Acknowledgments

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Foreword

Productive agriculture requires a reliable supply of good quality fresh water. This places water protection as a priority for those involved in farming, who primarily focus efforts on ensuring an efficient use of water, and avoiding water contamination. In fact, a diverse group of stakeholders including the crop protection industry, landowners and farmers are actively engaged in initiatives to safeguard the environment and deliver productive agriculture.

This report is part of a series of publications that aim to improve accessibility to scientific and regulatory topics related to pesticides and biodiversity in Europe. This edition looks at the specific example of freshwater biodiversity; it details the regulatory framework in place to ensure thorough pesticide risk assessment and risk management, and describes some of the technologies and best management practices at our disposal for producing a safe and plentiful supply of food, as well as keeping freshwater bodies in a good state.

It is our hope that this report leaves readers with new appreciation for the challenges we face in Europe, and confidence in modern solutions for sustainable agricultural productivity.

Jean Charles-Bocquet
Director General, ECPA

Thierry de l’Escaille
Secretary General, ELO

70% of Earth’s available fresh water is used for irrigation [1] in Europe, 44% [2].
Water and life on Earth

Water is a simple molecule, consisting of one oxygen and two hydrogen atoms; but the chemical simplicity of water is in stark contrast to its complex physical properties.

Water sustains all life on Earth and is essential for agricultural production; without the right quantity and quality of water we cannot grow crops or raise livestock. However, when water passes through farmland, agricultural practices influence the water cycle and can affect water quality.

Today, aquatic ecosystems are being altered or destroyed at a greater rate than any other time in human history, and the rate of degradation often exceeds that of restoration [3]. All habitat types, on both land and in water, are losing biodiversity; but the decline is greatest in freshwater habitats. Globally, freshwater species populations have shown an average 37% decline between 1970 and 2008; this figure is derived from an alarming 70% decrease in tropical freshwater species, and a contrasting 36% increase in temperate freshwater species [4].

Poor agricultural practices can contribute to this degradation, and ultimately risk the provisioning and regulating ecosystem services which support agricultural productivity [5]; this can only add to the challenge of securing global food supply. Farming represents both the foundation of our modern civilisation, as well as a sector that has environmental responsibility for the ecosystems upon which we also rely [6].

World population is expected to grow by more than a third (around 2.3 billion people) between 2009 and 2050. This is a slower rate of growth than seen in the past four decades, but the task of feeding a growing population remains. Projections show that feeding a world population of 9.1 billion people in 2050 will require raising overall food production by some 70 percent between 2005/07 and 2050 [7]. In the context of this global challenge, the EU is a major contributor to food security and a key player in efforts to reach the millennium goal on combating hunger and nutrition [8].

Over the last decades, crop yields have steadily increased, although for certain crops and regions yield increases have levelled off. There is also a huge difference to be found between crop yields in different regions; in low-income regions in particular, there is a large gap between actual and potential crop yields.

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**The water footprint of common foods**

- 13 litres of water for a tomato
- 25 litres of water for a potato
- 35 litres of water for a cup of tea
- 70 litres of water for an apple
- 75 litres of water for a glass of beer
- 120 litres of water for a glass of wine
- 140 litres of water for a cup of coffee
- 170 litres of water for a glass of orange juice
- 184 litres of water for a bag of potato crisps
- 200 litres of water for a glass of milk
- 2400 litres of water for a hamburger
This is mainly related to the lack of access to markets, inputs and capital, and lack of access to the best agronomic practices and technologies. In fact, globally, in the region of 1 billion smallholder farms (mainly in Africa and Asia) feed around 5 billion people, whereas around 15 million medium-to-large-scale farms feed about 1 billion people, who mainly live in cities [10].

Pressures from urban expansion, industrialisation and a changing climate mean that this increase in productivity will likely have to be achieved with less water, and less land [11]. At the same time, there is a growing need to improve the sustainable use of available land and water; some 25% of all agricultural land is highly degraded and many countries already face critical water scarcity [12]. Water security is a major and increasing concern in many parts of the world, including both the availability (including extreme events) and quality of water [13].

