Table 2.1), where approximately a billion poor people are supported by livestock.

Table 2.1. Current and projected consumption of animal products (from Herrero *et al.*, 2009).

		Annual per capita consumption		Total consumption	
Countries	Year	Meat (kg)	Milk (kg)	Meat (Mt)	Milk (Mt)
Developing	2002	28	44	137	222
	2050	44	78	326	585
Developed	2002	78	202	102	265
	2050	94	216	126	295

For poor smallholder farmers, livestock provide diverse products and services (e.g. they represent a major source of draught power) and an insurance against various shocks. Livestock are also an income source, and they provide livelihood diversification and improved nutrition. In addition to urbanization and changes in diet, other drivers also affect livestock production and illustrate how food security and consumption may drive agriculture and influence the management of agroecosystems (Table 2.2).

Table 2.2. Balancing food production, maintenance of ecosystem services and poverty reduction in livestock systems of the developing world through policy, investment and technology (adapted from Herrero *et al.*, 2009, 2010).

Drivers and pressures	Policy needs	Investment needs	Technology needs
		Agropastoral systems	
Significant rural–urban migrations, more conflicts, higher numbers of vulnerable people, increases in livestock numbers in some places, significant impacts of climate change in places, resource degradation	Frameworks for diversifying income sources, including payments for ecosystem services and others, insurance-based schemes	Roads, livestock markets, health and education establishments, development of water sources, food storage systems, telecommunications	Matching livestock breeds to the agroecosystems, livestock species changes in some places, suitable crops if required, early warning systems, mobile phone based telecommunication products, prices information and others

Table 2.2. Continued

Drivers and pressures	Policy needs	Investment needs	Technology needs
		Extensive crop–livestock systems	
Manageable increases in population density but significant rural–urban migrations, potential for increased crop and livestock production through intensification and though large impacts of climate change in some places	Policies to create incentives and an enabling environment to produce food in these regions, appropriate credit, land tenure rights, incentives for public–private partnerships, service and support institutions	Infrastructure: roads, postharvest storage systems, water sources and storage, health and education establishments, markets, development of value chains, involvement of the private sector, product processing plants, telecommunications	Crop varieties suitable for the agroecosystem, fertilizers and agricultural inputs, livestock feeds, breeding systems, livestock vaccines and health management
		Intensive crop–livestock systems	
Large increased population densities, reductions in the primary productivity of crops, water scarcity or soil fertility constraints, large increases in livestock numbers, increases in food prices, potential food insecurity, environmental degradation, increases in zoonotic and emerging diseases	Regulations for intensification/de-intensification, monitoring and evaluation frameworks for assessing environmental impacts, appropriate regulatory frameworks for global food trade	Infrastructure to support value chains – ports, railways, cold chains, processing plants, supermarkets and storage facilities; human capacity development to improve management skills	Options with high efficiency gains: more crop per drop, more crop per unit of fertilizer, species or animals with improved conversion efficiencies of feed into milk and meat
		Industrial landless systems	
Most growth in monogastric production, heavy dependence on grains as feed, expansion into areas further away from centres of demand as transport efficiency develops	Regulations for intensification/de-intensification, monitoring and evaluation frameworks for assessing environmental impacts; appropriate regulatory frameworks for global food trade	Infrastructure to support value chains – ports, railways, cold chains, processing plants, supermarkets and storage facilities	Animals with improved conversion efficiencies of feed into milk and meat, more efficient diet formulation, technologies for waste disposal

consume more energy and water-intensive diets (Kearney, 2010). Wealthier urban inhabitants are likely to consume both more calories and have higher protein diets (especially processed foods, and dairy and meat products, which have higher water requirements per calorie) than their rural counterparts (von Braun, 2007; Cirera and Masset, 2010; de Fraiture and Wichelns, 2010; Fig. 2.4).

