Avoiding Future Famines:

Strengthening the Ecological Foundation of Food Security through Sustainable Food Systems

A UNEP Synthesis Report

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GLOSSARY

Abiotic components – Non-living chemical and physical components of an ecosystem responsible for the shaping of the ecosystems.

Anadromous – The migratory patterns of certain fish (salmon, smelt, shad, striped bass and sturgeon) that are born in freshwater, spend most of their lives in sea water and then return to freshwater or estuarine water to spawn.

Benthic zone – The ecological region at the lowest level of a water body such as an ocean, including the sediment surface and some sub-surface layers. Organisms living in this zone are called benthos.

Biological corridor – Also referred to as an ecological corridor or corridor of conservation, this is the designation for a continuous geographic extent of two or more ecosystems, either spatially or functionally, with the aim of restoring or conserving their connectivity.

Biotic components – The living organisms that exist in an ecosystem and are responsible for shaping it.

Bottom trawling and dredging – An industrial fishing method that involves the dragging of large heavy nets along the sea floor or midway between the floor and the surface. These fishing methods usually lead to the modification or destruction of fish habitats.

By-catch – Fish that are caught unintentionally, while intending to catch other fish. By-catches are unwanted and often unused.

Carbon sequestration – The capture and secure storage of carbon dioxide (CO_2) in order to mitigate global warming.

Close-looped multi-species systems – Farming different aquaculture species such that wastes from one species serve as feed for another.

Demersal species – An aquatic species that lives on or near the bottom of the sea or lakes.

Ecological footprint – A measure of the amount of resources required to make a product, as well as its environmental impacts.

Ecosystem services – The benefits obtainable from the complex interactions between living organisms and their environment.

Environmental flow – The quantity, quality and timing of water flows required to sustain specific valued features of a freshwater ecosystem or to protect the species of interest for fisheries and for conservation of the ecosystem on which fisheries depends.

Eutrophication – The over-fertilization of an aquatic ecosystem by inorganic nutrients (e.g. nitrate, phosphate). This may occur naturally or through human activity (e.g., from fertilizer runoff and sewage discharge). It typically promotes excessive growth of algae, which could result in the depletion of available dissolved oxygen.

Evapotranspiration – The transport of water into the atmosphere from surfaces, including soil (soil evaporation), and vegetation (transpiration).

Feed conversion ratio – A measure of the efficiency of how animals (livestock or fish) convert feed mass to body mass. It provides an indication of how much feed will be required. A low feed conversion ratio is important for profitability and reduced demand on resources.

Hydroponics – A technique for growing plants using mineral nutrient solutions without soil.

Leguminous trees – Trees that fix nitrogen in their roots.

Microclimate – The specific weather conditions of a small area within a region.

Monoculture – The cultivation of a single crop within a given area over a period of time.

No-net-loss – The no-net-loss approach strives to balance unavoidable habitat, environmental and resource losses due to economic development with compensating actions aimed at ensuring that there is no overall net loss in these resources.

Pelagic species – Aquatic species that live near the surface of coastal, ocean or lake waters.

Permaculture – The conscious design and maintenance of agriculturally productive ecosystems which have the diversity, stability, and resilience of natural ecosystems.

Re-vegetating – The process of replanting and rebuilding the soil of disturbed land.

Salinisation – The build-up of salts in soil, sometimes to levels that are toxic for plants.

Siltation – Often caused by soil erosion or sediment spill, siltation refers to the pollution of water by fine particulate materials. It results in increased accumulation of sediments in a water body.

ACRONYMS AND ABBREVIATIONS

CA	Conservation Agriculture
CBD	Convention on Biological Diversity
CFN	Centre for Food and Nutrition
EAA	Ecosystem Approach to Aquaculture
EAF	Ecosystem Approach to Fisheries
EBA	Ecosystem-Based Adaptation
FAL	Chilean Fishery and Aquaculture Law
FAO	Food and Agriculture Organization of the United Nations
FIP	Fishery Improvement Programmes/Projects
GAP	Good Agricultural Practice
GDP	Gross Domestic Product
GLASOD	Global Assessment of Soil Degradation
HLPE	High-Level Panel of Experts on Food Security and Nutrition
IAA	Integrated Agriculture-Aquaculture
IAASTD	International Assessment of Agricultural Knowledge, Science and Technology for Development
IDF	International Diabetes Federation
IFAD	International Fund for Agricultural Development
INM	Integrated Nutrient Management
IPCC	Intergovernmental Panel on Climate Change
IPM	Integrated Pest Management
ISEAL	International Social and Environmental Accreditation and Labelling
ISRIC	International Soil Reference and Information Centre
ITQs	Individual Transferable Quotas
IUCN	International Union for Conservation of Nature
IUU	Illegal, Unreported and Unregulated fishing
IWRM	Integrated Water Resources Management
LCA	Life Cycle Analysis/Assessment
MPA	Marine Protected Areas
MSC	Marine Stewardship Council
MSY	Maximum Sustained Yield
NAMAs	Nationally Appropriate Mitigation Actions
NAPAs	National Adaptation Programmes of Action
NRM	Natural Resource Management
OECD	Organisation for Economic Co-operation and Development
PES	Payments for Ecosystem Services
RFMOs	Regional Fisheries Management Organisations
SAI	Sustainable Agricultural Initiative
SDC	Sustainable Development Commission
SMEs	Small and Medium Enterprises
SRI	System of Rice Intensification
SRP	Sustainable Rice Platform
TAC	Total Allowable Catch
UNEP	United Nations Environment Programme
WFP	World Food Programme
WHO	World Health Organization
WRI	World Resources Institute

FOREWORD

If the world is to feed seven billion people, rising to over nine billion by 2050, then producing sufficient, quality food in a way that also keeps humanity's footprint within planetary boundaries will be central.

There are several factors or 'pillars' that underpin food security, including access to food and availability – but increasingly scientists are seeing the environment as perhaps the missing, underpinning fifth pillar.

The environment supports agriculture in two fundamental ways. Natural resources such as fertile land and adequate supplies of freshwater are one domain; the other is the planet's ecosystem services such as the nutrient recycling and soil stabilization provided by forests and biodiversity, including pollination services by insects such as bees.

This report – ***Avoiding Future Famines: Strengthening the Ecological Foundation of Food Security through Sustainable Food Systems*** – is the result of a unique collaboration between 12 leading scientists and experts involved in world food systems, including marine and inland fisheries.

The institutions involved include the UN Environment Programme, the International Fund for Agricultural Development, the Food and Agricultural Organization of the United Nations, the World Bank, the World Food Programme and the World Resources Institute.

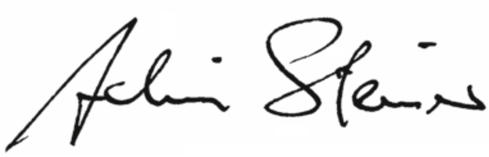
The report provides detailed analysis of the many factors threatening the world's food supplies and its ability to continue to generate calories and proteins in the 21st century. Yet it also provides a series of forward-looking recommendations and remedies to the many grim scenarios that often accompany the food security debate.

These options depart from the 'silver bullet' approach that so often reduces the food security debate to a small handful of answers: instead they embrace the complexity of food production and agricultural systems including the ecological foundation.

They include building centralized storage and cooling facilities for small-scale farmers to help them reduce food loss caused by delays in getting produce to market alongside new quality standards that can reduce food waste at the level of the retail outlet and household, especially in developed economies.

Other proposals focus on the promotion of more sustainable and healthier diets in order to counter some of the trends in increasingly affluent societies; better placement and management of agricultural systems within natural landscapes; and addressing the coastal water pollution that creates 'dead zones' and threatens some fish stocks.

The underlying message is that the security of our food supply will diminish unless we realize the central importance of the ecological foundation of the food system.



Achim Steiner
United Nations Under-Secretary-General, and
Executive Director United Nations Environment Programme

EXECUTIVE SUMMARY

1. Several different factors determine food security.

The World Food Summit defines food security as the condition when "all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food to meet their dietary needs and food preferences for an active and healthy life". The summit goes on to say that "the four pillars of food security are availability, access, utilization and stability. The nutritional dimension is integral to the concept of food security." The four pillars can be explained as:

- *Availability* - Food of adequate quality/nutrition is physically available to people.
- *Access* - Individuals can afford to purchase nutritious food supplies.
- *Utilization* - People have the ability to use food through not only an adequate diet, but also clean water, adequate sanitation and other non-food inputs to food security.
- *Stability* - The assurance that people will have access to food at all times, including during crises.

2. An important cross-cutting factor determining food security – the ecological foundation of the world's food system – is often overlooked.

While the above four pillars certainly provide a useful framework for understanding food security, there is also a vital environmental dimension of food security that underlies these other pillars. In this report we term this the "ecological foundation" of food security.

By undermining the ecological foundation of the food system we put a strain on food security in two ways:

- Firstly, we undercut the basic natural conditions needed to produce food (e.g. water, soil formation, biodiversity).
- Secondly, we produce side effects that are not sustainable (groundwater contamination, pollution of surface waters, greenhouse gas (GHG) emissions).

It is possible to almost entirely substitute the natural conditions of plant growth with artificial inputs, but over the long term, the high energy and other costs of doing so do not seem to be sustainable.

3. Both agriculture and fisheries are important to world food production and make an essential contribution to food security. Therefore the soundness of their ecological foundations is of concern to society.

Agriculture (crops and livestock) provides 90% the world's total caloric intake, world fisheries (marine, inland and aquaculture) provide the other 10%. But fish make a disproportionate contribution to global nutrition in that they provide nearly 16% of the world's total intake of animal protein, and almost 20% of average per capita intake of animal protein for more than 1.5 billion people.

Part I. Undermining the ecological basis of food security

Society is undermining the ecological foundation of its own food system

4. Science is gaining a clearer understanding of the ecological foundation of the world's food system. One way to view it is in two parts: its resource base and the ecosystem services provided by nature.

The resource base of agriculture includes the land and water available for growing crops and raising livestock. Some of the ecosystem services vital to agriculture are: soil formation and nutrient cycling, on-farm biodiversity, off-farm biodiversity, and climate conditions.

The resource base of fisheries consists primarily of the fish stock and fish habitat (inland, coastal and marine waters, and wetlands). Some of the ecosystem services upon which fisheries depend are good water quality and suitable environmental conditions, and adequate food sources.

5. There is abundant evidence that we are undermining the ecological foundation of the world food system. Some of the causes or threats are longstanding (over- fishing, agricultural practices that lead to soil erosion), but some are new or growing (climate change, coastal dead zones, competition for land between food and biofuels, competition for water between irrigation and other water use sectors).

5.1. Agriculture - Threats to its ecological foundation. Scientific studies around the world have shown that various aspects of the ecological foundation of agriculture are being undermined but up to now it has been difficult to quantify by how much and where. We do know from recent remote sensing surveys that more than 20% of cultivated lands have decreasing productivity due to degradation.

Threats to the ecological foundation of agriculture arise from many sources:

- **Competition for water -** While some experts believe that future food demands need to be met through additional irrigated land, others report that it will be difficult to meet these new irrigation water demands because of intense competition from rapidly growing domestic and industrial water withdrawals. For example, the Millennium Ecosystem Assessment projects a doubling of domestic water withdrawals in Sub-Saharan Africa, and a 20% to 90% increase in Asia, between the 1990s and the mid 21st century.
- **Competition for land –** Agriculture might expect continuing competition for land from bioenergy crops and expanding cities. Some scenarios indicate

an increase in land demands for bioenergy crops of about 0.8 to 1.7 million hectares per year between 2004 and 2030. The total surface area added during this period would be equivalent to the land area of Venezuela. Some or most of this land could compete with food production. Regarding urban areas, some experts believe that expanding cities will result in a minimal loss of farmland, whereas others estimate the loss of farmland to urban sprawl at around 1.6 million hectares per year in the early 2000s, and about 1.6–3.3 million hectares per year between 2000 and 2030.

- **Conventional agricultural practices** – Conventional practices have a variety of impacts on the ecosystem services underlying crop production. For example, monocropping leads to a reduction of on-farm biodiversity and a subsequent decrease in the resilience of crops to pests and diseases. In some cases, excessive tillage disrupts natural soil structure and promotes soil loss, including soil carbon loss. High fertilizer loading causes unsustainable impacts on the environment outside of farms, including eutrophication of surface waters and contamination of groundwater.
- **Traditional agricultural practices** – Traditional agriculture does not require the high artificial inputs (fertilizer, energy and water) of conventional agriculture, but if practised inappropriately (cultivation of steep slopes, overgrazing) it can lead to severe land degradation.
- **Deforestation and pesticide contamination** – Deforestation and pesticide contamination of lands adjacent to farmland can degrade "off-farm biodiversity", including the destruction of organisms responsible for pollination of crops or natural pest control. The Millennium Ecosystem Assessment has reported a decline in pollinators in at least one country on every continent (excluding Antarctica).
- **Climate change** – The impacts of climate change will compound the preceding threats to agriculture, generating a shift in crop-growing zones. While there will be an initial increase in crop productivity in cooler climates and an initial decrease of crop productivity in warmer climates (including poor countries in the tropics where food security is an issue), eventually crop productivity everywhere will decrease. The IPCC reported that by 2020, potential rain-fed crop yields could fall by up to 50% in some African countries (relative to an historical period).

5.2. Fisheries - Threats to its ecological foundation

The FAO estimated that, as of 2008, 53% of global marine stocks are fully exploited, 15% are either underexploited (3%) or moderately exploited (12%), while 32% of marine stocks are either overexploited (28%), depleted (3%) or are recovering from depletion (1%).

The ecological basis of **marine fisheries** is under threat from many factors.

- **Overfishing** is the foremost factor undermining the ecological basis of fisheries.
- **Loss of coastal habitats** such as coral reefs and mangrove forests is also an important factor. Approximately 35% of mangrove forests and 40% of coral reefs have been destroyed or degraded over the last decades.
- **Bottom trawling, dredging and destructive fishing practices** such as the use of dynamite and cyanide also lead to habitat loss or modification.
- **Degradation of coastal water quality** is a relatively new threat to marine fisheries. Nutrient runoff from farmland and municipalities is one of the principal causes of new areas of coastal eutrophication and zones of severely reduced dissolved oxygen and depleted aquatic life. This has decreased traditional areas of marine and migratory fish habitats. Over 400 such "dead zones" have been identified in coastal areas.
- **Climate change** will lead to warmer waters and a more acidified ocean, bringing many impacts on marine fisheries. In particular, the IPCC projects a global loss of 18% of the world's coral reefs over the next three decades due to multiple stresses compounded by climate change.

The sum of scientific studies suggests that **inland fisheries** are threatened by a range of factors. However, no overview exists of the state of inland fisheries. Such an overview is urgently needed in order to set policy priorities. Based on individual studies, the issues outlined below are presumed to be major threats.

- Infrastructure development such as dam construction in river catchments is destroying or modifying inland fishery habitats. More than 50% of the world's large rivers have been fragmented by dams on their main channel and 59% on their tributaries.
- Changing land use and removal of vegetation cover lead to increased runoff, erosion and sediment pollution of water. Human activities have increased sediment flow into rivers by about 20% worldwide.
- Agricultural expansion disrupts connectivity between floodplains and rivers – floodplains are among the most productive habitat for inland fisheries.
- Agricultural runoff and domestic and industrial wastewater discharges are degrading the quality of many inland waters. Wastewater loadings to inland waters in Africa may increase by a factor of four to eight between the 1990s and 2050.

6. Current patterns of food consumption have contributed to making the world food system unsustainable.

- As countries become wealthier, per-capita meat consumption tends to increase. In general, more resources (e.g., land and water) are required to produce meat than grains and fruits. One study indicates that 6 – 15 m^3 of water is required to produce a kilogramme of meat (poultry, lamb or grain-fed beef) compared to 0.4 – 3 m^3 for a kilogramme of cereals or citrus fruit.

- As people become more affluent, many take up poor eating habits which contributes to poor nutrition, obesity, and worsening health. The WHO reports that diseases related in part to obesity lead to the death of at least 2.8 million people each year.

The preceding section describes the direct causes of the weakening of the ecological foundation of food security, but these direct drivers are influenced by underlying driving forces such as population growth, income growth and changing lifestyles/diets linked to urbanization.

Part II. Towards sustainable food systems

Building sustainable world food systems is a means to secure the ecological foundation of food security.

7. Sustainable food systems, as part of a new Green Economy, provide an alternative to current food systems and can help secure the ecological foundation of agriculture and fisheries.

Sustainable food systems enable the production of sufficient, nutritious food, while conserving the resources that the food system depends on and lowering its environmental impacts. Such systems are based on the idea that all activities related to food (producing, processing, transporting, storing, marketing and consuming) are interconnected and interactive.

Sustainable food systems also fall within the overarching concept of a Green Economy, which has emerged recently as a new way of thinking about the economy. Through investment in sustainable practices and technologies, the Green Economy results in improved human wellbeing and social equity, while significantly reducing environmental risks and ecological scarcities. All of the following points are consistent with these concepts.

8. There are many options for achieving sustainable food systems. One general way is to promote sustainable food consumption.

Although current patterns of consumption have contributed to making the world food system unsustainable, it is likewise true that sustainable diets could help make it more sustainable. Promoting this type of diets makes an important bridge between agricultural, environmental and health policies. Sustainable diets aim to:

(i) reduce the impact of food production on resources and the environment by encouraging consumption of foods that require smaller amounts of resources than others, and
(ii) enhance the nutritious value of diets so that fewer people suffer from diseases related to malnutrition or obesity.

There is still no international agreement on the details of a sustainable diet, but most experts agree that consumers in developed countries should reduce their relative consumption of meat and dairy products and proportionately increase their consumption of vegetables and fruit products. One option would be to develop guidelines which could be tailored to different regions.

9. Another way to make the food system more sustainable is to reorient the food-supply chain.

Although significant scaling up is still needed, progress is already being made in this direction through:

(i) the application of life-cycle analysis as a tool to identify opportunities for improving resource efficiency in food-supply chains,
(ii) programmes for certification and standard-setting by public/private partnerships,
(iii) the adoption of enlightened sustainability policies by some major food manufacturers and retailers including their commitments to purchase products from environmentally friendly food producers,
(vi) policy actions aimed at promoting innovative cooperative solutions between the public, private sector, and farmers at a national and international level.

10. Food waste and loss are huge, but can be reduced at the front end (producers and distributors) and the back end (retailers and consumers) of the food supply chain.

- Globally, an estimated one-third of food produced for human consumption is lost or wasted, amounting to 1.3 billion tonnes per year.
- In developed countries, much of the food wastage (40%) occurs at the consumer and retail end.
- In the developing world, losses occur mainly in production and at the post-harvest stage. Up to 40% of food harvested might be lost due to the inadequacies of processing, storage and transport.
- There are many good options for reducing the loss of food at the front end of the food supply chain: assisting small-scale farmers to organise centralized storage, transportation, cooling and other facilities so as to reduce losses at the production and post-harvest stages; and providing training for food producers to help them abide by food safety standards so that less food needs to be thrown away.
- Likewise, there are many alternatives at the back end of the chain: increasing public awareness about the importance of not wasting food; relaxation of quality standards that do not affect the taste or safety of food such as weight, size and appearance; developing markets for sub-standard products and consumable products deemed as waste e.g., products with damaged packaging.

11. Strategies for making agriculture more sustainable cluster into two groups – those on the farm scale and those on the landscape scale.

12. On the farm-scale, many approaches have been found to be successful in lowering the impact of farming activities on natural resources and the environment.

These approaches include:

- Improving soil management and making agricultural water use more efficient.
- Increasing plant efficiency through integrated nutrient management.
- Controlling pests through integrated pest management.
- Using agroforestry techniques.
- Employing integrated livestock management.
- Improving and maintaining diversity of genetic resources.

13. Experience has shown that working on the farm-scale alone cannot achieve a sustainable agricultural system. A more successful strategy is to combine farm-scale activities with a "landscape approach", which integrates farming and non-farming activities over a larger area.

A landscape strategy is a regional planning process that aims to achieve a landscape with multiple beneficial purposes (food production, wood production, recreation and housing) and achieve positive synergies between actors and interests. A landscape approach is also a vehicle for engaging local households, communities and other stakeholders in sustainable agriculture, and for providing a long-term perspective for farming and non-farming communities. A landscape approach can lead to increased agricultural production and local livelihoods and increase resilience of agriculture to climate change.

14. There are many options for scaling up models of sustainable agriculture from the farm and landscape scale so that they can be used throughout a country. If several countries do this, sustainable agriculture will have significant impact on the world food system.

Sustainable agriculture can be scaled up by:

- Supporting farmers' and community learning, for example by educating a new generation of agricultural extension workers well-versed in the techniques of sustainable agriculture.
- Extending land tenure rights to farmers to encourage their stewardship of the landscape.
- Providing preferential access to credit for farmers willing to invest in more sustainable practices.
- Rewarding farmers and farming communities for ecosystem stewardship.
- Developing a "common vision" among stakeholders about how agriculture and food systems can be managed in a region.
- Strengthening national and international institutions, as well as private organisations, for the certification of sustainably grown farm products.

15. Economic strategies consistent with the Green Economy are also fundamental to scaling up sustainable agriculture. These strategies include:

- Scaling up investment by rationalizing export subsidies and redirecting cash flows towards agricultural investments.
- Increasing public investment in research and development to strengthen public institutional capacity.
- Encouraging the inclusion of smallholder farmers in collaborative supply-chain initiatives like certification and labelling.
- Improving access to finance for smallholders so that they can engage in sustainable agriculture practices that value the multi-functionality of agricultural landscapes.

16. Investments in sustainable agriculture will have many payoffs.

In order to enhance food security, the FAO estimates that annual agricultural investments to developing countries have to increase to around USD 209 billion by 2050. The UNEP Green Economy report found that investing 0.16% of global Gross Domestic Product (GDP) per year (USD 198 billion) in sustainable agriculture over the period 2011-2050 would lead to:

(i) improved soil quality, increased agricultural yield and reduced land and water requirements for agriculture,

(ii) an increase in GDP and the addition of up to 47 million jobs over the next 40 years compared to conventional scenarios,

(iii) transformation of agriculture from being a major greenhouse gas emitter to a net neutral and possibly a GHG sink, while reducing deforestation and freshwater use by 55% and 35% respectively.

17. The ecological foundation of marine and inland fisheries can be secured through sustainable management.

- Where technically feasible, Maximum Sustained Yields of marine fisheries should be calculated and adhered to with the help of governance and enforcement arrangements and economic incentives. Experience has shown that the allocation of fishing rights is essential to making a fishery sustainable.
- In poorer countries and for small-scale marine fisheries it may be impractical to take a Maximum Sustained Yield approach because of lack of technical and enforcement capacity. In these cases it has been shown that a co-management approach – in which fishers might agree to fish size or species limitations, seasonal closures of fisheries, or other actions – can work.
- Establish networks of Aquatic Protected Areas that provide habitat protection for fish.
- For inland fisheries, it is important to assess minimum environmental flows or flow regimes, and the minimum water quality necessary to support a vital fishery. It is equally important to identify measures to ensure that these minimum standards are met, for example by leaving some stretches of rivers impoundment-free.

- Also for inland fisheries, the approach of integrated water resources management should be applied to ensure that the needs of inland fisheries are reconciled with other legitimate user needs in a watershed.

18. Land-based pollution needs to be abated in order to maintain the water quality of inland and coastal waters and to avoid endangering fisheries in these waters.

As noted above, land-based sources of nutrients and other pollutants from farms, municipalities, and industries cause inland water pollution, which also finds its way to many coastal waters. The consequence is a reduction of fish habitat and interference with fish production. Practical steps can be taken to abate this pollution, such as:

- More efficient use of the fertilizers that are a main source of this pollution.
- Reducing soil erosion, which carries nutrients into surface waters.
- Treating municipal and industrial wastewater to remove nutrients and other contaminants from discharges to surface waters.
- Encouraging national participation in the Global Programme of Action (GPA) for the Protection of the Marine Environment from Land-based Activities.

19. Economic strategies based on Green Economy thinking can bolster the sustainability of fisheries. Action can be taken to:

- Eliminate harmful subsidies that contribute to overfishing and habitat destruction and redirect such subsidies into investment for sustainable fishery management and capacity building. Total subsidies going to the global fishery sector now amount to about USD 25-30 billion each year.
- Provide incentives for sustainable fisheries such as subsidies for conversion of fishing gear to less-damaging alternatives or for a shift from fuel-intensive fishing methods to more labour-intensive ones.
- Introduce fiscal measures such as taxation and levies on harvest volume and increase fines on illegal, unreported, and unregulated fishing to remove the economic incentive for its continuation.
- Encourage the development of market-led supply chain initiatives aimed at sustainable fisheries, such as Fishery Improvement Programmes/Projects.
- Encourage the adoption of certification and eco-labelling schemes for fish products that are in compliance with internationally agreed guidelines.

20. Aquaculture, a main source of animal protein in diets around the world, can also be made more environmentally friendly.

Fish raised by aquaculture are an important source of animal protein in the daily diets of many people, especially in Asia. But aquaculture also has major resource and environmental impacts. Aquaculture contributes to the depletion of marine fisheries because marine fish are used as feed in fish farms, and wastewater from fish farms is also a major source of water pollution.

These impacts can be reduced by:

- Minimizing the farming of carnivorous species such as salmon and shrimp, which rely on capture fisheries as a food supply.
- Informing aquaculturists about management practices for minimizing environmental impacts of aquaculture.
- Encouraging, where feasible, the integration of aquaculture with agriculture or mangrove farming, which has been shown to make an environmentally friendly combination.

21. Securing the ecological foundation of the world food system is a necessary condition for food security.

To achieve a food-secure world, we must deal with its four pillars – food availability, access, utilization and stability. But underlying these four pillars is the ecological foundation of agriculture and fisheries. This foundation must be secured in order to ensure that the food system remains productive. But the current models of agriculture and fishery exploitation, and other factors as well, threaten this foundation.

Making agriculture more sustainable on the farm- and landscape-scale and making fishery exploitation more environmentally sound through a wide range of options can solve the problem. How to achieve this? Studies have shown that investing in sustainable food systems can be greatly beneficial from the environmental, social and economic standpoint. But investment is not enough. These systems must also be built upon a strong collaboration among farmers, fishers, governments, the private sector, consumers and civil society.

It is true that hunger cannot be alleviated nor famines avoided only by making the food system environmentally sound. But neither can food be produced perpetually by eroding its ecological foundation. So a secure ecological foundation is a necessary condition for a secure food system.

Chapter 1:

Introduction

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1.1 BACKGROUND

As the world population and its food requirements have grown through the years, human ingenuity has always been able to keep pace by boosting food production. A good example is the Green Revolution, which increased production by 70 to 280%, depending on the continent, from the 1960s (Royal Society 2009). In so doing it helped meet the nutritional needs of a huge number of people, as well as lift many out of poverty (IAASTD 2009; Royal Society 2009).

But despite its accomplishments, the Green Revolution is not enough to fully ensure food security. Although food production has increased, many have been left behind, with some 925 million people still counted as undernourished as of 2010 (FAO 2010; IFRC 2011). Meanwhile, the growth in cereal productivity has been declining since the 1980s (OECD/FAO 2012), and the FAO estimates that 40% more cereal will need to be produced by 2050 to feed the nine billion people expected by that year (FAO 2009).

How then can we meet the challenge of food security? One thing we have learned is that food security is not a simple concept; it has many socio-economic dimensions, and we need to act on all of them. A sense of this broad scope is captured by the definition from the World Summit for Food Security:

Food security exists when all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food to meet their dietary needs and food preferences for an active and healthy life. The four pillars of food security are availability, access, utilization and stability. The nutritional dimension is integral to the concept of food security (WSFS 2009)

The four dimensions, or pillars as they are called here, are:

- Availability, in the sense that enough food of adequate quality/nutrition is physically available to people.
- Access, in that, individuals can afford to purchase nutritious food supplies; good nutrition is considered an essential aspect of food security.
- Utilization, meaning that people have the resources to use food through not only an adequate diet, but also clean water, adequate sanitation and other non-food inputs to food security.
- Stability, meaning the assurance that people will have access to food at all times, including during crises.

While the above four pillars provide a useful framework for understanding food security, there is also a vital *environmental* dimension of food security underlying them. In this report, we call this the ecological foundation of food security. By this we mean the natural stocks and flows that support the production of food in the world. We view this foundation as having two parts:

(i) the resource base supporting food production, and
(ii) ecosystem services provided by nature that underlie the production of food.