Society is challenged with the sustainable management of water resources, this includes implementing agricultural practices that make efficient use of water and safeguard water quality. We must find ways to extract the freshwater needed for our daily lives, whilst maintaining and protecting freshwater ecosystems [9] (Figures 1 and 2); however, we must also respond to the food security challenge. This will involve increasing yields more efficiently, without compromising resources such as water [14]. There may be ample land resources available for agricultural production; however, natural resource constraints, including the availability of freshwater are a limiting factor to expanded production.

Water is a major component of living organisms, it makes-up more than 70% of the human body [15] and more than 95% of the body of a jellyfish [16]. The sticky-elastic properties of water allow it to move through blood vessels, and through the capillaries and roots of plants. Water supports all anatomical functions.
Farming has an important role to play in the sustainable management of water resources; agriculture is the major user of water, accounting for about 70% of global fresh water withdrawals[12]. The scope of sustainable management of water resources in agriculture concerns the responsibility of water managers and users to ensure that water resources are allocated efficiently and equitably and used to achieve socially, environmentally and economically beneficial outcomes – including the conservation of ecosystems[11].

According to the European Environment Agency (EEA), Southern European countries use the largest percentages of extracted water for agriculture, generally accounting for more than two-thirds of total extraction; irrigation being the largest use of water in these countries (Figures 3 and 4). In contrast, Central European and the Nordic countries use the largest percentages of extracted fresh water for cooling in energy production, industrial production and public water supply[19].

Agricultural practices such as tillage, fertilisation, irrigation, drainage, grazing, use of heavy machinery and pesticides have influence over water quality and the volumes of water used for production. Efficient agricultural practices

Hydrothermal zones have been credited as nurturing first life[20]. The earliest known micro-fossils have been dated back as far as 3.5 billion years[21]; the earliest terrestrial plant fossils dated back to a relatively recent 480-460 million years ago[22] (the first amphibians some 200 million years later[23]). It is evident from these fossil records that water has provided Earth its most continuous habitat for life; it is therefore no surprise that a common theme of space exploration is the search for water.

"Ecosystem services are the benefits people obtain from ecosystems. These include ‘provisioning services’ such as food, water, timber, and fibre; ‘regulating services’ that affect climate, floods, disease, wastes, and water quality; ‘cultural services’ that provide recreational, aesthetic, and spiritual benefits; and ‘supporting services’ such as soil formation, photosynthesis, and nutrient cycling. The human species, while buffered against environmental changes by culture and technology, is fundamentally dependent on the flow of ecosystem services.” (Millennium Ecosystem Assessment, 2005)[17]
minimise the use of fresh water, and poor management practices can increase the likelihood of pesticides contaminating the freshwater environment.

Recent trends have seen species level improvements in the temperate freshwater environment \[^4\]; these improvements may be in-part due to improved land management practices which can ameliorate agricultural impacts on ecosystems \[^24\]; however, the continuing loss of global biodiversity indicates that further improvements are necessary.

Agriculture is faced not only with the challenge of using water more efficiently, but also using land more efficiently. Globally, the scope for expansion of agricultural land is limited. Total arable land is projected to increase by only 69 million hectares (less than 5%) by 2050, whereas additional production will need to come from increased productivity \[^12\] – this means producing more food with fewer land and water resources.

This report looks at the contribution that good water management and pesticides play in EU agriculture, and the roles of risk assessment and best management practices in safeguarding freshwater biodiversity. At the same time, this report underlines the importance of sustainable agricultural productivity for feeding the world and, keeping our water clean.
Figure 3: Water and agriculture – facts and figures

There is approximately 1.4 billion km$^3$ of water on Earth.

- Fresh water comprises around 3% of all water.
- Only 1% of fresh water is available (accessible) for human use.

Agricultural use: 44% of water extracted in Europe is used for agriculture.
Non-agricultural use: 56% of water extracted in Europe is not used for agriculture.

9.8% of agricultural land in Europe is irrigated.
Non-irrigated agricultural land: 90.2% of agricultural land in Europe is not irrigated.

Figure 4: National share of total irrigated area in the EU 27

- Spain: 30.1%
- Italy: 24.6%
- France: 14%
- Greece: 11.8%
- Germany: 4.6%
- Portugal: 3.9%
- Denmark: 2.3%
- Others: 8.7%

When this volume is represented as a cube, the length of each side equates to approximately the road distance between Amsterdam and Paris – around a 5 hour drive.

Agriculture

Non-agriculture

44% of water extracted in Europe is used for agriculture.

9.8% of agricultural land in Europe is irrigated.