Since the year 2000, a particular change related to demography is the increasing demand for energy from renewable resources (see also Box 8.3 in Chapter 8). The production of biofuels, particularly ethanol and biodiesel for use in the transport sector, has tripled and is projected to double again within the next decade (FAO, 2008b). This increase has been driven largely by policy support measures in the developed countries that are seeking to mitigate climate change, enhance energy security and support the agricultural sector. If the world switches predominantly from fossil fuels to the production of biofuels, this will have immense impacts on ecosystems and water availability (de Fraiture *et al.*, 2008; Bindraban *et al.*, 2009). Currently, biofuels account for 0.2% of total global energy consumption, 1.5% of total road transport fuels, 2% of global cropland, 7% of global coarse grain use and 9% of global vegetable oil use (FAO, 2008a). These shares are projected to rise over the next decade, as patterns of energy consumption shift in rural and urban areas; at present, two thirds of the world's poorest people still rely on fuelwood and charcoal as their major source of energy for heat and cooking (which represents over 40% of the wood removal from forest globally; FAO, 2006).

Climate Change

Future food, fodder and fibre production and ecosystem services will be under additional risk and uncertainty from climate change. Fundamental 'climate-related tipping points' have been proposed, which may seriously affect food security in various regions currently struggling with food security and poverty, including West Africa and South Asia (Lenton *et al.*, 2008), as well as from an increase in extreme events such as droughts and floods (IPCC, 2012). Recent studies of temperature trends confirm that warming is happening faster than anticipated and at a global scale, with extreme temperature events no longer being extreme as they occur more often (e.g. Hansen *et al.*, 2012).

Predicting the effects of global climate change is a process that is daunting in scale and uncertain at best in its application. Some ecosystems are more vulnerable to the negative effects of climate changes than others, with freshwater systems identified as being particularly vulnerable (Bates *et al.*, 2008). In certain cases, their resilience may be undermined to the extent that irreversible losses or complex shifts may occur in biodiversity and in various ecosystem services, such as the regulation of pests and water flows (Fischlin *et al.*, 2007; UNEP, 2007). Climate change is predicted to affect agriculture and forestry systems through higher temperatures, elevated carbon dioxide (CO_2) concentration, changes in precipitation and the pattern and timing of runoff, and increased pressure from weeds, pests and diseases (FAO, 2009b; Le Quesne *et al.*, 2010).

Of particular concern are the potential impacts on freshwater resources, as rainfall (or indeed snowmelt) patterns change because alterations in rainfall distribution, combined with decreases in volume, can result in significant decreases in streamflow. There are also suggestions of 'tipping point' features in hydrological systems, in which a small change potentially results in large impacts. A study of basins on the African continent modelled climate change as a reduction of 10% in annual rainfall. This might potentially result in a 25–75% decrease in streamflow in the 400–800 mm rainfall zones (de Wit and Stanckiewicz, 2006), i.e. a 'tipping point' feature in the response of streamflow with a marginal reduction of rainfall. The study also indicated a greater sensitivity of surface water availability in regions already subject to high seasonal and inter-annual rainfall and surface water availability, which applied to agriculture, society and ecosystem services. Other important features of the modelled climate change included the timing of the onset of rainy seasons, where new evidence is emerging that these – in, for example, the Sudano–Sahelian zone – are becoming less distinct with more 'false onsets' (de Wit and Stanckiewicz, 2006). Similar trends have been identified for the onset of the South Asian monsoon (e.g. Asfaq *et al.*, 2009; Washington *et al.*, 2012).

As agriculture is particularly dependent on the hydrological cycle, food production will obviously be greatly affected by changes in precipitation, streamflow, soil moisture and evapotranspiration. Local agricultural production may increase or decrease under conditions of climate change (and agriculture itself has well-established positive and negative feedbacks to climate change, see Box 2.3). Uncertainty is high for projections of rainfall patterns, and, as a result, the impact on major crop yields has been shown to vary significantly for different regions and scenarios of climate

Box 2.3. Agriculture-driven feedbacks on climate change.