For agriculture, the resource base includes the land and water available for growing crops and raising livestock. Among the ecosystem services vital to agriculture are soil formation and nutrient cycling, on-farm biodiversity, off-farm biodiversity, and climate conditions.

The resource base of fisheries consists primarily of their fish stock and fish habitat (inland, coastal and marine waters, and wetlands). Some of the ecosystem services upon which fisheries depend are good water quality and other environmental conditions, and adequate food sources.

By undermining the ecological foundation of the food system we put pressure on food security in two ways. Firstly, we undercut the basic natural conditions needed to produce food (e.g. water, soil formation, biodiversity). Secondly, we produce side effects that are not sustainable (groundwater contamination, pollution of surface waters, greenhouse gas emissions).

Now, it is true that conventional agriculture has achieved the benefits of high production largely by replacing natural growing conditions with artificial external inputs. For example, erratic or absent rainfall is replaced by irrigation; nutrient cycling by fertilizer application; and the natural equilibrium between biodiversity, plant disease and plant pests by genetic uniformity and agrochemical applications. But many experts believe that the high energy, water, and other costs associated with these inputs are now unsustainable.

How do conventional farming practices draw down the ecological foundation of agriculture? We will see in this report that pressure comes from the monoculture style of crop growing, from the high loadings of fertilizer, and sometimes from excessive soil tillage.

Not only has technology allowed us to substitute for natural conditions on cropland, it has also allowed us to extract more fish each year from marine and inland fisheries. But this too may be temporary since maintaining high fish production in the face of overfishing, pollution and other stresses looks less sustainable every year. As we will see, good quality fish stocks are already greatly depleted and water pollution and other factors are reducing fish habitat in both fresh and saline waters.

Of course, these are all the immediate causes of the decline of the ecological foundation of the world food system. Underlying these causes are more profound driving forces: population growth which leads to more consumers; increased income, causing, at least initially, a larger per capita consumption of food; and increased urbanization bringing along with it a change in lifestyle and changing tastes for food.

So if the ecological foundation of the world's food system is in decline, what should we do about it? This report proposes a wide-ranging, encompassing solution called "sustainable food systems" covering agriculture and fisheries production and consumption. It is based on the concept that all activities having to do with producing, processing, transporting, storing, marketing and consuming food are interconnected and interactive as part of a giant food system. This system is global, but made up of tighter operating sub-systems at the national and local level. A sustainable food system, then, is a food system with both a short- and long-term perspective. In the short run it acts to provide enough food for all every day, and in the long run it produces and consumes food in such a way that natural capital and ecosystem services are conserved for future generations.

How to act on these big ideas? The report shows that those ready to build a sustainable agriculture system have an extensive selection of options to choose from, some geared to the individual farm and some to the landscape. And progress is being made in this direction, as indicated by the annual addition of between five and six million hectares of conservation agriculture worldwide over the last two decades. (Kassam et al. 2009; Kassam et al. 2010; Friedrich et al 2012).

Those striving for sustainable marine and inland fisheries can also draw on a large portfolio of actions ranging from control of land-based marine pollution to establishing environmental flows for rivers.

Combined progress in sustainable agriculture and fisheries can be made by pursuing the new ideas of sustainable consumption and production, in which diets are geared towards good health and minimizing one's ecological footprint. Also, food losses and wastage are reduced, and actions are taken to make the food supply chain more sustainable.

All of these solutions find a home under the banner of the Green Economy, a new way of thinking that breaks down the artificial barrier between economy and environment (UNEP 2011). Proponents of the Green Economy believe that what we usually call the environment can also be viewed as "natural capital" and an essential ingredient in providing well being for people. According to Green Economy thinking we can have a vital economy, and one that provides good livelihoods in all sectors – including agriculture, fisheries, forestry, and energy – without drawing down our natural capital and undermining the ecological foundations of our activities.

1.2 OBJECTIVES OF THE REPORT

As we have seen so far, the ecological foundation of the world food system is another important building block of food security, as is the idea of constructing sustainable food systems. But it is difficult to describe them in a few words, which brings us to the purpose of this document.

The report has two main objectives and parts:

- The first objective is to explain the significance of the ecological foundation of food security, and how this foundation is being undermined by pressures from society. That is the subject of Part I of the report.
- The second objective is to explain how to solve this dilemma by building sustainable food systems. That is the subject of Part II, which begins by discussing sustainable food consumption and production and then moves on to the problem of food loss/waste and efficiency in supply chains and finally reviews approaches for making agriculture, fisheries and aquaculture more sustainable.

It should also be noted that the aim of this document is to complement the excellent reports recently published by such institutions and organisations as the International Assessment of Agricultural Knowledge, Science and Technology for Development (IAASTD), the High-Level Panel of Experts on Food Security and Nutrition (HLPE), the UK Foresight Project on Global Food and Farming Futures, the UN Secretary General's High Level Task Force on the Global Food Security Crisis, and the Committee on World Food Security. A multitude of stakeholders are also actively trying to bring about change on the ground, including such international organisations as the Food and Agriculture Organization (FAO), the World Food Programme (WFP) the International Fund for Agricultural Development (IFAD), the World Bank, and the World Resources Institute (WRI). These organisations are also involved in this report.

These institutions and organisations, along with the authors of this report, would agree that hunger cannot be alleviated nor famines avoided by just shoring up the ecological foundation of the world food system. There is no choice but to address the basic social and economic issues having to do with the availability, access, utilization and stability of food consumption and production. But addressing these issues is also not enough. Ultimately, we will not have food to distribute unless we find a way to produce it sustainably. And producing food sustainably requires a sound ecological foundation. So let us secure the ecological foundation of the food system, and make a vital contribution to food security.

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Part 1

Challenges to the Ecological Foundation of Food Security

Chapter 2:

The Ecological Foundation of Agriculture

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2.1 INTRODUCTION

Agriculture[1] plays an important role in human development. It provides 90% of the world's total caloric intake. Besides providing food, fibre and other biomaterials, the agricultural sector also provides employment for many people, especially in developing countries where it is a major source of income for the poor. Statistics indicate that approximately 2.6 billion people rely on one form of agriculture or the other (including fisheries) for their living (IAASTD 2009).

Although the population of the world keeps increasing, agricultural productivity has very much kept pace with this growth (IAASTD 2009). However, a large proportion of the world population – 925 million in 2010 – remains undernourished (FAO 2010; IFRC 2011). This suggests a continuing challenge to design an agricultural system that can meet the nutritional needs of an increasing world population.

Current agricultural systems range from traditional small-scale subsistence agriculture involving smallholders relying on traditional knowledge and low inputs, to large-scale conventional/industrial agriculture dependent upon substantial energy, fertilizer and other inputs from the outside. Whether small scale or large, agriculture generally depends on an ecological foundation for producing food.

Advances in agriculture research and development have introduced a large set of improvements in agricultural practices. However, many of these practices have large impacts on the environment, sometimes reinforcing and enhancing the ecological foundations that support productivity, sometimes replacing them, and sometimes damaging them. Recent reports on the state of agriculture indicate that the resource base and ecosystem services needed to support global agricultural production are being seriously undermined (World Bank 2007; IAASTD 2009; Foresight 2011; The Development Fund 2010; UNEP 2011). This chapter will present many examples of how they are being undermined.

2.2 THE ECOLOGICAL FOUNDATION OF AGRICULTURAL PRODUCTION

As noted in Chapter 1, we define the ecological foundation as the natural stocks and flows that support the production of food in the world. We consider that it is made up of two main components. The first is the resource base of agriculture, which includes water and land, as covered in this report. The second component is the set of supporting ecosystem services provided by nature to agriculture. These include:

- Soil formation and nutrient recycling;
- On-farm and off-farm biodiversity;
- Climate conditions and processes.

Figure 2.1 provides a schematic of the different components of the ecological foundation of agriculture and how they support food production. Each of these components is described below.

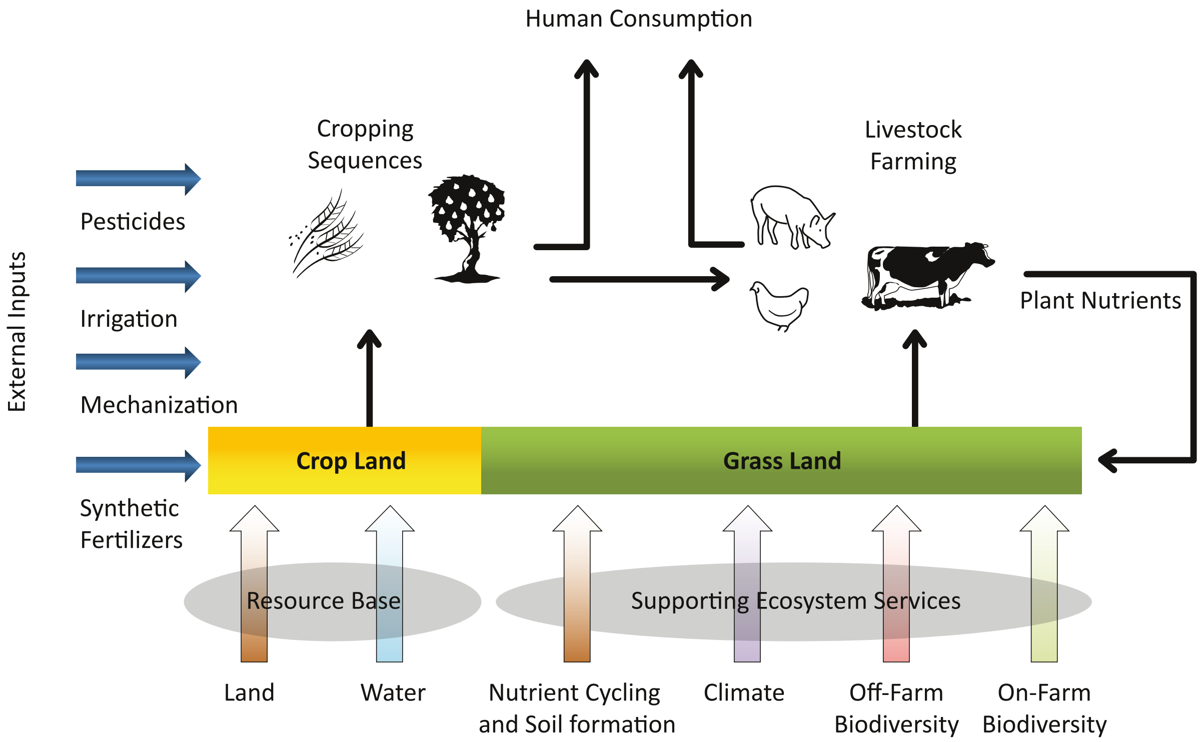

Fig 2.1. Principal resource flows and ecosystem services supporting agricultural systems

1 Although, agriculture generally refers to the cultivation of plants and animals including fish; in this chapter and Chapter 5, agriculture refers to the cultivation of only food crops and rearing of livestock, unless clearly indicated otherwise. Fisheries are discussed separately in Chapters 3 and 6.

2.2.1 The Resource Base of Agriculture

Availability of water

Water obviously plays a crucial role in agricultural productivity. Many processes affect water availability, both on the farm and in the landscape or watershed. Natural soil cover, consisting of either living plants or organic mulch, slows surface water runoff by restricting the flow of water over soils. This improves water infiltration and consequently water availability to plants.

Traditional farming systems rely on precipitation or rudimentary irrigation systems. In many cases, natural water availability has been substituted or supplemented by irrigation practices, increasing the amount of water use by agriculture. Water withdrawn for irrigation makes up about 70% of total global water withdrawals and its absolute volume is increasing steadily (UN Water 2009; FAO AQUASTAT 2011). With food demands increasing (see Chapter 4), some agricultural experts are projecting the need for increased irrigation area and water withdrawals over the coming decades (See Section 2.4.1). In the face of increasing competition from all water sectors, the agricultural sector has to demonstrate that it can produce food in a very water-efficient way.

Availability of land

Agriculture needs land as a base for plant growth. According to FAO (2003), agricultural land (arable land plus land under permanent crops) occupies 11% (1.5 billion hectares) of the globe's land surface (13.4 billion hectares) representing one-third of the land estimated to be suitable for crop production. They further reported that another 2.7 billion hectares could be brought into production. However, there are limits to the expansion (Reich et al. 2001), as this land may lack infrastructure, be partly under forest cover or include wetlands that have to be protected for environmental reasons, or the people who would exploit this land for agriculture may lack access to appropriate technology or economic incentives (FAO 2003).

2.2.2 Ecosystem Services to Agriculture

Soil formation and nutrient cycling

Agricultural productivity depends intimately on soil characteristics and functions. Natural soil fertility derives from the slow release of elements due to the alteration of deep bedrock material or from nutrient cycling. It is also dependent on organic matter, which improves soil structure and moisture and fertility retention. Soil biodiversity also enhances soil nutrient cycling. In situations where these services fail or are degraded, they become a limiting factor to agricultural productivity and are often compensated for by tillage practices, or the addition of soil amendments and/or fertilizers.

On-farm biodiversity

The variety and variability of animals, plants and micro-organisms at the genetic, species and ecosystem levels are necessary to sustain key functions of the ecosystem. For example, a diverse range of soil organisms interact with the roots of plants and trees and ensures nutrient cycling.

There is another important aspect to this on-farm biodiversity. Agricultural experts now generally accept that agricultural productivity depends on the level of complexity of an agricultural area; that is, how many different kinds of plants and animals are managed on the farm or landscape. It is also accepted that generally the more diversified the agricultural land, the more resilient it is to climatic and other disturbances, and the more it can produce relative to energy, water and other inputs. Diversity on the farm also helps maintain the genetic pools of plants and animals. Examples of diversified agricultural areas are those containing mixed livestock herds, mixed cropping, or landscapes with integrated crops, woodland and pastures.

A recent study by Kremen and Miles (2012) compared diversified farming with simpler conventional farming systems by examining 12 ecosystem services, including biodiversity, soil quality, water use efficiency, control of weeds, diseases and pests, pollination services, carbon sequestration, energy efficiency/greenhouse warming potential, resistance and resilience to climate change, and food production. The result of this study shows that diversified farming systems are capable of supporting substantially greater biodiversity, soil quality, water and energy use efficiency, carbon sequestration, and resistance and resilience to climate change than simplified farming systems. An analysis of the ecological role of biodiversity in agroecosystems by Altieri (1999) also indicates that diversified farming practices such as crop rotation, intercropping, agroforestry, and crop/livestock mixtures can help enhance functional ecosystem services in crop fields.

Moreover, even growing several varieties of the same crop within the same area reduces risks from plant diseases and pests, as well as climate and other stresses, and encourages the evolution of crops (Altieri and Nicholls 2004). In sum, there is convincing evidence that on-farm biodiversity is an essential component of the ecological foundation of agriculture (CBD 2012).

Off-farm biodiversity

The biodiversity of nature surrounding agricultural land is also crucial for productivity on the farm. For example, pests and diseases on agricultural land are kept in check partly by predators and disease-controlling organisms that have their habitats in adjacent woodlands or grasslands (Altieri and Nicholls 2004). Bees and other insect pollinators that live close to croplands contribute to the cross-fertilization of plants on agricultural land and wider ecological functions such as recycling of nutrients, regulation of microclimate and local hydrological processes, suppression of undesirable organisms, and detoxification of noxious chemicals (Altieri 1999). Trees also regulate microclimate, offering protection against winds, providing humidity, and regulating water processes.

Climate conditions and processes

The regional climate and the "microclimate" in the vicinity of growing plants are crucial to agricultural productivity. Elements such as wind, precipitation and temperature determine the productivity of crops at a particular location. Vegetation or the presence of water bodies can modify the microclimate.

Climate is probably the least substitutable among the factors that determine crop yield. Nevertheless, where potential yield is high and energy is freely available, plants are often grown in greenhouses, where temperature, humidity, water supplies and sometimes even air composition are controlled. These systems, particularly ones using hydroponics and supplementary lighting, represent the extreme of replacing local ecosystem services with external inputs to produce food.

2.3 CURRENT STATUS OF AGRICULTURAL SYSTEMS

2.3.1 Conventional Agriculture

Monocultures and intensive industrial farming systems are the result of classic agronomic thinking. These systems, geared for the delivery of high economic returns, are in a way simple to manage. They dominate in the developed countries as a result of their unique focus on the provision of commercial commodities.

Natural processes in the fields are generally substituted by practices reliant on external inputs, mainly energy, agrochemicals and fertilizers. Mechanized tillage substitutes for soil processes and fertilizers replenish the main nutrients lost during the production process. Water provided by irrigation systems compensates for erratic or insufficient rain. Standardized seeds reduce biodiversity to a minimum, simplifying agronomic practices and reducing unwanted natural variability. Chemicals are used to control pests and, in some extreme cases, artificial pollination methods are used as a substitute for natural pollinators. These food production systems have become heavily dependent on farmers' continuous investment in energy intensive machinery and fertilizer inputs (Tilman et al. 2002; Woods et al. 2007).

Various authors including Giampietro and Pimentel (1994); Ikerd (1994); Schiere and Grasman (1997); Bringezu and Bleischwitz (2009); and Altieri et al (2012) have reported that the sustainability of current agricultural and food systems is seriously compromised because of increasing reliance on non-renewable resources. For example, as a rough estimate, 100 calories of externally provided energy (mainly fossil fuels) are needed to produce 10 food calories in the US food system (Giampietro and Pimentel 1994). Some of these authors have also noted that a transformation to a more sustainable agriculture would be desirable, along the lines of what is described in the next section and Chapter 5.

Soil erosion has been reported to be higher in conventional agricultural systems involving intensive soil tillage than in soil subjected to conservative practices such as the no-till method (Montgomery 2007). Examples cited in this paper indicate that no-till practices reduce soil erosion by 2.5 to more than 1000 times (with median and mean values of 20 and 488 times respectively) as compared to conventional tillage practices. Soil erosion is a major contributor to land degradation. It is estimated that 24% of world's total land area and 20% of its croplands are losing productivity (see section 2.4.3 for more details) (Bai et al. 2008).

Conventional agricultural systems are also less resilient to external shocks due to long-term depletion of soil fertility and strong reliance on monocropping (Altieri 2009).

2.3.2 Traditional Smallholder Farming Systems

Traditional farming has been used for several generations to supply the nutritional and material needs of its producers. These systems represent the accumulated experience of farmers interacting with their environment using inventive self-reliance, experiential knowledge, and locally available resources. They are highly complex systems, focused on risk reduction and characterized by year-round vegetative cover, low levels of inputs and maximisation of energy yields. Because of their low inputs, they tend to be more environmentally friendly than conventional agriculture. Altieri and Koohafkhan (2008) reported that these systems cover around 60.5 and 193 million hectares of land in Latin America and China respectively. It is estimated that small farms occupy around 155 million hectares of land in South Asia as of year 2005 (Hazell 2011).

There are more than 1.4 billion traditional smallholder farmers and they usually belong to one of the lowest income categories in the country where they live. They are amongst the most vulnerable social groups, but at the same time they produce the bulk of the food in developing countries (Koohafkhan 2011). For example, Africa's 33 million small farms represent 80% of farms in the continent and produce a majority of grains and legumes and almost all root, tuber and plantain crops (Altieri and Koohafkhan 2008).

Since traditional systems rely on the carrying capacity of ecosystems, they are highly vulnerable to increased pressures such as population growth, economic cycles and climate change. Although traditional agriculture tends to be more environmentally sensitive than conventional agriculture, if practised inappropriately (e.g., overgrazing, leaving inadequate fallow periods or cultivating on steep slopes), it can lead to land degradation and/or suboptimal yields.

Traditional agriculture has limited scope for mechanization because many smallholders' plots are too small to realise the economies of scale required for most commercial farm machinery. In addition, the high cost of purchased inputs such as chemical fertilizers generally requires that at least some portion of the crops produced must be sold to recover costs (UNEP 2011).

2.3.3 Sustainable Agriculture/Agroecology

Under this category falls a wide range of practices and approaches aiming at intensifying production through enhancing natural supporting processes. There are many terms to describe these systems: synergic agriculture, permaculture, eco-agriculture, conservation agriculture, organic farming. According to this model, agriculture can be intensive, but also multifunctional (IAASTD 2009) in that it should produce different products on the same farm or over a wider landscape. Also, according to this model, farming should rely more on internal water and nutrient availability and less on external

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inputs of these and other resources. Under this approach, it is not unreasonable to expect farm level productivity to increase relative to conventional agriculture, especially in developing countries where the potential for increasing yields is large. A study of nearly 300 agriculture projects covering 37 million hectares in poor countries documented an average yield increase of 79%, substantial carbon sequestration, more-efficient water use, reduced pesticide use, and increased ecosystem services as a result of resource-conserving practices (Pretty et al. 2005). Another study found that agroecology practices (see Chapter 5) enhanced both species richness and abundance in a variety of agricultural landscapes (Batáry et al. 2011). Yet another study found that high biodiversity is compatible with high yields (Clough et al. 2011).

There is evidence that diversified agriculture will also be more resilient to climate change (PAR 2010) and have a high mitigation potential (Altieri et al. 2012). A report by the UN Special Rapporteur on the Right to Food (De Schutter 2011) indicates that agroecology systems are more resilient to extreme weather events such as flood, drought, hurricanes and landslides due to improved soil filtration, less soil erosion, greater crop diversity and the incorporation of trees, mulch and terraces which could serve as barriers. The report also indicated that improved diversity of species can protect against the invasion of new pests, weeds and diseases that could likely stem from global warming. In terms of mitigation, agroecology practices reduce greenhouse gas emissions by reducing the amount of fossil fuel inputs and greenhouse gas emissions relative to conventional agriculture and by improving the ability of the soil to serve as a carbon sink through improved soil organic matter. Lal (2011) reported that systems based on agroecology could potentially sequester 1.2–3.1 billion tonnes of atmospheric carbon per year, as well as increase yield of grain and root crops by between 30 and 42 million tonnes per year in developing countries.

In the last two decades, cropland under conservation farming (CA) (see Chapter 5) has increased by between five and six million hectares annually throughout the world (Kassam et al. 2009; Kassam et al. 2010; Friedrich et al. 2012), and has been adopted by both large commercial and small-scale farmers, with yields 20 to 120% higher than with conventional cultivation (ACT 2009; Derpsch et al. 2010; FAO 2010). CA is now used on about 106 to 117 million hectares across all continents, in many different agricultural ecologies (Kassam et al. 2009; Kassam et al. 2010; Friedrich et al. 2012).

2.4 UNDERMINING THE ECOLOGICAL FOUNDATION OF AGRICULTURE

We have seen in Section 2.2 that the ecological foundation of agricultural food production generally depends on its resource base and several ecosystem services. To recapitulate, two important components of its resource base are water and land and key ecosystem services include nutrient cycling and soil formation, on-farm biodiversity, off-farm biodiversity, and climate conditions. We have also seen that these are all under pressure to a varying degree throughout the world. In this section we look more closely at some of the driving forces of this pressure (Table 2.1), beginning with pressures on water and land.

2.4.1 Undermining the Resource Base of Agriculture

Pressure on water needed for agriculture

For millennia, society has supplemented the supply of rainfall for crops with irrigated water. Irrigation has always made and continues to make a substantial contribution to world food production, as confirmed by the often-repeated statistic that irrigated land makes up just 20% of the world's cultivated land but produces about 40% of the world's food (FAO 2007; UN Water 2009). Irrigation will have an increased role in meeting future food demands. The FAO has estimated that developing countries are likely to expand their irrigated area from 202 million hectares in 1997/99 to 242 million hectares by 2030 (FAO 2003), with water withdrawals for irrigation potentially increasing by 12% in 2025 relative to 1995, with Latin America and sub-Saharan Africa having the highest growth of 21 and 27% respectively (Rosegrant et al. 2002). The Millennium Ecosystem Assessment (MA 2005) gives an increase in total global irrigated area of up to 21 million hectares between 1997 and 2050, depending on scenario assumptions, with decreasing trends in developed countries exceeded by increasing trends in developing countries.

Table 2.1 Drivers of change to ecological foundation of agriculture

	Drivers	Impacts on Agroecosystem	Impact on food production	Implications for food security
Pressure on the resource base	Reduced water availability and competition for available water.	Reduced provisioning of water to agriculture (if increased water withdrawals are not an option).	Limitation to expansion of irrigated agriculture.	Expansion in supply from key cropping regions reduced, especially in arid areas.
	Competition for land from other land uses.	Restricted or reduced amount of land available for agriculture (if expansion into natural ecosystems is not an option).	Possible slower growth in food production due to diminished crop land surface.	Rapid reallocation of food resources and impact on trade. Higher food prices in short term.
Pressure on key ecosystem services to agriculture	On-farm practices: • Monocropping, excessive tillage, high quantities of inputs (pesticides and fertilizers). • Inappropriate agricultural practices (cultivation on steep slopes, overgrazing, and improper drainage).	Soil degradation: • water erosion, wind erosion, chemical deterioration (e.g. loss of nutrients or organic matter; salinisation; acidification; pollution); physical deterioration (compaction, sealing and crusting; water-logging; lowering of water table; subsidence of organic soils); disruption of soil microbiology. • Reduction of on-farm biodiversity. • Reduced water availability.	• "Sub-optimum" or decrease in crop yield and grassland productivity. • Some areas seriously constrained due to erosion or salinisation.	Higher costs to perform agriculture and in the long term, environmental problems lead to restrictions on agriculture. Depletion of phosphorus inputs may be a long term threat to production. Price rises will increase difficulties for most vulnerable groups.
	Landscape practices (Deforestation, pollution and removal of natural and semi-natural habitats).	Reductions of habitats of organisms that perform natural control of crop pests. Reduction in pollinators. Local micro-climate changed due to lack of trees.	Increased costs for increased use of agrochemicals. Reduction in yields especially for vegetable cash crops.	Maintaining crop yields involves greater costs.
	Changing climate conditions including: • Change in precipitation patterns. • Warmer temperatures. • Change in frequency of occurrence of extreme climate events.	Shifts in crop growing zones. Initial increase in crop productivity in cooler climates. Initial decrease in crop productivity in warmer climates. Eventual decrease in crop productivity throughout most agricultural areas.	Changes in potential crop and grassland production. Changes in crop suitability for particular regions.	Adaptation needed or possible reduction in food supply.

But these projections may be difficult to realise because new irrigation areas will have to compete more strongly with households and industries for additional water supplies (Cassman et al. 2005). For example, according to the Millennium Ecosystem Assessment scenarios (MA 2005), domestic water use is projected to double between 1997 and 2050 in sub-Saharan Africa, and grow by 20 to 90% in Asia, depending on scenario assumptions. Large increases are also projected for industrial water use. Irrigation projects also have to contend with new limits on how much they can withdraw from rivers based on new targets for maintaining a minimum amount of flow in rivers to sustain ecosystems (WWAP 2009).

Another indication of the increasing competition for water is the projection of the increasing number of people living in river basins under severe water stress. The Millennium Ecosystem Assessment projects a possible increase from 2.3 to 4.9-5.5 billion between 1995 and 2050[2], while the World Water Assessment Programme indicates that 90% of the three billion people to be added to the population by 2050 may live in regions already experiencing significant water stress (WWAP 2012). Where these billions live, the irrigation sector should expect increasingly vigorous competition for water resources from other sectors.

Climate change will further sharpen the competition for water in many river basins. One study found that the combined effect of projected climate change and increasing water use (between

2 The Millennium Ecosystem Assessment figures are based on a combination of population increase, per capita increase in domestic and industrial water use, and decreases in water availability in some regions due to climate change.

the 1950s and 2050s) could elevate the water stress in up to three-quarters of the river basin areas of the world (Alcamo et al. 2007a).

Hence, while some experts believe that future food demands must be met by additional irrigated land, the water supply for this and current irrigated cropland is coming under increasing pressure from climate change and competing water use. It is difficult to say exactly where and to what degree the competition for water will limit the expansion of irrigation[3], although it seems almost certain that this competition will intensify on a large scale.

Furthermore, the nexus between water, food and energy should be recognised: irrigation requires energy just as other agricultural practices. At the same time, water is a critical input to energy production, although impacts on water availability and quality vary with energy sources and production methods (UNEP/Oeko Institut/IEA Bioenergy 2011).

Pressure on land available for agriculture

Another threat to agriculture comes from land uses that compete with agricultural land. Here we focus on two types of land use most often cited in this regard – cropland for bioenergy and urban areas.