Pesticides and Freshwater Biodiversity
The value of aquatic ecosystems

Analysis of the monetary value of different groups of aquatic organisms reveals that freshwater environments including rivers, lakes, and wetlands make a greater contribution per hectare to ecosystems that provide food and water than most other environments, including tropical forests (Figure 5). In fact, biomes, inland wetlands, rivers, and lakes contribute more than five times the per hectare monetary value than tropical forest across key ecosystem services (Table 1).

It is the most intensively managed ecosystems (e.g. agro-ecosystems) that contribute the most towards vital provisioning services (production of food, feed and fibre, etc.); whereas, semi-natural ecosystems (e.g. grasslands) are key contributors of genetic resources and cultural services including aesthetic values [24].

In agricultural systems, biodiversity performs ecosystem services beyond the production of food, fibre, fuel, and income. Examples include recycling of nutrients, control of local microclimate, regulation of local hydrological processes, regulation of the abundance of undesirable organisms, and detoxification of noxious chemicals [27].

The ‘economic invisibility’ of the functions to which freshwater organisms make important contribution is perhaps explanation for the ‘silo thinking’ that sometimes fails to take into account the links between agricultural and ecological systems [28].

Sustainable productivity requires that agricultural practices contribute to sustaining valuable ecosystem services, and where possible promote ecosystem functions.

Figure 5: Percentage share monetary value contribution of inland wetlands (e.g. marshes), fresh water, and tropical forests to food and water provisioning services; based on 2007 price levels [29]
Table 1: Summary of monetary values for Ecosystem Services per biome  
(values in Int.$/ha/year, 2007 price levels) [29]

<table>
<thead>
<tr>
<th>Ecosystem Service</th>
<th>BIOME</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Inland wetlands</td>
<td>Fresh water (rivers/lakes)</td>
<td>Tropical forest</td>
</tr>
<tr>
<td>Provisioning services</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Food</td>
<td>614</td>
<td>106</td>
<td>200</td>
</tr>
<tr>
<td>Water</td>
<td>408</td>
<td>1,808</td>
<td>27</td>
</tr>
<tr>
<td>Raw materials</td>
<td>425</td>
<td>-</td>
<td>84</td>
</tr>
<tr>
<td>Genetic resources</td>
<td>-</td>
<td>-</td>
<td>13</td>
</tr>
<tr>
<td>Medicinal resources</td>
<td>99</td>
<td>-</td>
<td>1,504</td>
</tr>
<tr>
<td>Ornamental resources</td>
<td>114</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td><strong>1,659</strong></td>
<td><strong>1,914</strong></td>
<td><strong>1,828</strong></td>
</tr>
<tr>
<td>Regulating services</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Air quality regulation</td>
<td>-</td>
<td>-</td>
<td>12</td>
</tr>
<tr>
<td>Climate regulation</td>
<td>488</td>
<td>-</td>
<td>2,044</td>
</tr>
<tr>
<td>Disturbance moderation</td>
<td>2,986</td>
<td>-</td>
<td>66</td>
</tr>
<tr>
<td>Regulation of water flows</td>
<td>5,606</td>
<td>-</td>
<td>342</td>
</tr>
<tr>
<td>Waste treatment</td>
<td>3,015</td>
<td>187</td>
<td>6</td>
</tr>
<tr>
<td>Erosion prevention</td>
<td>2,607</td>
<td>-</td>
<td>15</td>
</tr>
<tr>
<td>Nutrient cycling</td>
<td>1,713</td>
<td>-</td>
<td>3</td>
</tr>
<tr>
<td>Pollination</td>
<td>-</td>
<td>-</td>
<td>30</td>
</tr>
<tr>
<td>Biological control</td>
<td>948</td>
<td>-</td>
<td>11</td>
</tr>
<tr>
<td></td>
<td><strong>17,364</strong></td>
<td><strong>187</strong></td>
<td><strong>2,529</strong></td>
</tr>
<tr>
<td>Habitat services</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nursery service</td>
<td>1,287</td>
<td>-</td>
<td>16</td>
</tr>
<tr>
<td>Genetic diversity</td>
<td>1,168</td>
<td>-</td>
<td>23</td>
</tr>
<tr>
<td></td>
<td><strong>2,455</strong></td>
<td><strong>0</strong></td>
<td><strong>39</strong></td>
</tr>
<tr>
<td>Cultural services</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Esthetic information</td>
<td>1,292</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Recreation</td>
<td>2,211</td>
<td>2,166</td>
<td>867</td>
</tr>
<tr>
<td>Inspiration</td>
<td>700</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td><strong>4,203</strong></td>
<td><strong>2,166</strong></td>
<td><strong>867</strong></td>
</tr>
<tr>
<td>Total economic value</td>
<td><strong>25,682</strong></td>
<td><strong>4,267</strong></td>
<td><strong>5,264</strong></td>
</tr>
</tbody>
</table>
Freshwater ecosystems and the variety of freshwater organisms

