FCRN Food Climate Research Network

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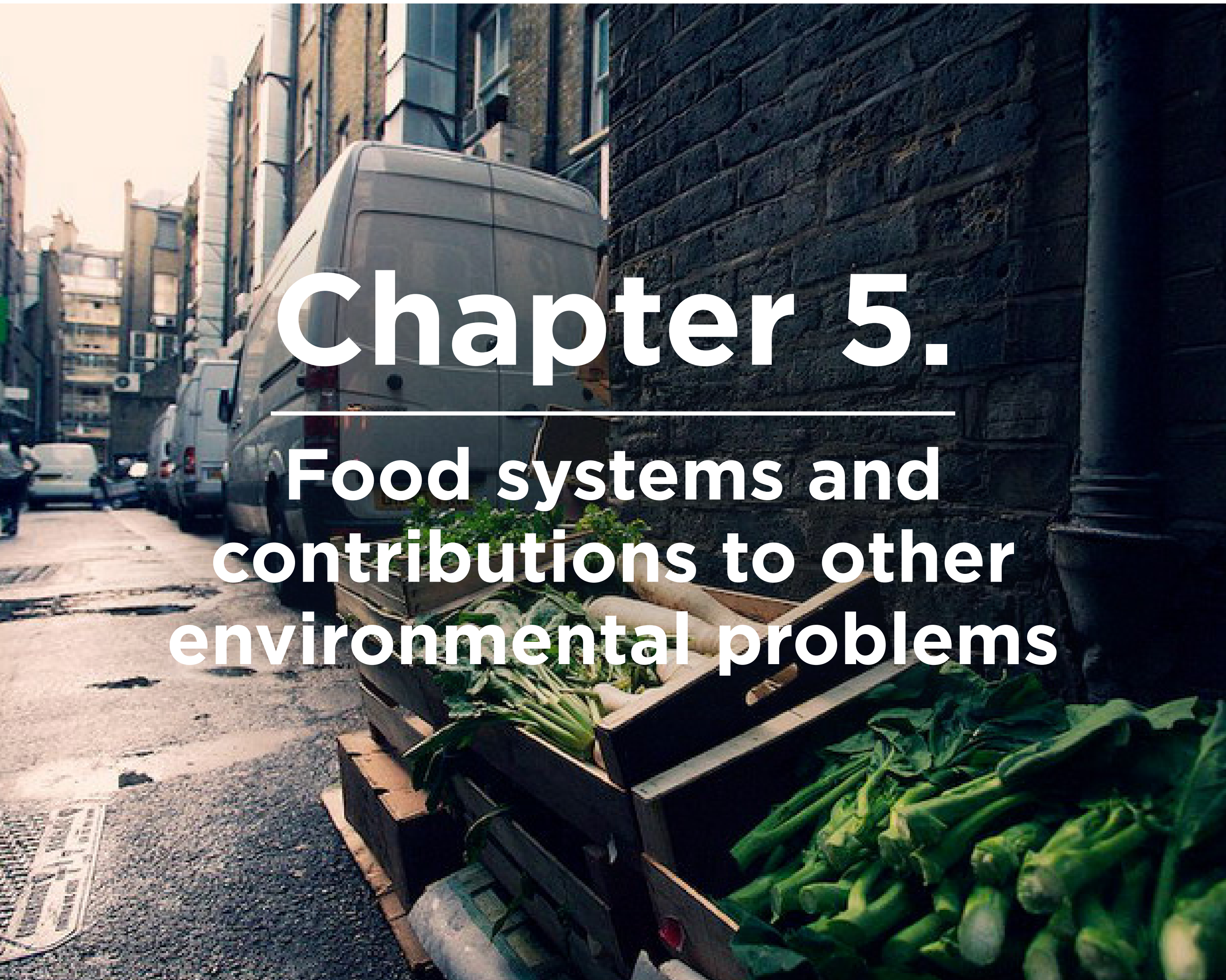
FCRN foodsource

A free and evolving resource to empower informed discussion on sustainable food systems



Chapter 5.

Food systems and contributions to other environmental problems

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Why should you read this chapter?

Food systems interact with, and affect, the environment in a great many ways beyond their greenhouse gas emissions. In order to feed humans, the global food system occupies over a third of the earth's land surface; extracts large amounts of fish and animals from natural habitats; makes huge claims on natural resources; and dispurses various pollutants into the environment.

An appreciation of this wide range of environmental impacts is needed to understand why food systems are central to solving many of our biggest environmental problems, and ultimately to maintaining human well-being. Also useful, is to understand that the causes and solutions to these problems are often interconnected through food systems, resulting in trade-off situations where a course of action can at the same time, make one issue better and another worse.

This chapter provides an overview of the following:

- What types of environmental problem are connected to food systems?
- How do food systems cause these problems and what are their impacts?
- How have these impacts developed and what do future trends look like?
- How can changes in consumption help reduce environmental trade-offs?

Key points

- Food systems impact on multiple interacting aspects of the environment including: water availability, water and soil quality, land use and land use change, GHG emissions, biodiversity, use of finite resources (e.g. phosphorus), and the aesthetics of the landscape.
- Together, impacts resulting from food systems affect the quality and the availability of a range of ecosystems services (including food supply), upon which the maintenance of human-well being and the viability of other life forms ultimately depends.
- Agriculture is the largest human use of water. The source and use of water by agriculture varies according to local context, as does the severity of any impacts, depending on the degree to which water is available in a particular location.
- Water running off agricultural land can quickly carry fertilisers (nitrogen and phosphorus), pesticides, and sediment into natural water courses and lakes. There, excessive nutrient levels, toxicity, and sedimentation can lead to ecosystem disturbance, and to localised collapse.
- Agriculture is the largest human use of land and its expansion has come at the expense of the loss of biodiversity and natural ecosystems worldwide, via habitat destruction, degradation, and fragmentation.
- Ecosystems are strongly affected by agricultural practices and, in particular, by intensification measures designed to increase outputs (e.g. yields), such as the application of pesticides and fertilisers, and more frequent disturbance of land.
- Biodiversity impacts must be considered at multiple spatial scales, because there is a tradeoff between the intensity of agricultural production, and the area of land needed to supply that food.
- Whether it is optimal to increase biodiversity locally on farmland (which generally requires less intensive practices), or to intensify production on existing land in order to spare biodiverse habitat elsewhere, is complex and often unclear.
- Food systems extract resources and species from natural ecosystems; especially from aquatic and freshwater environments where 85% of global fisheries are now fully exploited or are overfished. Ecosystems are degraded through changes in food webs and damage to habitat through destructive harvesting methods.
- To overcome limits to resource extraction from wild sources, the farming of aquatic species (aquaculture) has grown rapidly to meet growing demand. However, alongside this growth has arisen a new suite of linked environmental problems.
- Food loss and waste is a global problem which exacerbates all of the problems detailed above by requiring more agricultural production than would otherwise be necessary. It occurs at every stage of the food life cycle.

5.1 Why are the environmental impacts of the food system a concern?

5.1.1 The food system's impacts on the environment are multiple and connected

The food system's impacts on the environment are multiple and connected

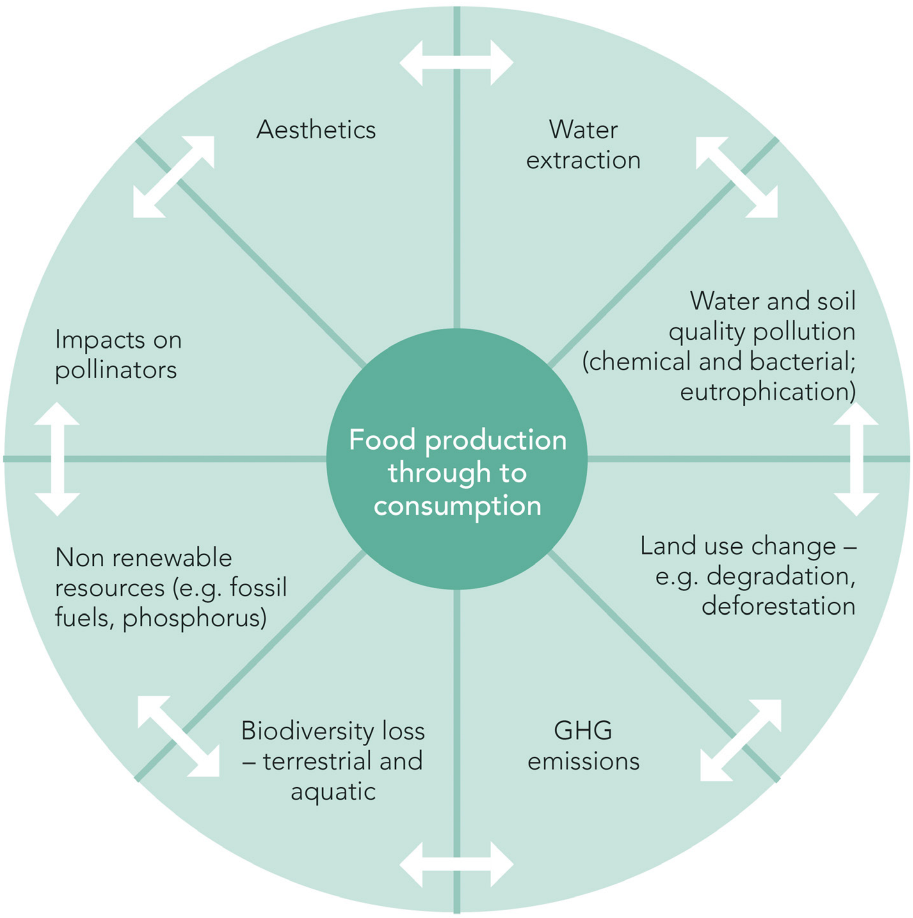

Figure 1: The multiple impacts of food systems on the environment.

Source: FCRN. (2017).

The food system – spanning production, distribution, manufacturing, consumption and waste disposal – impacts upon the environment in multiple ways. Agriculture is the stage responsible for the majority of these impacts. Chapter 2 gives more detail about how these impacts are categorised and quantified using a life cycle assessment approach.

All forms and systems of food production generate environmental impacts. However, the intensity of these impacts varies and forms/systems of production will also differ in the extent to which they impact upon one issue of concern (biodiversity for example) as compared with another (non-renewable energy use).

When thinking about how to design more sustainable food systems, decisions will need to be made about which environmental impacts are of most concern and whether the goal is to 'optimise' across multiple environmental dimensions (i.e. by reducing impacts across the board), or focus on minimising impacts in one or two key areas over and above what might be possible using an optimisation approach – but accepting that impacts on other areas of concern could increase.

5.1.2 These environmental impacts have a direct bearing on our wellbeing and survival

These environmental impacts have a direct bearing on our wellbeing and survival

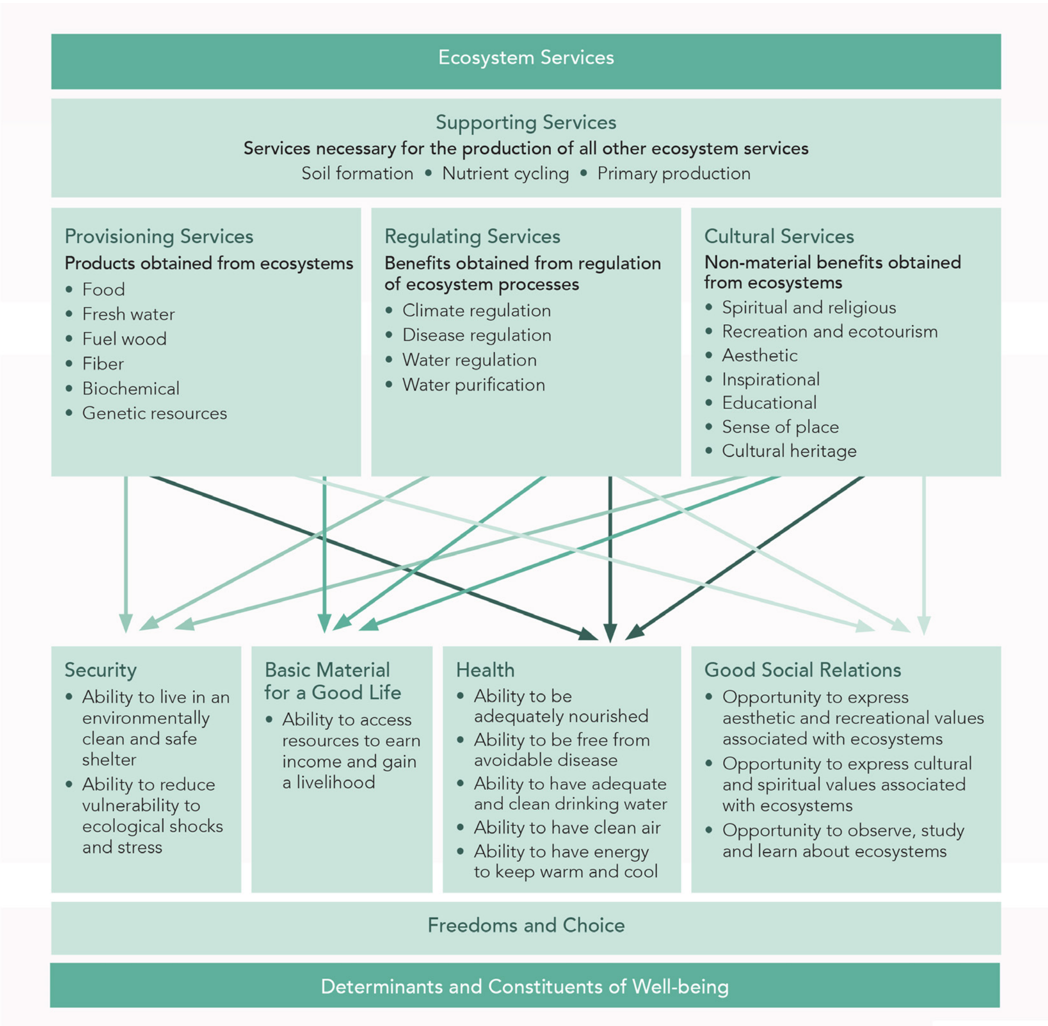

Figure 2: A framework for how ecosystem services contribute to human well-being.