Climate change is clearly a driver that will affect food and water security for the foreseeable future, albeit with a high degree of uncertainty in the precise way in which the impact will be felt for specific locations and crop and crop–livestock systems. As knowledge of its impacts increases, so should understanding also improve of the diversity and complexity of the concomitant feedback effects from agricultural food production on climate change.

For example, by recent estimates, the agricultural sector as a whole accounts for roughly 14% of global greenhouse gas (GHG) emissions, of which three quarters comes from developing countries (Parry *et al.*, 2007; FAO, 2009b). The contribution of livestock (especially cattle) production to global anthropogenic GHG emissions alone has been estimated at 18%, through methane (CH_4, 25–30%), carbon dioxide (CO_2, 30%) and nitrous oxide (N_2O, 25–30%) (Steinfeld *et al.*, 2006; O'Mara, 2011); these amount to more emissions per kilocalorie when compared with crops (for more details on emissions from livestock production systems see, e.g. Tilman *et al.*, 2001; Pelletier and Tyedmers, 2010; Bouwman *et al.*, 2011). Emissions vary both regionally and in intensity, mainly in relation to the species (monogastrics are more efficient than ruminants), the product (milk, white meats and eggs are more GHG efficient than red meat) and the productivity of the animal (the higher the productivity the lower the emissions per unit of product; see FAO, 2010). In turn, these aspects depend on feed type, quantity, quality and provenance, and on the manure management system implemented. Stored manure and wet rice cultivation also contribute CH_4 to the atmosphere (Mosier *et al.*, 1998), while excessive and inappropriate fertilizer applications result in N_2O emission (Smith and Conen, 2004; Oenema *et al.,* 2005), and CO_2 is released from microbial decay or the burning of plant and soil organic matter (Janzen, 2004).

Conversely, many agricultural and natural ecosystems serve as carbon sinks, absorbing atmospheric CO_2 and thereby potentially slowing down climate change. Overall, terrestrial ecosystems have taken up approximately 25% of anthropogenic carbon in the past century (WWAP, 2009); however, ecosystem degradation is known to be limiting such buffering capacity. For example, the world's grazing lands store 10–30% of total soil carbon (Schuman *et al.*, 2002). Sahelian rangelands are highly degraded, but with proper management they could potentially capture 0.77 t carbon/ha annually (Woomer *et al.*, 2004; see also Chapter 4). There is also increasing evidence for other feedback linkages between factors such as changes in land use and land cover, and their impacts on precipitation (e.g. Gordon *et al.*, 2010), for example, through reduction in tree cover (Makarieva *et al.*, 2010).

In addition to experience of the effects of such positively and negatively reinforcing feedback loops on climate change as a driver, there is, of course, considerable knowledge of best practices for mitigating climate effects (e.g. Metz *et al.,* 2007), with up to 70% of the potential for technical and economic mitigation coming from agriculture in developing countries (FAO, 2009b).

change (e.g. Lobell *et al*., 2008; Knox *et al*., 2011). Several projected trends will adversely affect food security in developing countries, particularly in Africa, and increase the dependency of many of these countries on food imports. It is estimated that climate change will reduce Africa's potential agricultural output by 15–30% by the 2080–2100 period (FAO, 2009b; Ericksen *et al*., 2011).