Aquatic ecosystems can be broadly classified as either freshwater or marine. Marine zones are massive, and include the oceans, seas, intertidal areas, estuaries, salt-marshes and coral reefs; they support organisms unique to marine ecosystems like sea urchins, starfish, cuttlefish and corals. Freshwaters account for only 0.8% of Earth’s surface and as little as 0.009% of its total water; in comparison marine zones cover about 71% of the Earth’s surface, containing the vast majority (97%) of the planet’s water.

In contrast to their relatively small share of Earth’s water, freshwater bodies are home to an enormous range and quantity of organisms, including two important ecological groups, plankton and benthos (Table 2). Plankton drift in the open water and benthos inhabit the sediment that forms the water bottom. Many of these organisms – although small and inconspicuous – are of huge importance as they provide essential ecosystem services.

Continental Europe has several million kilometres of flowing water, and over a million lakes; precipitation, geology, soil type and a multitude of other factors – including human activity – exert influence on their form and behaviour, with implications for the life forms that rely on freshwater habitats. Aquatic organisms have very specific demands of the freshwater environment, relying on specific conditions and often complex combinations of properties.

Insects which quantitatively make-up the majority of animals and dominate terrestrial and freshwater environments (over 75% of all known animal species are insects) are rarely found in the marine environment, having largely failed to establish themselves in the world’s oceans and seas.

Expressing the value of ecosystem services in monetary units is a way of understanding the relative value that today’s society places on these services. This information can be used, for example, to guide resource allocation where demand from competing uses exists, and to highlight the importance of incentives for conservation and sustainable use. The monetary valuation of ecosystem services is often underpinned with the warning that market-based valuations reflect the current needs of society and often fail to take into consideration the needs of future generations. The ‘Economics of Ecosystems and Biodiversity’ (TEEB) is an important collection of studies aimed at initiating the process of analysing the global economic benefit of biological diversity, the costs of the loss of biodiversity and the failure to take protective measures versus the costs of effective conservation. For more on the TEEB, visit www.teebweb.org.
### Organism or group of organisms