Source: Adapted from MEA, 2003.

This diagram, developed by the United Nations' four year Millennium Ecosystem Assessment (2001-2005) is one approach to conceptualising the links between the 'services' provided by the ecosystem, and human survival and wellbeing.

These services are categorised into 'supporting' services (the foundations for the others), 'provisioning services' (food and so forth), 'regulating' services (that keep systems functioning) and 'cultural' services (such as aesthetic and spiritual value).

Other diagrams have also been developed to conceptualise these linkages (see for example some of the graphics in UK National Ecosystem Assessment, 2014).

A related term 'Natural Capital' is also often used.

Natural Capital can be defined as the stock of resources (soils, air, water, geology, living organisms) which generate ecosystem services.

A useful discussion of ecosystem services, natural capital and the difference between them (which can be found here) points out that *"Ecosystem services are the flows of benefits which people gain from natural ecosystems, and natural capital is the stock of natural ecosystems from which these benefits flow... The crucial link between natural capital and ecosystem services is that when some classes of ecosystem services are appropriated by humanity at an unsustainable rate, the stocks of natural capital which provide them may be depleted."*

Both concepts are intended to make the value of nature to humanity more immediately visible; an additional step taken has been to assign monetary value to these stocks and flows of goods and services, meaning that harm to them incurs a cost, and safeguarding or enhancing them a payment. For many stakeholders this valuation-based approach is essential if the environment is to be taken seriously and factored into decision making and actions. For others, putting a price on nature – as this approach does – is seen as flawed both practically and morally (see for example here).

One important point made by critics is that the environment can be argued to have intrinsic value, over and above its utility to humans.

5.2 How do food systems affect water use?

5.2.1 Agricultural water usage

Agriculture uses high volumes of fresh water

Food production requires significant amounts of fresh water.

Some foods are more water intensive than others, e.g. livestock products (livestock have extensive direct and indirect water demands – e.g. drinking/washing and irrigation of feed crops, respectively), many horticultural products, rice and processed foods.

The amount of water the production, distribution and consumption of a product uses can be expressed as its total water usage.

However, the ‘type’ of water used and the geographical context of its use are very important.

‘Blue water usage’ expresses the amount of water diverted or drawn from stored water sources – e.g. ground sources, rivers or lakes. Excessive abstraction can deplete these stores. Agriculture is responsible for 70% of these water withdrawals (primarily for irrigation).

However, these metrics do not account for water scarcity – whether water is abundant or scarce within a region – nor, in a related term, whether the region is experiencing water stress (a concept that encompasses not just the abundance of water, but its quality and accessibility for human use).

There is huge variation in current scarcity of water and the impacts of water use will therefore vary widely.

In a world of potentially increasing water stress, how we use ‘blue water’ is significant. Agricultural water needs in coming years will increasingly face competition from other sectors.

The water footprinting approach is increasingly used: it provides a way of quantifying and understanding the water use of a product, and its potential impacts on the environment.

Water footprints

Water footprint is a metric that quantifies the amount of water used to produce each of the goods and services we use. It allows these goods and services to be compared in terms of their water impact, and so to the impact on limited water resources of consumption by individuals, organisations, and even nation states. Water footprints incorporate all the water used – i.e. unable to be used again due to evaporation or removal in products – across the full lifecycle of a produce from production through to consumption, including all inputs to production (e.g. feed crops used in pork production). It has three components: (1) green water - rainwater used in soils; (2) blue water - freshwater sources; (3) grey water - water amount needed to dilute pollution to safe levels.

5.2.2 Types of water usage, water scarcity and water stress

Water usage terminology

In terms of food system water use, we may consider two categories of water: green and blue

- **GREEN** water refers to water from rainfall or other forms of precipitation that would be falling on the land anyway.
- **BLUE** water refers to water taken from ground or surface water stocks (i.e. it is water that is extracted or abstracted).

It is also important to note the difference between water stress and water scarcity: For a useful explanation of the difference, see here.

In short: water scarcity refers to a shortage in the absolute volume of available water, while water stress is a broader and more inclusive concept encompassing considerations of human need for the water in that area. For example, two areas may have similar levels of water scarcity (i.e. a similar lack of water), but if one area has a much higher local human population depending on its water supply, that area could be said to be more water stressed than the other.

The stress-weighted blue water use of a product refers to the blue water use of a product adjusted to take account of the water stress level of the region from where its embedded water derives.

Note that most literature on this topic will refer to 'water footprints' or 'virtual water use'. However, as these terms are used slightly differently by different stakeholders, leading to some ambiguity about what is and is not being included in the phrase, we have opted here to refer to water 'use' or 'usage' as a more general term encompassing both direct water use and – where context indicates – indirect water use.

Rainfall, water extraction and water stocks are interrelated

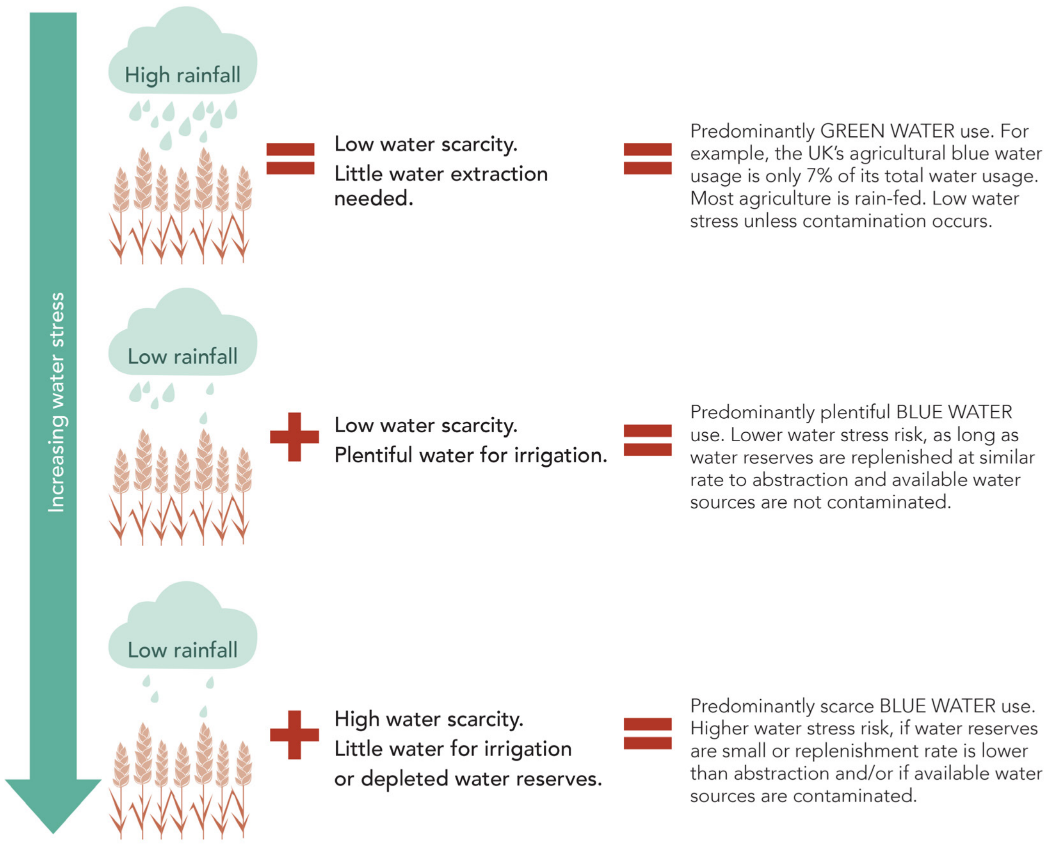

Figure 3: The relationship between rainfall, water extraction and water stocks.

Source: FCRN, (2016).

The sustainability of water use depends not only on the absolute volumes of water required to produce a product, but also on the relationship between green water, blue water, and the reliability, maintenance and abundance of blue water sources.

Regions with high rainfall do not need to rely on blue water to irrigate crops, but regions with lower rainfall will need to extract water to use for irrigation. When extraction rates are greater than replenishment rates, then water stress will increase. Water stress potentially undermines future food production and potentially causes other problems such as reduced availability for drinking water, sanitation and other non food uses. Over exploitation and drying of rivers and aquifers also has negative environmental consequences including damage to aquatic and terrestrial ecosystems, eutrophication, organic matter pollution and saline intrusion.

When weighted for impact on water resources (i.e. for how water-stressed the production region is), a product that uses a large volume of green water in its production may have a lower water usage than a product that uses a smaller volume of blue water in a water-stressed region (see below).

Eutrophication

Eutrophication refers to the buildup of nutrients in a body of water (e.g. nitrogen and phosphorus) to a level in excess of what would occur naturally and to which aquatic ecosystems are adapted. This can result in detrimental impacts on many aquatic plants and animals, as well as the rapid overgrowth of some plants and algae.

5.2.3 Factors determining the impact of water scarcity and water stress

The relationship between blue water usage, water scarcity and water stress is important

It is important to understand how much blue water is used in relation to how scarce the water is in the region of production. The relationship between the two is key. There is huge variation in the scarcity of water use and therefore in the impacts of water use. Stress-weighted water usage can show more clearly whether products are being produced in ways that increase the risk of water scarcity.

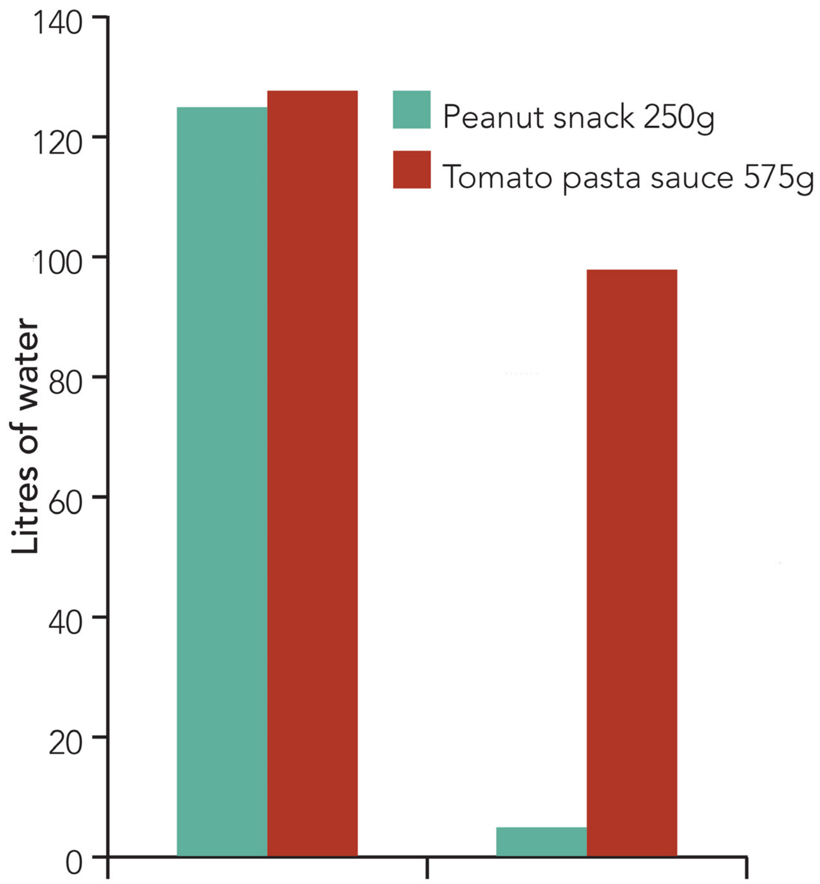

Figure 4: Comparison of water usage between a peanut snack and tomato pasta sauce. Right hand columns show the water us adjusted for water stress.