Climate change will also have a variety of effects on the water sector itself, including effects on its institutions and their inherent capability for successful adaptation (Cook *et al*., 2010). Water planners will be less able to use historical data to plan, design or operate hydrological systems; though new prediction models are under development, which will facilitate the necessary policy solutions (Molden, 2007). However, the current trend in reduced hydro-meteorological monitoring (e.g. synoptic weather stations, streamflow gauging stations) does have an impact on the availability of monitored data to ground-truth models, in addition to its effect on the generation of statistical trends of change, such as in rainfall amounts and distribution (e.g. Hannerz, 2008). With increasing variability in rainfall (amounts and events) it will be more important to store water in the soil (as soil moisture) and in the landscape (as ponds and dams) at various scales, to reduce the risk of additional crop and livestock losses through climatic extremes (Bates *et al*., 2008; McCartney and Smakhtin, 2010). As an adaptation strategy, increasing the storage of water to bridge dry spells, droughts and dry seasons may need careful consideration to maximize synergies between multiple uses of water in landscapes, such as the use of water by agriculture and ecosystems within and downstream from water storage interventions (e.g. environmental flows, see Chapter 10).

In contrast, the climate change impact on temperature is more consistently modelled in climate change scenarios. It is increasingly a concern that 'worst case scenarios' appear to be confirmed by measured global temperatures during the last decennium. Although the increase in the average temperature may benefit some areas of the globe, it is likely to have a negative effect on yields in current crop-producing areas, such as southern Africa, central Asia and Brazil (Lobell *et al.*, 2008); a higher degree of uncertainty remains for some areas. Various crops are also significantly differentially sensitive to temperature, as well as to the joint change in climate brought about by the combination of temperature increases and altered rainfall patterns (Parry *et al.*, 2007). Current outlooks for climate change suggest that it will disproportionately adversely affect sub-Saharan Africa (Ericksen *et al.*, 2011), where food production per capita is already the lowest globally (McIntyre *et al.*, 2008), and lack of food security and accessibility are recurrent problems at local and regional levels. The adequacy of forecasts is further complicated by the impacts that agriculture itself may have on climate change (Box 2.3).

Globalization of Economies and Governance

A third driver of significance for the linkages between food security, water and ecosystem services is the role that global and local markets, and also the governance of resources access and use, may play in the future. There are currently a number of economic, market-related issues that are affecting, and may in the near future have further significant impacts on, food and water security.

As a driver, global food commodity prices play an important role as producer incentives. While up to 80% of the produce of smallholder farmers is sold at local markets, these markets are not disconnected from global markets and prices. Therefore, as consumers, smallholder farmers and rural populations in developing countries are affected by price hikes, without necessarily being able to benefit from them as producers. The 2007/8 and 2010/11 worldwide price hikes on staple foods (e.g. FAO, 2012a) are examples that show how food security is affected by global drivers at multiple scales. The most recent rise in prices has driven 110 million more people into poverty, both in rural and urban areas. Over the next decades, food prices are predicted to remain at current levels (OECD and FAO, 2012; Fig. 2.5). The sudden increase in food prices that 2006/7 brought was largely unanticipated and has resulted in an increased burden on the

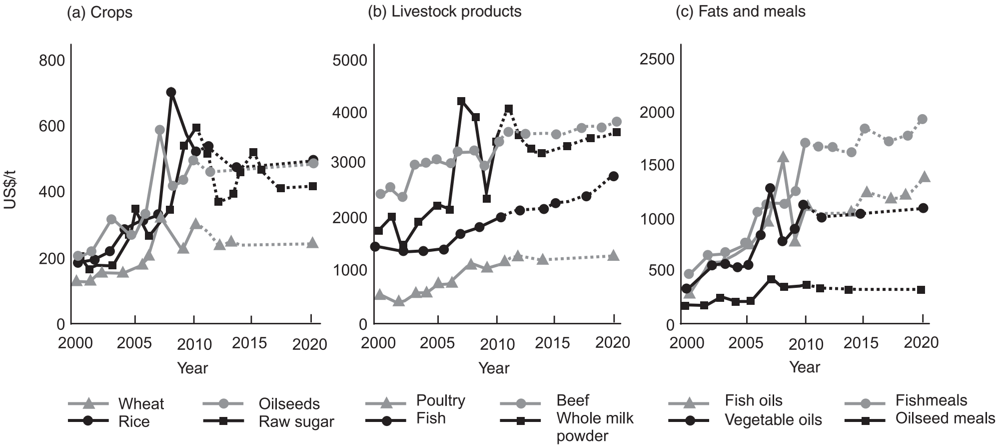

Fig. 2.5. Past actual and projected price development at global markets for (a) key crops, (b) livestock products and (c) fats and meals, for the period 2000–2020 (OECD and FAO, 2011).