<table>
<thead>
<tr>
<th>Organism or group of organisms</th>
<th>Key characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bacteria</td>
<td>Single cell structure with relatively simple organisation. May form colonies.</td>
</tr>
<tr>
<td>Blue-green algae</td>
<td>Also called <em>Cyanobacteria</em>, these bacteria-like cell structures obtain energy through photosynthesis.</td>
</tr>
<tr>
<td>Unicellular organisms:</td>
<td></td>
</tr>
<tr>
<td>Possess complex cellular organisation. Often form colonies.</td>
<td></td>
</tr>
<tr>
<td>Green algae</td>
<td>Often move by means of flagella (a whip-like appendage), green in colour.</td>
</tr>
<tr>
<td>Diatoms</td>
<td>Among the most common types of phytoplankton. To be found drifting in open water.</td>
</tr>
<tr>
<td>Amoebae</td>
<td>Comprise part of the benthos, living on, in or near to the bed of the sea. Change their body size.</td>
</tr>
<tr>
<td>Heliozoa</td>
<td>Mobile amoeboids with a sun-like shape. Predate on other microorganisms.</td>
</tr>
<tr>
<td>Ciliates</td>
<td>Extremely mobile organisms with complex body structures. Feed often on bacteria.</td>
</tr>
<tr>
<td>Plants:</td>
<td></td>
</tr>
<tr>
<td>Multi-cellular organisms that generate organic matter through photosynthesis (autotrophy)</td>
<td></td>
</tr>
<tr>
<td>Rooted plants</td>
<td>Relatively large structures, attached to the ground by roots.</td>
</tr>
<tr>
<td>Rootless plants</td>
<td>Floating plants, often located on the surface of water.</td>
</tr>
<tr>
<td>Invertebrates:</td>
<td></td>
</tr>
<tr>
<td>Animals lacking a backbone</td>
<td></td>
</tr>
<tr>
<td>Sponges</td>
<td>Bodies full of pores and channels – lacking nervous, digestive and circulatory systems. Found in clean water.</td>
</tr>
<tr>
<td>Jellyfish and hydra</td>
<td>Small, largely transparent predators. Hydra are a sessile (immobile) organism and usually remain anchored to a solid form. Jellyfish float and swim.</td>
</tr>
<tr>
<td>Worms</td>
<td>Includes flatworms, annelids, and roundworms. Mostly inhabit the benthic zone.</td>
</tr>
<tr>
<td>Snails and mussels</td>
<td>Molluscs with helical (most snails) or two-part hinged shells (Bivalvia e.g. mussels).</td>
</tr>
<tr>
<td>Insects</td>
<td>Adult insects may live in water (i.e. some species of beetle) or on the water surface (Hemiptera, ‘true bugs’, like pond skaters).</td>
</tr>
<tr>
<td>Insect larvae</td>
<td>Many insects which have wings and are able to fly as adults pass their larval stage in water – including dragon flies, midges, and ephemerids (mayflies). Larvae are therefore aquatic animals, whereas the adult forms inhabit terrestrial environments which are often (but not always) close to the water.</td>
</tr>
<tr>
<td>Crustaceans</td>
<td>Possessing an exoskeleton, many are small, some float (e.g. water fleas), others are large and live under water (e.g. crayfish).</td>
</tr>
<tr>
<td>Vertebrate animals:</td>
<td></td>
</tr>
<tr>
<td>Animals possessing a backbone</td>
<td></td>
</tr>
<tr>
<td>Fish</td>
<td>Live exclusively in the water – exhibit a wide variety of living behaviour including migration.</td>
</tr>
<tr>
<td>Amphibians</td>
<td>Aquatic larvae (e.g. tadpoles) and terrestrial adults (e.g. newts, salamanders, frogs, toads).</td>
</tr>
<tr>
<td>Birds</td>
<td>Many birds live on and around water. Hunting prey in the water and/or breeding at the surface.</td>
</tr>
<tr>
<td>Mammals</td>
<td>Some large mammals (e.g. beavers and otters) require an aquatic habitat.</td>
</tr>
</tbody>
</table>
Blue-green algae (Cyanobacteria) obtain energy through photosynthesis.

Pond skaters (fam. Gerridae), are insects that live on the surface of pond water.

Nymphaea alba, the European water lily, a rooted aquatic plant.

An adult damselfly (suborder Zygoptera) molting from larval stage. Damselflies live the larval stage of their lifecycle in the water.

Adult damselflies are predators which can be often observed in the vegetation near the water, watching for prey.

Many water-inhabiting insects like this aquatic beetle (fam. Dytiscidae) are able to leave the water, fly large distances and populate other water bodies.
Freshwater ecosystem services

The Millenium Ecosystem Assessment groups ‘Ecosystem Services’ into key categories\(^1^7\).

- **Provisioning Services**: products which people obtain from ecosystems, like food and fuel;
- **Regulating Services**: benefits which people obtain from the regulation of our environment, like air quality, water purification and climate regulation;
- **Cultural Services**: non-material benefits such as recreation and aesthetics;
- **Supporting Services**: the services required to maintain the conditions for life on Earth, through supporting the other key ecosystem services as listed above.

Table 3 lists some of the ecosystem services supported by aquatic organisms; this is not an exhaustive list of services but goes some way to illustrate the importance of aquatic organisms for human wellbeing.