Source: Graph produced from data in Ridoutt and Pfister (2010).

This study used water-stress indicators to produce stress-weighted water usage of 2 different products and compared them with their total, green and blue water use. The products compared are here used to illustrate the importance of water stress, rather than to imply that these specific products have any particular role to play in sustainability.

While the blue water usage of the peanut snack was very similar to that of the tomato pasta sauce, the stress-weighted water usage for the tomato pasta sauce was much higher. This was because generally the tomatoes used in production were grown in hot, dry, irrigated and water stressed environments, while the ingredients for the chocolate peanut snack were produced in regions that were less water stressed.

Thus the significance of a given product's water usage will depend upon a). Whether abstracted water or 'green' water was used; b). whether it was grown in a water scarce area, c). whether it was using blue water at levels that depleted overall water stores faster than they were being replenished, and d). whether there could arguably be an alternative, more societally valuable use for that water.

As such, the simplified metric of 'blue water usage' does not capture the full impact of water scarcity relative to the product since in principle if blue water is extracted at a sustainable rate (no faster than it is being replenished) and there is no competition with competing activities, its use is not a problem. However, if it is being extracted at an unsustainable rate, problems clearly arise. Unlike the carbon footprint (GHG emissions – see Chapter 3) where greenhouse gas emissions are of global importance, water scarcity is therefore a more locally specific concern. As such, generalisations about water usage can be misleading if local stress indicators are not included.

Note that the impact of the activity on the water discharged also needs to be considered: regions with abundant water that is nevertheless contaminated will still be water stressed. Potential agricultural impacts include pesticide, heavy metal or bacterial contamination and eutrophication.

GHGs

GHGs is an abbreviation for greenhouse gases. These include gases such as carbon dioxide, methane, and nitrous oxide, which are released as a result of human activity, and which trap heat within the earth's atmosphere, leading to global warming.

Exporting water scarcity: food consumption in one region/country affects water use and water scarcity elsewhere

One study that examined the blue (irrigation) water impact of current UK food consumption found that two-thirds (~67%) of the UK's blue water requirement for food production is met from overseas.

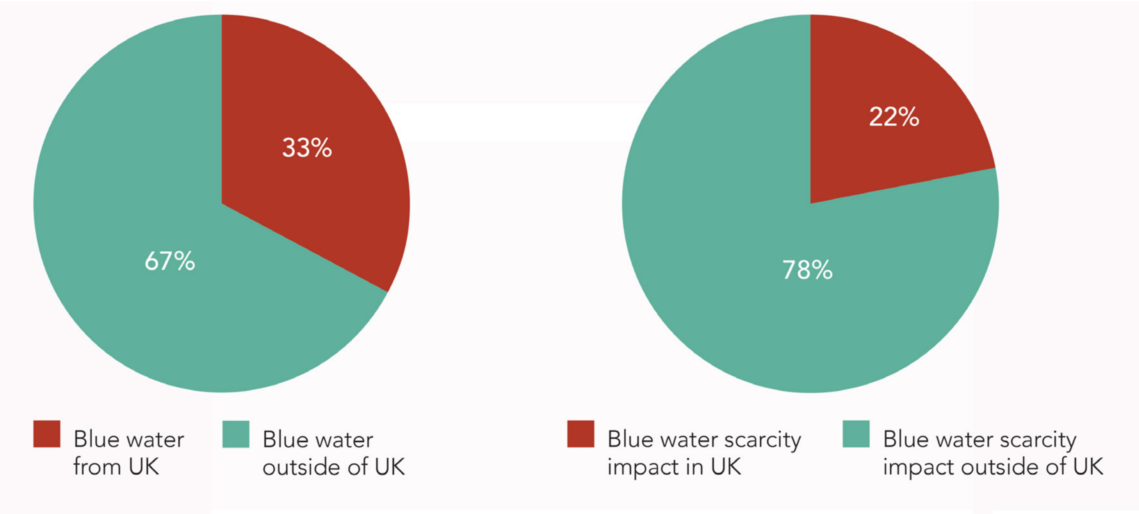

Figure 5: Blue water use (left) and blue water scarcity impact (right) of food consumed in the UK, comparing the proportion of impacts taking place inside and outside of the UK.

Source: Graph produced from data in Hess *et al*. (2014).

But when considering the water scarcity footprint – that is, considering how food consumption potentially affects water stress – a higher 78% of the scarcity burden is borne overseas, while the UK only carries 22% of the blue water scarcity impact of its own consumption.

This illustrates several important points:

- That consumption within a country affects water use abroad.
- That consumption within a country may therefore be responsible for water scarcity elsewhere.
- And that, crucially, there is often a disparity between the absolute amount of water that is 'imported' (in the form of embedded water use in food) and the impact on water scarcity that this causes. In other words, as shown above it is not just the amount of water used but also the water stress in an area which determines the impact of that water use.

The same product can use very different amounts of irrigation water, depending on region and context

The water extraction requirements of agricultural produce can vary enormously between regions. Here, a study showed that the blue water usage of livestock varied greatly between regions. Regions with lower rainfall need to rely more on water extraction and irrigation to produce livestock.

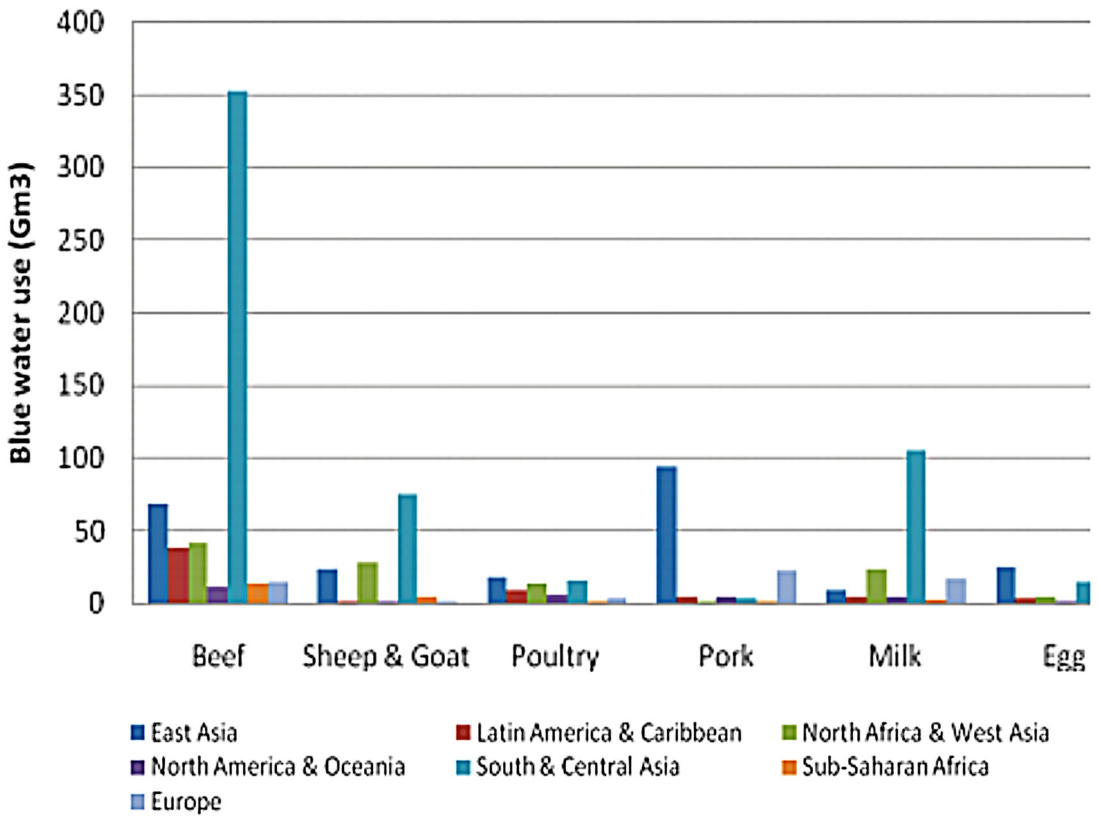

Figure 6: A comparison of blue water use to produce agricultural products between regions.

Source: Ran (2010).

5.2.4 The relationship between dietary patterns and water stress

Dietary patterns influence water usage

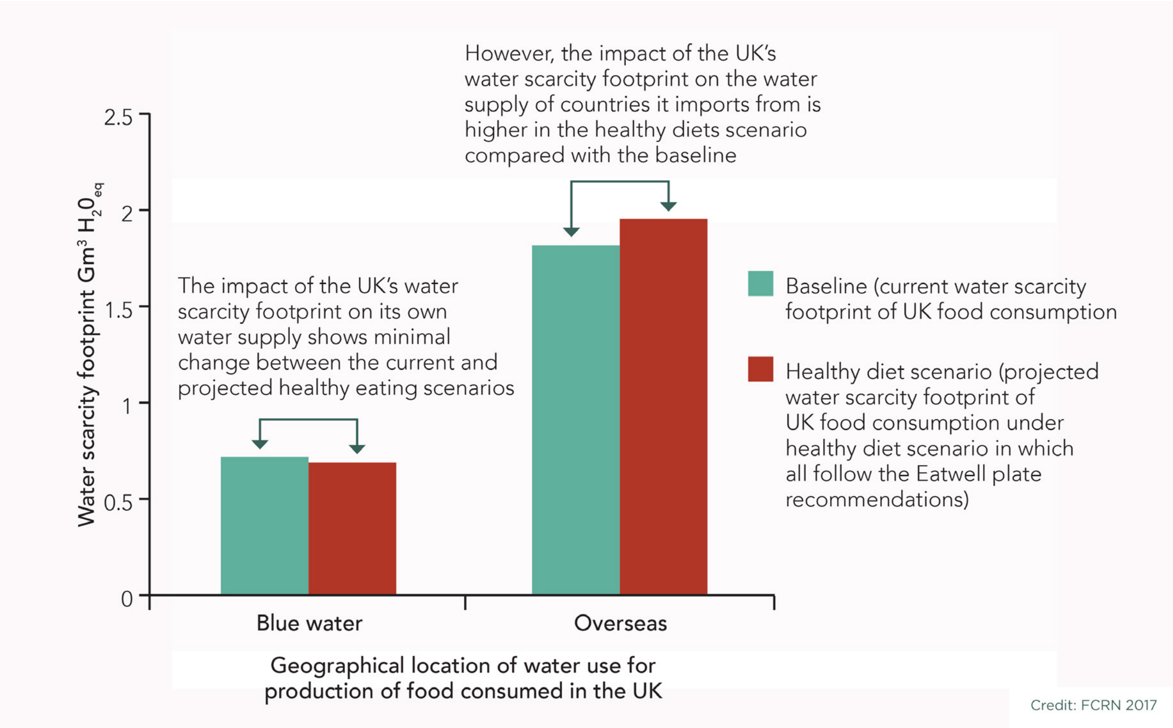

Figure 7: A comparison of the effects of dietary pattern on water scarcity footprint in the UK and overseas, resulting from UK food consumption.

Source: Adapted from Hess *et al.* (2014).

See Chapter 9 for more on healthy diets.

A study on how UK eating habits affect water requirements in the UK and in the countries it imports from (Spain, Egypt, India, South Africa, Pakistan, Belgium, US, Israel, Morocco) found that changes in food consumption towards healthier dietary patterns potentially has a greater effect on blue water scarcity overseas than in the UK. This is because under a healthy diet scenario fruit and vegetable intakes would increase – and much of the fresh produce consumed in the UK is imported from water stressed regions. Globally, shifts in dietary patterns towards increased consumption of highly water-intensive foods (e.g. increased livestock and processed foods in developing countries experiencing the nutrition transition – see Chapter 7) are expected to increase blue water use and subsequently to increase pressure on water-stressed regions.