As is well known, there has been a steady increase in the production of bioenergy crops for gaseous, liquid and solid fuels, motivated largely by aspirations of energy security and reducing greenhouse gas emissions.[4] Between 2000 and 2007, for example, world production of bioethanol for transport fuels grew from 17 billion to more than 52 billion litres, and biodiesel production from less than one billion to almost 11 billion litres (UNEP 2009). By early 2012, at least 46 countries at the national level and 26 states and provinces had enacted biofuel blending mandates (REN21 2012).

The main issue here is whether land devoted to bioenergy production competes, or will compete, with food production. There already seems to be competition between using maize for either food, feed, or biofuels (Banse et al. 2008; OFID 2009). Some observers believe that the sharp food price surges that occurred in 2007/2008, which made food purchasing more difficult for the poor, were evidence of bioenergy crops competing with food crops (Alexandratos 2008; Babcock 2011). One estimate from the International Energy Agency and FAO is that the total area devoted to bioenergy crops could grow from about 13.8 million hectares in 2004 to between 34.5 and 58.5 million hectares in 2030, depending on scenario assumptions (FAO 2008). This amounts to an increase of roughly 0.8 to 1.7 million hectares per year up to 2030[5] - the surface area added during this period would be equivalent to the land area of Venezuela. According to Lambin and Meyfroidt (2011), biofuel production will require an increase of between 1.5 and 3.9 million hectares of land per year in order to meet current policy mandates of petroleum substitution. These figures may not seem important compared to the 1,560 million hectares of land available for cropland expansion (OECD/FAO 2009), but there is evidence that bioenergy crops compete with staple crops for prime farmland (Howarth and Bringezu 2009). Considering population, consumption and other global trends, it is possible that the competition between bioenergy and food crops could intensify. This provides a great incentive to develop more efficient ways of producing and using bioenergy, e.g., using wastes and residues as feedstock or combining food and energy systems (UNEP 2009; UN Energy 2010).

Expanding cities also put pressure on food production, although there are two viewpoints about the extent of this threat. One argues that the threat from cities is marginal. Since urban land only makes up between 0.2 and 2.4% of terrestrial land surface as of year 2000 (World Bank 2005; Potere and Schneider 2007), it is argued that an extension of this relatively small surface cannot pose a threat to arable land which occupies 11% of the world's land surface (World Bank 2005). In addition, a declining proportion of land used for agriculture around a city may be accompanied by more intensive production for land that remains in agriculture (Satterthwaite 2010).

An opposing viewpoint is that a disproportionate amount of global food production (15-20%) occurs in areas adjacent to cities (UNEP 2009a), suggesting that cities may have an over-proportional impact on displacing agriculture.[6] Further support for this belief comes from an FAO paper which estimates a global annual rate of urban expansion for the year 2000 of around 20,000 km^2. Eighty percent of this expansion is assumed to occur on agricultural land, giving an annual loss of agricultural land to cities of around 1.6 million hectares (FAO 2006). These estimates are consistent with the scenarios of Lambin and Meyfroidt (2011), who project an annual loss of agricultural land to cities of about 1.6–3.3 million hectares between 2000 and 2030.

Yet another estimate is that cities will grow by 2.5 times in area by 2030, covering some 100 million hectares or 1.1% of the total land area of countries, with a possibility of extending into as much as 5-7% of total arable land (World Bank 2005).

2.4.2 Impacts of Agricultural Practices on Ecosystem Services to Agriculture

Now that we have examined pressures on the water and land agriculture depends on, we shift our attention to the ecosystem services that are part of the ecological foundation of agriculture.

In Section 2.3, we described how modern farming systems achieve high yields through mechanization and high inputs of energy, fertilizer, pesticides, and in some cases irrigation

3 For an appreciation of the many factors that will affect the feasibility of irrigated area expansion, see, World Bank (2003).

4 However, the effectiveness of bioenergy in reducing emissions as compared to fossil fuels is not always clear, and depends strongly on the type of bioenergy crop, the circumstances under which they are grown, the process by which they are converted to usable fuels, and the way in which these fuels are then used. UNEP (2009), for example noted that ethanol derived from sugar cane achieved greater net reductions of greenhouse gas emissions than palm biodiesel derived from palm oil.

5 This range of figures reflects assumptions about future energy demand, the percentage of energy supplies to be delivered by biofuels, the type of bioenergy crops cultivated and processed, and other factors.

6 However UNEP (2009a) points out that there is great uncertainty associated with this 15-20% figure.

water. This style of agriculture obviously departs from natural conditions at crop sites, and thereby inevitably alters the natural level of nutrient cycling, soil formation and other processes. Furthermore, in some parts of the world traditional agriculture has taken on unsustainable practices such as overgrazing pastures or planting on erodible slopes because of population pressures or a break-down in cultural traditions. In sum, these practices have undermined the ecological foundation of agriculture.

Fertilizer loading alters the cycling of nutrients

A characteristic of modern agriculture is the intensive use of fertilizers that supplement the nutrients available to plants from internal cycling within soils. Overall, the global annual consumption of fertilizers providing the three major nutrients (nitrogen, phosphorus, and potassium) has approached 164.4 million metric tonnes; 105 for nitrogen, 37.9 for phosphorus and 21.5 for potash (VFRC 2012).

Without the addition of fertilizer, a relatively small amount of nitrogen available for plant nutrition is synthesized by a microbiological process at the level of the roots. Very little leaves the plant zone and instead it is "recycled" within plants and between soil and plants. But under annual cropping systems, with external nitrogen inputs, substantial nitrogen losses occur (up to two thirds in wetland rice) and impose an unsustainable burden on other aspects of the environment. These losses occur because plants on average only take up a small fraction of applied nitrogen fertilizer, which means that nitrogen leaches out of the crop soil zone and escapes into the atmosphere and water environment.

The impacts of nitrogen escaping from the plant zone include the following:

- Nitrogen loadings from agriculture often cause contamination of groundwater and bioaccumulate in the food chain (UNEP 2007).
- A large fraction of applied nitrogen ends up being released to the atmosphere in the form of nitrous oxide, a powerful greenhouse gas which makes a substantial contribution to global warming (8% of total global greenhouse gas emissions). Agriculture accounted for about 60% of global nitrous oxide emissions from anthropogenic sources in 2005 (Barker et al. 2007).
- A large amount of the escaped nitrogen finds its way to surface waters where it contributes to eutrophication (over-fertilization) of rivers and lakes. This process is characterized by extreme growths of algae sometimes causing the depletion of dissolved oxygen resources of natural waters. Some of this escaped nitrogen also finds its way to the coastal zone where it is thought to be one of the causes of eutrophication and depletion of dissolved oxygen over large coastal areas around the world. These "dead zones" pose a threat to the marine fishery (See Section 3.2.5 of Chapter 3).

Reliance on large phosphorus inputs poses its own risks. As with nitrogen, only a fraction of the applied phosphorus is taken up by plants and the rest finds its way into natural waters where it also contributes to eutrophication and associated algae blooms and the appearance of coastal dead zones (MA 2005). Moreover, there is some uncertainty about the lifetime of phosphorus mineral reserves upon which fertilizer supplies depend. UNEP (2011) has pointed out that the known supply of cheap, high-grade reserves is becoming increasingly limited while phosphorus fertilizer demand continues to increase. But UNEP has also pointed out that there is a lack of agreement on how long economic reserves of mineral phosphorus will last, with some experts projecting a lifetime of 300-400 years and others a few decades which would lead to a peak production of mineral phosphorus already between 2030 and 2040. But the fertilizer industry is well aware of these problems. New technologies are being developed to optimize plant uptake over time and to improve the efficiency in the processing phase[7], but it is not clear that these technologies will be affordable to small-scale farmers in developing countries.

Of course, we have to keep in mind that these high nitrogen and phosphorus inputs have enabled high crop yields from land that would otherwise have low productivity, and this certainly has contributed to food security. But the point is made in Chapter 5 that it is possible to enhance the input of nutrients to soils and achieve high yields in a sustainable fashion, without disrupting the cycling of nitrogen, phosphorus, and other nutrients in the soil.

Excessive tillage compacts soil and inhibits soil formation

Excessive tillage often leads to physical degradation of soils, destroying the natural soil structure. It also leads to more than needed aeration of soils which causes the mineralization of organic matter and finally reduced soil biodiversity. This process hampers the natural nutrient recycling processes and makes the soil dependent on external inputs. Deep tillage on vulnerable soils, typical in arid regions, can also expose layers with high concentrations of salts, greatly increasing the risk of soil salinization.

Conventional tillage also buries the soil cover that protects the surface from the erosive effect of water, leading to erosion and eventually land degradation, as seen in Section 2.3.1, and further discussed below.

Monoculture reduces needed on-farm biodiversity

In Section 2.2.2 we described the evidence that on-farm biodiversity, i.e. a diversity of crops and vegetation on a farm, tends to mitigate crop diseases as compared to planting fewer or single crops. The Millennium Ecosystem Assessment (Cassman et al. 2005) cites examples where mixed planting of resistant varieties of crops with other varieties of crops has reduced the incidence of wheat mosaic virus, fungal pathogens of sorghum and rice blast across the whole crop. The same reference points out that monoculture, tillage, pesticide use and other facets of modern agriculture often tend to have negative effects on the diversity of soil organisms which play an important role in nutrient cycling, in regulating the dynamics of soil formation and decomposition, and in sequestering carbon.

7 4 barrels of oil energy equivalent are required to synthesize 1 tonne of urea

Pollution and deforestation impacts on off-farm biodiversity

In Section 2.2.2 we explained that the ecological foundation of agriculture depends on a healthy natural biodiversity in areas adjacent to agricultural lands because organisms living there are needed to provide services to agriculture. For example, bees and other insects living in nearby woodlands and grasslands are needed for pollinating crops. Also, various other organisms living there provide natural pest control. In this respect it can be said that natural biodiversity outside the boundaries of cultivated land provides important services to crops. According to the Millennium Ecosystem Assessment (MA 2005), a decline in pollinators has been reported in at least one country or region on each continent (outside of Antarctica, which has no pollinators). They also noted that declines in pollinators have rarely caused a complete failure to produce seed or fruit but more often resulted in fruits of reduced viability or quantity.

It is also known that the services provided by off-farm biodiversity to agriculture are sometimes undermined by pesticides applied to crops that find their way into adjacent fields and woodlands and destroy pollinators or the organisms responsible for natural control of crop pests or diseases. The habitat of these helpful organisms is also destroyed by deforestation of lands adjacent to croplands.

2.4.3. Aggregate Impacts of Agricultural Practices: Land Degradation

We have discussed different individual factors that lead to pressure on the ecosystem services underlying agriculture such as nutrient cycling and soil formation. It is a fact that in many parts of the world these pressures become so severe that they result in large-scale land degradation, a catch-all phrase meaning the serious loss of land productivity. Land degradation can also be defined as "long-term decline in ecosystem function, measured in terms of net primary productivity" (Bai et al. 2008), which emphasises its dynamic nature. Two things should be noted here: first, since soil degradation is a process, it may be clearer to refer to "degrading" land rather than "degraded" land. Second, degrading land according to this definition may still produce food, but at a declining rate.

What is the extent of degrading land? A recent ISRIC survey using remote sensing found that almost one fifth of cropland is degrading (Bai et al. 2008), and that about "1.5 billion people depend directly on the degrading areas." To keep this in perspective, the survey also found that around 20% of total croplands showed improved productivity (but with no statement as to the sustainability of this improvement). Nevertheless, the area with improving productivity does not necessarily compensate for the large cropland areas losing their productivity since it was also indicated that much of the degrading area occurs where food security is an issue such as Africa south of the Equator (13% of global degrading area), and Indo-China, Myanmar, Malaysia and Indonesia (6% of the global degrading area)[8]. As highlighted in the above statistics, the problem of soil degradation is particularly severe in Africa, where soils are inherently low in organic carbon, limiting their capacity to hold water and nutrients. Henao and Baanante (2006) reported that 85% of African farmland had nutrient mining rates[9] of more than 30 kg per hectare of nutrient yearly, and 40% had rates greater than 60 kg per hectare yearly during the 2002-2004 cropping season, and over 95 million hectares of land have been degraded to the point of greatly reduced productivity.

What is behind land degradation? The processes involved include some of those described in previous paragraphs as well as many others. The classic Global Assessment of Soil Deterioration study (Oldeman et al. 1991) classified the different components of land degradation as water erosion (loss of topsoil, land mass movements); wind erosion (loss of topsoil); chemical deterioration (loss of nutrients or organic matter; salinisation; acidification; pollution); physical deterioration (compaction, sealing and crusting; water-logging; lowering of water table; subsidence of organic soils); and degradation of biological activity.

Credit: Christian Lambrechts

8 Note that these statistics also include degrading woodland and forest areas.
9 Soil nutrient mining refers to the deterioration in the physical, chemical and biological properties of soils due to the lowering of soil organic matter and loss of nutrients.

As has been mentioned previously, many processes contribute to land degradation, such as cultivation on steep slopes with fragile soils and inadequate vegetative cover (often in combination with erratic and erosive rainfall patterns), declining use of fallow, limited recycling of dung and crop residues to the soil, limited application of external sources of plant nutrients, deforestation and overgrazing (Stocking and Murnaghan 2001). The FAO points to "overexploitation of vegetation for domestic use (fuelwood, domestic timber)" as an important factor in the Sahel, western Argentina, Iran and Pakistan; and biological degradation caused by industrial pollution (e.g. toxic wastes, acid rainfall) in some European countries. The FAO (2010) also notes that overgrazing is the principal proximate cause in most dryland areas, including the Sahel, as well as many parts of Central Asia, Argentina, and in drylands of developed countries including Australia and Western United States.

Underlying these proximate causes are background driving forces (Fitsum et al. 2002) such as population pressure, poverty, high cost and limited access to agricultural inputs and credit, low profitability of agricultural production of many conservation practices, high risks facing farmers, fragmented land holdings and insecure land tenure, short time horizons of farmers, and many other factors.

The consequences of land degradation are reduced land productivity, socio-economic problems including uncertainty in food security, migration, limited development and damage to ecosystems (run-off and pollution of marine environments). Degraded land is costly to reclaim and, if severely degraded, may not recover enough to provide the range of ecosystem functions and services that are critical for society and development. On the positive side, in areas where very little natural habitat remains, degraded land taken out of production can play a valuable role as a refuge for wild plants and animals.

2.4.4 The Influence of Climate Change

On top of all the previous pressures on the ecological foundations of agriculture comes climate change. Long-term trends of warmer temperatures and changing precipitation patterns alter crop and grassland productivity by modifying the conditions for evapotranspiration of crops, and in some cases by making conditions more favourable for pests and diseases. Changing climate alters the suitability of crops for different areas and will lead to shifts in crop zones, as in the case of wheat being grown further north in the Northern Hemisphere. Changing patterns of extreme climate events will also dramatically affect agriculture: more- or less-frequent floods will change how often crops are inundated, while a changing frequency of droughts and heat stress will obviously affect food production.

It is important to understand that the sum of studies suggest that moderate increases in local temperature (1 to 3°C) are likely to lead to more favourable conditions on the average for cereal production and pasture yields in high and middle latitudes (IPCC 2007). But this does not take into account the impacts of a possible increase in extreme climate events. For example, while it was found that changes to climate may boost average crop production in many areas of Russia, at the same time an increased frequency of drought may triple the frequency of "food production shortfalls" in key crop-growing regions by the 2070s (relative to a "climate normal" period) (Alcamo et al. 2007b). Overall, an increased frequency of heat stress, droughts, floods, and pest outbreaks will make conditions for crop growth more difficult in many regions, especially in "subsistence sectors at low latitudes" (IPCC 2007)

Moreover, IPCC (2007) reports that at lower latitudes, especially in the dry tropics, even moderate temperature increases (1 to 2°C) are expected to reduce cereal yields and increase the risk of hunger. The IPCC indicates that impacts on crop production may be severe for several areas in Africa including the Sahel, East Africa and southern Africa, and that some countries may experience decreases in potential rain-fed yield of up to 50% by 2020. The IPCC study confirmed that Africa is the most vulnerable continent to climate change because of multiple stresses on agriculture and because of the continent's low adaptive capacities.

In East and Southeast Asia, crop yields could increase up to 20%; however, yields could decrease up to 30% in Central and South Asia by the mid-21st century (IPCC 2007). In total, the overall effect would be little, if any increase.

In drier areas of Latin America, climate change is expected to lead to salinity and desertification of agricultural land. Productivity of some important crops is projected to decrease and livestock productivity to decline, with adverse consequences for food security.

Climate change will also affect agriculture in indirect ways, for example by making less water available in some areas for irrigation, as noted earlier. All in all, it appears that a changing climate will pose a clear challenge to the ecological foundations of agriculture.

To sum up, the ecological foundation of agriculture depends on its resource base, including the availability of water and land, and ecosystem services provided by nature such as soil formation and nutrient cycling, on-farm biodiversity, off-farm biodiversity, and climate conditions. We have seen that society is undermining this foundation in many ways. Competing users threaten the water supply needed for expanding irrigated area. Growing urban areas and bioenergy cropping are competing with agriculture for available land, while some agricultural land drops out of production because of land degradation caused by poor agricultural practices. Some practices lead to disruption of the farm-level nutrient cycle, soil formation and biodiversity. Deforestation and pollution disrupt the habitat of organisms outside of farms, and some of these organisms provide pollination and pest control of crops. Climate change complicates all of these other disturbances and affects basic climate conditions in agricultural areas. While the current approach to agriculture undermines its ecological foundation, Chapter 5 points to an alternative model that is much more ecologically sustainable.

Chapter 3:

The Ecological Foundation of Fisheries and Aquaculture

Helga Josupeit (FAO); Patrick Dugan (WorldFish Centre); Rolf Willmann (FAO).

Credit: UN Photo / Eskinder Debebe

3.1 AN OVERVIEW OF FISHERIES AND AQUACULTURE

Fish are a crucial food source, providing about 10% of the world's total caloric intake (UNEP 2009). Fish are especially important for developing countries as they provide at least 50% of animal protein and minerals to 400 million people in the poorest countries of the world (PaCFA, 2009), underlining the critical importance of fish to food security and nutrition in these countries. The vital role of fish in nutrition is also due to their richness in micronutrients generally not found in other foods. They are an important source of vitamins A, B1, B2 and D. Fish are also a source of iron, phosphorus and calcium and other important trace elements. Marine fish are a good source of iodine. Among the general adult population, consumption of fish, particularly fatty fish, lowers the risk of mortality from coronary heart disease (FAO/WHO 2010).

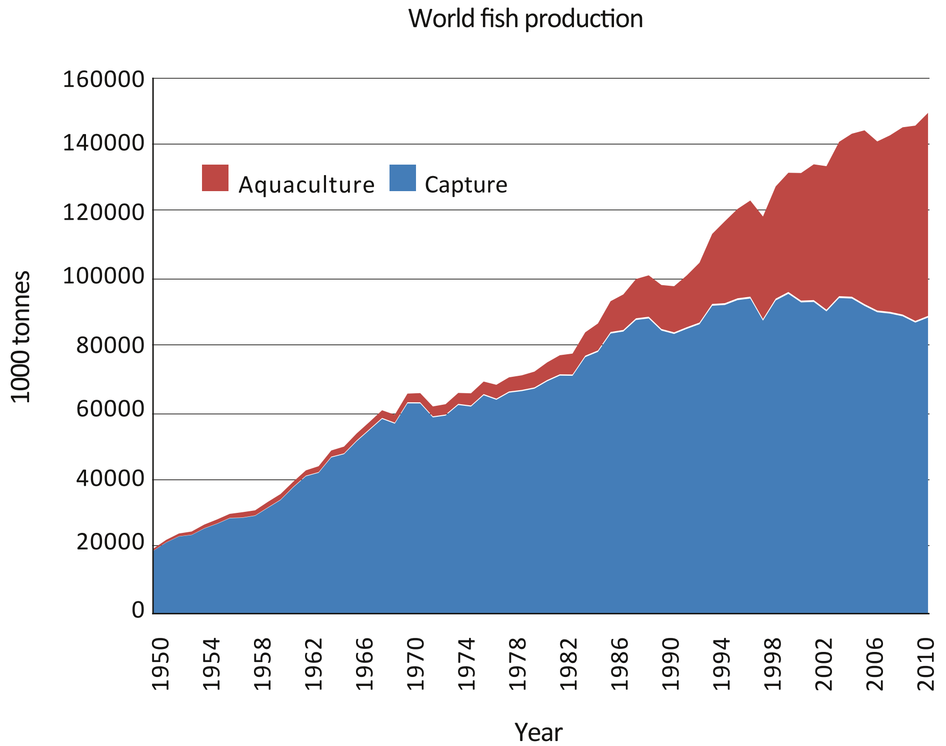

Figure 3.1. World Fish Production showing contribution from capture fishery and aquaculture. Source: FAO FishStat Plus 2012

It is encouraging, therefore, that global fish production (the sum of capture[10] and aquaculture[11] harvests, excluding aquatic plants) has shown a steady increase, from 137 million tonnes in 2006 to 154 million tonnes in 2011 (FAO 2012). All the additional supply came from aquaculture production, which in 2010 reached up to 40% of the total output of world fisheries (Figure 3.1). Of total fish production, some 73% is used for human consumption, while the remainder is processed as fishmeal (FAO 2010). The average global per-capita fish supply for food was estimated at about 18.6 kg (live weight equivalent) in 2010 (FAO 2012). Fish accounts for 15.7% of the global population's intake of animal protein, 6.1% of all protein consumed and almost 20% of average per capita intake of animal protein for more than 1.5 billion people (FAO 2010; OECD/FAO 2011). Though these figures do not seem very high, it was noted above that fish account for a much larger portion of the daily intake of animal protein in many of the poorer countries of the world. The world's per capita fish protein consumption has generally increased since 1961 (Figure 3.2). More details on this consumption will be given later for the different kinds of fisheries.

According to the FAO (2010), the fish sector is also an important source of income and livelihood for millions of people around the world, with an average employment creation growth rate of 3.6% per year. The FAO also reported that the fish sector produced more than 180 million jobs worldwide in 2008, including jobs related to secondary fishing activities and post-harvest work. Moreover, on average, each jobholder provides for three dependents or family members. Thus, the sector supports the livelihoods of an estimated 540 million people, or 8% of the world's population, according to the FAO. The great majority of fishers and aquaculturists are in developing countries, mainly in Asia.

Of particular interest are small-scale fisheries[12] because of the important contribution they make to livelihoods and poverty alleviation – especially in developing countries. Such fisheries support more than 90% of the world's 35 million

10 All kinds of harvesting of naturally occurring living resources in both marine and freshwater environments are referred to as capture or wild fisheries and could be classified as industrial, small-scale/artisanal or recreational depending on the scale/purpose of operation.

11 Aquaculture is the farming or cultivation of aquatic animals or plants under controlled conditions.

12 Defining small-scale fisheries can be challenging. According to an FAO glossary, small-scale fisheries which are sometimes referred to as artisanal fisheries, are defined as "traditional fisheries involving fishing households (as opposed to commercial companies), using relatively small amounts of capital and energy, relatively small fishing vessels (if any), making short fishing trips, close to shore, mainly for local consumption. In practice, definitions vary between countries, e.g. from gleaning or a one-man canoe in poor developing countries, to 20 metre trawlers. Artisanal fisheries can be subsistence or commercial fisheries, providing for local consumption or export" (FAO 1998)

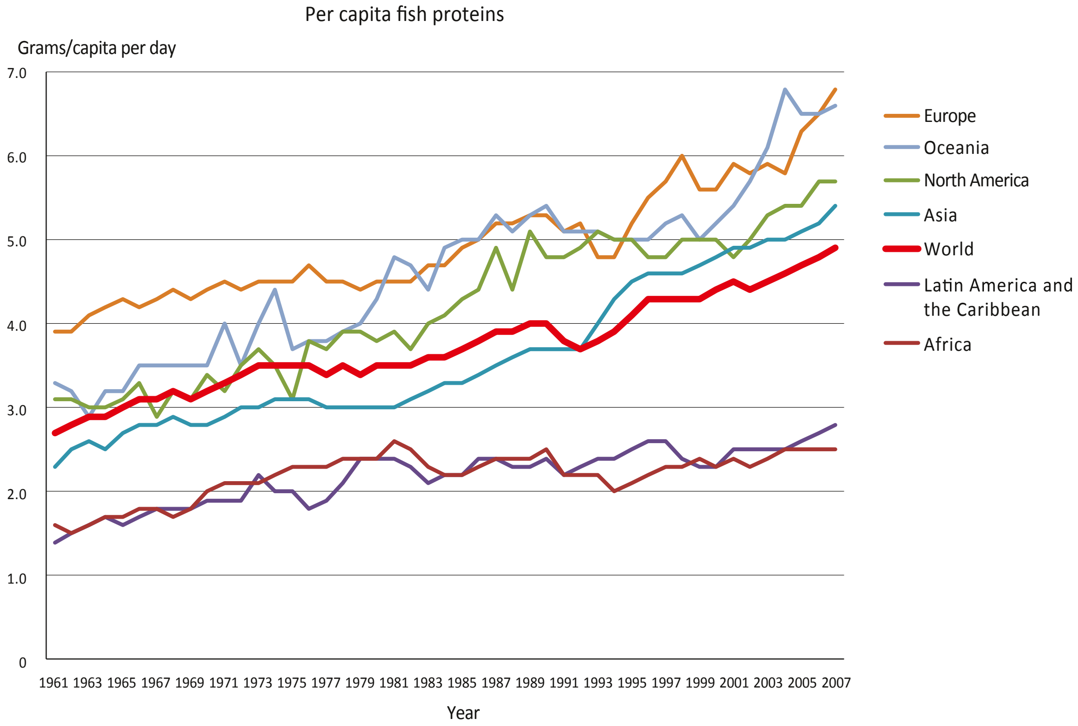

Figure 3.2. Worldwide and regional trend of per capita fish protein supply between 1961 and 2007
Source: FAO FishStat Plus 2012

capture fishers and another 84 million people employed in jobs associated with fish processing, distribution and marketing (FAO 2010). Despite this significant contribution, small-scale fisheries are still faced with constraints that hinder their sustainable development, including inadequate governance and institutional arrangements, insufficient management approaches, various post-harvest and trade issues, and inadequate availability of science and information (FAO/RAP/FIPL 2004; Garcia and Rosenberg 2010). For this reason, the FAO's Committee on Fisheries has called for the development of international guidelines on sustainable small-scale fisheries as a complement to the Code of Conduct for Responsible Fisheries[13] (FAO 2011a; 2011b).

Although policymakers mistakenly assume that fisheries and the aquaculture industry are male domains (FAO 2010; Dey de Pryck 2012), it turns out that women play a major role here. According to the FAO, almost half of the people working worldwide in small-scale fisheries are women and this figure goes beyond 50% for inland fisheries (FAO 2010).

Fish and fishery products are among the most-traded food products and provide a source of foreign currency earnings especially for developing countries. Trade in these products represented about 10% of total agricultural exports (excluding forest products) in 2008 (van der Heijden 2012). Figure 3.3 shows the trend in world fisheries production and quantities destined

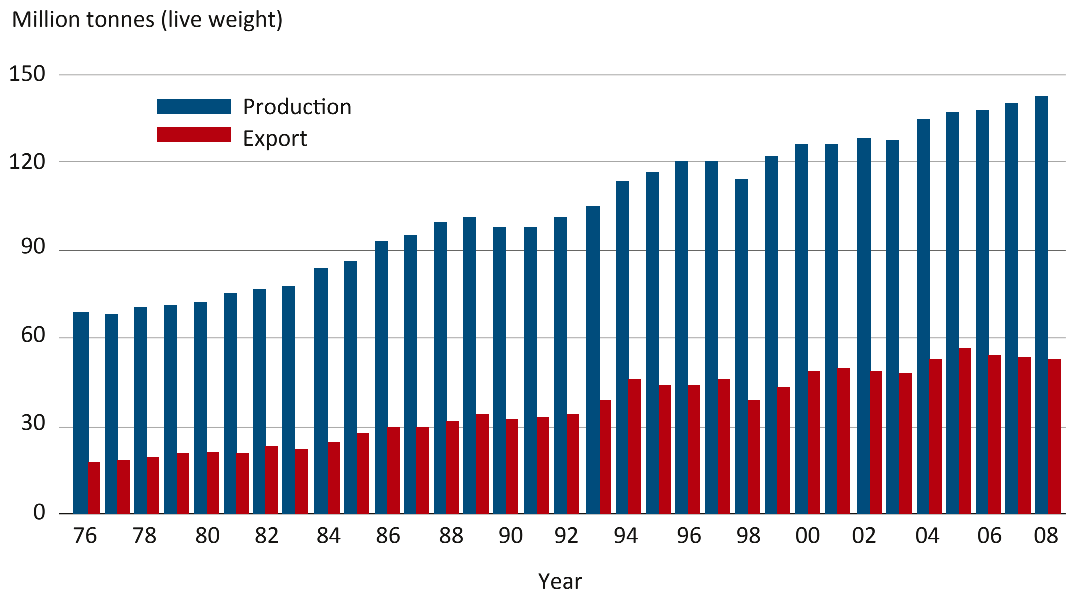

Figure 3.3. World Fisheries production and quantities destined for export between 1976 and 2008.
Source: FAO 2010

13 Details on the development process of the Sustainable Small-scale Fisheries Guidelines are provided at: http://www.fao.org/fishery/ssf/guidelines/en

for export between 1976 and 2008. Fish trade continues to expand and much of the trade is from developing to developed countries. Exports are estimated to have reached a new record of USD 120 billion in 2011 from the USD 110 billion in 2010, with about half coming from developing countries. Developed countries are the largest importers of fishery products and are responsible for 76% of the total 2010 import value of USD 110 billion (FAO Committee on Fisheries 2011).