### Table 3: Overview of Ecosystem Services which are provided by aquatic organisms\(^5^\)\(^1^7\)

<table>
<thead>
<tr>
<th><strong>Provisioning services</strong>: Products which people obtain from ecosystems</th>
<th><strong>Examples of the roles of aquatic organisms</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Food, fibre</td>
<td>Provision of fish, and provision of aquatic organisms as fish feed</td>
</tr>
<tr>
<td>Genetic resources</td>
<td>Conservation of genetic diversity</td>
</tr>
<tr>
<td>Natural medicines</td>
<td>Provision of molecules for pharmaceuticals</td>
</tr>
<tr>
<td>Fresh water</td>
<td>Water purification</td>
</tr>
</tbody>
</table>

**Regulating Services**: Benefits which people obtain from the regulation of our environment

| **Climate regulation** | Carbon sequestration |
| **Water regulation** | Stabilisation of sediment |
| **Water purification** | Degradation of natural and synthetic pollutants |
| **Disease regulation** | Antagonism to vectors of waterborne disease |
| **Hazard regulation** | Stabilisation of surface waters |

**Cultural services**: Non-material benefits

| **Aesthetic values** | Contribution to attractive landscapes and plants |
| **Recreation and ecotourism** | Contribution to a diversity of attractive and interesting animals and plants |

**Supporting Services**: Required to maintain provisioning, regulating and cultural ecosystem services

| **Photosynthesis** | Algae and aquatic plants provide biomass for aquatic food chains |
| **Nutrient cycling** | Metabolisation of organic nutrients |
| **Soil formation** | Degradation of organic matter supports soil formation |
Water purification

Fresh water is readily valued for extractive uses (e.g. water for utilities, irrigation, and industry), but the benefits of leaving water in freshwater bodies to support healthy aquatic ecosystems are sometimes overlooked [3].

Ecosystems can store and recycle certain amounts of organic and inorganic human waste through dilution, assimilation and chemical re-composition. Wetlands and other aquatic ecosystems are capable of acting as ‘free’ water purification plants, treating relatively large amounts of waste resulting from human activities [36]. The value of these natural processes is illustrated in their use in controlled conditions in wastewater treatment plants.

Fish and fisheries

The majority of fish consumed by humans are caught in the sea; however, freshwater aquaculture yields more than 20% of European fish harvests [38] (Table 4). The European Union is the fifth largest fisheries and aquaculture producer worldwide with a turnover of roughly EUR 3.5 billion and some 85,000 employees [38]. A UK Government evaluation of the UK’s freshwater fisheries estimated that they support about £1 billion of household income, the equivalent of 37,000 jobs [39].

Freshwater fish are also important for recreational angling, a popular pastime for many Europeans and a ‘cultural’ ecosystem service [40] [41].
<table>
<thead>
<tr>
<th>Category</th>
<th>Tonnes live weight</th>
<th>Percentage share of total live volume</th>
<th>Value in thousands of Euro</th>
<th>Percentage share of total value</th>
<th>Category</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mussel</td>
<td>492,413</td>
<td>39.18%</td>
<td>428,773</td>
<td>11.91%</td>
<td>Marine mollusc</td>
</tr>
<tr>
<td>Trout</td>
<td>185,539</td>
<td>14.76%</td>
<td>499,904</td>
<td>13.89%</td>
<td>Freshwater fish</td>
</tr>
<tr>
<td>Salmon</td>
<td>170,591</td>
<td>13.57%</td>
<td>752,116</td>
<td>20.90%</td>
<td>Anadromous fish (born in freshwater, spends most of life in the sea and migrates to freshwater to spawn)</td>
</tr>
<tr>
<td>Oyster</td>
<td>98,751</td>
<td>7.86%</td>
<td>438,512</td>
<td>12.18%</td>
<td>Marine mollusc</td>
</tr>
<tr>
<td>Carp</td>
<td>73,860</td>
<td>5.88%</td>
<td>136,467</td>
<td>3.79%</td>
<td>Freshwater fish</td>
</tr>
<tr>
<td>Gilt-head seabream</td>
<td>72,900</td>
<td>5.80%</td>
<td>370,251</td>
<td>10.29%</td>
<td>Marine fish</td>
</tr>
<tr>
<td>Seabass</td>
<td>67,809</td>
<td>5.40%</td>
<td>369,812</td>
<td>10.28%</td>
<td>Marine fish</td>
</tr>
<tr>
<td>Clam</td>
<td>37,028</td>
<td>2.95%</td>
<td>171,597</td>
<td>4.77%</td>
<td>Marine mollusc</td>
</tr>
<tr>
<td>Other freshwater fish</td>
<td>13,989</td>
<td>1.11%</td>
<td>No data</td>
<td>No data</td>
<td>Freshwater fish</td>
</tr>
<tr>
<td>Turbot</td>
<td>10,799</td>
<td>0.86%</td>
<td>70,949</td>
<td>1.97%</td>
<td>Marine fish</td>
</tr>
<tr>
<td>Bluefin tuna</td>
<td>No data</td>
<td>No data</td>
<td>145,374</td>
<td>4.04%</td>
<td>Marine fish</td>
</tr>
</tbody>
</table>