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Demand for water is increasing globally – and agriculture competes with other sectors

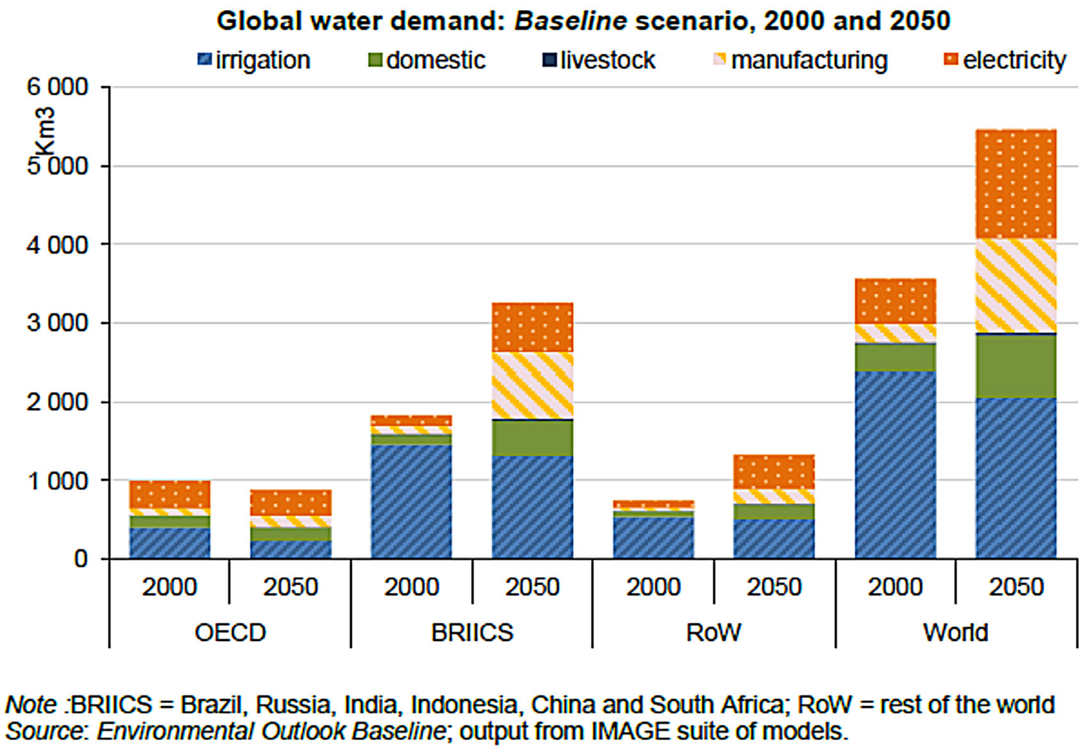

Figure 8: Projections of global water demand for 2050, compared to a 2000 baseline.

Source: OECD (2012).

With rising industrialisation and population growth, water demand across all sectors is predicted to increase globally by 55% between 2000 and 2050. The main demand pressures will come from domestic, manufacturing and electricity sectors in the emerging BRICS economies (Brazil, India, China and South Africa).

As such, there will be more competition for water, allowing for no significant increase in water use for agricultural irrigation. In the context of predicted rises in demand for food, water will need to be used more efficiently in agricultural production if water scarcity is to be avoided.

Greater efficiencies can be achieved through both production and consumption side shifts. Production- and consumption-side changes (in relation to food and GHG emissions) are discussed in Chapter 4.

5.3 How do food systems contribute to water pollution?

5.3.1 Eutrophication caused by fertiliser excesses in run-off

Excess nutrients in agricultural run-off can cause eutrophication

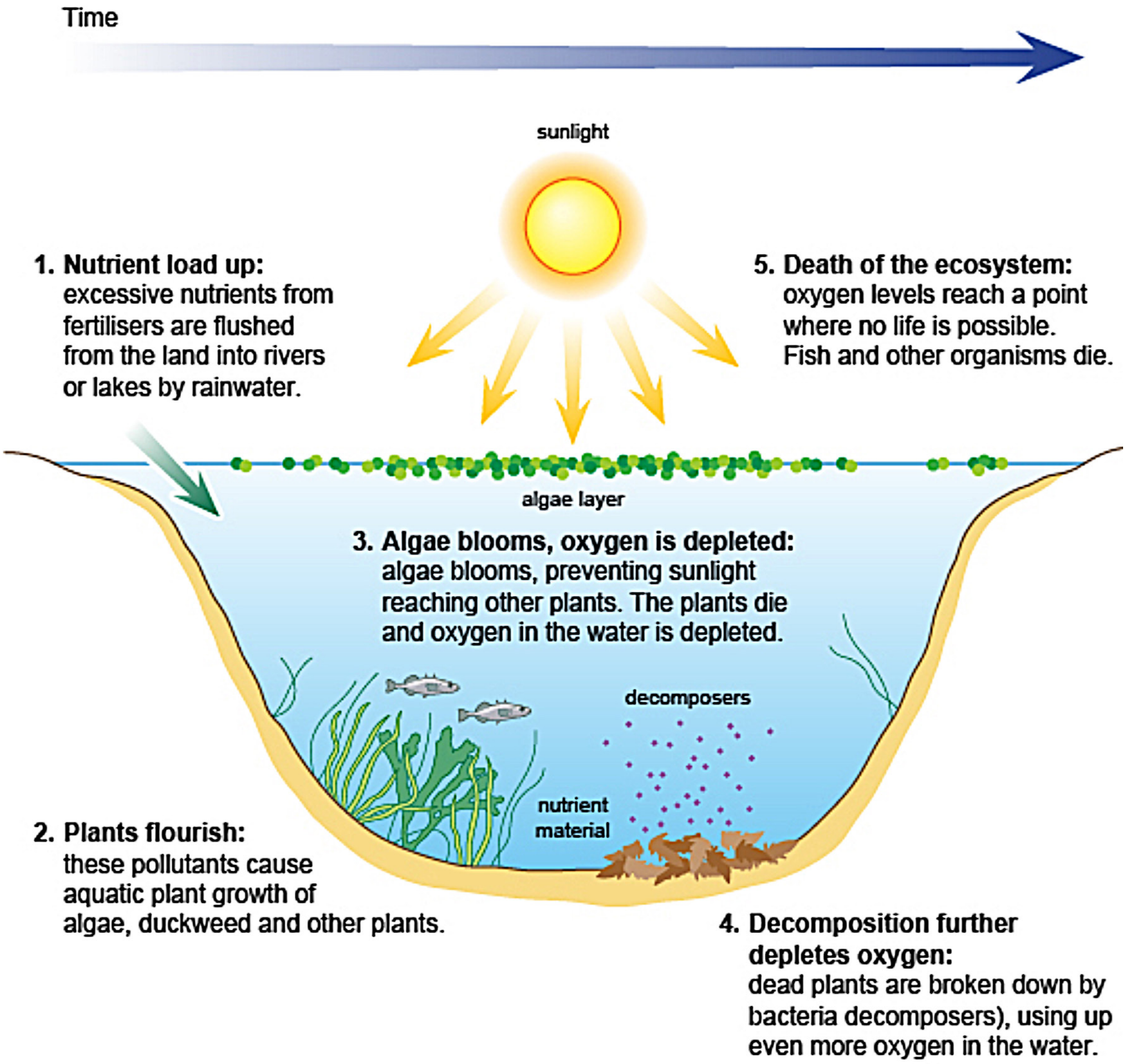

Figure 9: A schematic diagram of how eutrophication results from agricultural runoff.

Source: BBC GCSE Bitesize.

Agricultural run-off containing nitrates and phosphates from excessive fertiliser use can lead to waterways (both freshwater and marine) becoming enriched with nutrients, beyond levels that can be absorbed or dissipated by the natural system. This enrichment can promote algal blooms. These may directly damage ecosystems through the release of toxins, or prevent sunlight reaching aquatic plants growing in deeper water. These plants are then unable to photosynthesise, and so die and decay. The decay process uses up oxygen, leading to hypoxic (low oxygen) conditions, causing further death and decay of aquatic organisms. This process is called eutrophication.

Global prevalence and impact of nutrient excesses and resulting eutrophication

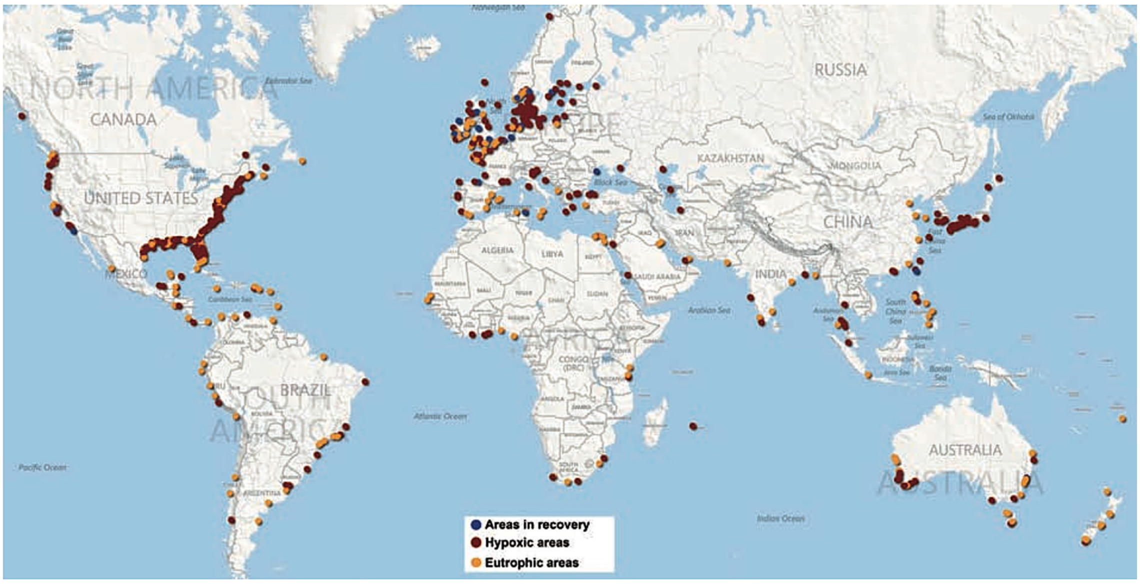

Figure 10: Map showing the location of eutrophic (excess nutrient) and hypoxic (insufficient oxygen) hotspots in coastal waters, as well as areas showing recovery from past hypoxic conditions.

Source: Sutton *et al.* (2013).

The Our Nutrient World report summarises research into global nitrogen (N) and phosphorous (P) flows between 2000 and 2010. The cited studies find that:

- There is a 120 million tonnes per year surplus of N in agricultural soils.
- 95 million tonnes of N and 2-7 million tonnes of P enter freshwater systems (aquifers and rivers) from agricultural systems each year.
- 40-66 million tonnes of N and 9 million tonnes of P enter the ocean from rivers each year.

The UK as an example

It is estimated that approximately 60% of nitrates and 25% of phosphorus in UK water bodies has agricultural origins.

"*Currently, only 24% of surface water bodies in England and 36% of surface water bodies in Wales meet 'good ecological status' as defined by the Water Framework Directive. 22% of water bodies achieve good status in Northern Ireland and in Scotland 65% of water bodies are deemed good or better, but for the 35% which are failing, agriculture is deemed to be a major pressure.*" (Watts, et al., n.d.)

The contribution of aquaculture

Data concerning the contribution of aquaculture to the problems of excessive nutrients are more difficult to find, as aquaculture is usually considered to be on the receiving end of water pollution problems or as a part of possible solutions (see for example the study by Rose, et al. (2014) discussing the potential role of shellfish aquaculture in managing nitrogen in coastal waters). However, some studies have sought to quantify aquacultural contributions to marine or freshwater nutrient loading. One study (Karakassis, et al., 2005) reported that fish farming contributes less than 5% of anthropogenic nutrient addition to the Mediterranean, which experiences an annual increase in N and P of just 0.01%, making the contribution of fish farming in this case arguably negligible. For a more detailed discussion of the contribution of aquaculture to excessive nutrients in the environment, see the Olsen, Holmer and Olsen (2008) report by the Norwegian Seafood Research Fund (FHF).

Aquaculture

Aquaculture refers to the breeding, rearing and harvesting of animals and plants in aquatic environments.

5.3.2 Pesticide contamination

- Pesticides (insecticides and herbicides) sprayed onto fields can accumulate in sediments that become washed into water bodies.
- Interstitial waters (water trapped in sediments or in pores in sedimentary rocks) can become particularly concentrated with pesticides.
- One study has shown that such interstitial water contamination can inhibit photosynthesis in microalgae, suggesting the ecological impact that pesticide contamination can have.
- Pesticides also pose a toxicity threat to both humans and wildlife. For example, pesticides are a known source of arsenic in soils and ground waters, compounding problems of naturally occurring arsenic in rocks, the accumulation of which in food systems is a serious health threat, affecting ~130 million people worldwide.