Marketing of fishery products has experienced important changes during the last decade with more fish now being traded by supermarkets instead of the traditional specialist fish traders, fishmongers or market stalls. For example, Murray and Fofana (2002) reported that the supermarket share of fish sales in the UK increased from 16% to 66% between 1988 and 2001. They further reported that the trend is not confined to the UK alone, as fish sales are becoming more concentrated in supermarket outlets across Europe and beyond. This change has had an important impact on traditional fish traders and producers, and has resulted in the marginalization of small-scale producers and traders.

The trends described above highlight the role of fisheries in overall food and nutritional security, both in terms of fish as food and a source of income, as well as being a contributor to economic growth and development. It is generally believed that contributions from fisheries will be needed in the future in order to meet the challenges of food and nutrition security. However, in order to maintain or increase these contributions, it is very important that the foundation for continual production of fisheries is preserved. Current knowledge, especially related to capture fisheries, indicates that the ecological foundation for this sustained production is being undermined. In the subsequent sections of this chapter we discuss this ecological foundation and the factors that are threatening it. Later in Chapter 6, we present some options for securing this ecological foundation.

3.2 MARINE FISHERIES

3.2.1 Introduction

Marine fishing is one of the few remaining economically important sectors providing food from natural resources. Coastal fishing communities are present in many countries. Fishing activities mainly take place in the productive shelves adjoining the world's continents, down to about 200m depth. They provide a major source of food, nutrition, employment and income for people living along these continental shelves and coastal areas. Unfortunately, poor governance arrangements have created open access to marine fish resources, resulting in overexploitation of many stocks (see Section 3.2.3) and the deterioration of the ecosystem required for their continued productivity.

3.2.2 Importance of Marine Fisheries

Marine fisheries (either small-scale or large-scale) are important to both the developed and the developing world. About 40% of the world's population is believed to live within 100 km of the coast (SCBD 2012) and largely depends on marine fisheries for food.

Marine fisheries support the livelihoods of millions of citizens along Africa's long coastline. They contribute significantly to food security, income generation, and economic welfare. The New Partnership for African Development reported that marine fisheries are an important source of income and foreign exchange to governments through fishing agreements, licence fees and from activities of distant water fishing fleets, which are serviced at regional ports. Fish, as a highly traded commodity, is one of the leading export commodities for Africa, with an annual value of nearly USD 3 billion (AfDB 2008).

In the Pacific region, coastal fishing is of fundamental importance since much of the nutrition, welfare, culture, employment and recreation of a large population is based on the living resources in the zone between the shoreline and the outer reef. Hence the continuation of current lifestyles, opportunities for future development and food security are highly dependent on coastal fishery resources (Gillett 2010).

The marine fishery is important for health and nutrition. Over one billion people depend on ocean fish as their main source of animal protein (Aerni 2001). Of particular importance are many least-developed countries with food deficits such as Bangladesh and Senegal, where marine fisheries play an important role in providing essential nutritional needs. For example, closely spaced pregnancies, often seen in many of these developing countries, can lead to the depletion of the mother's supply of essential fatty acids, leaving younger siblings deprived of this vital nutrient at a crucial stage in their growth. This makes fatty fish such as tuna, mackerel and sardine – all of which are commonly available from marine fisheries in developing countries – a particularly good choice for the diet of pregnant and lactating women.

In the developed world, apart from being a source of food and income, marine fisheries also play an important role in recreation. Total expenditures on recreational fishing across Europe were reported to exceed 25 billion Euros per annum and the sea angling industry is estimated to be worth between eight and ten billion Euros (Pawson et al. 2008). Ihde et al (2011) reported on the increasing importance of recreational fishing in the US because of its economic impact, the number of people involved, and the magnitude of the catches. For some marine species, catch from recreational fishing now dominates the total catch.

3.2.3 Current Status of Marine Fisheries

Statistics indicate that global production of marine capture fisheries reached a peak of 86.3 million tonnes in 1996 before experiencing a decline (FAO 2010). Figures for 2008 indicate production to be 80 million tonnes. Trends between the 1990s and 2000s indicate that the global marine catch has stabilized at a level of 80-88 million tonnes since 1990 (World Bank/FAO 2009). This levelling hides several underlying trends in the composition of the catch. Between 1950 and 1970, the recorded catch of both the demersal (bottom dwelling) and pelagic species (species that live in the upper layers of the ocean) grew considerably. The demersal catches have however stabilized at around 20 million tonnes since 1970, while the pelagic catches grew to a peak volume of almost 44 million tonnes in 1994, after which catches have fluctuated between 36 and 41 million tonnes. Hence, the contribution of marine capture fisheries to global fish supply increasingly relies on lower-value species characterized by large fluctuations in year-to-year productivity. This is masking the decline of high-value demersal resources (World Bank/FAO 2009). It should be noted however that the low-value pelagic species are still important for food security and nutrition as they provide cheap protein to the poorer population.

According to the FAO, 53% of global marine stocks are fully exploited, 15% are either underexploited (3%) or moderately exploited (12%), while 32% of marine stocks are either overexploited (28%), depleted (3%) or are recovering from depletion (1%) (Figure 3.4). The proportion of marine fish stocks estimated to be underexploited or moderately exploited declined from 40% in the mid-1970s to 15% in 2008, while there is an increasing trend in the proportion of overexploited, depleted and recovering stocks from 10% in the mid-1970s to above 30% in 2008 (FAO 2010). Although these figures have to be treated with caution due to some uncertainty[14], the general nature of the trend is a cause for concern.

It is essential that the habitat remain adequately oxygenated and within acceptable limits of water quality, including temperature, for eggs and larvae development. The ability to migrate is also important, since most fish move to and from feeding areas to congregate when it is spawning season. Typical examples for marine fish are the salmon and striped bass *(Morone Saxatilis)* which exhibit an anadromous pattern, moving from marine environments to estuarine or freshwater environments for spawning. Any departure from these conditions will affect productivity.

3.2.5 Undermining the Ecological Foundation of Marine Fisheries

In sum, human activities are the major drivers of changes leading to the undermining of the ecological foundation of marine fisheries. Overfishing and destructive fishing activities, as well as infrastructure development and oil and gas and other mineral extraction, alter the resource base of marine ecosystems or leads to their pollution, thereby hampering their productivity. Table 3.1 provides an overview of the different drivers of change to the ecological foundation of fisheries and their impact on fish production and food security.

Key ecosystems, such as coral reefs and mangroves, may have reached or may soon reach critical thresholds, disproportionately

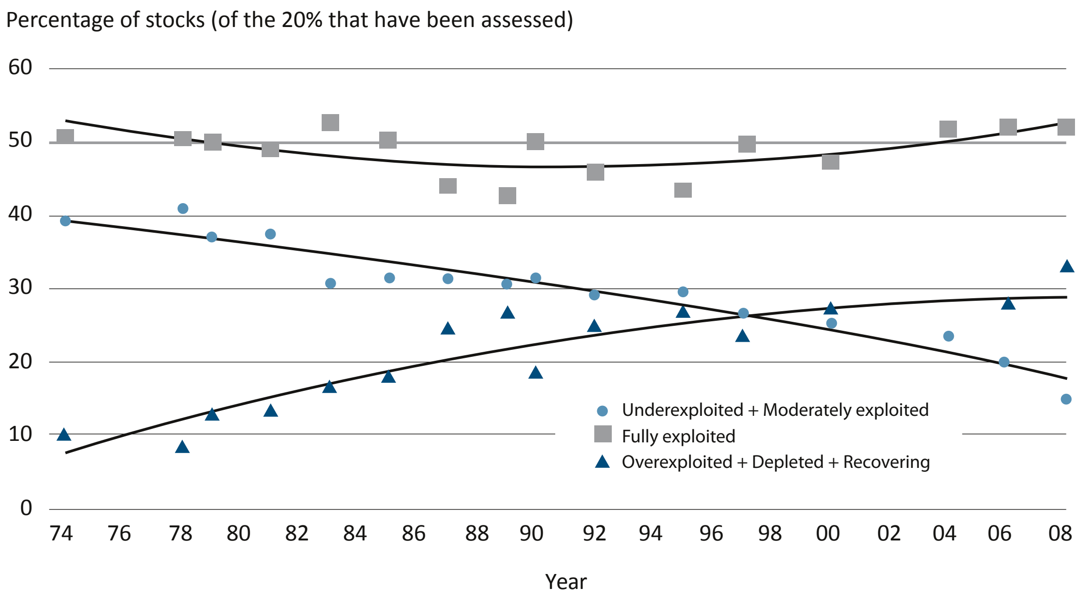

Figure 3.4. Global trends in the state of world marine stocks since 1974
Source: FAO 2010

3.2.4 Ecological Foundation of Marine fisheries

The continuous productivity of marine fisheries is dependent on several factors including the availability of food sources and adequacy of habitat for breeding, feeding and growth. Habitat is adequate if it is pollution- and pathogen-free, has a stable ecosystem, minimal disturbance and appropriate climate conditions. All of these factors will influence the reproduction, recruitment and growth of resources within a marine habitat.

impacting the people and communities that are most vulnerable and reliant on marine ecosystems for food security. The Millennium Ecosystem Assessment reported that approximately 35% of mangroves have been lost or converted over the last few decades, and approximately 40% of coral reefs worldwide have been destroyed or degraded (MA 2005). Some of the drivers of change are discussed in this assessment, as well as in Nellemann and Corcoran (2006), Nelleman et al (2008), Worm et al (2009), and references cited in them. They are summarized below.

14 Since only 20% of global catch has been assessed using traditional stock assessment models (Branch et al. 2011)

Overfishing has been recognised as the foremost force in the global degradation of coastal ecosystems. As stated earlier, FAO's estimate indicates that 85% of marine fisheries are either fully exploited, overexploited or depleted as of 2008 (FAO 2010). Furthermore, targeted fishing leads to changes in community structure and size and alters the trophic and other interactions between ecosystem components. According to the Millennium Ecosystem Assessment (MA 2005), overfishing may result in the removal of important components of the ecosystem, such as algal-feeding fish in coral reef systems, with a consequence of altered ecological states that may be impossible to restore.

Fishing methods such as bottom trawling and dredging and destructive practices such as the use of dynamite and cyanide can further disrupt marine ecosystems as they may lead to habitat loss, damage or modification. According to the Millennium Ecosystem Assessment, it may take hundreds of years for vulnerable habitats such as cold water corals and seamounts to recover from the impact of destructive fishing. Furthermore, illegal, unreported and unregulated fishing and by-catch can worsen the impacts of fishing on the food web and can also alter ecosystem structure and function, thereby negatively impacting productivity and resilience to the impacts of other drivers. Additionally, marine debris from lost fishing gear can continue to trap fish for some time. This debris can also entangle a wide variety of wildlife, thereby negatively impacting their productivity and growth, especially those species whose lifecycle requires them to migrate for spawning.

The coastal boundary zone surrounding continents is the most productive part of the world ocean, yielding about 90% of marine fishery catches (MA 2005). Human activities including infrastructure development, urbanization, port activities, and tourism also take place in this zone. When these activities are not properly planned or implemented, they can affect productivity and ecosystem services within the coastal zone. The ultimate result of poorly designed activities is the alteration, destruction or pollution of marine ecosystems.

Furthermore, increased energy and mineral demands means that the marine realm is now seen by many as the next frontier for mineral exploitation, especially for oil and gas and other energy sources (wind, gas hydrates, and currents), and for tin, cobalt, manganese, and polymetallic nodules in offshore seabed mines. Oceans are also being used for waste dumping or for discharge of wastewater from land. These activities not only alter fish habitats, but render these ocean hotspots more vulnerable to pollution (e.g., oil spills) with negative consequences to their productivity. For example, recent research indicates that coral reefs close to the site of the Deepwater Horizon oil spill in the Gulf of Mexico are showing strong signs of stress (White et al. 2012), which could affect their ability to support marine fisheries.

The increase of nutrients, including reactive nitrogen and phosphorus entering oceans, particularly from agricultural runoff, has led to eutrophication in many coastal areas of the world. Diaz and Rosenberg (2008) stated that more than 400 dead zones have been reported, affecting a total area of more than 245,000 km^2. Aquacultural activities (see Section 3.3.4) are also a source of pollution and biodiversity concerns as they may lead to the introduction of pathogens, strains and/or species that can alter marine habitats. Apart from its impacts on productivity, pollution also has health impacts, in that pollutants can accumulate in fish and transfer to humans when consumed.

Climate variability has always been a significant determinant of fish stock growth and decline. Rising atmospheric temperatures could lead to a change in ocean temperature, circulation patterns, frequency and intensity of storms, salinity, and oxygen levels, with a resultant effect on diversification of marine life, change in fish migration patterns, and possible loss of breeding habitats – including the coral reefs. IPCC (2007) projects a global loss of 18% of the world's coral reefs over the next three decades. But it must be noted that these projected losses are expected to be due to multiple stresses compounded by the impact of climate change. Furthermore, climate change has led to ocean acidification, which is expected to have a negative impact on calcifying organisms in the marine environment, as decreased pH of oceans will likely impair shell formation in a wide range of planktonic and shallow benthic marine organisms (IPCC 2007). Garcia and Rosenberg (2010) reported that the effects of climate change are already evident and could impact both positively and negatively on marine productivity. Studies from Barange and Perry (2009); Daw et al (2009); and Perry (2010) indicate that climate change – specifically, warming of sea water – could affect the distribution and abundance of marine populations. The distribution of marine life could shift poleward, resulting in an increase in fish abundance in the polar regions and a decrease in equatorial regions.

Apart from direct drivers, other factors such as population growth, changing food demand, globalisation, new economic policies, and changes in governance and management structure, all play an indirect but important role in threatening the ecological foundation of marine fisheries.

3.3. INLAND FISHERIES

3.3.1 Introduction

Most of the world's major rivers and lakes support important inland fisheries. In Europe, North America and Australia these are primarily of importance for recreation, but in Africa, Asia and Latin America they play a critical role in providing food and employment to tens of millions of people. Inland capture fisheries operate in a large variety of environments, are generally labour intensive and in most cases do not lend themselves to mechanization and industrialization. Although inland fisheries are typically not wealth creators for individual fishers, they are a massive supplier of food and income when aggregated and are therefore a significant contributor to rural food security and income generation (UNEP 2010). According to the FAO, there are probably more people involved in inland fisheries today than ever before. Unfortunately, inland fisheries face threats from other economic sectors and human activities, which have negative impacts on the integrity of the ecosystem needed for its continuous sustenance (FAO 2010).

Table 3.1 Drivers of change to the ecological foundation of fisheries

	Drivers	Ecosystem impacts	Impact on fish production systems			Implications for food security
			Marine	**Inland**	**Aquaculture**	
Pressure on the resource base	**Habitat Loss** (e.g. loss of wetlands and coastal habitats)	Loss of key breeding and feeding habitats for fish.	High where coastal habitats are lost and degraded.	High	Limited	Significant local impact on coastal and inland fishing communities and value chains.
	Changes to ocean and inland waters (e.g., infrastructure development such as dams and dikes, urbanisation and port activities)	Alters timing and quantity of river flows, leading to loss of breeding and feeding habitats. Results in loss of floodplain and other wetlands. Blocks fish migrations preventing access to breeding and feeding areas.	Limited in selected coastal areas.	Severe – can lead to complete loss of affected fisheries.	Limited	Severe for food insecure communities dependent on inland fisheries for income, protein and micronutrients.
Pressure on ecosystem services	**Changes to fish stocks** (through overexploitation)	Depletes fish populations; Alters food chains and biodiversity; Shifts fish catch to smaller species and individuals.	High, with 85% of marine stocks either fully exploited, overexploited, or depleted.	High in a limited number of fishery systems.	Reduces fish available for fish meal and oil. Potential to affect the production of high value species.	Severe for communities that are dependent on impacted marine and inland fisheries. However in some areas, smaller sized species might represent accessible food for poorer segments of the population.
	Pollution (e.g., land-based including run-off, marine-based, introduction of pathogens, strains or invasive species)	Diminishes water quality, leading to fish mortality. Leads to changes in composition of plankton and other organisms. Alters food chains and changes composition of fish communities.	Locally high near many urban centers or in catchments with intensive food production systems.	Locally or regionally high, notably as a result of eutrophication, and/ or oxygen depletion and toxicity.	Locally high where polluted waters are used for fish farms.	Significant impact on productivity in areas of high pollution. Can lead to health and safety issues where contaminated fish are consumed by people.
	Climate change (CC) (e.g. warming, changes in water flow, acidification)	Changes in water flow regimes and loss of breeding and feeding habitats. Changes in coastal systems as a result of sea level rise and salinity increase; Coral bleaching	Projected to increase significantly.	Already high where climate variability is high; projected to increase substantially.	High, in particular in coastal areas. subject to sea level rise and salinity increase	Could be locally severe, with national or regional impacts where highly productive systems such as deltas and major river basins are affected. However, in some marine areas (e.g., flooded areas and areas closer to the poles); CC is expected to result in increased production. The impact on food security might thus be positive in some areas, at least, in the short term. However, little is known of the interactions involved (Barange and Perry 2009; Daw et al. 2009); and Perry 2010).
	Demand	Higher prices, hence an incentive for increased exploitation, with resultant ecological impact.	Overexploitation driven by demand for demersal species	Locally high (e.g., Lake Victoria)	High, more aquaculture production of high value species for exports	Leaves less fish within the reach of the poor and more fish going to wealthy and developed countries. Prices have increased by 20% between 2009 and 2011. Exports of fish to developed countries have increased by 15% during the last two years. Less fish available to consumers in developing countries, but export industry creates jobs and enhances food security in exporting countries.

3.3.2 Importance of Inland Fisheries

The conservative estimate of 10-13 million metric tonnes of fish from inland fisheries accounts for 25-29% of fish harvested for direct human consumption. However, because this harvest comes almost exclusively from small-scale fisheries, inland fisheries contribute a larger share (35-39%) of the global catch of 29-33 million metric tonnes from small-scale fisheries. Some 94% of the catch from these small-scale fisheries is consumed within the country of origin and mostly in developing countries (Mills et al. 2011). Inland fisheries therefore play a particularly important role in food and nutrition security in these countries.

Over 200 million of Africa's one billion people regularly consume fish (Heck et al. 2007), and nearly half of the officially recorded supply comes from inland fisheries (FAO 1997; Neiland 2005). Freshwater fish are a vital source of animal protein in the countries of the Lower Mekong Basin, with Cambodia and Laos having amongst the highest fish protein consumption of non-island states (UNEP 2010). In Bangladesh (the second largest of the major inland fishery producer countries), fish contribute over two-thirds of the animal protein intake and are especially important in the diet of poor households who can better afford fish than more expensive forms of animal protein (Bose and Dey 2007).

In many countries, the role of inland fisheries in supplying micronutrients – especially vitamin A, calcium, iron and zinc – is even more important than their role as a source of protein. Small freshwater fish are especially rich in these micronutrients and when consumed frequently in everyday diets contribute substantially to nutrition and health and mental development of children. For example, detailed studies of poor rural households in Bangladesh have shown that daily consumption of small fish contributes 40% of the total daily household requirement of vitamin A, and 31% of calcium (Roos et al. 2007). In Cambodia, fish and other aquatic animals contribute 51% of calcium, 39% of zinc, and 33% of iron intake for women (Chamnan et al. 2009). Similarly, in Malawi a modified daily menu for preschool children incorporating small dried fish (*Engraulicypris Sardella* known as usipa) has been shown to increase iron, zinc and calcium intake (Gibson and Hotz 2001).

In addition to their direct contribution to food security, inland fisheries also improve access to food by providing millions of jobs along the value chain, many of them in processing, trading, and other support services. A recent joint study by the World Bank, the FAO and WorldFish Centre shows that inland fisheries employ about two million people in large-scale fisheries and 56 million in small-scale fisheries globally (World Bank/FAO/WorldFish Centre 2010). In both India and Nigeria the number of those employed in these fishery-related jobs is four times the number of those who fish (Dugan et al. 2010).

More than 50% of the total number of people employed in inland fishery-related jobs are women (World Bank/FAO/WorldFish Centre 2010). Women fill more than 50% of these jobs in Cambodia, China, India and Nigeria (Dugan et al. 2010). The non-fishing jobs are particularly important for women: 80% of workers in Cambodian fish sauce factories are women (Rab et al. 2006); while in India, 72% of people employed in small-scale inland fisheries are women, 90% of them engaged in processing and marketing (BNP 2008). Furthermore, fish caught by women are generally used for household consumption, thereby meeting household nutritional needs, while those caught by men are more often sold at market (Béné et al. 2009; Kawarazuka 2010).

The monetary value of the inland fish catch is large. In the Lower Mekong Basin the estimated fish catch of 2.1 million tonnes is worth USD 2.1-3.8 billion at first sale and between USD 4.2 and 7.6 billion on retail markets (Hortle 2009; Baran 2010). In Africa, the Lake Victoria Basin is the largest producer with just over one million tonnes harvested each year. The beach value of this catch is estimated at between USD 350 – 400 million with export earnings estimated at around USD 250 million (Balirwa 2007; LVFO 2008).

3.3.3. Current Status of Inland Fisheries

Official statistics put the annual fish catch from freshwater ecosystems at approximately ten million metric tonnes globally (FAO 2009a). However, detailed analysis from a few countries raises this to 13 million metric tonnes (BNP 2008), and the FAO's estimates of under-reporting (FAO 1999; 2003) suggest that the more accurate figure could be at least twice this. The production trend since 1950 as reported by the FAO is shown in Figure 3.5.

The official global catch has grown steadily since 1950 but is now levelling off. Asia produced 66% in 2008, Africa 25% and Latin America 4%. China, Bangladesh, India and Myanmar are the largest producers with a total harvest of 5.1 million tonnes. Another 16 countries (Uganda, Cambodia, Indonesia, Nigeria, Tanzania, Brazil, Egypt, Thailand, Democratic Republic of Congo, Russia, Philippines, Vietnam, Kenya, Mexico, Pakistan and Mali) all report catches over 100,000 tonnes each; together the top twenty countries produce over 8.7 million tonnes, representing 85% of officially recorded global production (Dugan et al. 2010).

There is a general impression among inland fishers that inland fishery resources are declining due to an observed decrease in individual catch per fisher. However, this might not necessarily be true as this decrease in catch per fisher could be related to an increase in the total number of people involved in inland fisheries. Hence, it is possible that the aggregate catch from inland fisheries is still increasing. It is important to note, however, that increased production does not mean that inland fisheries have not reached their sustainable harvest level. On the contrary, inland fisheries could be overfished but this could be masked by the resilience of inland fish communities which allows total catches to temporarily exceed long term sustainable levels (FAO 2010).

Unfortunately, getting accurate yield data from inland fisheries is extremely difficult, since the majority of inland fisheries are not licensed and are widely dispersed along the lengths of all rivers and streams as well as a variety of water bodies and wetlands, and there are no centralized points where data can be easily collected (de Graaf et al. 2012).

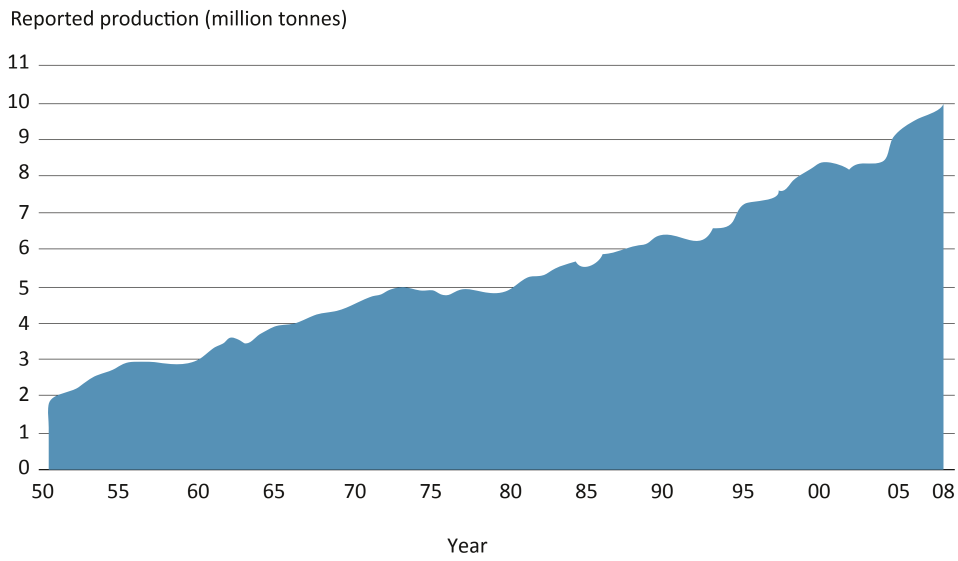

Figure 3.5. Production of inland fisheries reported by FAO since 1950
Source: FAO 2010

3.3.4. Ecological Foundation of Inland Fisheries

The amount of fish present in different freshwater ecosystems is dependent on five principal factors: the success of reproduction and recruitment; the quantity and quality of the food supply; migration into or out of the system; mortality due to natural or human-induced causes; and the fish harvest. Ecosystem health and functioning drive the first four of these, and degradation of aquatic ecosystems reduces their capacity to support fisheries. The quantity and value of fish harvested from these systems is in turn driven by the interaction between accessibility of the fishery, demand for fish, and governance arrangements. Ecological conditions required for a productive inland fishery include adequate food resource, adequate environmental flow[15], availability of floodplain habitats, adequate oxygen levels, pollution- and pathogen-free habitats, adequate habitat temperature, and siltation free habitats.

Fish reproduction is generally timed to occur when food resources are abundant, and other conditions are most favourable. In temperate regions these periods occur during the warmer seasons, while in the tropics suitable environmental conditions are much more dependent on rainfall and water level. Many species in equatorial lakes breed throughout the year, but river species generally spawn just prior to, or during, the flood season, which allows the young fish to benefit from the abundant food resources and shelter from predation on the floodplain (Welcomme 1985; Wootton 1990). Some species of long-distance migrants time their upstream spawning so that their fry arrive at the downstream floodplains as the flood arrives. Should adult fish be unable to achieve breeding conditions or access spawning grounds, or if larvae are unable to access suitable nursery and feeding areas, reproductive success will be low. This can occur naturally during times of severe drought when, for example, lake or river levels fall and breeding areas are inaccessible. In general, however, such reductions in reproductive success are more frequently the result of human activities that cause changes to water flow and floodplain areas, reduced access to breeding and nursery areas, or mortality of spawning fish, eggs and larvae.

3.3.5. Undermining the Ecological Foundation of Inland Fisheries

Inland fisheries are particularly vulnerable to environmental change as well as direct and indirect drivers which interact to alter ecosystem functioning and diminish the quantity and/or quality of services that these ecosystems provide.

Human activities that could challenge the ecological foundation of these fisheries include industrialization, urbanization, deforestation, mining and agricultural land and water use. These activities can result in degradation of the aquatic environment, which is the greatest threat to inland fish production. Some of these drivers were presented in Table 3.1 and are summarized below.