poor, who already spend one half to three quarters of their income on food. Major food-producing countries have restricted exports of food to keep costs down domestically, which has raised international food prices even more. Increased food costs are likely to push governments to invest more in agricultural productivity, but this will take years to offset the current high food prices (WWAP, 2009).

There are multiple reasons for these price spikes, which are only partly explained by the agronomic conditions of food production. Increasingly, food is traded as a commodity, and thus is subject, for example, to similar financial speculations such as those for housing, metals and insurances. Some advocate that the global food commodity market is non-transparent and hence inherently flawed as market mechanisms cannot operate (e.g. Oxfam, 2011). A recent review by Huchet-Bourdon (2011) on agricultural commodities and global price volatility over the last 50 years suggests that global markets are being increasingly interconnected. Consequently, price volatility characteristics in the past cannot readily be compared with today's market conditions, where price information and commodities are being shifted much faster.

In the developing world, more than 1 billion people still rely on their own production of food for food security (IFAD, 2010), and approximately 450 million are actively engaged in farming as either self-employed or employed. On a global level, the number of people directly relying on agriculture has increased marginally from 2.2 billion in 1980 to approximately 2.6 billion today. This growth of 20% from 1980 is substantial in absolute numbers but is still far less than the 90% increase in the corresponding non-agricultural share of the population during the same time period (Fig 2.6). As a driver of change, it will be important to consider the implications of this shift, for instance with regards to local–regional availability of labour and the skill sets needed to ensure the transformation of food systems to more desirable, sustainable states in the long term.

Still, the farming community that is producing crops to ensure food security for themselves and other consumers is by far more diverse and multifaceted than are the global retailers that are transferring produce and food commodities between producers, retailers and consumers. On disaggregating cereal exporters globally, for example, it emerges that a handful of nations supply 60–80% of globally traded cereals. Similar statistics can be found for other key agricultural commodities, such as soybeans (or products thereof), cocoa, sugar, wine, and fibres such as cotton. Thus, a small group of countries

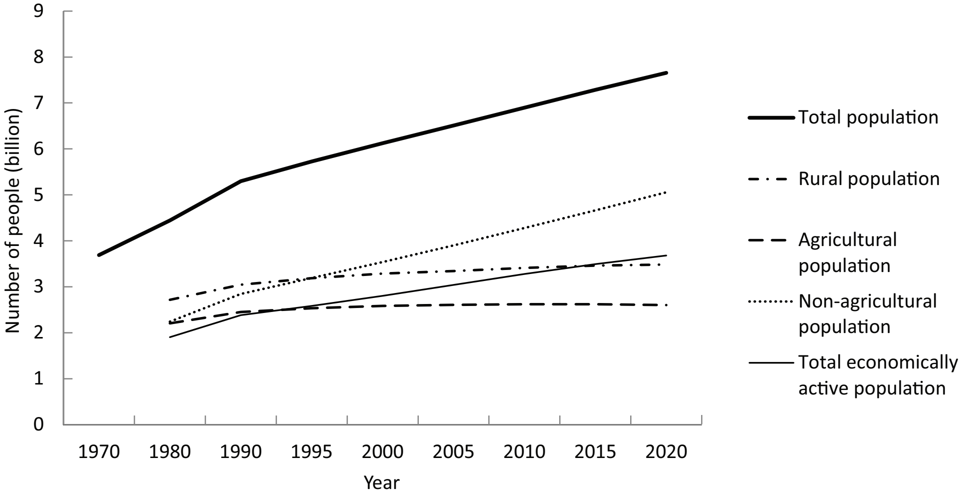

Fig. 2.6. Actual and projected total, rural and agricultural population of the world (after FAOSTAT, 2012).

constitutes a major player in food production and food security at key times and locations.