Interstitial waters

Interstitial waters refers to water trapped in sediments or in pores (voids or spaces) in sedimentary rocks – rocks formed by the deposition and cementation of material, as opposed to rocks formed by volcanic processes.

Microalgae

Microalgae are microscopic algae typically found in freshwater and marine ecosystems

Pesticide contamination

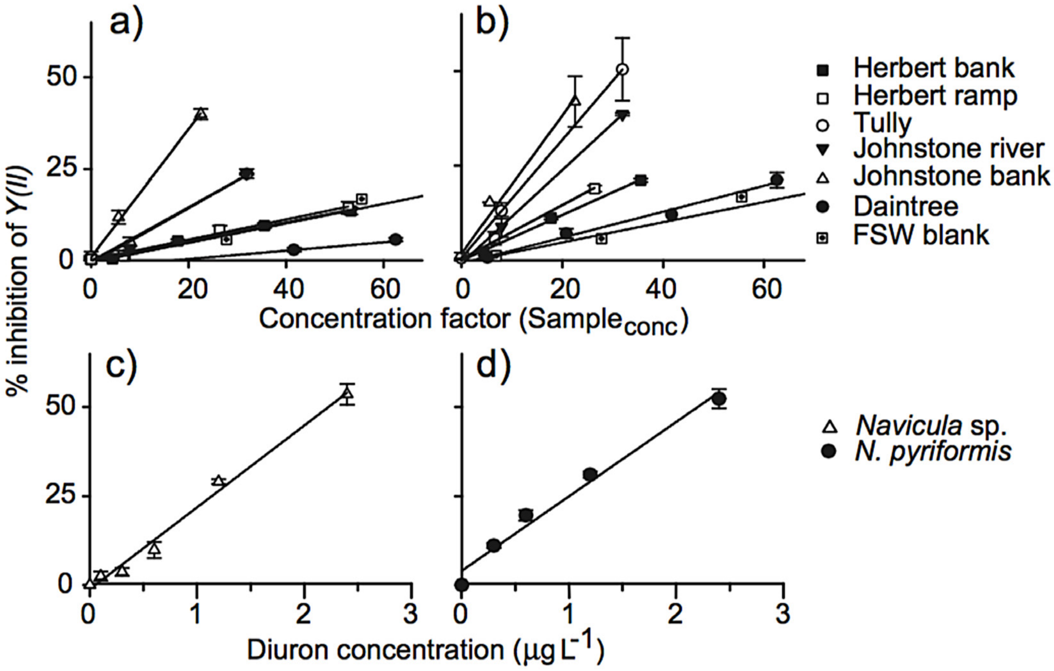

Figure 11: Inhibition of photosynthesis in microalgae according to concentration of pesticides in sediment interstitial waters.

Source: Magnusson, *et al*. (2013).

The UK as an example

Although only very small percentages of surface or ground water bodies in the UK fail to meet 'good status' requirements as a result of pesticides, 15% of Drinking Water Protected areas in England and Wales are at risk of failing standards, owing to very stringent drinking water safety standards.

China as an example

In recent years, excessive fertiliser and pesticide usage in China – and their impacts – have come under intense scrutiny. For a general discussion of soil and water pollution in China, considering both fertilisers and pesticides together, see the following news articles:

- Meng, Y. (2012) The damaging truth about Chinese fertiliser and pesticide use. Chinadialogue [online].
- Watts, J. (2010) Chinese farms cause more pollution than factories, says official survey. The Guardian [online].
- Patton, D. (2015) China farm pollution worsens, despite moves to curb excessive fertilisers, pesticides. Reuters [online].

For more specific research pertaining to China's fertiliser and pesticide situation, see:

- Sun, B., Zhang, L., Yang, L., Zhang, F., Norse, D. and Zhu, Z. (2012) Agricultural non-point source pollution in China: causes and mitigation measures. Ambio, 41(4), 370-379.

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- Li, H., Zeng, E.Y., and You, J. (2014) Mitigating Pesticide Pollution in China Requires Law Enforcement, Farmer Training, and Technological Innovation. Environmental toxicology and chemistry / SETAC 33 (5), 963–71.

Statistics concerning China's pollution can also be found in Chinese here.

5.3.3 Sediment and silting

Sediment and silting

Picture credit: Lynn Betts, U.S. Department of Agriculture. Available here.

Agriculture is a major source of excess sediment in waterways (e.g. it is estimated that 75% of sediment that is polluting water bodies in the UK is as a result of farming). This can be caused by upland drainage management practices that lead to greater volumes and rates of runoff into waterways; this may cause faster river flows and subsequent increased downstream erosion of river banks, producing excess sediment. Along with the eutrophication and toxicity associated with chemicals contained within sediments, sediment can act as a physical pollutant by:

- increasing the turbidity of the water (i.e. making it cloudier) reducing the depth to which light can penetrate, with negative consequences for photosynthetic plants and algae in the water and ecosystems they support;
- leading to silting, i.e. deposition of sediment on the riverbed, which changes the dynamics of the water flow. This increases the risk of flooding as well as potentially creating blockages for human users of the waterways.

Turbidity

Turbidity refers to the amount of light that can pass through water (i.e. its cloudiness), as a result of particles that are suspended within the fluid. It can vary naturally depending on location, but can have detrimental impacts on ecosystems if cause by human activity. For this reason, it is often used as an indicator of water quality.

Silting

Silting refers to the transport and deposition of sediment on the riverbed, which changes the dynamics of the water flow and can affect aquatic ecosystems.

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5.4 How do food systems affect land-use and biodiversity?

5.4.1 Food systems and deforestation

Deforestation is continuing, with tropical, rather than temperate, forests most affected since the early 20th century

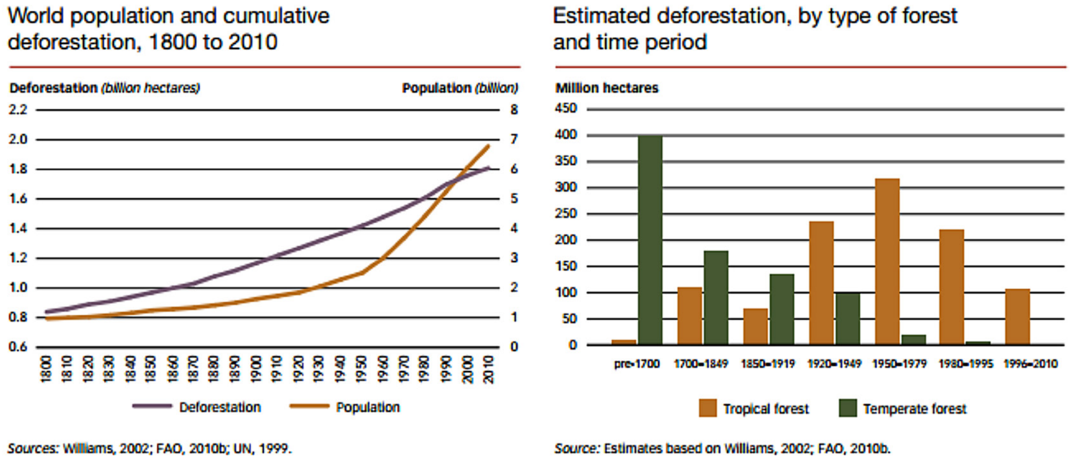

Figure 12: World population and cumulative deforestation, 1800 to 2010 (left). Estimated deforestation, by type of forest and time period (right).

Source: FAO (2012).

Deforestation for human purposes has a long history. Historically, deforestation has often gone hand-in-hand with human population growth and development. Up until the 20th century, most of this growth, development and therefore deforestation took place in temperate regions.

More recent deforestation has taken place in tropical regions, particularly in South America and South East Asia but also in Africa.

What effect do food systems have on deforestation and forest degradation?

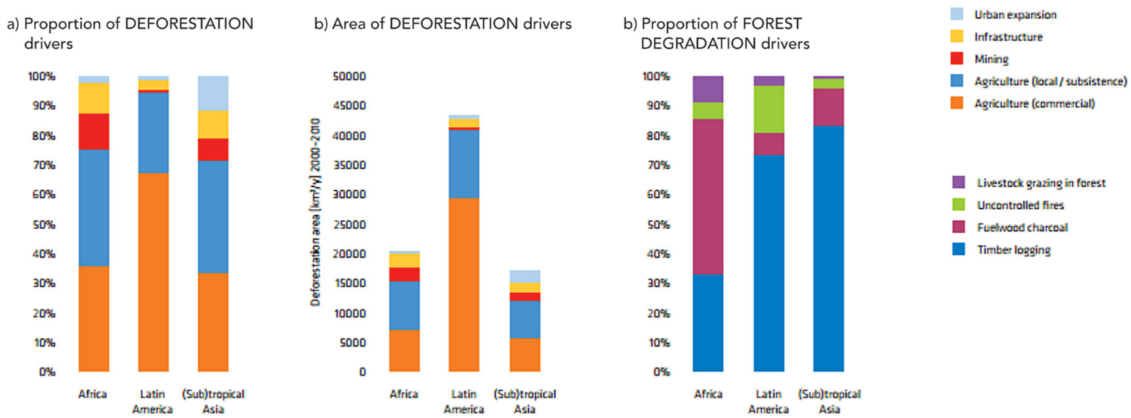

Figure 13: Global drivers of tropal deforestation. (a) proportion of drivers in each region. (b) contribution of drivers to total deforestation in each region. (c) proportion of forest degradation drivers.

Source: Kissinger, Herold and De Sy (2012)

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Agriculture has historically been the biggest driver of deforestation, responsible for about 80% of deforestation in the key tropical regions of the world (Africa, Latin America and subtropical Asia). The main driver of deforestation in Latin America has been commercial agriculture, but in Africa and subtropical Asia, subsistence farming has played a significant role. In contrast, forest degradation (where forests deteriorate through mismanagement, rather than the forest being cleared for alternative use) is caused more by timber logging and fuelwood than by agriculture.

Growing demand for food is expected to further increase pressure on forest.

Why does deforestation matter?

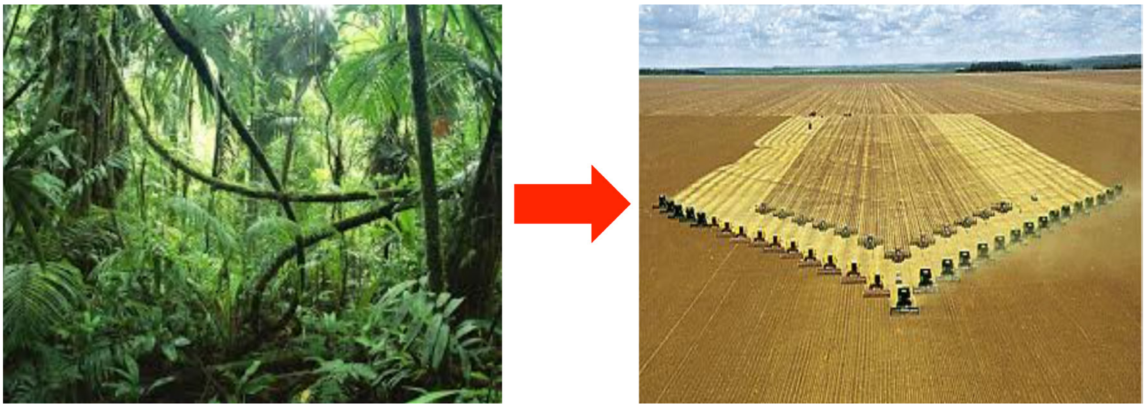

Figure 14: Land use change from tropical forest releases carbon stored in forests and soils and impacts upon biodiversity.

Land-use change from forest to agriculture releases carbon stocks held in forests.
The release of carbon contributes to global GHG emissions.
Land-use change also causes significant biodiversity loss.

CO_2 is released when carbon stocks such as forests are cleared for agricultural purposes – see Chapter 3 for a discussion of how significant this is in relation to overall food GHG emissions.

The benefits of halting deforestation are significant, potentially reducing global GHG emissions by around 3 gigatonnes per year in 2030. To put this in context, total global GHG emissions in 2010 were 49 gigatonnes carbon dioxide equivalent (GtCO2eq).

Restoring degraded agricultural land by 12% could also reduce GHG emissions by up to 2 gigatonnes per year.

Deforestation contributes to significant biodiversity loss (see below).