Industrialization and urbanization activities, such as dam construction in the catchment, change the quality and quantity of water available to inland fisheries. They may interrupt the connectivity of river systems, form barriers to fish migration, and reduce the availability of breeding and feeding habitat. By retaining water, dams with large reservoirs alter seasonal flood regimes and retain sediments that underpin the productivity of downstream floodplains. This, in turn, diminishes the production and catch of fish dependent upon this wetland productivity. Dams and their impact on hydrological regimes of rivers are a major driver of change in inland fisheries. It is estimated that more than 50% of the world's large rivers have been fragmented by dams on their main channel and 59% on their tributaries (UNEP 2010).

River channelization and dredging may reduce riverine or flood plain habitats directly through physical changes, or indirectly

15 Environmental flow refers to the quantity and timing of water flows required to sustain specific valued features of freshwater ecosystems or for protecting the species of interest for fisheries and for conservation of the ecosystem on which fisheries depend (IWMI 2007).

by altering flow and flood patterns. Construction of roads and other infrastructure may have similar impacts by reducing wetland connectivity, and diminishing the capacity of aquatic ecosystems to absorb floodwaters and remove pollutants.

Water abstraction for urban-industrial uses also reduces downstream flows, diminishes the availability of feeding and breeding habitats, and exacerbates the problems of water quality in many locations. Furthermore, developments resulting in deforestation and other types of land use change also change patterns of water flow, and lead to increased runoff, erosion and siltation in watersheds, thereby reducing water quality. Trees sometimes provide shade and food for many inland fisheries and their removal during deforestation can have a detrimental effect on fisheries productivity. It is estimated that human activities have increased sediment flows in rivers by about 20% worldwide (MA 2005). According to the International Union for Conservation of Nature (IUCN), 12% of Africa's freshwaters are under threat of habitat loss due to deforestation and more than 15% are under threat from sedimentation (IUCN Red List 2011).

Expansion of agriculture often involves the conversion of freshwater habitats – especially floodplains – resulting in the loss of biodiversity (MA 2005) and disruption of connectivity between floodplains and rivers. Agriculture also results in drained wetlands through the abstraction of water for irrigation. Floodplains provide some of the most productive inland fishery habitats. FAO reported that more than 40% of the floodplains of Bangladesh have been modified and impoldered for rice growing (FAO 2010).

Furthermore, agrochemicals and harmful waste from excessive agricultural effluents can cause pollution and eutrophication of inland waters with a resultant depletion of available oxygen, thereby negatively impacting the growth and productivity of aquatic species. It is also possible for toxins to accumulate in fish rendering them unsuitable for human use. IUCN data indicate that 10% of Africa's freshwater taxa are threatened by habitat loss due to agricultural activities (IUCN Red List 2011).

Other pollution sources such as salinisation and discharge of toxic wastewater from domestic, industrial and mining activities can have major impacts on aquatic ecosystems and result in the eradication of native faunas. There are also signs that the magnitude of wastewater discharges will substantially increase over the coming decades as a side effect of development, especially in developing regions. The Millennium Ecosystem Assessment scenarios indicate that wastewater loadings may increase in Africa between the 1990s and 2050 by a factor of four to eight (Alcamo et al. 2005). Because of the increasing rate of degradation of inland waters in developing countries, the UNEP Foresight Panel in 2011 identified "Shortcutting the degradation of inland waters in developing countries" as one of 21 important emerging issues for the 21st century (UNEP 2012).

The introduction and spread of pathogens and invasive species have also brought substantial ecological change in many freshwater systems, and are of particular concern in systems with high numbers of endemic species.

As in the case of marine fisheries, climate change, although hard to predict, is likely to have important impacts on freshwater ecosystems and thereby on inland fisheries. The IPCC (2007) indicated that many climate-related changes are occurring or will occur that will most probably be deleterious to the health of inland fisheries:

- Lakes and rivers around the world are already warming, and consequently are experiencing changes in their thermal structure and water quality. This warming is affecting the abundance, productivity, and other characteristics of freshwater species.
- In the future, many arid and semi-arid areas (e.g., Mediterranean Basin, western USA, southern Africa, north-eastern Brazil, southern and eastern Australia) are likely to experience a decrease in water resources. This may reduce in-river flows and available fish habitat.
- A combination of factors – higher water temperatures, increased precipitation intensity and longer periods of low flows – will worsen different kinds of water pollution, and this in turn will have an impact on ecosystems.

It must be noted however, that climate change could have some positive impact on inland fish production, including increased productivity in flooded areas (Barange and Perry 2009; Daw et al. 2009).

Also, as with marine fisheries, indirect drivers pose challenges to the ecological foundation of inland fisheries. These indirect drivers drive the process of change that leads to inland fishery degradation and include demographic, economic, socio-political and technological changes.

3.4 AQUACULTURE

3.4.1. Introduction

For several decades aquaculture has been the world's fastest-growing food production sector and has contributed to the growth in per-capita consumption of fish in most regions. With rising demand for fish and limits to capture fisheries, this trend is set to continue. In turn, for aquaculture to remain sustainable, its future growth must be carried out in ways that do not erode natural biodiversity or place unsustainable demands on ecosystem services.

3.4.2. Importance of Aquaculture

Aquaculture contributes to food security in vulnerable populations by providing fish from farm ponds for home consumption, by providing low-cost animal protein for urban consumers, and by providing employment in production and along the value chain. In integrated smallholder systems, fish ponds not only generate crops of fish but also offer additional flexibility to farmers for using available water for alternative crops or for irrigation, or for household needs if rains are late or smaller than expected (Miller 2009). For example, in Malawi, small-scale integrated aquaculture has improved total

Credit: Shutterstock / Federico Rostagno

farm productivity by 11%, increased farm income by 60%, and increased household consumption of fresh fish and dried fish (Dey et al. 2007; 2010). Because of its small total production, this type of subsistence-oriented, smallholder aquaculture has had little impact on national food supplies, but it has improved the food security and nutrition of participating smallholders and helped improve resilience in times of drought.

More intensive forms of aquaculture target urban consumers and, with growing international trade and stabilization of capture fisheries production, provide an alternative to wild fish in many markets. For example, the Vietnamese striped catfish *(Pangasionodon Hyophthalmus)* industry is the fastest-growing commodity of a farmed single species ever recorded, producing close to 700,000 tonnes in 2007 (Phan et al. 2009; Phuong and Oanh 2009). Over 90% of this production is sold internationally and has rapidly penetrated markets in Europe and North America where it provides an affordable and acceptable substitute for white fish formerly supplied by marine fisheries. Similarly, farmed tilapia from China is now being sold in southern Africa as a cheap source of fish for lower-income urban consumers.

The monetary value of the world's aquaculture harvest, excluding aquatic plants, was estimated at USD 98.4 billion in 2008 (FAO 2010), underlining aquaculture as an important source of income. This amount is expected to be higher when the values of aquaculture hatchery and nursery production and that of breeding of ornamental fish are included (FAO 2010).

As to the future role of aquaculture, the OECD-FAO Agricultural Outlook 2011–2020 estimated that by 2015, fish for human consumption originating from aquaculture will for the first time exceed those from capture fisheries (54% of total human consumption by 2020) (OECD/FAO 2011). A recent report indicates that global aquaculture production may reach 65 to 85 million metric tonnes by 2020 and 79 to 110 million metric tonnes by 2030 (Hall et al. 2011).

3.4.3. Current Status of Aquaculture

Globally, aquaculture production has grown at an average annual rate of 8.4% between 1970 and 2008 (Hall et al. 2011) and reached 59.9 million tonnes in 2010 (FAO 2012). Between 1980 and 2010, the proportion of aquaculture in total fish production for food increased from 9% to 47% (FAO 2012). Given the unlikely prospect of increased yields from wild capture fisheries, this value will increase as aquaculture production grows. This growth in farmed fish has significantly outpaced growth in world population. While world population has increased at an average 1.5%, farmed food fish production has increased at an average of 7.1%, resulting in an increase from an annual per-capita value of 1.1 kg in 1980 to 8.7 kg in 2010. The estimated average per-capita consumption of food fish from wild and farmed sources combined was 18.8 kg in 2011 (FAO 2012).

The rapid growth of aquaculture has been driven by growing demand for fish combined with stabilization of supply from wild capture fisheries. This demand is in turn partly due to population growth, but primarily due to rising wealth and associated increases in per-capita consumption of fish and other animal source foods.

The developing world accounts for the vast majority of global aquaculture production and increasingly is a producer of fish for the developed world. Over 90% of global aquaculture production is from Asia, 63% from China alone (Ocean Conservancy 2011). Table 3.2 presents aquaculture production between 1950 and 2010 by the major producing countries.

As highlighted earlier, Asian aquaculture has expanded onto international markets. But in Africa, aquaculture has been in response to national demand (Gordon 2009; Bené et al. 2010). Most of the African production occurs in Egypt (635 000 t) and has helped drive per-capita consumption from 8.5 to 15.4 kg/

Table 3.2 Aquaculture production, by major producing countries, in million tonnes

	1950	1960	1970	1980	1990	2000	2010
China	0.1	0.6	0.8	1.3	6.5	21.5	36.7
India	0.0	0.0	0.1	0.4	1.0	1.9	4.6
Vietnam	0.0	0.0	0.1	0.1	0.2	0.5	2.7
Indonesia	0.0	0.1	0.1	0.2	0.5	0.8	2.3
Bangladesh	0.0	0.0	0.1	0.1	0.2	0.7	1.3
Thailand	0.0	0.0	0.1	0.1	0.3	0.7	1.3
Norway	0.0	0.0	0.0	0.0	0.2	0.5	1.0
Others	0.4	0.8	1.4	2.5	4.3	5.8	9.9
TOTAL	0.6	1.7	2.6	4.7	13.1	32.4	59.9

Source: FAO FishStat Plus 2012

person/yr between 1994 and 2008 and led to a doubling of the contribution that fish make to the Egyptian diet. This has been driven in part by the low cost of fish, with prices of tilapia well below those for chicken meat (35% lower in urban markets and 42% lower in rural markets in 2007) (WorldFish Centre 2011).

Per-capita consumption in sub-Saharan Africa is the world's lowest, and indeed fell from 9 to 6.6 kg per year between 1973 and 1997. This, combined with limited supply from capture fisheries and costly imports, is driving rapid growth in aquaculture production. Five of the ten countries with the most rapid rates of production increase are now African: Uganda, Mozambique, Malawi, Togo and Nigeria (WorldFish Centre 2008; FAO 2009a; Hall et al. 2011).

3.4.4 Ecological Impacts of Aquaculture

Some forms of aquaculture, especially of seaweed and molluscs, provide food and support ecosystem services through the removal of anthropogenically generated nutrients (Soto 2009). However, the farming of fish and shrimp is dependent upon a wide range of provisioning and regulating ecosystem services - land, water, seed, feed and the dispersion and assimilation of wastes, including escaped farmed organisms (Beveridge et al. 1997; Soto 2009; Béné et al. 2010). The extent of consumption of these ecosystem services is largely determined by farmed species, and the type and intensity of production methods. While land and water use per unit production decreases with intensity of production methods, demand for seed, feed, energy, the use of ecosystem processes to disperse and assimilate wastes, and the risk of diseases tend to increase.

Under current projections for aquaculture production, special actions will be needed to sustain the ecological processes required for future expansion, and minimize its negative impact on the environment. These negative impacts are detailed in Emerson (1999), EJF (2003), EJF (2004), Cao et al (2007), Hall et al (2011) and FAO (Online) and are summarized below.

Some aquaculture practices lead to conversion of mangroves to ponds and destruction of wetlands resulting in the loss of essential ecosystem services from mangroves including the provision of fish/crustacean nurseries, wildlife habitat, coastal protection, flood control, sediment trapping, water treatment and carbon sequestration. It is estimated that as much as 38% of recent mangrove loss globally may be due to aquaculture – in particular, shrimp farming (EJF 2004). In Vietnam, more than 80% of original mangrove cover has been removed. Mangrove cover in the Mekong Delta's Ca Mau province has reportedly dropped from over 200,000 ha to about 70,000 ha between 1975 and 2002, and shrimp aquaculture has been the major culprit (EJF 2003; EJF 2004 and references therein). Similarly, aquaculture is said to be the main cause of a nearly 50% drop in mangrove cover between 1975 and 1993 in Thailand (EJF 2004 and references therein).

Aquaculture sometimes causes water pollution through the disposal of waste which could include particulate matter from faeces and uneaten food, compounds applied to construction materials, pigments incorporated into feeds, disinfectants and chemotherapeutics. Solids can cause gill irritation and damage fish health. Urine and faeces from aquatic animals can result in high ammonia nitrogen content and increase biochemical oxygen demand. Excess nitrate concentrations together with the presence of other essential nutrient factors can result in eutrophication. It is believed that 1.3 billion m^3 of aquaculture effluents are discharged into coastal waters annually in Thailand alone (Mock et al. 1998). In the US, discharges from aquaculture reportedly contributed to the creation of a 15-acre sediment delta in the Laguna Madre (EJF 2004).

Other aspects of pollution caused by aquaculture include the release of bacteria and pathogens, translocation of strains or species, and introduction of invasive species (Goldburg et al. 2001). Translocated species or strains may carry exotic diseases that could spread and affect indigenous wild populations. Invasive species or escaped farmed fishes could spread and lead to reduced biodiversity through habitat modification, competition, or by interbreeding with native stocks. Up to 600,000 escapes were reported between 1987 and 1997 in the US alone (Goldburg et al. 2001).

Aquaculture could also lead to salinisation of agricultural and drinking water supplies and land subsidence due to groundwater abstraction. For example, shrimp farming is believed to be primarily responsible for increased soil salinity, which has been implicated in a 68% decline in tree cover in an area of Bangladesh. Similarly, aquaculture-induced salinity is believed by local communities to be responsible for the loss of half of the 32 traditionally grown crops in another area of Bangladesh (EJF 2004).

The use of fishmeal and fish oil as food in aquaculture is another concern as it can result in depletion of marine catch fisheries. Roughly a third of global captured fish in 2004 was destined for non-food uses and reduction into fishmeal and fish oil and/or for direct animal feeding. A 2003 estimate indicated that aquaculture was responsible for 53.2% and 86.8% consumption of global fishmeal and fish oil production respectively (FAO 2006). Apart from the depletion of marine catch fisheries, another concern is the fact that it is possible that a good portion of the fish destined for reduction into fishmeal and fish oil is being diverted away from human consumption, especially for the poor communities who still depend on small oily fish including anchovies, sardines, and menhaden for their food security. Furthermore, it is suspected that carnivorous fish which require these fish-based meals consume more fish protein than they produce (FAO 2009b). This concern, however, needs to be put in the right context. Despite the increased trend in aquaculture production, the majority of production is still of omnivores and herbivores (whose feedstuffs are of vegetable origin). However, greater intensification of production is expected to result in increased dependence on feeds and this brings with it concerns about the resultant demands on biophysical resources and impacts on food security. On the other hand, it must be noted that fish convert a greater proportion of the food they eat into body mass than livestock and the environmental demands per unit biomass or protein produced are therefore likely to be lower.

Great care is needed in interpreting these overall concerns around aquaculture and its use of ecosystem services. While there are some broad efficiencies associated with farming fish because they are cold blooded and feed near the bottom of the food chain, the specific impacts of aquaculture depend on the species and production systems and management used. There are clear trade-offs between extensive systems that place higher demands on land use, and ecosystem services such as water, fuel, nutrient cycling, and intensive systems that require higher levels of fossil fuels, feed and produce more wastewater. Of particular significance for the food insecure is the fact that the bulk of developing world aquaculture is of herbivores and omnivores, in contrast to the intensive production of carnivorous marine finfish that dominates developed world aquaculture (Tacon and Metian 2008). This highlights the potential to increase supplies of fish and improve food security in developing countries without increasing demand for fish meal and fish oil from marine fisheries.

Part 2

Towards Sustainable Food Systems

Chapter 4:

Increasing Resource Efficiencies: Sustainable Consumption and Production in Food Systems

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4.1 INTRODUCTION

The ecological foundation for food systems and how it is currently being undermined have been described in Chapters 2 and 3. In this and following chapters we discuss ways to reverse this trend. Making agriculture and fisheries more sustainable is one answer and is taken up in Chapters 5 and 6. In this chapter we discuss a more fundamental approach, namely how to make food consumption more sustainable and how to increase resource efficiency, as well as reduce the wastage associated with food production, processing, supply, sale and consumption. We will see that by consuming more sustainably and reducing waste we can decrease the burden of the current food system on resources and ecosystem services, and thereby reinforce the ecological foundation of agriculture and, in turn, food security.

4.2 THE (UN)SUSTAINABILITY OF CURRENT FOOD SYSTEMS

What people eat affects the biosphere both directly and indirectly. The direct effect depends on the quantity and mix of plants and animals they consume, while the indirect effect is determined by changing patterns of what they eat and how the food is produced. Data suggests that modern patterns of food production and consumption are unsustainable when considering their impacts on resources and the environment (see Chapters 2 and 3). Furthermore, present food consumption patterns seem to pose threats to public health through their linkage with obesity and poor nutrition. The World Health Organization (WHO) has reported that non-communicable diseases, which are largely preventable through changes in diet and other habits, are the leading global cause of death, with not less than 2.8 million people dying each year as a result of disease related to being overweight or obese (WHO 2011a). Diseases related to being overweight or obese are also of economic concern as they result in increased national healthcare expenditure and loss of billions of dollars of national income (Wang et al. 2008; WHO 2011a). In the USA, for example, total health care costs attributable to illnesses stemming from obesity or excessive weight may double each decade up to 2030, rising to annual costs of USD 860.7 to 956.9 billion, which would account for 16-18% of all US health care costs in that year (Wang et al. 2008).

The (un)sustainability of the current food system can also be illustrated in a qualitative sense by examining its so-called ecological footprint. This is a measure of the resources required to produce food, as well as its environmental impacts. Using this measure it has been estimated that by 2030, the resources of the equivalent of two planets will be required to feed, clothe and maintain the world's population at today's average level of consumption (WWF/ZSL/GFN 2010).

4.3 SUSTAINABLE CONSUMPTION

4.3.1 Drivers of Food Consumption and Implications for the Ecological Foundation of Food Security

Food consumption patterns are directly influenced by food availability, accessibility and choice. These factors are in turn indirectly influenced by income, socioeconomic status, geography, demography, urbanisation, globalisation, marketing/advertising, religion, culture and consumer attitudes (Figure 4.1) (Kearney 2010).

Of particular concern with respect to the (un)sustainability of the current world food system is the influence of increased income on food consumption patterns. As household income

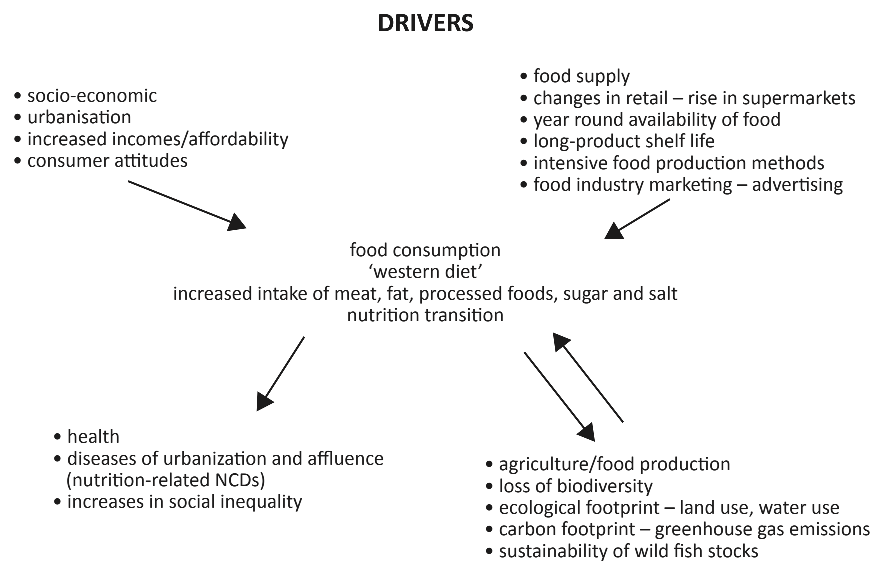

Figure 4.1 Drivers and consequences of food consumption changes
Adapted from Kearney (2010)

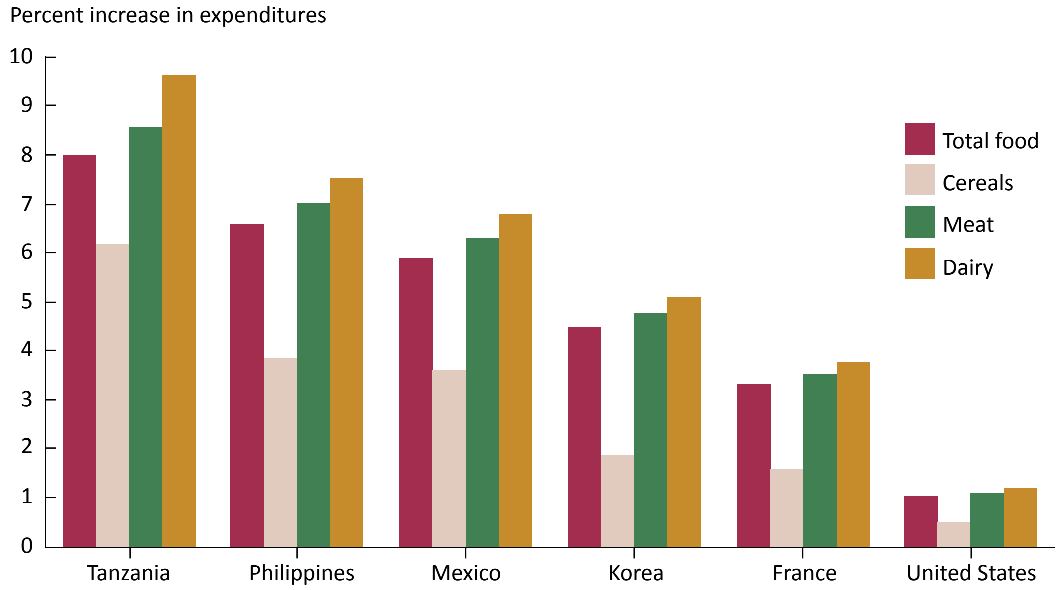

Figure 4.2. Percentage increase in household expenditure on food due to a 10% increase in income. Low-income countries make a greater overall food spending adjustment with increased income and nearly all countries tend to spend disproportionately more on high-value foods (meat and dairy). Source: Seale et al (2003)

rises, food expenditure tend to increase and people tend to modify their diets by eating more and more often, and consuming an increased variety of foods (Kinsey 1994; Kearney 2010). Furthermore, in many cultures, higher income is accompanied by greater consumption of meat and dairy products (Figure 4.2) (Kinsey 1994; Seale et al. 2003; Du et al. 2004), which often require more land, water and other inputs than the foods they replace. A joint report by the Stockholm International Water Institute and the International Water Management Institute indicated that an average of between 0.4 and 3 m^3 of water is required to produce a kilogram of cereals or citrus fruit or palm oil, while an average of 6 and 10 m^3 is required for a kilogram of poultry and lamb respectively. The figure is even higher – 15 m^3 or more – for a kilogram of grain-feed beef (SIWI/IWMI 2004). Another report jointly published by the Wegener Centre and the Sustainable Europe Research Institute indicated that while between 0.25 and 1.82 kg of "material inputs[16]" are required to produce a kilogram of most fruits and vegetables, 4.58 kg and 5.10 kg are required for poultry and pork respectively. The value rises to 17.7 kg for beef and 32.8 kg for dried, salted or smoked meat (Friedl et al. 2007).

Furthermore, increased production of meat and dairy products also undermines the ecological foundation of food security due to its contribution to land degradation, water pollution, biodiversity loss and climate change (Steinfeld et al. 2006; Goodland and Anhang 2009).

Taken together, these trends add up to a greater ecological footprint per person, meaning as personal income increases each person requires more land, water, energy and other resources to produce the food they consume. Likewise, each person is responsible for more greenhouse gas emissions, water pollution and other environmental impacts associated with modern agriculture.

16 Material input is a measure of the amount of resources needed for the production of goods

Apart from its ecological impacts, increased consumption of meat and dairy products may also lead to the diversion of grains for livestock production with implications for food security. Although there is currently no shortage of cereals at the global level, the competition for grains for direct human consumption and for livestock production could drive prices up. This could limit economic access to this staple food, especially for low-income communities where grains constitute a relatively large part of household expenditure (Seale et al. 2003). Whereas food constitutes approximately 10% of household budgets in the US, in developing countries food remains a significant expenditure for households – about 70% in Tanzania and 45% in Pakistan (HLPE 2011).

4.3.2 Nutrition Transition: Health Impact of Unsustainable Food Consumption

As stated earlier, the present patterns of food consumption are posing a significant and rising threat to public health through obesity and poor nutrition, especially in affluent societies. It is ironic that greater wealth partly brings poorer health with regards to food. Popkin (2001) and (2002) called this the "Nutrition Transition", referring to the phenomenon by which increased income leads not only to a larger quantity of consumed food but also to a shift in the nutritional value of foods consumed. People gravitate from water to soft drinks, and eat more fatty, sugary, processed foods. Studies across the developing world show a convergence towards diets high in saturated fats, sugar, and refined foods but low in fibre, often termed the "Western diet" (Popkin 2002). This shift in food preference has been linked to the effectiveness of advertising in selling these types of products to the public (See Box 4.1).

A major negative consequence of the Nutrition Transition has been the creation of new patterns of non-communicable disease such as heart disease, strokes, and cancers (WHO 2011b). For

Box 4.1 Advertising and the Nutrition Transition

The shift in food preference has been linked to the effectiveness of advertising, which studies show influence the food-consuming behaviour of children and young people (Hastings et al. 2004; Sassi 2010). Figures for food advertising are confidential, but one estimate is that expenditure on all food and non-food advertising grew by 50% from 1995 to 2009 (Shaw 2009), reaching nearly USD 500 billion in 2011 (Marketing Charts 2011). Food is the third-highest advertising sector, after personal care products and cars (Johnson 2010), and the products promoted include fast foods and soft drinks, as well as ready-made and high-priced processed products.

example, increased affluence in India has been accompanied by a diet-related increase in the incidence of non-communicable diseases. Estimated figures suggested a projected rise from 3.78 million deaths in 1990 to about 7.63 million in 2020 (Gaiha et al. 2010). WHO indicates that 1.4 billion adults (20 years and older) were overweight as of 2008[17] yet 925 million people are undernourished (FAO 2010; IFRC 2011). Hence, it seems that more people are overweight than hungry. There is also real concern that the steady increase in life expectancy in some affluent OECD countries might actually be reversed by the health impacts of obesity and over-eating (Olshansky et al. 2005). Indeed, some developed countries are beginning to recognise the high financial burden of diet-related ill-health (Wanless 2002). Obesity was estimated to be responsible for up to 6% of national health care costs in the WHO European Region (WHO 2007).

4.3.3 Sustainable Diets as a Driver of Sustainable Food Systems

So what should the response be to consumption patterns that are environmentally-damaging and unhealthy? One answer is sustainable food consumption. The objectives of sustainable food consumption are three-fold: firstly, to reduce the impact of food production on resources and the environment by encouraging consumption of foods that utilize smaller amounts of resources for production; secondly, to enhance the nutritional value of peoples' diets so as to reduce dietary-related illnesses; and thirdly, to influence consumer behaviour regarding food utilization and wastage at the household level.

If current diets are unsustainable or unfavourable from the standpoint of health and environment, then how can this pattern be reversed? One way of achieving this is through the promotion of sustainable diets, which could provide an entry point for policy makers and stakeholders to create the much-needed connection between sustainable production and nutritional value.

Sustainable diets are defined as *"...those diets with low environmental impacts which contribute to food and nutrition security and to healthy life for present and future generations. Sustainable diets are protective and respectful of biodiversity and ecosystems, culturally acceptable, accessible, economically fair and affordable; nutritionally adequate, safe and healthy; while optimizing natural and human resources"* (FAO and Bioversity International 2010).

17 See WHO factsheet No 311 - http://www.who.int/mediacentre/factsheets/fs311/en/

While this definition gives a clear statement of the goals of such a diet, it does not explain what such a diet would include. In this regard, two questions in particular stand out:

- Would a sustainable diet contain meat? This may be the most sensitive consumption issue because of the high water and carbon footprint of meat and dairy products (Tukker et al. 2009; Audsley et al. 2010). Advice on the kind of meat, the amount that can be consumed, and how it should be produced as part of a sustainable diet is likely to vary from place to place. This has challenging implications for policymakers when considering state support for agriculture (Barling 2007).
- Would a sustainable diet contain fish? Most existing national nutritional guidelines promote fish consumption while many conservationists do not, or encourage only the consumption of fish that can be shown to be sustainably harvested.