In a similar fashion, another driver of change that may be central for food security is the concentration of trade in food and agricultural commodities within a limited set of multinational corporations, traders and retailers. According to Oxfam (2011), only three major companies control 90% of global cereal trade. Yet a recent analysis by OECD and FAO (2011) of major food commodities[2] indicated that market thinness (i.e. measures of the number of actors trading) is not increasing but slightly decreasing both on the export (supply) and import (demand) sides (Liapis, 2012). The study, which used three measures of market thinness, revealed that the number of actors on the export side is in the order of 10–100, whereas major importers are in the order of 100–200. So there is a significant step up in magnitude to reach both the numbers of primary producers (2.6 billion as above) and consumers (around 7 billion globally). This concentration of trade and markets can have a significant impact on food security. Despite the study on market actors and market thinness by Liapis (2012), it is clear that the power of the markets of the major food commodities is a challenge if it is taking place within non-transparent fora. First, there is little record of the trading, volume, value of trade or actual registration of the private companies concerned. Secondly, a concentration of trade may affect the way that food is produced, including standards and quality, as well as potentially affecting choices of production systems. Both farmers and consumers may in the end be affected by this concentration in the trade and retailing of food commodities.

Governance from global to local scales is important to set the vision and pathway for the integrated, cross-sectorial management of water, food security and ecosystem services.[3] The current state of food trade is globally complex, with private and public interventions, national and international rules, regulations and subsidies affecting agriculture, food production systems and trade. While arguably as complex, presently there is a more coherent consensus on the governance of water resources (including the wide adoption of integrated water resources management, or IWRM; see Chapter 10).

As a global driver, governance principles are being put in place for sustainable water allocation for food production and security, in particular at national level and at the trans-boundary basin scale. These governance principles operate within the same space as the negotiation and accounting of other societal and infrastructure demands on the same water resources. However, there is scope for further development, in particular to account for the water needs of ecosystem services (see Chapter 10). Moreover, explicit accounting for water demands as ecosystem services is not necessarily better in countries with high development indices (Harlin, 2011). As a driver of change, the governance of water, and of land and biodiversity, will need to be taken into account in forecasting food security at local, regional or global scales. In the case of the coupled natural–human systems that are important for food production, not only do the types of social, economic and political settings (e.g. economic development, demographic trends, political stability, government resource policies, market incentives, media organization) set the stage for sustainability, but the system of governance is itself a subsystem central to the whole (Ostrom, 2009). Evidence across multiple cases suggests that there are conditions where resource users have self-organized to manage and improve resource governance towards more sustainable pathways (Ostrom, 2009). These examples can be used to inform other cases of less successful governance and development.

There is a range of sources of funding for developing food security and food production systems in currently low-producing and poverty-affected regions. Important global and local drivers of investments may be public, private or external North–South overseas development aid (ODA). Development aid to agriculture decreased by some 50% between 1980 and 2005, to an approximate 7.2 billion US$/year for bilateral and multilateral funds, even though total official development assistance increased significantly by 112% over the same period (OECD-DAC, 2010, 2011; Lowder and Carisma, 2011). This meant that the share of aid funds going to the agricultural sector fell from 17% in 1980 to 3.8% in 2006, with the same downward trend observed in national budgets. At the same time, the global commitment to address food security (MDG Target 1A) by halving the amount of hunger by 2015 is a powerful vision that still guides millions of US dollars of ODA. This reduction of North–South transfers has given an opportunity to new actors and policies of change, for example in Africa. At a continental level, the African Union commitment is to devote 10% of national gross domestic product (GDP) towards agricultural sector development in order to address food security in its respective countries (African Union, 2003). Another large driver of investment is the transfer of individual remittances, from north to south or from urban to rural. The amounts are globally of a similar order of magnitude to the total annual ODA, but there is limited synthesized knowledge on how reinvestments are made on the receiving end. Further knowledge of the source and use of investments is needed to determine how they are currently affecting food security and its linkages with water and ecosystem services.