5.4.2 Food systems and biodiversity loss

Biodiversity loss from wider agricultural impacts

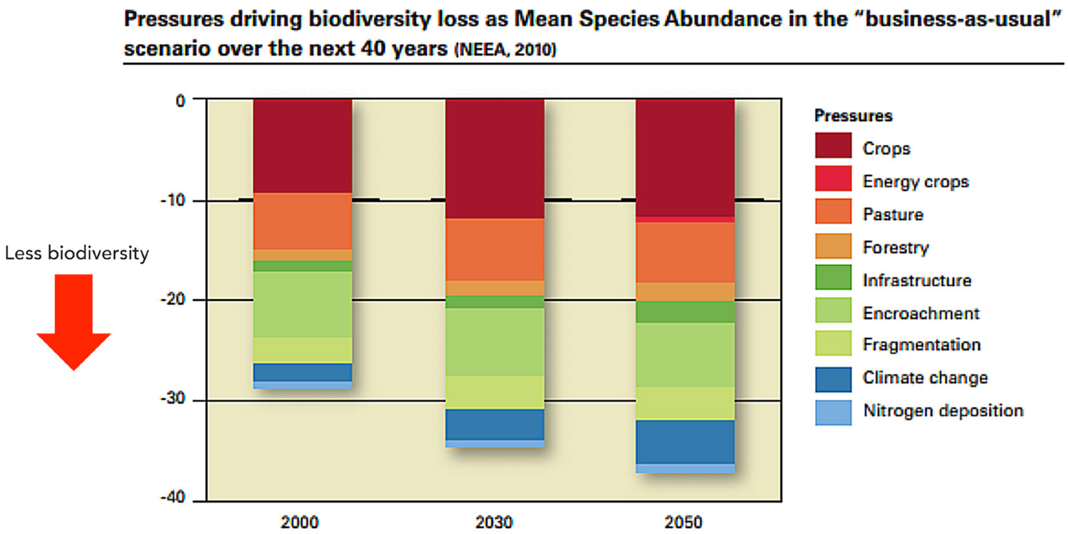

Figure 15: Without action, continued agricultural expansion, driven by the need for more cropland and pasture, will lead to significant biodiversity loss.

Source: Adapted from NEAA (2010).

Without action, increased demand for food, and in particular for resource-intensive food such as meat, will lead to significant and continued biodiversity losses. This would primarily arise from agricultural expansion into new areas to grow crops (often to feed livestock), from the creation of new pasture lands, and encroachment on and fragmentation of ecosystems. Note that a degree of uncertainty exists around population growth, demand for food, and how food production responds to these changes. For discussions about expected population change, see Chapter 1, Chapter 4 and Chapter 7.

These biodiversity losses could be modified or reduced by increasing the extent of protected areas, through yield increases in food production, better forest management, by actions to moderate demand for resource-intensive food consumption, and by limiting climate change. Some of these options are explored in Chapter 4, in relation to addressing greenhouse gas emissions.

5.4.3 Food systems and soil degradation

Deforestation, climate change and unsustainable soil management practices all contribute to soil degradation

Poor management of agricultural soils combined with other environmental drivers can lead to degradation of soils, including (but not limited to):

Salinisation: the accumulation of soluble salts of sodium, magnesium and calcium in soil to the extent that soil fertility is severely reduced. Source: see here.

Compaction: the result of physical pressure exerted on soils, e.g. by heavy farm machinery which leads to air spaces between soil particles being reduced, resulting in poorer water infiltration and drainage.

Acidification: the gradual reduction in soil pH as the result of acids in rain or produced by fertilisers.

Organic carbon loss: Soil organic carbon, from living or dead and decaying organisms in the soil, plays several crucial roles in soil function. According to this fact sheet by the Joint Research Centre of the European Commission, "Soil organic matter is a source of food for soil fauna, and contributes to soil biodiversity by acting as a reservoir of soil nutrients such as nitrogen, phosphorus and sulphur; it is the main contributor to soil fertility. Soil organic carbon supports the soil's structure, improving the physical environment for roots to penetrate through the soil." Organic matter also absorbs and holds water, improving drainage and soil structure. Threats to soil organic matter (i.e. processes that lead to its reduction) include: soil temperature rises (linked to both climate change and tillage), waterlogging and the physical removal of vegetation (including crops every harvest) without replacement of the organic matter.

5.4.4 Direct impacts of agriculture on wildlife and ecology

In addition to the indirect impacts of agriculture on wildlife – through its contributions to deforestation, climate change and other forms of environmental damage – agriculture can also have direct localised impacts on the wildlife sharing the farmland. For example, Benton et al. (2003) present the below scheme showing the various ways in which bird populations on a local up to a national scale may be affected by agricultural activities.

Direct impacts of agriculture on wildlife

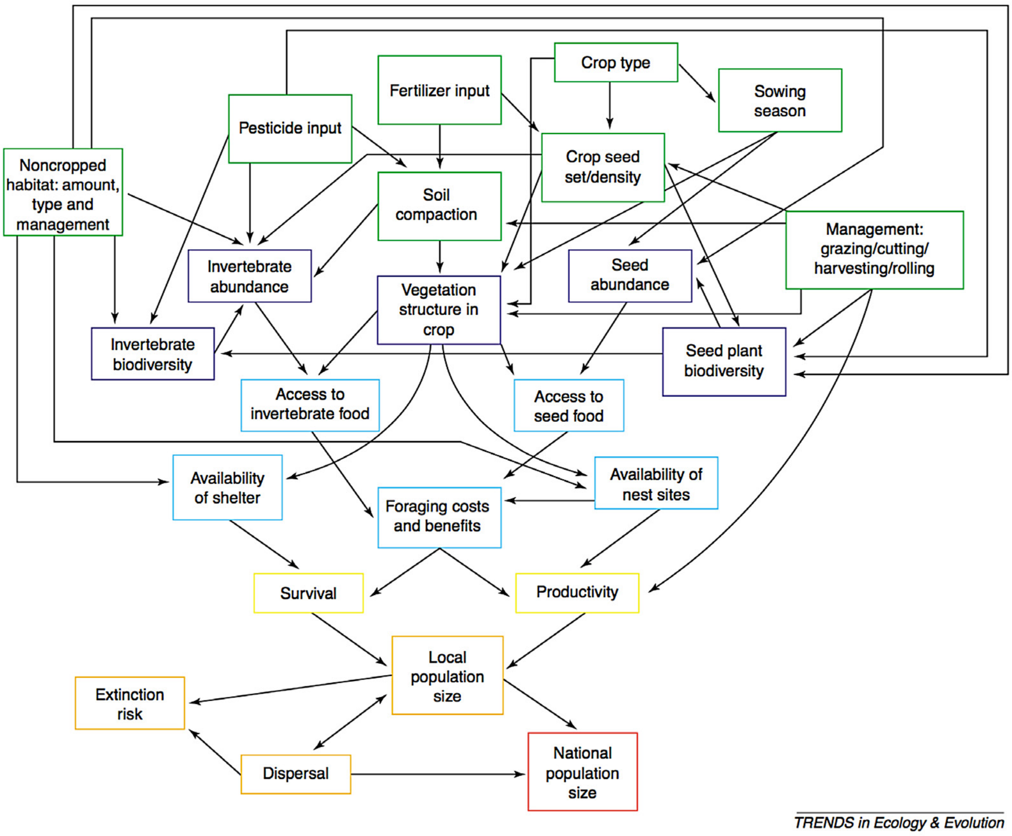

Figure 16: Routes by which farming practices impact upon farmland birds.

Source: Benton (2003).

Another currently relevant example is that of the link between neonicotinoid pesticides and declining global bee populations. A number of studies have provided evidence that bees of various species are directly adversely affected by such pesticides – for example, Whitehorn et al. (2012) exposed bumble bee (Bombus terrestris) colonies to field-realistic concentrations of a neonicotinoid pesticide then allowed the colonies to develop in field conditions. They found that the colonies had a significantly impaired growth rate, as well as producing 85% fewer queen bees than untreated colonies. Godfray et al. (2015) summarised and reviewed the latest advances in the scientific understanding of the relationship between neonicotinoids and pollinating insects and reported that:

- There is evidence that residues of the neonicotinoid pesticides applied to crop seeds, which become distributed throughout the plant as it grows, can be detected in pollen and nectar produced by the plants, although there is a wide variation in the reported concentrations in the literature.

- There is some literature (limited in number of data and in species considered) reporting that neonicotinoid pesticide residues can be detected in wild pollinators as well as in honeybee and bumblebee colonies.

- While some studies find that pollinators can be exposed to lethal levels of neonicotinoid pesticides, most exposures are found to be at sub-lethal levels. However, multiple studies report behaviourally and physiologically detrimental effects of these sub-lethal dosages, although the range of dosages and the range of reported effects are both very wide.

As a result of the evidence available, the EU has placed restrictions on the use of nicotinoid pesticides, although exceptions can be granted in geographically specific areas where viable alternatives are not available.

5.4.5 Multi-scale impacts of agricultural intensification

Multi-scale impacts of agricultural intensification

- As has been shown above, agricultural intensification and expansion can contribute to land use change and biodiversity loss in its immediate vicinity.
- However, the impacts of all agricultural activities must be viewed across multiple scales.
- Intensification may be associated with negative impacts at the field scale but additionally impacts (potentially positive or negative) on the farm, landscape, country, regional or even global scale may also arise.
- For example, agricultural intensification by one farm may free up land for wildlife conservation elsewhere in the same or even another country (so called 'land-sparing'). This may benefit wildlife. On the other hand, productivity increases arising from intensification may, by increasing food supply, drive down prices, so stimulating demand and triggering further production, thereby undermining the land sparing gains.
- Similarly, adoption of more 'wildlife-friendly' farming may be associated with lower yields, thus requiring the additional cultivation of land elsewhere within the same country, or importing of food from other countries (potentially associated with land use change and biodiversity loss in the exporting country). On the other hand, wildlife friendly farming could in principle be implemented in parallel with more systemic shifts towards the consumption of less resource and land intensive foods, thereby reducing the 'leakage' effect.
- It may be argued that individual farms undergoing intensification and causing localised biodiversity loss may contribute on a wider landscape scale to disproportionately damaging habitat fragmentation; that is, the breaking up of continuous habitat into smaller more isolated patches.

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Habitat fragmentation

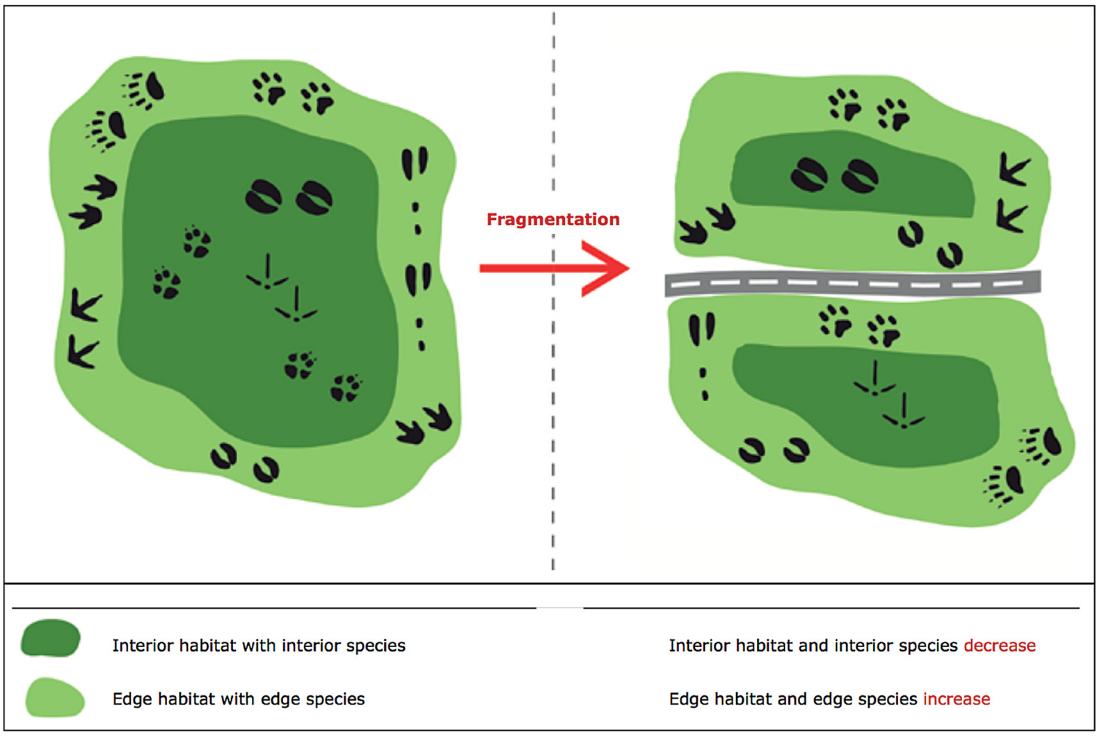

Figure 17: Change in habitat availability resulting from fragmentation.