But some consistent views are emerging from the literature on what would be contained in a sustainable diet (Duchin 2005; Defra 2007; NFA 2009; SDC 2009; Barilla CFN 2010 and references cited in them). There is broad agreement, for example, that consumers in developed countries should reduce their consumption of meat and dairy products and proportionately increase their consumption of vegetables and fruit products based on environmental and/or health considerations. Furthermore, experts also advise consumers to reduce consumption of food and drinks with low nutritional value. They also recommend that food purchasers accept the variability and seasonality of supply – that is, that they accept that some food products may not be available due to seasonality of growing patterns or crop failures. Finally, proponents of sustainability diets also suggest that consumers devote a higher percentage of their food budget to foods produced with respect for the environment. This would reduce the impacts of food production on soils, water quality and biodiversity.

However, it must also be noted that sustainable diet guidelines have potentially negative impacts including economic instability due to a reduction in the size of the food, drink and livestock industries; an increase in land use to meet demand in regions that normally depend on imported food; reduction in trade with developing countries; and infringement of regional trade rules on free movements of goods (SDC 2009). For example, in 2009 the food and environmental agencies of the Swedish Government submitted a proposal for an EU food consumption standard to the European Commission (NFA 2009). The document was withdrawn in 2011 when the agencies were notified that some of its content (e.g. eating seasonally and locally) probably infringed upon EU internal trade rules designed to facilitate free movement of goods.

Furthermore, an international agreement on sustainable diets could be difficult from the viewpoint of environmental impact, since different foods have different impacts depending on where they are produced (Foster et al. 2006). An obvious example is that a crop grown in a greenhouse in Northern Europe uses more energy than a similar crop grown outdoors in Southern Europe (Cellura et al. 2012). Another consideration is the large geographic variation in patterns of food consumption and production that influences their environmental impact. A plausible solution would be to develop guidelines that could be tailored to different regions.

These unresolved issues highlight the need for creating a process for developing sustainable diet guidelines at the national and international levels, and the utility of more research in this area. Once achieved, sustainable diets can help reduce the resource and environmental impacts of food production that undermine the ecological foundation of food security, and at the same time provide healthier eating habits for the world.

4.4 WASTES IN THE FOOD SYSTEM

Despite the fact that a large percentage of the world's population is still undernourished, a huge amount of food is lost or wasted within the food system. This loss occurs throughout the system - from the production stage to household consumption. Food is "lost" at the front end of the food supply chain at the production, post- harvest and processing stages and food is "wasted" at the back end by retailers and consumers (See Box 4.2 for definitions) (Parfitt et al. 2010; Gustavsson et al. 2011). Despite advances in the efficiency of the supply chain, the world still experiences high levels of food loss and waste.

4.4.1 How Much is Lost and Wasted?

According to Gustavsson et al (2011), an estimated one-third of food produced for human consumption is lost or wasted globally, amounting to 1.3 billion tonnes per year. On the whole, more food is lost and wasted in industrialized countries than in developing countries with an estimated per capita loss/ waste of between 280 and 300 kg/year in Europe and North America and between 120 and 170 kg/year in South/Southeast Asia and sub-Saharan Africa (Figure 4.3).

Of these total figures, per-capita food wastage by consumers in Europe and North America accounts for 95 to 115 kg/year, while sub-Saharan Africa and South/Southeast Asia consumers waste only 6 to 11 kg/year (Figure 4.3) (Gustavsson et al. 2011). More than 40% of waste in developed countries is due to consumer's and retailer's wastage, while this figure is only about 6% in sub-Saharan Africa. American consumers throw away 25% of all food they purchase (Bloom 2010; Gunders 2012); British consumers throw away roughly one-third of their purchased food due to

Box 4.2: Definitions of Food Loss and Food Waste

The FAO makes an important distinction between food loss and food waste:

Food loss: Food losses take place at the production, post-harvest and processing stages in the food supply chain. Food losses are greatest in developing countries where agricultural technologies and infrastructure are less developed.

Food waste: Food waste occurs at the end of the food chain (retail and final consumption stages) and relate to retailers' and consumers' behaviour. Food waste is most prominent in developed countries.

Both food loss and waste are measured only for products that are for human consumption, and exclude feed and parts of products that are not edible.

Gustavsson et al (2011)

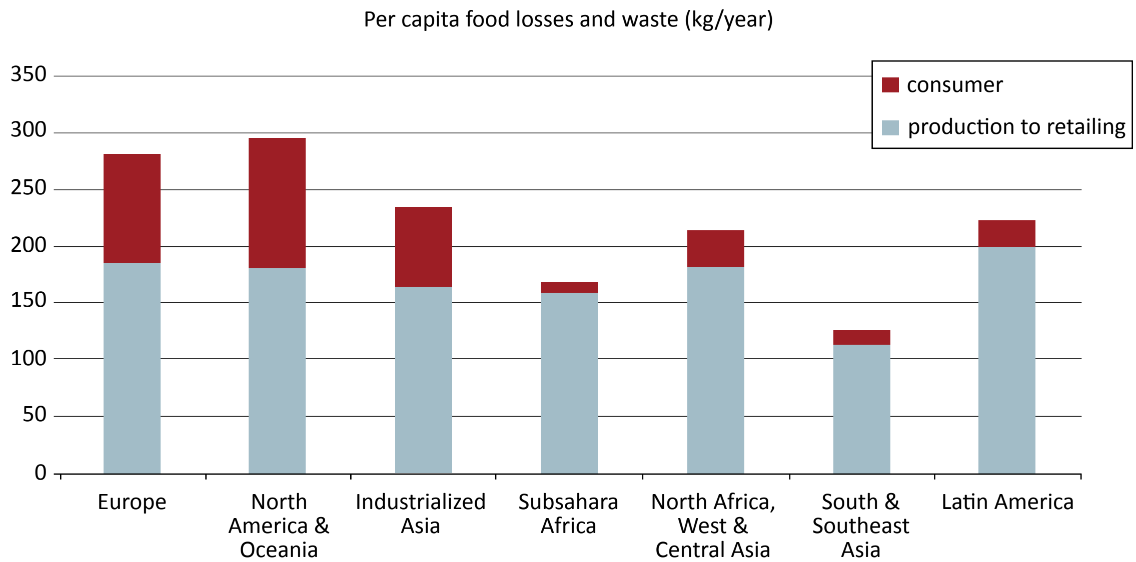

Figure 4.3. Per-capita food losses and waste at the consumption and pre-consumption stages in different world regions. Source: Gustavsson et al (2011)

factors such as over-purchasing in response to marketing offers and obeying expiry dates on products (WRAP 2008).

The food lost in the supply chain or wasted by consumers or retailers also means that the huge amounts of resources invested in their production and supply have been used in vain. According to Gunders (2010), getting food from farm to fork represents 10, 50 and 80% of US energy budget, available land and freshwater consumption respectively. Hence foods thrown away by consumers in the US have a spinoff effect that 4% of the energy budget, 20% of available land and 32% of freshwater use is wasted. Furthermore, this wastage results in greenhouse gas emissions, which cause climate change and thus put further stress on crop production. All together, the food lost or wasted puts unnecessary pressure on the ecological foundation of food production.

Credit: Shutterstock / Berna Namoglu

4.4.2 Reducing Food Loss in Supply Chains

In developing countries, the major cause of food loss is the lack of infrastructure for processing, transportation, storage, and cooling of food. According to the World Resources Institute, up to 40% of food harvested in developing countries might be lost because of this gap in infrastructure (WRI in UK Cabinet Office, 2008), but also because of inadequate market systems and a failure to meet food safety standards (Gustavsson et al. 2011). However, the lack of processing facilities and infrastructure seem to be the major drivers. Post-harvest losses of maize in East Africa range from 5 to 35%, while that of rice in Asian countries ranges from around 10 to 25% or more (Hodges et al. 2011; World Bank 2011). More generally, post-harvest loss of perishable crops in developing countries is estimated to be around 16 to 49% (Parfitt et al. 2010; UK Foresight 2010 and references therein).

Options for curbing these losses include increased public and private investment in market, transport and storage infrastructures, especially in developing countries. Taking these steps would help curb grain loss caused by pest and fungal infestation during storage, as well as loss of fresh produce caused by the lack of well-managed and hygienic municipal market infrastructure and unavailability/inadequate cold-storage facilities (Gustavsson et al. 2011).

Experts in the literature (Parfitt et al. 2010; UK Foresight 2010; Gustavsson et al. 2011 and references cited in them) have identified other options for reducing food loss at the front end of the food supply chain, such as:

- Organising small-scale farmers in order to help them scale up their production especially by sharing centralized transportation, storage, cooling and marketing facilities.
- Developing knowledge and capacity for stakeholders involved in food production and supply (including farmers, processors, distributors and retailers) in order to ensure that safety standards are adhered to, thus preventing losses associated with disposal of unhealthy foods.

4.4.3 Reducing Wastage at the Retail and Consumption Stages of the Food Supply Chain

Many factors lead to food wastage at the retailers' and consumers' end of the food supply chain, including: demand for high quality standards for food in terms of appearance, weight, size, and shape; demand for a wide variety of food types by consumers; and the need for retailers to order a range of different food types in order to get beneficial wholesale prices. Wastage can also be caused by the production of food amounts exceeding demand and the inexpensiveness of disposal compared to cost of reuse (Gustavsson et al. 2011).

Options for minimizing wastage at the end of the food chain as identified in the literature (Kader 2005; Choudhury 2006; SEPA 2008; EC 2008; Stuart 2009; Parfitt et al. 2010; WEF 2010; UK Foresight 2010; and Gustavsson et al. 2011) include:

- Increasing public awareness about the importance of not wasting food, and the need for a cultural shift in the way consumers value food.

- Improving food labelling and better understanding of labelling and its impact on waste levels (e.g., storage instructions, nutritional value, and meaning of expiry dates).

- Relaxation of quality standards that do not affect the taste or safety of food such as weight, size and appearance.

- Developing a market for sub-standard products and consumable products deemed as waste e.g., products with damaged packaging and trimmings from potato chip production.

- Change in business behaviour aimed at waste reduction. This could take the form of developing business models that reduce waste. One example is the closed-loop model in which wastes are fed back into the value chain. Concrete measures include reuse of packaging and utilization of combustible material for energy generation.

Supermarkets can play an important role in waste reduction, as they account for a major part of the food market in many industrialized countries and a rapidly growing share in developing countries (Reardon et al. 2003; Barling et al. 2009). If they so desire, they can make an important contribution to sustainability by unilaterally implementing the above actions.

4.5 IMPROVING RESOURCE EFFICIENCIES OF FOOD SUPPLY CHAINS

In this section, we discuss how to make the food system more sustainable by improving the efficiency of the food supply chain, while encouraging the participation of smallholders. The first idea is to use Life Cycle Analysis (LCA) to identify opportunities for improving resource efficiency. The second idea is to promote certification and standard-setting of food products. The third idea involves strengthening cooperation between companies and smallholders in order to achieve a sustainable food chain, while the fourth idea is to develop markets for "low value" crops.

4.5.1 Life-Cycle Analysis as a Major Driver of Resource Efficiencies in Supply Chains

The sustainability and efficiency of a food supply chain can be further boosted by adopting a life-cycle approach to better understand where inefficiencies in the chain occur (Box 4.3). Life Cycle Analysis (LCA) or life cycle thinking has become an important tool used by governments and industry to monitor and evaluate the environmental impact of food systems. It is also used to improve efficiencies in supply chains by providing a better understanding of key environmental impacts and major leverage points in the chain. LCA helps to build a holistic picture of the supply chain and thereby helps producers and processers to maximise the effect of their intervention and improve their use of resources. Life-cycle thinking is now a mainstream approach for addressing sustainability in the food system (UNEP-SETAC 2009). For example, the International Dairy Federation released a publication titled: 'A Common Carbon Footprint Approach for Dairy – The IDF Guide to Standard Lifecycle Assessment Methodology for the Dairy Sector' to improve its industry's environmental performance.

4.5.2 Stakeholders and Resource Efficiency: Certification and Standard-Setting as a Tool for Sustainability

The various actors involved in the food supply chain can encourage a more sustainable food system in many ways, for example:

**Box 4.3: Life Cycle Analysis:
Environmental Impacts and Resource Efficiency of Food Consumption and Production.**

Life cycle analysis (LCA) is a common analytical tool used for assessing the environmental impact and resource efficiency of food production and consumption (Heller and Keoleian 2000; Tukker et al. 2006). A typical LCA provides a snapshot of the environmental impact of a product across its entire life cycle: production of raw materials, crop production or livestock raising and their inputs, distribution of products and their transport, processing, and preparation, as well as waste management of packaging material.

It is essential to define boundaries and criteria of LCAs in order to obtain meaningful results and identify and balance the effects of all resource efficiencies. This is illustrated by the results of a study comparing the energy impacts of domestic versus imported lamb and apples to the UK from New Zealand. Researchers came to different conclusions about the relative impacts of these commodities depending on the type and number of factors taken into account (Saunders et al. 2006; Williams et al. 2006). The lesson is that such assessments need to be spatially precise and adjusted to growing conditions, seasonality and inputs. They must also factor in supply chain logistics, such as refrigeration and storage time and the period between harvest and placement in the retail market, alongside transport mode and costs (Edwards-Jones et al. 2008). In addition, a key component of the LCA of a food supply chain is the behaviour of the domestic consumer. For example, to drive 6.5 miles to a shop produces more CO_2 than air freighting a pack of green beans from Kenya to the UK (DfID 2007).

LCAs can also incorporate social, health and economic factors in the analysis, in addition to standard environmental factors. As an example of a beneficial economic impact that might be identified in an LCA, the Natural Resources Institute (2006) found that UK imports of fresh produce grown in sub-Saharan Africa (excluding South Africa) support over 700,000 workers and their dependents. Social criteria associated with food products are now being developed for use in LCAs (UNEP-SETAC 2009).

- Through certification of products produced through agricultural practices with reduced environmental impacts and higher efficiency, such as Integrated Farm Management, Integrated Pest Management and Good Agricultural Practice. Examples include the certification programmes of GlobalGAP and the Sustainable Agriculture Initiative (GlobalGAP 2008; SAI 2008). These are mainstream business-to-business standards that bring together a mix of best practices including food safety criteria such as the safe use of pesticides and hygienic harvesting practices (see Chapter 5 for more details about these agricultural practices).
- Through business-to-consumer standards at the farm or fishery level that are often accompanied by labelling of products. Product labels not only signal the sustainability of a product to consumers, but they are also a useful tool for encouraging farmers to adopt practices that have lower impacts on natural resources and ecosystems. Examples include ethical or environmental standards such as Fairtrade, Rainforest Alliance and organic certification programmes. Another example is the certification for sustainable fisheries from the Marine Stewardship Council (MSC 2012). MSC certification is often the desired, but not the only, end result of Fishery Improvement Programmes, which are emerging as the industry-led answer to sourcing sustainable seafood.
- By convening a large stakeholder group from a particular sector or commodity group to promote sustainability benchmarks or standards for lower environmental impact. These public-private initiatives tend to be established for a number of reasons - scarcity of supply, consumer concern, decreasing yields and deforestation, among others. The Roundtable for Sustainable Palm Oil[18] is one example.
- By some supermarkets unilaterally adopting standards that suppliers are asked to adhere to before contracts are signed (see below).

It must be noted however, that standard-setting could have both negative and positive impacts on producers. On the positive side, exporters in developing countries seeking access to developed country markets have the opportunity to participate in more environmentally sensitive food production.

On the negative side, there is evidence that standards used by buyers in cross-continental food chains have marginalized smaller producers in favour of larger ones who are better able to meet required specifications (Dolan and Humphrey 2000). Standard-setting also increases the burden on farmers who, if they supply several supermarkets, may well have to comply with different sets of standards for each (Fulponi 2006). The situation can be improved by helping farmers to meet standards and by harmonizing standards across the food chain.

Some initiatives are already being reported along these lines. For example, two of the largest multi-national food companies, Walmart and Unilever, have pledged to increase their reliance on small-scale producers and to help them improve their agricultural practices (Unilever 2010; Walmart 2011). Such actions are often motivated by the belief that their source of raw products will be more resilient and secure if it is based on a large pool of small providers that produce efficiently. Unilever aims to link 500,000 smallholder farmers into their supply network, while Walmart plans to train one million agricultural producers, half female, in areas such as crop selection and sustainable agriculture techniques by 2015.

4.5.3 Strengthening Cooperation between Companies and Smallholders towards Achieving Sustainability.

At the global level, food systems have become integrated both vertically and horizontally. The four biggest seed companies, for

Credit: UN Photo / Evan Schneider

18 Palm oil is a widely found ingredient in manufactured food products

example, occupy more than half the commercial seed market (ETC 2008); the biggest ten corporations (four of them among the top 10 seed companies) together account for 82% of the world's pesticide business (Emmanuel and Violette 2010).

The presence of these and other big transnational companies in developing countries gives local farmers the opportunity to become part of national and international food value chains, especially through contract farming. In some developing countries, the share of contract farming relative to total farming is high, and the involvement of transnational companies is also high. For instance in Brazil, 75% of poultry production and 35% of soya bean production is largely through contract farming to large transnationals (UBA 2005). The story is similar in Vietnam, where 90% of total cotton and milk, 70% of sugarcane, 50% of tea and 40% of rice is produced under contract (ADB 2005). In Kenya, about 60% of tea and sugar production is under contract (Ochieng 2005).

However, as was already mentioned in Section 4.5.2, not all farmers are in a position to benefit from the increasing presence of transnational supermarket chains or food processors in their countries' markets. Small-scale farmers in remote areas are particularly ill-equipped to cope with the changing nature of the value chain. For farmers who fail to meet the requirements of agribusiness firms, market conditions can become increasingly difficult. Evidence from dairy industries in Argentina (Barbero and Gutman 2008) and Brazil (Farina 2002) show that the smaller producers who did not meet the threshold scale of operation required for supplying retailers (mainly transnational corporations) have exited the industry or now operate in the informal sector.

Besides the actions of companies, governments and other organisations also have a key role to play in creating an enabling environment and investment climate conducive to more sustainable and inclusive supply-chain practices. The key idea here would be for governments and others to help strengthen the linkage between large processors and retailers and small-scale farmers. The UN Conference on Trade and Development (UNCTAD 2009) spells out some concrete ideas on how to strengthen these linkages:

- Improve the capacity of smallholders to supply products in a consistent and standardised manner.
- Help make the technology needed for modern farming available to smallholders.
- Improve the access of smallholders to capital.
- Improve local transportation and other infrastructure to make it possible for even remote producers to gain access to markets and improve capacity for timely delivery.
- Increase the role of farmer organisations.
- Provide adequate legal instruments for settling disputes between farmers and the business community.

Meanwhile, international agencies are also beginning to link small producers to growing urban markets within developing countries in order to promote greater resource efficiency. For example, UNEP, in partnership with the International Rice Research Institute, key governments, NGOs and companies in the global rice sector, has convened the Sustainable Rice Platform (UNEP 2011). The Platform is working to set standards for more resource-efficient production and to encourage links of producers to markets. Another interesting initiative is the "Purchase for Progress" action of the World Food Programme (Box 4.4).

4.5.4 Developing Markets for Alternative Low-value Crop Supply Chains

As we saw in Chapter 2, traditional small-scale farming is adapted to local conditions and often requires lower external inputs like artificial fertilizer and pesticides per hectare. Hence, in many circumstances it can be more environmentally friendly than conventional agriculture. The problem is that income from well-adapted, local crops like cassava is typically very low, and so traditional farming can also reinforce rural poverty and food insecurity.

One solution to this dilemma is to create markets for crops that are traditionally considered of low or no value as alternative sources of raw materials for industry. An example of this is the replacement of barley with sorghum in the beverage industry. Another is substituting cassava for wheat in flour production (Box 4.5), and for maize in starch production. The benefits of this substitution are two-fold. First, it creates a market for excess crops that would normally go to waste. Second, relatively environmentally friendly crop production is encouraged.

Box 4.4. World Food Programme "Purchase for Progress" Initiative[19]

WFP's Purchase for Progress (P4P) pilot initiative offers smallholder farmers opportunities to access agricultural markets and invest in sustainable production in 20 countries. A major buyer of staple food, WFP bought USD 1.23 billion worth of food in 2011 – more than 70% of this in developing countries. Through P4P, WFP has since 2008 contracted over USD 80 million worth of food commodities either directly from farmers' organisations or through structured trading platforms such as warehouse receipt systems. Over 133,000 farmers, warehouse operators and small and medium traders have been trained by WFP and partners in marketing, food quality and storage, organisation management, sustainable farming techniques, quality control and post-harvest handling. P4P also encourages other buyers of staple commodities, including governments and the private sector, to increasingly buy from smallholders.

19 More details at http://www.wfp.org/purchase-progress

Box 4.5. Creating Markets for Low-Value Crops: A Case Study of Cassava

Cassava is increasingly being processed in developing countries and exported to developed countries for non-food uses. According to the FAO, over 55% of the world annual production (233 million tonnes) comes from only five countries, Nigeria being the largest producer (36.8 million tonnes), followed by Thailand, Indonesia, Democratic Republic of Congo and Brazil[20]. Thailand is the largest exporter of cassava products, channelling about 50% of its annual production to the starch industry. However, many starch producers are still reluctant to replace maize with cassava because of the uncertainty of quality and consistency of supply.

Increased adoption of cassava as a starch source addresses directly the three key aspects of sustainable development:

Environmental: Substituting crops such as maize with cassava for starch production can reduce the burden of farming on the local environment and can reduce the risk of clearing forests for agricultural use.

Social: The processing of cassava increases local job opportunities and may lead to more stable revenues for the community.

Economic: Developing an export market for cassava supports local economic development and has the potential of lowering costs for starch in importing countries.

20 Data from FAOSTAT http://faostat.fao.org/

4.6 TOWARDS RESOURCE EFFICIENCY – A NEED FOR JOINT ACTION

We have seen in this chapter that achieving a sustainable system for food production and consumption will help maintain the ecological foundation of the world food system by lessening the pressures on natural resources and ecosystem services that support agriculture. For this and other reasons the movement towards more sustainable food production and consumption has become a driver of change in the food system. This chapter has described many actions being taken by the public and private sectors in this direction.

One important collaborative action not yet mentioned is the formation of the Sustainable Food Systems Programme by the FAO and UNEP to improve resource efficiency and reduce the pollution intensity of food systems while also taking into account food and nutrition security and waste reduction. To further the objectives of the programme, an Agri-Food Task Force was established by several countries, UN agencies, NGOs and the private sector.

While these and other actions are encouraging, many observers believe that sustainable food production and consumption will only become a reality if individual consumers begin to change their food consumption habits. However, this is a sensitive issue since society also pursues economic growth by stimulating consumption (Jackson 2009). It is generally accepted that changing consumer behaviour will require public engagement, and a wide range of measures from consumer education to sustainable dietary guidelines.

In sum, a combination of both 'push' factors (improving the efficiency of the food supply chain) and 'pull' factors (encouraging sustainable food consumption) is likely to bolster the sustainability of food systems, provide a higher level of food security, and encourage healthy eating habits.

Chapter 5:

Strategies For Sustainable Agricultural Production Systems

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Credit: Shutterstock / Hannamariah

5.1 INTRODUCTION

Chapter 2 of this report, which outlined the ecological foundations of agricultural productivity, shows how these foundations are being undermined by present practices and policies. Many experts believe that it is urgent to make agricultural production systems more sustainable so that we can meet the world's food needs without jeopardizing these foundations.

Already, concepts of sustainable agricultural intensification and sustainable land management are gaining currency in policy and scientific circles as a goal for both public and private action (Pretty 2008; Meyer 2009; Royal Society 2009; HLPE 2011; CSACC 2011). This chapter reviews how this new way of thinking can be achieved by bringing together technical innovations, commercial activities, policy support, institutional changes, and cultural evolutions for better managing natural resources and ecosystems for human benefit. The chapter highlights farm-level and landscape-scale innovations that are ready for mainstreaming, and then summarizes options for action at the policy, production, and market levels for scaling up sustainable agricultural systems.

5.2 ESTABLISHING MORE SUSTAINABLE SYSTEMS AT FARM SCALE

In this century, agricultural systems will need to evolve in ways that intensify production to ensure nutrition and food security while sustaining the associated ecosystems on which this depends (Uphoff 2002; McIntyre et al. 2009; NRC 2010; Giovanucci et al. 2012). Coordinated strategies and appropriate technologies are needed to support this transition.

The following approaches and management systems have proven to be effective and can be applied to improve farm production and/or restore degraded landscapes (Tiffen et al. 1994; German et al. 2012). However, no single initiative by itself is a sufficient response; farmers need to combine the approaches most suitable for their particular farming systems.

5.2.1 Improve Soil Systems as the Basis for Production and Ecosystem Health

As noted in Chapter 2, good management of soil systems provides the foundation for any productive and sustainable agricultural system. Environmental benefits include better absorption and retention of rainfall, reduced erosion and flooding, and carbon sequestration for climate system stability.

One way to more effectively manage soil systems is through conservation agriculture (CA). Key elements are: minimizing mechanical soil disturbance (no tillage), maintaining permanent soil cover, and diversifying crop rotations. Permanent ground cover and cessation of ploughing reduces water and wind erosion of soil, maintains soil structure, and enhances biological activity in the soil, thereby improving the fertility and sustainability of soil systems and restoring degraded lands.

Over the last two decades, cropland under CA has increased globally by around five to six million hectares each year (Kassam et al. 2009; Kassam et al. 2010; Friedrich et al. 2012). Conservation agriculture has been adopted by both large commercial and small-scale farmers who have achieved yields 20 to 120% higher than those under conventional cultivation (ACT 2009; Derpsch et al. 2010; FAO 2010). It is estimated that CA is now being used on about 106 to 117 million hectares across all continents, in many different agricultural ecologies and at various scales (Kassam et al. 2009; Kassam et al. 2010; Friedrich et al. 2012). Higher yields with lower input costs increase profitability for farmers, while reductions in labour requirements and increased soil and farm biodiversity are also often achieved (Milder et al. 2011).

5.2.2 Make Water Resource Management more Comprehensive and Efficient

We saw in Section 2.2.1 that a reliable supply of water is essential for sustaining food production. It was also noted that irrigation faces steep competition from other water-use sectors. In the face of this competition it makes good sense to make the most of available water supplies by boosting efficiency on the farm and off. The efficiency of using two kinds of water needs to be improved – that of "green water", and that of "blue water".

Green water is rainfall that infiltrates into soils and is stored there and in vegetation and plant root zones, both on and off farms. In contrast, blue water is what flows overland or underground through streams, rivers and aquifers, and is held in ponds, lakes, and reservoirs and is available for diverse uses (Falkenmark and Rockström 2010). Both sources need to be managed purposefully. The supply and availability of green water can be maximised, for example, through sound soil management that conserves soil moisture. This can increase the economic efficiency of farming by enabling more crop production for less water usage. It also increases the environmental efficiency of farming because less water is required per hectare, meaning lower water withdrawals for irrigation and less polluting runoff from fields. Improvements in the functioning of agricultural watersheds, for example, by maintaining well-forested upland areas that slow down the runoff from precipitation, can help augment overall water supplies for human and ecosystem needs (Achouri 2002; Milder et al. 2011).

Along with better use of green water, it is also important to increase the efficiency of using blue water. This can be achieved through means such as sprinkler or drip irrigation; laser levelling of fields; deficit irrigation (Fereres and Soriano 2007; Geerts and Raes 2009); groundwater development, provided that extraction does not exceed regeneration; rainwater harvesting at field to farm to community scales (Box 5.1); and water recycling, including the use of treated wastewater (Molden et al. 2007). Small-scale technologies can have a substantial cumulative effect if used across whole landscapes.

Box 5.1. A '5% Solution' to Water Stress in India

An Indian NGO working with rural communities in upland areas has developed a low-cost water-harvesting technology called 'the 5% model' that is spreading rapidly. PRADAN encourages farmers to take 5% of their rain-fed paddy fields out of production, and to build catchment ponds that can trap and store water which runs over their fields during monsoon rains. This enables farmers to provide supplementary irrigation when their crops come under stress for lack of rainfall or soil moisture later in the season. It also increases percolation which augments water availability downstream. An investment of Rs. 80,000 (1,775 USD) per hectare can increase up to seven households' food security by 20-30%, and family incomes by 10%-25%, depending on the crop mix (information provided by PRADAN field staff).