Conclusions

The future of food security, and with it water resources and ecosystem services, is affected by a range of external drivers of change at global and local scales, often with uncertain outcomes. In this chapter, key drivers have been discussed that have potential multiple, sometimes coupled, impacts – namely, demographic change, climate change, and economic markets and governance. The purpose is to ensure that we address food security–water–ecosystem service issues in multidimensional and interconnected ways in global and local systems, as they are affected by and have impacts upon a range of drivers important for human well-being. That fundamental thresholds of the earth's biochemical cycles have been exceeded (Rockström *et al*., 2009b; Barnosky *et al*., 2012) suggests that ecosystems and ecosystem services are already in precarious states and potentially subject to undesirable tipping points. Humanity's demand for increased food, fodder and fibre is on a trajectory towards fundamental detrimental impacts on ecosystem services, at various scales, unless immediate action to reinvent and more responsibly manage our food production system is taken.

As Butchart *et al.* (2010) and others have attested, efforts to date to slow down the loss in natural capital that encompasses the biodiversity (from habitats and species to genetic diversity) and various ecosystem services that are so valuable for food security have been grossly insufficient. Moreover, Butchart *et al.* (2010) underscored the 'growing mismatch between increasing pressures and slowing responses' (Fig. 2.2).

It is all too evident that agricultural practices need to become more deliberately systemic, creating synergies between production systems and ecosystem health, and ensuring productive and resilient landscapes for multiple benefits (Molden, 2007; Gordon *et al*., 2010; Turral *et al*., 2010). Appropriate strategies, safeguards, options and technical solutions need to be developed and applied to ensure that water can provide for a wide set of ecosystem services, including agriculture, and for diversified incomes and food security in an environmentally sustainable manner. These approaches should be based upon a better understanding of the values and benefits, as well as the functioning, of ecosystems – be they terrestrial, aquatic or marine – and also of their interrelations with the quantity and quality of water.

The pressure of consumption and demand by the processing industry for certain characteristics of produce can be a major impact on production. There is great need for additional knowledge on how these drivers change agricultural production systems, and what the consequences are for water and ecosystem services at local and at aggregated global levels. The knowledge and skills to achieve change will be critical at farm and at management levels as well, so as to improve food production systems. Ultimately, multiple drivers will need to be explored in combination to identify and best characterize more sustainable agricultural productions systems. Such efforts are urgently needed to find synergistic pathways of development for addressing food security and sustainable water and ecosystems management. The future research and management of agriculture for ecosystem services and water must consider a range of drivers of change, with high or low degrees of certainty, in order to support best-bet investments and policy action.

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Notes

[1] There are other issues relating to population and food systems, in particular issues of over-consumption and obesity, as well as changing age distribution in populations. Although these are important drivers for food systems, they are not considered here, as the scope of the chapter is on food production and security related to ecosystems and water resources.

[2] The study included maize, rice, wheat, sugar (raw, refined), beef, butter, soy (bean, oil) and milk (cream, powder).

[3] A full treatment of the topic of governance as it pertains to environment and energy is beyond the scope of this book. Other factors also affect agricultural production systems and ecosystems but have not been thoroughly discussed in this chapter in order to maintain the focus on linkages with water over the entire volume. These include changes in global governance of key resources, energy price development, and advances in technologies, in production, in processing and in consumption, as well as in information technologies. The role and value of innovation in contributing to more efficient and sustainable production systems have not been addressed; nor has the value of research and the effect of improved governance in contributing to the understanding of water–food–ecosystem complexities.

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