Source: FOEN and EEA (2011).

In addition to simply reducing habitat area, habitat fragmentation poses multiple additional threats to biodiversity: for example, so-called 'edge effects' caused by the simple geometric fact that a fragmented habitat will have more exposed edges than a continuous habitat of the same total area. This can drastically alter the species composition of the area since the interior habitat area is reduced (amounting to habitat loss for the species that depend on it) while edge habitat area increases (amounting to habitat expansion for edge species, which may be more versatile/ adaptable anyway) (see Figure 17).

5.5 How do food systems affect fish stocks and marine habitats?

5.5.1 Pressures on wild fish stocks and threats to marine ecosystems

Wild fish stocks are under increasing pressure

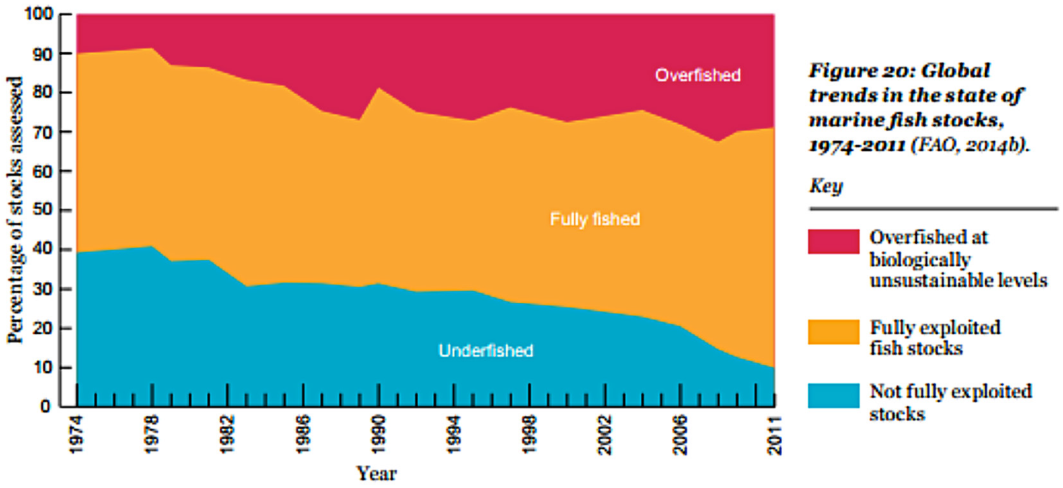

Figure 18. Marine vertebrate populations declined 49% between 1970 and 2012 29% of marine fisheries are overfished.

Source: WWF (2015).

The last 50 years have seen dramatic reductions in wild fish stocks, due mainly to over-fishing and destructive fishing techniques by humans. Around 85% of fisheries are now fully exploited or overfished.

Fish are an important food source, however, and nearly 3 billion people rely on fish as a major source of protein. Fisheries therefore need to be protected on grounds of 'self interest' – to safeguard global food security – as well as for intrinsic environmental reasons.

The Marine Resources Assessment Group report identifies the following key threats to wild fish stocks caused by fishery-linked activities:

- Overcapacity – taking a larger number of fish out of the environment than can be replenished naturally, leading to decreasing populations.
- Perverse subsidies – made to those in the fishing industry for such purposes as vessel construction or to offset fuel tax; this lowers the real cost of fishing, meaning that fishing activities can extend beyond the point at which they become unprofitable.

- Poor governance – leading to little or no local sustainable management of fisheries (in contrast, good governance may involve implementing protected areas where fishing is restricted or forbidden, in order to allow fish stock recovery).

- A lack of data – on, for example, the state of wild fish stocks, the state of the wider environment, or concerning the operation of fisheries. Such data provides the basis for understanding how sustainable management might be put into place and of measuring progress towards or away from key goals.

- By-catch and discards – which can lead to damaging reductions in populations both of species that are deliberately caught (for example not returning live caught fish that are too small to sell) and of species caught incidentally and unintentionally (for example when nets and other fishing equipment are not able to distinguish between target and non-target fish).

(For more on the proposed solutions to these problems, see the Marine Resources Assessment Group report).

Trawling causes direct damage to ecosystems (especially coral reefs) irrespectively of the amount of fish caught.

Only 3.4% of the oceans are protected. Certification of sustainable fisheries does exist, although coverage is not high and illegal fishing continues.

Other environmental damage to marine ecosystems includes the increase in oxygen-depleted dead zones resulting from nutrient run-off from agriculture, loss of coral ecosystems and mangrove systems. Some of the mangrove loss is a consequence of aquaculture / seafood farming although the influences are diverse and changing (see Richard and Friess, 2015). See later in this chapter for more on aquaculture.

5.5.2 The rise of aquaculture

Aquaculture can reduce *some* of this pressure

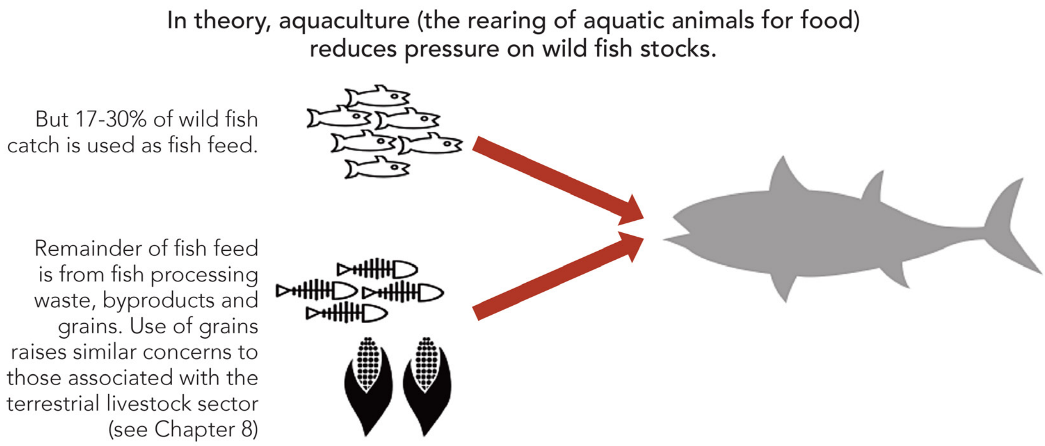

Figure 19: Aquaculture feed is also associated with environmental pressures.

Source: FCRN (2016).

Critics of aquaculture production argue that the industry uses wild fish as feed ingredients for farmed fish, thereby depleting marine stocks, albeit at a lower trophic level. This criticism is based on the argument that catching fish in order to feed other fish does not make any sense, depletes wild fish stocks of smaller fish and disrupts marine food chains.

However, in recent practices fishmeal composition has changed, making use of marine catch byproducts such as fish guts as well as the byproducts from farmed fish processing. Additionally, fishmeal can be made from fish such as sand eels that are not usually eaten by humans, or from fish that have low demand from humans or are caught long distances from markets (such as anchovy) – although how 'low demand' is defined is still controversial. It is also the case that the major reduction fisheries (i.e. fish harvested as feed ingredients) such as the Peruvian anchovy are often well managed and stocks are not being depleted. Other components of fishmeal include grains and agricultural byproducts, and while the same arguments exist as for feeding grains to livestock, the energy conversion from grain to fish flesh is generally better for fish than livestock.

Using modern feed combinations, it is now the case that for every tonne of wild fish used for aquaculture, around 1.92 tonnes of farmed fish (averaged over all fish types) are produced. Obviously there are variations between types – salmon is still the highest user with a FIFO ratio of 1.68, meaning that for every tonne of whole wild fish used 0.595 tonnes of salmon are produced.

Consumption of farmed fish is increasing, but China dominates the industry

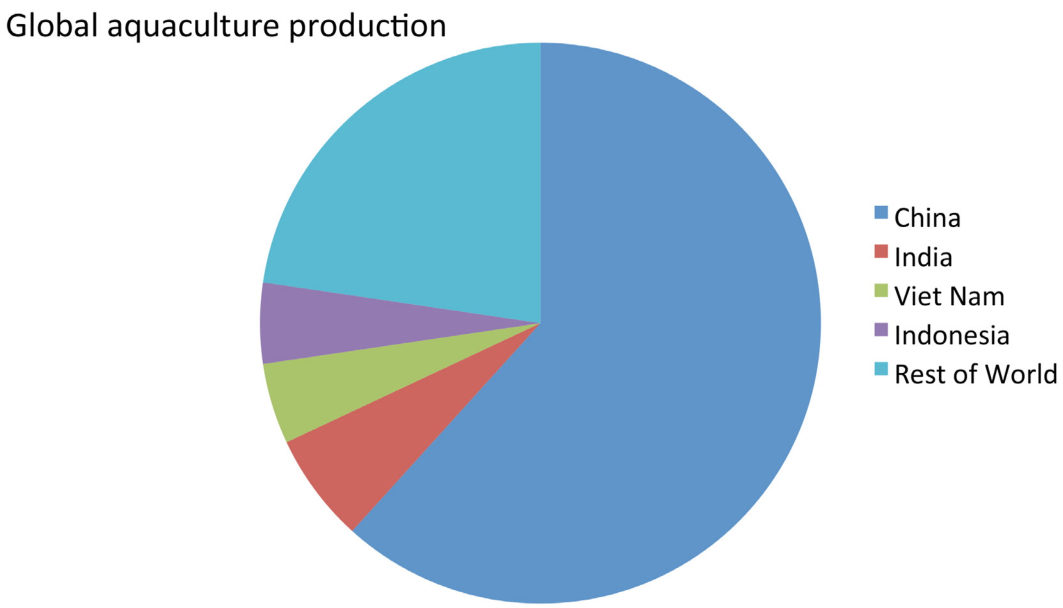

Figure 20: Share of global aquaculture production produced by the top four countries compared to the rest of the world.

Source: FAO (2012).

- Aquaculture now contributes around 50% of fish consumption.
- Aquaculture production increased from 36.8 million tonnes in 2002 to 66.6 million tonnes in 2012.
- However, China skews the figures significantly accounting for about 50% of the world's aquatic production and consumption. China is also the world's largest exporter of farmed fish.

In the last 20 years there has been significant increase in aquaculture production and consumption on a global scale. Although China represents over 60% of global production, and much of it is consumed there, it is also the largest exporter of farmed fish. The sustainability of aquaculture, and by extension wild fish stocks, is therefore greatly influenced by China.

The next section looks at this relationship in more detail and looks at what is needed to ensure sustainable wild fish stocks.

Aquaculture and its environmental impacts

Growth in aquaculture production has been linked to many environmental concerns including:

- Mangrove destruction and habitat loss.
- Pollution of the aquatic environment (eutrophication, oxygen depletion, pesticide contamination).
- Escapes and genetic interactions with wild fish populations; use of non native species.
- Transmission of zoonotic diseases to wild fish.
- Use of fish meal and fish oil as major feed inputs.

5.5.3 The diversity of aquacultural systems

Aquaculture systems are highly diverse so it is hard to generalise about their environmental impacts

Aquaculture enterprises vary by:

- Intensity of production: extensive systems (consuming nutrients naturally present in water), semi-intensive (fertiliser inputs to increase nutrient content, or some supplementary feeds); intensive (commercially prepared feeds based on wild fish, fish processing byproducts and/grains and soy).
- Species type (from crustacea through to salmonids) and trophic level (filter feeders, herbivores, carnivores).

- Water type and source – rainfed (natural pond) systems or irrigated; fresh, brackish or salt water.
- Containment type – ponds and sea pens, through to tanks.
- Market orientation (subsistence/semi-subsistence, production for local market, production for national or international markets).
- Degree of integration with other agricultural practices, seasonal or year round, and so forth.

The diversity of aquaculture systems

Aquaculture exists in a multitude of different forms. Each has a different balance of environmental and socio-economic benefits and drawbacks. A small sample of different systems is shown here (text adapted from and images courtesy of Dave Little (personal communication)):

Cage culture:

Cage culture is a popular, simple and relatively inexpensive form of aquaculture to establish, whereby fish are enclosed in a cage in either flowing or static water. A key design element is that water moves in and out of the cage either through the natural flow or through movement of the fish themselves. Such free exchange makes cage culture vulnerable to pollution from other water users and also liable to impact surrounding water quality through excess feed (leading to fertilisation effects and eutrophication).