Credit: PRADAN

5.2.3 Increase Plant Efficiency through Integrated Nutrient Management and Modified Crop Management

Conventional agriculture depends heavily on the use of inorganic fertilizers (Section 2.3.1). As an alternative approach, Integrated Nutrient Management (INM) reduces dependence on these fertilizers by building on the techniques of good soil management.

INM aims to better utilize nutrient cycles in the soil and relies more on organic means of fertilization, supplemented with selective, careful use of inorganic fertilizers on soils that require them. The latter are applied to enhance the productivity of available organic inputs, rather than vice versa, with the aim to continuously improve the structure and functioning of soil systems (Uphoff et al. 2006). Supporting this approach, a study conducted in western Kenya shows that applying synthetic nitrogen fertilizer has negative economic returns until levels of organic carbon in the soil have reached at least 3% (Marenya and Barrett 2009).

To raise and maintain agricultural productivity, it is essential to build up soil organic matter, particularly where soils are relatively infertile. Green manures, cover crops and nitrogen fixing trees enrich the soil and lower soil temperatures for the benefit of soil organisms while inhibiting weed growth. This approach works best where farmers have access to substantial amounts of organic material, given competing demands for straw and other crop residues. Producing biomass that enriches the soil may contribute more to agricultural production than direct efforts to raise crop output on deficient soils.

An example of how INM and modified crop management can increase yield is the System of Rice Intensification (SRI) which has shown potential to increase yields from existing rice varieties, both improved and unimproved, without requiring artificial inputs and with less application of water (see Box 5.2). This is done by enhancing soil organic matter, and promoting active soil aeration (PWE 2011; SRI-Rice 2012). Environmental benefits include reduced demand for water and agrochemicals. SRI concepts and methods have achieved similar yield increases from wheat, sugarcane, finger millet, teff, rapeseed, various legumes, and vegetables (Prasad 2008; ICRISAT/WWF 2009; Araya and Edwards 2011).

The sustainability of increased yields from these methods are still being discussed; but so far the higher yields have usually been sustained over time and even increased, provided that organic matter is returned to the soil to maintain its fertility. These methods are not limited to 'organic' production since inorganic fertilizers can be used along with the other

Box 5.2: Agroecological Practices Increase Food Security in Nepal and Ethiopia

The FAO-European Union Food Facility Programme in western Nepal, which works with households among the poorest and most vulnerable in the country, has introduced the System of Rice Intensification (SRI) through Farmer Field School plots, initially each with 25 farmers from a district. The technique has produced yields of 6.0 to 8.4 tonnes per hectare which are 48–153% higher than farmers now obtain with conventional practices. Given its lower production costs, SRI crop management gave rice farmers an 84% higher net return on average. The programme has calculated that with the new methods, a household of five persons could meet its staple food needs for one year with just 0.15 hectare (FAO/EU 2011)

Planting of single rice seedlings on an SRI plot and harvesting rice in western Nepal
Credit: FAO/EU (2011)

In dry Tigray province in northern Ethiopia, an NGO, the Institute for Sustainable Development (ISD), has pioneered a similar set of principles called 'planting with space'. Finger millet yields, normally about 2.8 tonnes/hectare, have reached 7.6 tonnes, with as many as 39 panicles (heads) on a single plant. Yields of teff, the nationally preferred cereal grain, which are typically about 1 tonne/hectare, have increased to 4.8 to 6.0 tonnes with modified crop management (Araya and Edwards 2011).

management methods if cost or availability considerations limit the ability of a farmer to apply organic matter to the field.

5.2.4. Manage Pests and Diseases through Biological Control and Ecosystem Management

Section 2.2.2 explains that natural control of crop diseases and pests is carried out by organisms living inside and outside the boundaries of cropland. It was also pointed out that pesticides applied to crops sometimes spread to the vicinity of these organisms and destroy them. One important way of protecting these helpful organisms is through "Integrated Pest Management" (IPM), a pest management system that enables farmers to make targeted and focused decisions about pesticide application[21]. IPM relies not only on biological control methods and ecosystem management, but also on better monitoring and understanding of pests. Pest control strategies become a combination of observation, cultural practices, mechanical and biological control, and targeted pesticide application if needed. As an example, in 2008 potato farmers in the State of Maine, USA saved USD 17 million in the form of avoided crop loss and reduction in pesticide usage by better anticipating the conditions under which potato blight could become a threat and by monitoring fungal infections.[22]

In its present form, IPM is being mainstreamed into sustainable farming standards, and is being practised widely in both small- and large-scale farming systems throughout the world. IPM is also expanding to include emerging knowledge of ecological dynamics which enables agriculture to move beyond one-plant/one-pest (or pathogen) control strategies and towards an integrated approach to plant health (Baumann 2000; Waller et al. 2005). With this and other new knowledge, it may be possible to even further decrease pesticide requirements.

21 See http://www.fao.org/agriculture/crops/core-themes/theme/spi/scpi-home/managing-ecosystems/integrated-pest-management/ipm_what/en/ and http://www.epa.gov/oecaagct/tipm.html for detailed explanation of IPM concept

22 From Northeastern IPM Insights (http://www.northeastipm.org/about-us/publications/ipm-insights/ipm-saves-maine-potato-growers-17-million/)

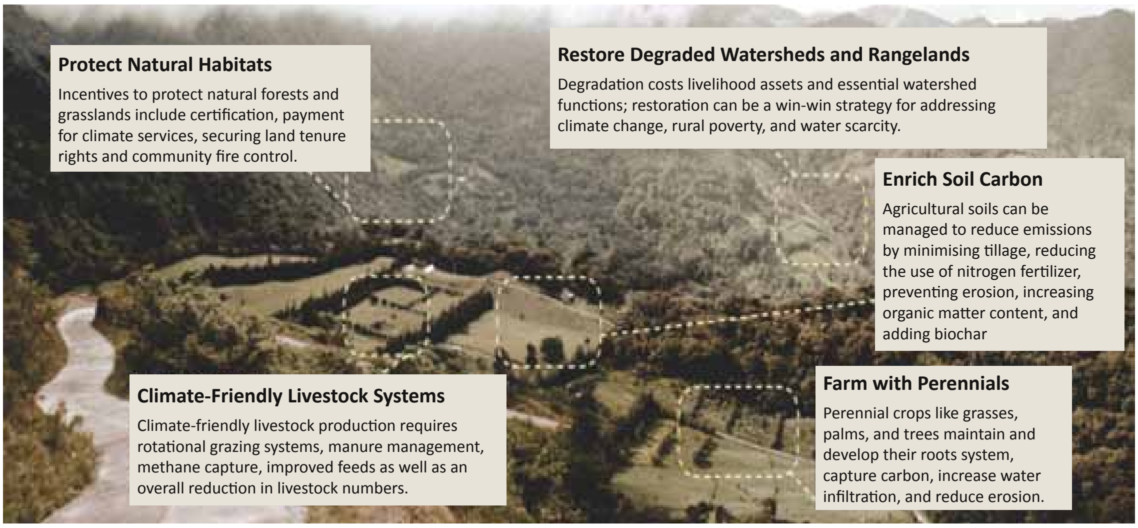
5.2.5. Agroforestry: Grow Perennials On-farm for Food Security, Income and Ecosystem Benefits

Trees, shrubs and palms integrated into a farm can provide year-round vegetative cover that reduces soil disturbance and can often provide habitat for wild species, including crop pollinators. The practice of using perennial trees and shrubs within a farm system is referred to as "agroforestry". Experiments in Zambia and Nigeria have shown that agroforestry can improve rainfall use efficiency (Sileshi et al. 2011). Trees serving as windbreaks can improve microenvironments for crop production, reduce evapotranspiration and improve soil water utilization. Diverse tree species can provide food, proteins, vitamins, bioenergy, building materials, medicines and raw materials for local enterprises, and replace the extraction of wood from forests and natural habitats (Dewees et al. 2011). One promising avenue is developing perennial varieties of annual cereal crops (DeHaan et al. 2007; Glover et al. 2010).

Leguminous trees, which fix nitrogen in their roots, can often increase crop productivity and economic returns at low cost (Mafongoya et al. 2006). Fertilizer trees have been shown to add more than 60 kg N per hectare per year to soils, thereby reducing mineral N fertilizer requirements by 75% (Akinnifesi et al. 2010). Farmers in Malawi and Zambia who intercropped with fertilizer trees increased their average maize yield by 75% to 280%, all else remaining constant (World Agroforestry Centre 2009). More research is however needed to refine such systems and assess their limits and sustainability, but perennials will surely play a larger role in future agriculture.

5.2.6 Undertake Integrated Livestock Systems Management

Farmers have become specialized in either crop or livestock production as the need for economies of scale and efficiencies has become a significant determinant of profitability. However, climate and other factors are likely to make production units



An agroforestry landscape in Costa Rica supports increased agricultural production, local livelihoods, and ecosystem services, including climate change mitigation and adaptation.

Credit: EcoAgriculture Partners

that combine both crops and livestock more attractive in the future. Improved pastoral systems (as described in Box 5.3) and livestock mobility can offer advantages by buffering shocks of weather and other disasters.

Plant breeding can also support more sustainable agriculture by focusing on less-commonly-researched crops like millet and sorghum, legumes, and food or fodder trees. Crop varieties could be developed with traits that benefit ecosystem management and conservation as well as yield, such as deeper rooting and shade tolerance that increase farmers' ability to cope with climate pressures, or varieties that are high-yielding in polycultures.

Box 5.3. Holistic Planned Grazing

A strategy called 'holistic management' for livestock on semi-arid ranges, developed first in Zimbabwe, has demonstrated counter intuitively that grasslands can become more productive (and desertification reversed) when heavily stocked with more animals per unit area. The key is to stock the animals for short periods using a planning process that addresses social, environmental and economic factors. Careful range management mimicking nature's past evolution of grasslands accelerates pastures' mineral cycles, energy flows and community dynamics, as explained in Savory and Butterfield (1999).

Unretouched photo of a landscape in eastern central Australia. The green land is under "holistic management", while the surrounding brown land is not. Both areas receive the same rainfall, with no irrigation. Credit: Holistic Management International (www.holisticmanagement.org)

More integrated production systems would reduce livestock wastes and greenhouse gas emissions, and increase input and resource efficiency. Farmers could take advantage of synergies among plants, trees and animals. Livestock would produce manure for enhancing soil fertility and the non-marketable biomass from crop production could be used to feed livestock. This style of farming would also reduce the water pollution and waste problems that arise from intensive rearing of cattle, pigs, chickens and other animals (Box 5.4).

5.2.7 Improve and Maintain the Diversity of Genetic Resources

As explained in Chapter 2, improved genetic resources and a greater diversity of species and varieties of crops, grasses, trees, soil microorganisms, and pollinators will be needed to sustain productive agroecosystems and adapt to climate change and an expected decline in the availability of water resources at some locations (Jarvis et al. 2007).

5.3 DEVELOPING MORE SUSTAINABLE SYSTEMS AT LANDSCAPE SCALE

Section 2.2 points out that the ecological foundation of agriculture depends on maintaining ecosystem services, both on the farm and outside the farm, as well as managing land and water, both on agricultural land and outside of this land. Indeed, many experts have concluded that sustainable agriculture will not work at the individual farm level; they believe that a broader "landscape approach" is needed in which many different farms cooperate with the surrounding population over a wide area (Scherr and McNeely 2008; Phalan et al. 2011).

Box 5.4. Low-Confinement Integrated Hog Production Systems in the U.S.

In the U.S., owner-operated, low-confinement, integrated hog-producing systems are now competing effectively with large factory farms. Meat products are produced sustainably, marketed through farmer cooperatives that sell under their own brand names and certified for humane animal treatment, with no antibiotic use and with chemicals used only for parasite control. The higher costs of production (17%) are no larger than the public subsidies going to large-scale corporate farms for concentrated animal feeding operations (NRC 2010).

Biotechnology techniques can enhance conventional crop and livestock breeding (Wang et al. 2005; Chi et al. 2010). As an example, certain soil fungi can confer drought-resistance on rice (Redman et al. 2011). The advantages and disadvantages of genetic modification are still open to debate but some believe that it can make a contribution to sustainable agriculture. For example, some believe that genetic modifications can enhance crops' resistance to various environmental stresses, such as drought, salinity and cold stress (Garg et al. 2002).

5.3.1 Potential Benefits of Landscape-scale Investment and Management with Community Action

Community-coordinated action among sectors at landscape scale can provide important additional options that reduce farming systems' vulnerability and promote resilience. Examples include sub-catchment scale rainwater harvesting, re-vegetating degraded farm and common lands to improve watershed functions, protecting wild crop pollinators, designating pasture reserves for use during droughts, regulating water withdrawals for irrigation to ensure availability for downstream water users, and organising the harvest of products from community and government forests to ensure sustainability and equitable access. Biofuel production can in some cases be integrated strategically into areas of the landscape that do not displace food production (Milder et al. 2009).

5.3.2 Principles of Integrated Landscape Management

Achieving multiple objectives across entire landscapes requires integrated management. These go by various names: ecoagriculture, participatory watershed management, biological corridors, landcare, landscape restoration, socio-ecological landscapes, and other terms, depending on their history and entry point for action (Scherr and Shames 2012).

5.3.3 Landscape Priorities for Action and Current Efforts to Scale up the Approach

Taking a landscape approach does not mean that the same actions must be taken at every location. In fact, the type of action can vary greatly from place to place. For example, in dry areas experiencing more erratic rainfall due to changing climate, priority may be given to watershed management and water use efficiency. By comparison, in areas with chronically low or declining productivity due to land degradation, priority may be given to investments in soil-building and for restoring production-related ecosystem services for nutrient cycling, pollination, and pest and disease control. Because the task of building sustainable agriculture will be different from place to place, it is sensible for national programmes supporting sustainable agriculture to factor in this diversity.

Credit: Shutterstock / David Brimm

These strategies share some common principles:

- Landscape interventions are designed to meet **multiple purposes**, including human well-being, food and fibre production, climate change mitigation, and conservation of biodiversity and ecosystem services.
- Ecological, social and economic interactions among different parts of the landscape are managed to attain **positive synergies** among interests and actors, and to reduce negative trade-offs.
- The essential **roles of local communities and households** as both producers and land stewards are acknowledged and reinforced.
- A **long-term perspective** is taken for sustainable development, adapting strategies as needed to address dynamic social and economic changes.
- **Participatory processes** of social learning and multi-stakeholder negotiation are institutionalized, involving all parts of the community and ensuring that the livelihoods of the most vulnerable people and groups are protected or enhanced (Milder et al. 2012a).

Landscape-wide strategies are also especially relevant to climate change adaptation and mitigation. Such strategies include: climate-smart practices at the field and farm scale; diversity of land use across the landscape; and management of land use interactions at landscape scale. Diversity at the landscape level supports climate mitigation and adaptation in several ways: by sustaining minimally-disturbed carbon stocks within the landscape mosaic; by reducing risks of production and livelihood losses from erratic and difficult climate conditions; by utilizing certain areas of the landscape strategically for food, feed, fuel, and income reserves; by adding value to smaller scale climate-smart practices; and by rationalizing climate mitigation efforts (Scherr et al. 2012). There is an excellent opportunity to include this landscape-thinking in Nationally Appropriate Mitigation Actions (NAMAs) and National Adaptation Programmes of Action (NAPAs) now being set up in many countries to address climate change (Shames et al. 2011).

Efforts at scaling up landscape initiatives are underway in China, the Great Green Wall initiative in the Sahel, and the continent-wide TerrAfrica partnership. Rwanda has begun a nationwide Landscape Restoration Initiative (IUCN 2011; Newton and Tejedor 2011; UNCCD 2012). The potential for relatively quick, large-scale payoffs is illustrated by the Loess Plateau experience in China (Box 5.5).

person learning from another (Warner 2007; Love et al. 2010), and by local institutions such as schools and colleges becoming platforms for sharing knowledge about sustainable agriculture.

Box 5.5: Landscape Restoration Catalysing Agricultural Development in the Loess Plateau of China

Beginning in 1994, municipal officials and farmers took a landscape approach to restore the condition of natural ecosystems in over 15,600 km^2 of China's northwestern provinces. Among other actions, they educated people about sustainability practices such as keeping goats in pens and planting trees. Within ten years, per-capita grain output in the region increased by 62% while household income nearly tripled. As perennial vegetation cover increased from 17% to 34% across the plateau, erosion and dust storms greatly diminished, while the level of sediment flow into the Yellow River decreased by more than 100 million tonnes per year (World Bank 2007).

5.4 SCALING UP SUSTAINABLE AGRICULURAL SYSTEMS

Although the previous paragraphs show that sustainable agriculture policies and practices are being adopted throughout the world, these activities must become mainstream at both farm and landscape scales for a shift to sustainable food systems and healthy ecosystems to occur.

Several factors explain why sustainable agriculture has not yet become commonplace, such as lack of knowledge, lack of social support, socio-cultural constraints, lack of tailored equipment, lack of access to sufficient capital at the outset, a delay on return on investments, lack of tenure security, and non-conducive policy environments (Perret and Stevens 2007; Rodriguez et al. 2008; Lipper et al. 2011; Derpsch et al. 2010). Furthermore, the structure and incentives in existing agriculture and food supply chains do not enable a speedy transition to sustainable agricultural systems.

To change this situation and to support the adoption of sustainable agriculture throughout the world, policy makers can:

(1) Strengthen institutional support for farmer and community innovation.
(2) Secure land and resource tenure and access.
(3) Facilitate access to finance.
(4) Reward farmers for ecosystem stewardship.
(5) Provide support for collaboration amongst stakeholders.
(6) Create an enabling market mechanism through standard setting and certification.

We now discuss each of these in turn.

5.4.1 Institutional Support for Farmer and Community Innovation

Some observers believe that implementing sustainable agriculture requires ongoing development of land management practices and technologies for food production and processing (Buck and Scherr 2011). Such changes can be encouraged, for example, by peer learning, i.e. one farmer or agribusiness

Another option for scaling up sustainable agriculture is to train a new generation of agricultural extension workers well versed in techniques of ecosystem management, agricultural intensification according to ecological principles, and group learning and cooperation. The knowledge needed for implementing sustainable agriculture can also be communicated to farmers and the community through non-traditional means such as internet websites, mobile telephony, and programmed learning.

5.4.2 Secure Land and Resource Tenure and Access

Without secure tenure rights, farmers and communities have less incentive to manage their lands sustainably because they have no guarantee that they will be able to reap the long-term gains of their investments in production and ecosystem stewardship. In many situations, achieving multiple product and service functions will require reforming land and resource tenure and access rights (WRI 2005; Meinzen-Dick and Mwangi 2009). In Niger, for example, a change in the land code which transferred tree ownership from the central government to farmers led to a rapid spread of farmer-managed natural regeneration of trees on farms after 1993. Between the mid-1980s and 2007, tree cover was restored on five million hectares of farm land, and is also thought to have contributed to elevated crop yield on these lands (WRI 2008; Reij et al. 2009).

5.4.3 Access to Finance

Most farm-level innovations described above will enhance household incomes and reduce risks within one to five years. But they often require increased expenditures initially: for labour to build catchment dams for water harvesting, to purchase simple weeders that aerate the soil, or to mitigate possible risks and losses when learning and adapting new practices. Financing arrangements are needed to help cover these initial costs.

Preferential financial arrangements to support more sustainable practices can encourage and enable farmers to make the necessary initial investments. There are numerous models for using preferential access to credit to support more sustainable practices. The African Wildlife Foundation's Heartlands Programme ties credit for farm production and agro-processing operations to farmers' contractual agreements to undertake sustainable land management. African Heartland combines national parks and local villages, government lands and private lands into a large, cohesive conservation landscape that often spans international borders (AWF 2012).

5.4.4 Rewarding Farmers for Ecosystem Stewardship

Achieving ecologically sustainable agricultural systems requires recognising and rewarding farmers for providing ecosystem services (good water quality, flow and infiltration; protection of wildlife and their habitat; prevention of erosion and sedimentation, carbon dioxide sequestration) that benefit other businesses and population groups. Various systems of rewards and direct payments for ecosystem services (PES) are being developed around the world to realise this vision, to compensate farmers for converting land from production to conservation, or to encourage a transition to production systems that themselves contribute ecosystem services. The majority of examples up to now are payments by public agencies. Increasingly, private companies or conservation groups are paying farmers directly, such as beverage and water bottling plants seeking to protect their input water quality. Some developed countries have put in place "cap-and-trade" or "floor-and-trade" systems for regulating water nutrients and greenhouse gas emissions, or for conservation wildlife habitat conservation, as a flexible regulatory system (FAO 2010; Scherr and Bennett 2011).

Already by 2009, it was estimated that the financial value of PES to all land managers for biodiversity protection was about USD 1.8 billion; for carbon sequestration and storage USD 182 million; for watershed protection over USD 15 billion and for landscape beauty and recreation over USD 7 billion. Only a modest share of these are disbursed for environmentally friendly farming, principally through large public payment programmes in the US, Europe and China (Bennett 2008; Milder et al 2010; Madsen 2011). In the future, governments might play a critical role as regulators and enablers of PES, to expand private PES systems, and to ensure smallholder farming communities can benefit from them (Scherr and Bennett 2011; FAO 2012).

5.4.5 Supportive Policy and Multi-stakeholder Collaboration

As described in Chapter 4, the construction of sustainable agricultural and food systems requires stakeholders with diverse goals to work together. At national, state and local levels, governments need to overcome "sectoral silos" to harmonize policies and programmes to achieve productive, sustainable food systems supported by healthy ecosystems. They can strengthen financial incentives by shifting subsidies from agricultural inputs or activities that degrade ecosystems to those promoting sustainability. For example, they can support companies to invest in no-tillage equipment manufacturing or develop environmentally friendly agro-chemicals, or require development activities to offset any ecological damage by investing in ecosystem-enhancing activities.

Policies should encourage and support local multi-stakeholder dialogue, planning and action. One way to accomplish cooperation among stakeholders is to develop a shared vision for managing large areas of land to satisfy many different demands over the long-term (Hemmati 2008; Buck and Scherr 2011; German et al. 2012). This vision can include new norms and regulations for land management, including rules for resource access.

Box 5.6. Farmer Organisation and Innovation through Landcare in Australia

Australia's Landcare programme began at the state level and went national in the 1990s. Close to 5,000 community Landcare groups throughout Australia are now organised at the regional level into 56 groups, known as Catchment Management Authorities or Integrated Natural Resource Management (NRM) groups. The Government substantially supports this structure, but cedes control to community groups to take the initiative. Landcare is now being promoted and practiced beyond Australia in South Africa, Philippines, Kenya, Uganda, Fiji and Sri Lanka (Cullen et al. 2003; Catacutan 2008).

5.4.6 Market Incentives through Standard Setting and Certification

As covered in Section 4.5.2, farmers are highly responsive to the demands of the market, such that it is unlikely that they will transform their current farming practices to more sustainable practices unless there are clear market signals that sustainable produce is of value to buyers, processors and the food industry. Future agricultural businesses may focus less on non-renewable inputs and more on economic opportunities based on full food cycle/system productivity, food-based health enhancement, waste management, and provision of ecosystem services (Giovanucci et al. 2012).

One way to ensure clear market signals is to use sustainability standards and certification to facilitate voluntary adoption of sustainable practices at the farm, landscape, and supply chain levels. Eco-certification and eco-labelling systems have grown dramatically over the past twenty years, championed by groups like Rainforest Alliance (RA), ISEAL Alliance and the Sustainable Agricultural Initiative platform (Box 5.7). The market size for certified agricultural products is over USD 64 billion. Of this, organics account for over USD 50 billion. RA certified bananas account for more than 15% of all bananas sold globally, and certified coffee for 8% of all coffee. Major commodity roundtables have developed certification systems for more sustainable palm oil, soy, biofuels, cocoa, sugar and more recently for rice. Such markets are projected to grow at 15% annually in the short-term (Andersson and Oberthur 2008; Majanen and Milder 2010; Milder et al. 2012b). Business-to-business standards like GlobalGAP, which were originally developed for large-scale farm operations and to ensure food safety, have also, since 2002, evolved to include smallholder farmer groups and have strengthened their environmental criteria.

In 2010, company members of the Consumer Goods Association, worth almost USD 2.8 trillion of processed products, made a commitment to help achieve zero net deforestation by 2020 by eliminating from their supply chains all products associated with tropical deforestation (CGF/CG/HP/MS 2011).

While the first generation of eco-labelling systems was geared towards higher-value products and larger commercial producers, more companies are now committed to sourcing from smallholders. New models allow group certification, locally developed certification standards, and other innovations. A study to assess the benefits of sustainability certification for small-scale farmers in Asia found that certification may help some farmers reach more lucrative markets, gain greater returns for the crops produced, help them improve their farming skills, learn new production techniques, and better understand the functioning of markets (Blackmore et al. 2012).

Chapter 4 gives more information on standards and certification.

5.5 THE ROLE OF THE GREEN ECONOMY IN SUSTAINABLE AGRICULTURE

Many of the ideas discussed in this chapter are connected to the overarching concept of a Green Economy (UNEP 2011). The Green Economy provides a new way forward from the current food system. It involves the application of food production and consumption practices that ensure productivity and profitability without undermining ecosystem services, and rebuilds ecological resources by reducing pollution and using resources more efficiently.

5.5.1 Increasing Investment in Agriculture

From 1980 to 2005, the agriculture and food sector witnessed a decline of public agricultural investments at the international level. Official development assistance going to the agriculture sector fell from 13% in 1980 to 2.9% in 2005-06 (UN-DESA 2008). Recent trends indicate a slowdown in the decline and the beginning of an upward trend bolstered by international agreements like the G8 L'Aquila pledge and the Maputo Declaration in which African countries committed to spending 10% or more of their national budgets on agriculture and rural development by 2008 (UNESC ECA 2007).

Looking to 2050, the FAO estimates that the annual required gross investment levels in developing countries are in the order of USD 209 billion. Even with the current upward trend in investment levels, this amounts to an increase of about 50% over average annual investments during the past decade (around USD 142 billion over the past decade) (FAO 2009).

This investment shortfall contrasts markedly with the large sums currently being directed to subsidize agriculture. The latest OECD figures indicate that total support to the agricultural sector across OECD countries stood at USD 375 billion in 2007-09, equivalent to 0.9% of OECD GDP, down from 2.3% in 1986-88 (OECD 2010).

5.5.2 Green Economy and Sustainable Agriculture

The potential impact of this increased investment was modelled in UNEP's Green Economy Report (UNEP 2011), which laid out different investment scenarios for the agriculture sector. Even though this exercise modelled the cumulative impacts of increased investments at farm rather than landscape level, the scenarios make for compelling reading. In the most ambitious scenario, 0.16% of GDP is invested in sustainable agriculture per year (equal to USD 198 billion) for the period 2011-2050 compared to a business-as-usual scenario where the same amount is invested in conventional and traditional agriculture. Under the green or sustainability scenario, the additional investments are undertaken in four key areas: sustainable agricultural management practices; prevention of pre-harvest losses including pest control activities; food processing; and research and development.

Some key conclusions:

- Increased investment leads to improved soil quality, increased agricultural yield and reduced land and water requirements.
- GDP and employment will increase with the potential to create 47 million additional jobs compared to the conventional scenario over the next 40 years.

Box 5.7: Examples of Sustainable Agriculture Supply Chain Initiatives

Rainforest Alliance – This non-profit conservation organisation develops environmental and social standards and certification for tropical crop, livestock and forest production systems and links producers to consumers.

SAI (Sustainable Agriculture Initiative) – SAI was founded by international food companies to facilitate sharing at a precompetitive level, and promotes knowledge and initiatives to support development and implementation of sustainable agricultural practices by different stakeholders of the food chain.

ISEAL Alliance (International Social and Environmental Accreditation and Labelling) – A global association for social and environmental standards, working with voluntary standards systems to help strengthen their effectiveness and impact.

- Transformation of agriculture from being a major GHG emitter to a net neutral and possibly a GHG sink, while reducing deforestation and freshwater use by 55% and 35% respectively.

While Green Economy scenarios show in a general sense some of the potential benefits of investing in sustainable agriculture, much can already be done on the ground to realise these benefits. The following are some economic or market-based options for encouraging the sustainability of the food and agriculture sector and moving towards a "Green Economy".