Gher system in Bangladesh:

Co-production of rice with prawns, shrimp and fish. Gher systems have helped diversify livelihoods as farmers produce prawn and shrimp (mainly for export) as well as rice, vegetables and fish species for local consumption. Co-production reduces the overall nutrients required (since the fertilisers applied to the rice increase natural feed available for stocked and wild aquatic animals that share the space) and reduces pesticide use compared to rice monocultures. However, the use of pesticides in the modified rice fields has to be carefully managed to avoid poisoning the aquatic animals.

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Extensive/semi-intensive aquaculture ponds:

Common for shrimp in countries like Bangladesh and the Philippines. The ponds retain nutrients but also provide environmental services by removing nutrients from surface water. Although mangroves have been lost in the past through conversion to shrimp farms, in many areas shrimp ponds have increasingly been established on formerly unproductive rice land. Inland, semi-intensive aquaculture relying on additional fertilisation and feed inputs tends to add nutrients to the farm or local environment which may have negative or positive impacts depending on context. Semi-intensive aquaculture ponds remain the dominant form of aquaculture in the Asia Pacific region, generating an increasing proportion of the fish consumed and supporting large numbers of poor livelihoods.

Intensive white-legged shrimp production:

In China reared in intensive concrete lined ponds with on-farm effluent recycling and reuse and relatively high feed conversion efficiencies achieved through use of commercial feeds: The species has been subject to domestication and selective breeding in recent years. High stocking densities of shrimp and limited water exchange are made possible through use of commercial formulated water-stable feeds, the use of aeration and recycling of water on the farm. Such management reduces the risk to pathogen exposure and pollution of surrounding water resources. However, feed and energy costs are high and comparative LCAs find overall environmental impacts to be higher in intensive than in semi intensive systems.

5.5.4 Addressing environmental concerns of aquaculture and overfishing

Progress is being made to address some environmental concerns:

For example:

- Destruction of mangroves is slowing.
- Aquaculture production may be sited on unproductive agricultural land.
- Alternatives to fish meal are being sought (partly on cost grounds).

And in some contexts aquaculture can contribute positively to the environment, for example:

- Filter feeders (e.g. molluscs) can remove excessive nutrients from water ways.
- Aquatic systems, especially if well sited and designed, can attract birds and other wildlife.

Increasing demand for aquatic products will require both sustainable aquaculture as well as marine protection and fishery regulation

"Increasing aquaculture production can dampen the fishing pressure on wild stocks, but this effect is likely to be overwhelmed by increasing demand and technological progress, both increasing fishing pressure. The only solution to avoid collapse of the majority of stocks is institutional change to improve management effectiveness significantly above the current state."

A recent study has modelled future pressure on wild fish stocks under different economic drivers of increased aquaculture production, increased demand for fish as a food, and technological advances in marine fishing. The study focused on four key fish: cod, salmon, tuna and seabass, both wild and farmed, under variable increases in demand. At expected rates of demand increase, it concludes that realistic increases in aquaculture alone will not protect existing wild fish populations, due to the magnitude of increase in demand.

If the increase in demand can be moderated, then the requirements on aquaculture and pressures on wild stocks will be reduced. More effective marine ecosystem protection and widespread fishery regulation are also needed to prevent stock collapse.

5.6 How are food losses and waste an environmental concern?

5.6.1 Food waste is a global problem

Approximately 1/3 of the food produced globally is not eaten

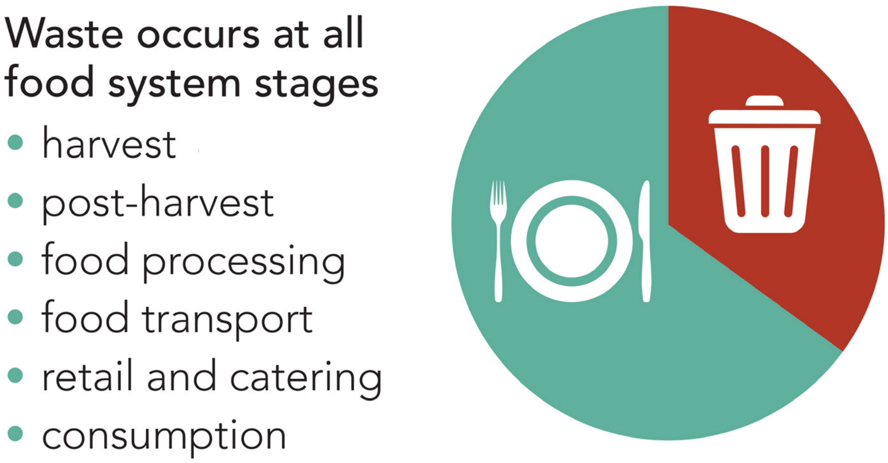

Figure 21: Food loss and waste across food system stages.

Source: FCRN. (2016).

Globally around one third of the food we produce is not eaten. Put into context, if food production requirements are to nearly double by 2050, then wasting one third of our existing food output is a luxury we can ill afford.

Food waste and losses contribute to GHG emissions both directly and indirectly. Direct emissions are in the form of methane and are generated when organic matter decomposes (e.g. in landfill). Food losses and waste contribute indirectly since, for a given level of consumption more food needs to be produced than is consumed since a proportion of it is wasted. The emissions from this additional production can be seen as avoidable GHG emissions (and avoidable use of water, land and so forth).

When all of the environmental impacts from food systems are considered – GHG emissions, water use, deforestation and both terrestrial and marine biodiversity loss – and taking into account existing world nutritional challenges (see Chapter 1), then food waste presents an important focal issue to be addressed (see Chapter 4 for more on mitigation of food system GHGs).

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5.6.2 Food losses and waste occur throughout the food system

Food waste hotspots vary regionally

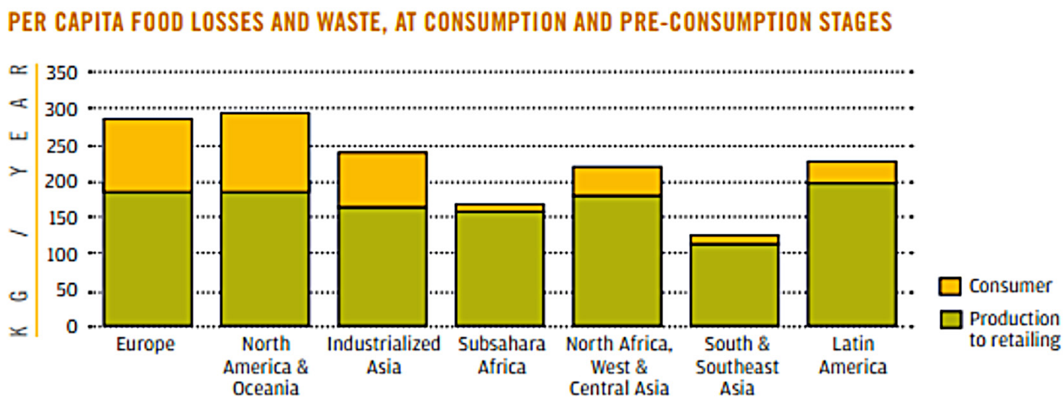

Figure 22: Share of food loss and waste taking place at pre-consumer and consumer stages, across regions.

Source: FAO (2013).

> In developed countries food waste occurs at the production and consumption stages.
>
> In poorer countries, almost all food waste arises at the production, post-harvest and storage stages.

Problems with food waste are not equally distributed across regions.

In this report, production refers to agricultural production, post-harvest handling and storage, processing and distribution to retailing. Consumption refers to food waste by consumers.

In poorer countries, per capita losses are higher at the production, harvesting, transport and storage stages (i.e. up until the point of sale and consumption.). One of the reasons for this is a lack of infrastructure and technology for safe storage and efficient transport from farm to market. Hungrier populations also tend to waste less food at home, resulting in relatively lower consumer-stage waste (around 4%–16% of the total).

In wealthier countries, food waste per capita is in general higher, and more evenly distributed across all food system stages, but levels of waste at the consumption stage are particularly significant.

Waste at the consumption stage in middle and high-income regions ranges from 31%–39%.

5.6.3 Food waste contributes significantly to GHG emissions

Avoidable GHG emissions of wasted food are very significant

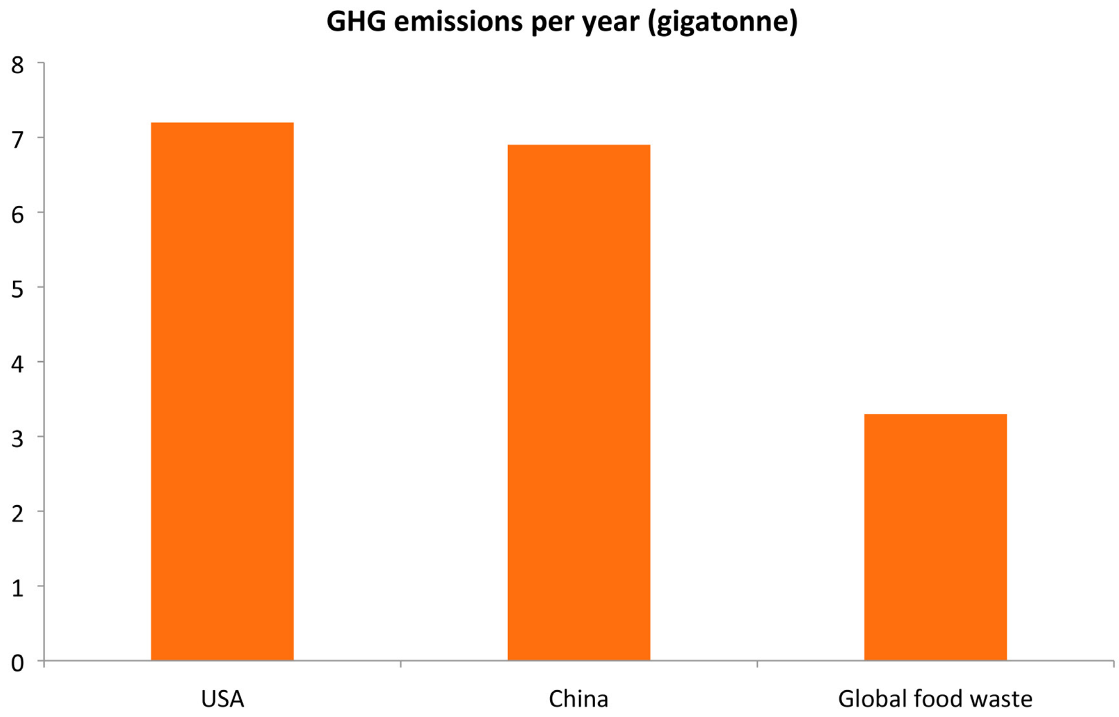

Figure 23: Annual greenhouse gas emissions attributable to global food waste compared to total emissions from the USA and China.

Source: Graph produced from data in FAO (2014).

> The GHG emissions required to produce the food that is wasted would make food waste the third highest GHG emitting country.
>
> The blue water used to produce the globe's wasted food is more than any individual country's agricultural blue water usage (see earlier in this chapter information on blue water usage).

The environmental burden of producing so much food is very high.

The estimated GHGs emissions from producing food that is not eaten would make 'food waste' the third highest GHG emitting country in the world.

The estimated blue water usage (see earlier in this chapter) of food waste is higher than the food-related blue water usage of any country.

In terms of land-use, the land required to produce this food represents 28% of the total available agricultural land.

While these are estimates, they clearly show that, the environmental and societal cost of food waste is high. At the same time, efforts to reduce food waste could yield both social and environmental benefits.

However, the rebound effect does need to be taken into account. For example at the consumer stage, if consumers buy less food because they are wasting less, they save money. This money could be used on other energy using, and GHG-emitting goods and activities – from new electronic goods to shoes to holidays. For a discussion and an estimate of its significance in the UK see Chitnis, et al. (2014). (For more about the similar concept of the 'substitution effect,' see Chapter 9).

5.7 Conclusions

- Food systems contribute to multiple and interconnected environmental concerns.
- Agriculture is a key driver of deforestation and biodiversity loss.
- It is a major user of water and driver of unsustainable levels of water extraction.
- Overfishing, a consequence of rising demand and poor governance, is placing unsustainable pressure on wild fish stocks. Aquaculture can reduce some of this pressure, but not all.
- All of these impacts will grow if in global demand for food, especially for resource intensive animal products, increases in line with current projections.
- An important cross cutting concern is food waste.

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