- *Scale up investment by rationalizing export subsidies and redirecting cash flows towards agricultural investments.* Discussions on subsidies are complex but it is widely acknowledged that export subsidies in particular have led to an artificial reduction of world market prices and that they have generally set back the development of agriculture in developing countries, diminishing their competitiveness, and making it frequently unprofitable for smallholder farmers and others to produce commodity crops. Supports that lead to oversupply of commodities produce the greatest distortions in the markets. Although this type of support is falling percentage-wise, it still represents 51% of total producer support in the OECD.
- *Increase public investment in research and development to strengthen public institutional capacity.* In particular, capacity is needed to 1) make new technology and innovation publically available to farmers, 2) engage in co-innovation with the private sector and 3) increase the regulatory capacity of governments to understand the impact of intellectual property rights for new technology on farmers.
- *Implement supportive policies for a transition towards more sustainable agriculture by all actors involved in the food and agricultural sector.* More and more financial and investment institutions are taking initiatives to facilitate access of smallholders to markets and to promote adoption of sustainable practices, rather than just being a provider of finance. Hence, when assessing feasibility and viability of investments in agribusiness they are increasingly considering social and environmental sustainability a core value (see Box 5.8).

- *Encourage the inclusion of smallholder farmers in collaborative supply-chain initiatives such as certification and labelling (see Chapter 4 and Section 5.4.6).*
- *Reward farmers for ecosystem stewardship (see Section 5.4.4)*
- *Improve access of smallholders to financing for sustainable agriculture (see Section* 5.4.3)

5.6 TOWARD ECOLOGICALLY SUSTAINABLE AGRICULTURE – NEED FOR COLLABORATION

This chapter has pointed out that practices consistent with sustainable agriculture are already being practised throughout the world. On individual farms and over entire landscapes, sustainable agriculture is restoring the resource base and ecosystem services that make up the ecological foundation of food security. But these practices are still far from becoming part of mainstream agriculture. To become mainstream, sustainable agriculture must have the cooperation of the various actors involved in the food supply chain, from farmer to consumers, and including processors and distributors. Moreover, a transition to more sustainable agriculture also requires advances in science, emerging market opportunities, and innovations in social organisation.

Box 5.8 African Development Bank's Strategy on Agriculture

The Bank's strategy for the period 2010 to 2014 focuses its agricultural operations on agricultural infrastructure and support for natural resource management. This strategy is aimed at ensuring that investments in infrastructure are resilient to climate change and otherwise sustainable. The expected outcomes are to have, by 2014, 75% of the Bank's agriculture operations "climate–proofed," 500,000 ha of land under improved water management, 50,000 people trained in good agricultural practices, a yield increase of between 15 and 20% and a 25% decrease in degraded agricultural land and forests (AfDB 2010)

Chapter 6:

Strategies for Sustainable Fisheries and Aquaculture

Caleb McClennen (Wildlife Conservation Society); Jacqueline Alder (UNEP).

Credit: Shutterstock / EcoPrint

6.1 INTRODUCTION

Chapter 3 of this report described the contributions of marine and inland capture fisheries to food security, the ecological foundation for their ongoing productivity, and how this ecological foundation is being undermined. Chapter 3 also highlighted the growing importance of aquaculture as a supplier of fish, its projected future growth, and its impact on the environment. This chapter sets out a series of policy options for making marine and inland fisheries more sustainable and demonstrates the economic benefits of investing in more sustainable fisheries. It also provides policy options for reducing the environmental impacts of aquaculture activities. It should be noted that the policy options provided in this chapter are aligned with the FAO Code of Conduct for Responsible Fisheries (FAO 1995), which now guides worldwide efforts at managing fisheries[23].

6.2 IMPROVE STOCK MANAGEMENT AND PROMOTE FISHERIES CO-MANAGEMENT

Overfishing remains the top source of pressure on both marine and inland fisheries. Hence, to secure the ecological foundation of marine and inland fisheries, it is critical to put in place management strategies that will ensure sustainable harvest levels. These include rigorous science-based approaches such as calculating and meeting harvest levels at or below Maximum Sustained Yield (MSY). They also include effective governance arrangements, enforcement protocols, and economic incentives for maintaining harvests at sustainable levels.

To this end, the following policy options may be considered:

- Where practical, stock assessment methodologies[25] should be used to determine acceptable harvest levels and ensure that fishery extraction is below calculated sustained yield, using either a rights- or quota-based system. It is important that stock assessments are done in consultation with those taking decisions and those affected by these decisions. Also, efforts should be made to ensure that the data collection systems are functioning well and used appropriately, as current and reliable information is required for effective stock assessment management. International and local support may need to be provided to help achieve this (see Box 6.1)
- Increased investment and support for capacity building should be provided for improved monitoring and control programmes in order to improve fishery performance. Also needed is political commitment and adequate capacity for the enforcement of the monitoring and control regulations (Sumaila et al. 2006). This is particularly important in developing countries where effective governance is rare (IWMI 2007). This will help mitigate, in particular, illegal, unreported and unregulated fishing, which is a direct threat to the food security of coastal communities (Metuzals et al. 2009) and the ecological foundation of capture fisheries.
- Governance measures – such as the allocation of fishing and/or management rights – should be encouraged to ensure that fishery extraction are below calculated MSY. The allocation of fishing rights is an important part of fisheries management as experience has shown that where these rights are clear and equitably distributed, fisheries are more sustainable ecologically and often socially as well. The allocation of fishing rights is very important in small-scale fisheries to ensure food security, and in some cases, the subsistence of coastal communities (Allison et al. 2012) (see Box 6.2).
- In fisheries where technical capacity is unavailable for full stock assessment and enforcement (e.g., small-scale fisheries), interim measures such as size limits, seasonal- and area-based closures, gear improvements or limitations, species limitations, and by-catch mitigation, can be implemented as a precautionary measure for sustainability (Jennings et al. 2001).

Box 6.1: Supporting the Collection of Fisheries and Oceanographic Data

The Norwegian government, in collaboration with the FAO, has supported the Dr Fridtjof Nansen Project in the collection of fisheries and oceanographic data, and more recently environmental data in West Africa. The buildup of this body of knowledge has empowered fishery managers in the region. The FAO provides training and support to ensure that the scientists from African countries participating in the Nansen Project can gather the data they need. Support is also given to local and national fisheries managers, NGOs, community representatives, marine biologists, Regional Fisheries Bodies and artisanal and commercial fishers – to ensure that they have the know-how for managing fisheries in a sustainable manner. For example, Sierra Leone, Liberia, Tanzania and Seychelles are designing management plans for artisanal fisheries. Ivory Coast, Ghana, Togo and Benin are seeking ways to minimize damage caused by beach seine fisheries.

(Source: FAO 2012)

However, some or all of these management strategies might be too expensive to implement in poorer parts of the world and in small-scale fisheries. In such cases, fisheries co-management in its many forms might be an option for obtaining improved harvest levels and for improving the overall socio-ecological performance of fisheries[24] (Gutiérrez et al. 2011; Cinner et al. 2012).

23 This is a set of voluntary guidelines that cover a range of activities in managing fisheries from stock assessment to mitigating the effects of fishing on the ecosystem.

24 The ability of fishers to successfully manage small-scale near-shore fisheries using a cooperative approach has been demonstrated in Maine, USA (Schlager and Ostrom 1992). Other examples include the qoliqoli system in Fiji (Teh et al. 2009) and the emerging beach management unit (BMU) in Kenya (Cinner 2009), in which communities are allowed exclusive rights to manage their near-shore marine resources, semi-autonomously from national fisheries authorities.

25 Commonly used stock assessment methods include surplus production models, statistical catch at age models, and virtual population analysis models.

Box 6.2: Loco Fishery in Chile

The 1991 Chilean *Fishery and Aquaculture Law* (FAL; D.S: 430) regulates the access of artisanal fishers to benthic (lower layers of the ocean) and pelagic (upper layers of the ocean) coastal resources. The FAL gives artisanal fishers user rights through three provisions:

(a) exclusive fishery access rights within a zone that extends to five nautical miles from the shoreline and around 2500 km of coastline;
(b) artisanal fishers are restricted to working within the coastal region adjacent to their area of residence; and
(c) the allocation of exclusive harvesting rights for benthic resources are given to legally registered artisanal small-scale fishing associations.

Since this system of property rights was applied to loco *(Concholepasconcholepas)* fisheries in 1992, stocks of target species have been maintained along with fishers' incomes. Although, there are still problems associated with this system such as theft by encroaching fishers, overall this system has worked well.

Castilla and Gelcich (2008).

6.3 CONSERVE AND PROTECT CRITICAL HABITAT FOR MARINE AND INLAND FISHERIES

As already highlighted in Chapter 3, adequate habitat is a prerequisite for the sustainability of marine and inland fisheries. It was also pointed out that destructive fishing practices and other activities such as infrastructure development (including dam and dike construction), mineral exploration and port activities are undermining the ecological foundation of fisheries. Since these activities are likely to be carried out in any event, it is important that they also take into account the sustainability of fisheries and aquatic ecosystems. In particular, attention is needed to protect critical habitats such as coral reefs, mangroves, wetlands and seagrass. The following options would help accomplish this:

- An ecosystem approach to fisheries management (EAF)[26] can be adopted. As outlined in the FAO technical guidelines for the ecosystem approach to marine fisheries (FAO 2003), this includes conservation of habitats needed for ecosystems and their services. Furthermore, the EAF should consider all stages of fish lifecycles and the components of the ecosystem that are critical to these various stages.
- Development projects adjacent or close to marine and freshwater systems should adopt a no-net-loss approach[27] to critical habitat protection. In some cases this may mean setting aside areas of similar size and habitat so that the total loss is negated. In other cases it can mean rehabilitating a degraded site to restore some of its lost ecosystem services.
- Networks of Protected Areas (e.g., Marine and Coastal Protected Areas[28], fish sanctuaries, parks) should be encouraged to provide outright protection for coastal and marine waters. In order to be effective, protected areas should have explicit objectives, be embedded in an overall ecosystem management regime, and involve early and full stakeholder involvement[29]. When designed and managed appropriately, protected areas can provide benefits for fishery resources inside the enclosure in terms of abundance (in number and biomass) and average individual size of populations. As demonstrated by Lester et al (2009), a complete stop to fishing and other activities resulted in a fourfold increase in fish biomass. Furthermore, protected areas can provide other benefits such as an opportunity for fisheries to adapt to climate change.

Harmful industrial fishing methods such as bottom trawling should be prohibited from sensitive coastal and marine areas, especially when lower impact small-scale fisheries and/or economically viable non-destructive alternatives are possible (See Box 6.2).

6.4 MINIMIZE LAND-BASED POLLUTION TO PROTECT WATER QUALITY OF MARINE AND INLAND FISHERIES

Another driver of change as discussed in Chapter 3, is the pollution of marine and inland waters originating from agriculture, forestry, industry, households, urbanization, and shoreline development. The nutrients associated with this pollution are causing eutrophication of coastal and fresh waters, and this is significantly disturbing aquatic ecosystems, in particular by depleting their dissolved oxygen (Diaz and Rosenberg 2008). The following actions could be taken to address this problem:

- Encourage more efficient use of fertilizers in agricultural production and improve the management of soils especially

26 As defined by FAO (2003) "an ecosystem approach to fisheries strives to balance diverse societal objectives, by taking account of the knowledge and uncertainties about biotic, abiotic and human components of ecosystems and their interactions and applying an integrated approach to fisheries within ecologically meaningful boundaries".

27 The no-net-loss approach strives to balance unavoidable habitat, environmental and resource losses due to economic development with replacement actions aimed at ensuring that over-all, there is no loss in these resources.

28 An expert group of the CBD defines marine and coastal protected areas as "any defined area within or adjacent to the marine environment, together with its overlying waters and associated flora, fauna and historical and cultural features, which has been reserved by legislation or other effective means, including custom, with the effect that its marine or coastal biodiversity enjoys a higher level of protection than its surroundings" - http://www.cbd.int/doc/ publications/cbd-ts-13.pdf. IUCN also defines a protected area as "a clearly defined geographical space, recognised, dedicated and managed, through legal or other effective means, to achieve the long-term conservation of nature with associated ecosystem services and cultural values" - http://www.iucn.org/about/ work/programmes/pa/pa_what/

29 It must be noted that the use of protected areas as a standalone management tool to control fish mortality or to sustain fish populations is likely to result in overall lower fisheries yield and higher costs of fishing. Hence, protected areas should be combined with other management measures that control fishing efforts outside the protected area. Protected areas should be an integral part of overall fisheries management plans. In its design, the potential negative impacts, including the socio-economic impacts and costs must be taken into consideration. To clarify the role of marine protected areas, the FAO has published "Fisheries management. Marine protected areas and fisheries, FAO Technical Guidelines for Responsible Fisheries. No 4" - http://www.fao.org/ docrep/015/i2090e/i2090e00.htm

in watersheds with particularly sensitive freshwater and marine habitats.

- Strengthen and build capacity among agriculture and forestry concession holders to mitigate soil and nutrient runoff into aquatic systems, including using coastal and riverine buffers[30] such as vegetative covers. These activities can also be incorporated into an ecosystem management programme.
- Enact and enforce regulations that minimize the sources of water pollution.
- Encourage inter-agency and inter-jurisdictional collaboration to share information across different economic sectors and improve mitigation of land-based pollution. Many coastal countries are signatories to one of the Regional Seas Conventions and Action Plans, which often have a Land-Based Source of Pollution Protocol. In particular, countries can become active in the Global Programme of Action for the Protection of the Marine Environment from Land-based Activities (GPA), which is an intergovernmental platform for taking action to reduce land-based water pollution. Countries can use these and other international institutions for sharing information, establishing technical and financial mechanisms for reducing pollution, and for cooperating on integrated coastal zone management (Rochette and Billé 2012).

Credit: UNEP / Grid Arendal Peter Prokosch

6.5 IMPROVE WATER MANAGEMENT FOR INLAND FISHERIES

Inland fisheries are particularly impacted by demands for water resources including use for agriculture (irrigation), electricity generation and urban/domestic supply. To satisfy all of these demands, and also maintain the productivity of inland fisheries, it is important that these demands are balanced using appropriate water management strategies. The following options could be considered for achieving this:

- Assess and identify the "environmental flows" (minimum flows and/or flow regimes) and water quality needed to maintain ecosystems of inland waters[31]. This will require an ecosystem approach, and the engagement of a range of government agencies at national and local levels in the management of water, land, agriculture and industrial activities.
- Assess and mitigate the impacts of infrastructure such as dams on inland fisheries. Consider keeping some rivers free of impoundments to better sustain aquatic ecosystems. Where dams exist, consider regulating downstream flow so that "environmental flows" are maintained.
- Apply the comprehensive thinking of Integrated Water Resources Management (IWRM)[32] to watersheds in order to ensure the sustainability of the inland fishery along with other competing goals.
- Apply the "no-net-loss" approach described in Section 6.3 to inland waters.

6.6 A POLICY FRAMEWORK FOR SUSTAINABLE AQUACULTURE

In order to develop an aquaculture that is ecologically sustainable and profitable and will provide a net positive benefit for food security, a portfolio of strategies and policy options needs to be put in place. Similar to capture fisheries, these strategies need to be pursued by all stakeholders including the public and private sector. Strategies are needed to encourage a

30 Buffers help mitigate the flow of pollution sources, such as nutrients and sediments from erosion, into rivers or coastal water bodies. They also maintain habitat at the edge of aquatic communities that provide cover and foraging for many fauna.

31 Environmental flows refer to the quantity, quality and timing of water flows required to sustain specific valued features of freshwater ecosystem or for protecting the species of interest for fisheries and for conservation of the ecosystem on which fisheries depends (IWMI 2007).

32 IWRM is an ecosystem approach which promotes the coordinated development and management of water, land and related resources in a manner that helps satisfy competing needs for these resources.

low feed conversion ratio[33], reduce the use of capture fish as feed, and develop innovative production systems that can reduce the impact of introduced species on native species. Furthermore, action is needed to manage waste discharges, halt vulnerable habitat conversion for aquaculture production, encourage intensive production systems that provide safeguards against potential environmental impacts, and improve understanding and management of diseases. Here are some options for taking action:

- Continuous support and investment by both the private and public sector for research and innovation in the aquaculture sector, especially for the development of productive technologies that make more efficient use of land, water, feeds and other resource input, and that minimize demands on ecosystem services.
- Continuous support for the education of aquaculturists on improved management practices and understanding of the environmental impacts of aquaculture and mitigation options.
- Encourage the adoption of an Ecosystem Approach to Aquaculture (EAA)[34]. The ecosystem approach facilitates the implementation of the FAO Code of Conduct for Responsible Fisheries and also helps in the integration of the aquaculture sector with other users of aquatic resources, while allowing sustainable intensification and a climate-smart aquaculture.
- Where feasible encourage innovative aquaculture practices such as Integrated Agriculture Aquaculture (IAA)[35], integrated mangrove-aquaculture farming[36] and close-looped multi-species systems[37]. Case studies have shown that apart from being effective in environmental conservation, such practices can also help increase agricultural and fishery productivity, as well as improve food nutrition of farmers[38].
- While research seeks better options for feeding carnivorous species such as salmon and shrimps, their farming should be minimized in order to reduce the impact of their production on capture fisheries. Similarly, introduction of exotic species should be minimized and should follow strict and established protocols (Primevera 2006).

33 The food conversion ratio measures the efficiency of how fish convert feed mass to body mass. It provides an indication of how much feed will be required to grow the fish. A low feed conversion ratio is important for profitability and reduced demand on resources.

34 EEA is a strategy to balance socioeconomic, environmental and governance objectives. It involves the integration of the activities within the wider ecosystem in such a way that it promotes sustainable development, equity, and resilience of interlinked social and ecological systems. (FAO 2007)

35 IAA is based on the concept of integrated resource management. It is an approach by which resources in the form of wastes and by-products from agriculture (crop or animal production) are used as feed inputs for aquaculture. Wastes, wastewater, and other outputs from aquaculture could also serve as input for agricultural production, thereby resulting in an efficient use of resources and conservation of the environment.

36 This is based on the fact that mangroves and aquaculture are not necessarily incompatible. Some aquaculture species can be grown in mangroves and co-managed for mangrove conservation or restoration. Fish ponds can also be located adjacent to mangroves, which can then be used to process nutrients in pond effluents (Primavera 2006).

37 Closed-loop multi-species systems involve farming different aquaculture species such that wastes from one species serve as feed for another.

38 For example, small-scale integrated aquaculture increased farm productivity and income in Malawi (See Sec. 3.4.2). Similarly, integration of fish into rice paddies increased productivity of rice by 10% while also providing 1500 kg per ha of fish and also eliminating the need for pesticides (IWMI 2007 and references therein). More examples of the application of IAA are provided in the publication entitled "Integrated Agriculture-Aquaculture – a primer" (FAO/ IIRR/WorldFish 2001).

Credit: Jacqueline Alder

- Put in place mechanisms to ensure that regulators and policymakers are able to keep pace with developments in the aquaculture sector. Ensure that they are able to develop policies that incorporate the costs of environmental impacts of aquaculture into the planning and implementation of aquaculture enterprises.
- Boost the capability of local and national agencies to develop regulations and monitor compliance. The FAO Code of Conduct for Fisheries covers aquaculture, and national agencies should encourage producers and buyers to follow the Code.

6.7 MEASURES TO ENHANCE THE ABILITY OF AQUATIC ECOSYSTEMS TO ADAPT TO CLIMATE CHANGE

As reviewed in Chapter 3, expected climate change impacts on freshwater and marine ecosystems include changes in precipitation regimes, sea level rise, warming waters, and acidification. These may have large social and economic impacts on the fisheries sector (Sumaila et al. 2011). Coping with these impacts will require a serious effort to build more resilient and adaptive aquatic ecosystems. To this end, the following policy options could be considered:

- Given the uncertainty of climate change impacts, a logical hedging strategy would be to try and reduce as much as possible all other stresses on aquatic ecosystems (e.g. thermal discharges from power plants, wastewater discharges from municipalities and industries, and so on). Reducing such stresses would bolster the ability of ecosystems to withstand climate change impacts and adapt to new climate conditions.
- Employ ecosystem-based adaptation measures that use biodiversity and ecosystem services to help people adapt

to climate change[39]. These measures often provide multiple benefits including support for the marine or inland fishery. For example, the re-planting of mangroves to protect coastal populations against increasing storm surges also provides habitat for breeding fish, which can contribute to maintaining fish stocks, and enhance food security and cash income for coastal residents. In addition, ecosystem-based adaptation measures are often more cost-effective than engineered measures (CBD 2009; World Bank 2009).

- Undertake research to better understand the response of aquatic ecosystems critical to fisheries to climate change (coral reefs, mangroves and estuaries). This information is needed for developing efficient and effective management policies.

6.8 APPROPRIATE ECONOMIC STRATEGIES FOR ACHIEVING SUSTAINABLE FISHERIES

Many of the options described above would require substantial investment in the fisheries sector. Financial investment is required for measures to adapt fishing fleets, promote the use of appropriate gear, strengthen markets in fishery products, encourage research and development, promote partnerships between researchers and fishers, and provide for technical assistance and human capacity building especially in developing countries (UNEP 2011a). Unfortunately, both public investment and official development assistance (ODA) towards agriculture has been declining since the late 1970s. Financial investment in the fishery sector is of even more concern considering the fraction of total agricultural investment that it receives. Of the total ODA commitment of USD 6.2 billion towards agriculture in 2007, only 6% was earmarked for fisheries (OECD-DAC 2010). Furthermore, government budgetary resources dedicated to fisheries and aquaculture management are often grossly inadequate.

Another economic challenge facing the fishery sector, with a direct impact on the ecological foundations of fisheries, has to do with subsidies[40]. While there are some beneficial subsidies[41], a substantial part of existing subsidies play a role in undermining the ecological foundation of the fishery sector (UNEP 2011b), as they tend to encourage the expansion of fishing capacity and therefore overexploitation of fish stocks. For example, by reducing the cost of harvesting through fuel price subsidies or provision of grants for construction of new fishing vessels, subsidies enable fishing to continue at uneconomic levels exceeding the natural regenerative capacity of fisheries (World Bank/FAO 2009).

Furthermore, some of the economics of fisheries really do not add up in terms of sustainability. Cost-benefit analysis suggests that economic instruments, such as fines, are not capable of discouraging illegal, unreported and unregulated (IUU) fishing (OECD 2004; Sumaila et al. 2006). The basic economic idea is that IUU fishers undertake a subjective cost-benefit analysis, and will engage in IUU fishing if the expected net return is positive (OECD 2004). A cost-benefit analysis of a number of apprehended vessels between 1986 to 2000 showed that benefits were 24 times larger than cost, implying a huge incentive to continue with IUU fishing (Sumaila et al. 2006).

Taking a longer-term perspective, UNEP's Green Economy Report (UNEP 2011a) laid out different investment scenarios for the fisheries sector. In the most ambitious scenario, 0.16% of GDP is invested in sustainable fisheries per year for the period 2010 – 2050 compared to a business-as-usual scenario where the same amount is invested in conventional and traditional fisheries. Under the sustainability scenario, investments are undertaken to reduce over-harvesting (through vessel buyback programmes[42]), retrain and relocate employment (lost due to reduced fishing capacity) and improve fisheries management (in order to support fish stock regeneration). This scenario shows that:

- Employment in the fishing sector would be 27 to 59% higher by 2050 relative to a baseline.
- Around 70% of the amount of fish stock available in 1970 would be available by 2050 against 30% under the business-as-usual scenario.
- Resource rents could increase from negative USD 26 billion per year to positive USD 45 billion per year.

In such a scenario, the total value added to the global economy from fishing is estimated at USD 67 billion a year. Even without accounting for the potential boost to recreational fisheries, the potential benefits of "greening" fisheries are at least four times their investment cost.

All in all, there are many economic and market-based options for ushering in a more sustainable world fishery industry and moving towards a Green Economy, many of which have been highlighted in the UNEP Green Economy Report (UNEP 2011a). Here are some of these options:

- As discussed, because of the importance of fisheries, governments should consider increasing the level of funding for this sector. This could be through direct funding from national budgets, increased contribution from multilateral funds, or by earmarking a share of government taxes, levies or revenues for fisheries.
- Implement fiscal measures such as taxation and levies on harvested fish volume in order to raise funds and promote sustainability (Arnason 2000; OECD 2005). This will ensure that benefits from the exploitation of fisheries are captured by the fishers while society at large is also compensated. Furthermore, imposing taxes or levies on volume captured could provide natural incentives for reducing fishing efforts, and dampen overexploitation.

39 Examples of ecosystem-based adaptation measures are: sustainable water resources management; sustainable management of grasslands and savannahs; conservation and sustainable use of biodiversity; sustainable agricultural production including landscape management, protection of water resources and incorporation of local knowledge in agro-ecological production; strategic management of forests such as urban reforestation; and establishment and management of protected areas.

40 Subsidies are financial transfers or contributions, direct or indirect, from a public entity to the fishery sector that reduces the cost of fishing, thereby helping the sector make more profit than it would otherwise make (Milazzo 1998; World Bank 2009). Examples of subsidies in the fisheries sector include grants, concessional credit and insurance, tax exemption, fuel price support, direct payment to industry, and public financing of fisheries access agreements (World Bank and FAO 2009).

41 Examples of beneficial subsidies include those that fund effective fisheries management or marine protected areas.

42 Vessel buyback programmes literally buy and remove vessels from a fishing fleet to decrease capacity, thereby curtailing over-harvesting.

Credit: Christian Lambrechts

- Eliminate and redirect existing harmful subsidies that contribute to overfishing and habitat destruction. The economic gains from the eliminated subsidies can provide significant additional funds for making the fishery sector sustainable. According to Sumaila et al (2010), fishery subsidies in 2003 were around USD 25-29 billion globally. By eliminating the harmful subsidies, while leaving the beneficial ones, approximately USD 19 billion can be saved, which could then be directed into sustainable investments (UNEP 2011a).
- Provide incentives (for example in the form of beneficial subsidies) for sustainable fishery activities. For instance, funds could be provided for conversion of fishing gear to less-damaging alternatives or for shifting from fuel-intensive fishing methods to more labour-intensive ones.
- Apart from strengthening the monitoring and control of IUU, it is important that economic incentives for continuous IUU are removed. This could be through an increase in fines at a level that equalizes the expected costs and benefits (Sumaila et al. 2006).
- Create livelihood alternatives for small-scale fishers and for fishers who predominantly exploit unsustainable fishing habitats. This could help alleviate human pressure on both inland and marine fisheries[43] (World Bank 2004).
- Encourage the development of market-led initiatives such as Fishery Improvement Programmes/Projects (FIP) that could motivate stakeholders in the fisheries sector, including government, fishers, processors and other members of the supply chain to adopt more sustainable practices and management of fisheries.

43 Some successful examples of this include World Bank projects in China, where alternative employment was found in aquaculture, and in Indonesia, where alternative livelihood was provided mostly outside the fishery sector (World Bank 2004).

The adoption of certification and eco-labelling schemes for fisheries and aquaculture which are in compliance with internationally agreed guidelines[44] could be a result of such initiatives. It is also important to increase awareness of these schemes among consumers.

It must be noted however, that increased financial investment in the fishery sector without effective management regimes would not be sufficient to achieve sustainable fisheries.

6.9 TOWARDS ECOLOGICALLY SUSTAINABLE FISHERIES

The above strategies will contribute strongly to securing the ecological foundation of marine and inland fisheries and to decreasing the environmental impacts of aquaculture production. Depending on the specific environmental and socio-economic situation, a mix of these policy options may be in order. Furthermore, the policy options need to be tailored to different regional, national and local settings. Basic to all options is the need to encourage co-management of fisheries by all stakeholders (including the private sector), especially in the case of small-scale fisheries. It is also important to build capacity for the assessment, management and governance of fisheries, and to conduct research to better understand the effect of global change on the ecological foundation of fisheries.

44 Examples of these guidelines include - FAO (2009) - Guidelines for the Ecolabelling of Fish and Fishery Products from Marine Capture Fisheries. Revision 1, http://www.fao.org/docrep/012/i1119t/i1119t00.htm; FAO (2011a) - Guidelines for the Ecolabelling of Fish and Fishery Products from Inland Capture Fisheries. http://www.fao.org/docrep/014/ba0001t/ba0001t00.pdf; and FAO (2011b) - Technical guidelines on aquaculture certification. http://fao. styluspub.com/books/BookDetail.aspx?productID=313019

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