Table 4: The top 10 species produced in aquaculture in the European Union (2011), ranked by tonnage live weight (volume in tonnes live weight and percentage of total) [38]
The European Red List of Freshwater Fishes shows that there are declining population trends for many species; of 524 species native to Europe (425 of which are endemic), 18 species are described as extinct and 194 species (37%) are classified as threatened; the situation in the EU27 is no better, with 39% of 382 native species considered threatened [42]. The WWF Living Planet Index (2012) offers some better news, informing that between 1970 and 2008 a 36% increase in temperate freshwater species was recorded [41].

In the search for molecules with curative properties, the freshwater environment is also a source of natural medicines. Natural compounds can provide the resources or inspiration for medical innovations. The leech *Hirudo medicinalis* is a worm that favours freshwater pools and ditches and feeds by sucking blood from warm-blooded organisms like humans. A leech’s salivary glands produce the protein hirudin which possesses anticoagulant properties to prevent blood from clotting during digestion. Using recombinant biotechnology, hirudin-based anticoagulant medicines have been developed and are used to treat and prevent conditions including thrombosis and heart failure. [43]
The impacts of human activities on freshwater organisms

For centuries Europe’s land has been used to produce food, timber fuel and space for living; currently more than 80% of the land in Western Europe is under some form of direct management. Consequently, European species are to a large extent dependent upon the semi-natural habitats created and maintained by human activity [44].

Deforestation, cultivation and the growth of cities and industry have been the major contributors to the modification of inland waters since the Bronze Age; since medieval times, human activities have been dominant in shaping most European landscapes [45]. Following the rapid growth of the human population and the global economy over the past century, human uses of freshwater ecosystems have grown so steeply that they now produce large, widespread, negative ecological impacts. This fact is particularly alarming given the critical importance of the goods and services provided by freshwater ecosystems, which are among the most heavily altered ecosystems, subjected to an over proportional loss of biodiversity [46] [48]. Efforts to manage and guard against the impacts of climate change (e.g. engineering work/structures for flood prevention), can further threaten the freshwater environment [46].

Like all biodiversity, freshwater organisms suffer when their habitats are damaged or destroyed – a growing problem in Europe. Agricultural land use has seen the draining of ponds and puddles to ease the use of heavy machinery and maximise available productive land; ditches are utilised for drainage and irrigation, and natural channels converted to subterranean drainage systems in order to provide more effective growing spaces. Small water bodies may be an undervalued element of the freshwater environment; ponds – and not lakes or rivers – are the most extensive aquatic habitat and support considerably more species than other freshwater waterbody types [47] [48].

Threats to freshwater biodiversity include five interacting categories: misuse of freshwater resources, water pollution, habitat degradation, flow modifications, and invasions by alien species. Environmental changes (e.g. nitrogen deposition) and climate change (temperature shifts and changes in precipitation and runoff patterns) on the global scale are superimposed upon all these threat categories [49]. The combined and interacting influences of these threats result in a population decline and range reduction of freshwater biodiversity worldwide [49].

The IUCN Red List for Europe offers an assessment of the status, trends and threats to many European species [50]. The Red List is compiled with the aim of informing action for biodiversity conservation, and can be used to gain insight to the health of species reliant on the freshwater environment.
The protection of freshwater biodiversity is particularly challenging, because to be fully effective, it requires control over upstream drainage, surrounding land, the riparian zone (the banks and area immediately adjacent to water sources), and—in the case of migrating aquatic fauna—downstream reaches [49].

The unique conservation challenge presented by freshwater biodiversity perhaps explains why assessments generally conclude that freshwater biodiversity is possibly more threatened than biodiversity in other systems [51].

Taking the example of rivers, Table 5 describes the potential extent of human interference with river systems, and goes someway to illustrate the complexity and range of potential sources of human interference with the freshwater environment. Impacts can occur through local activity, such as direct modification of a river channel or abstraction of water, or through changes to the local environment through management of riparian vegetation; impacts also result from supra-catchment activities, such as the acidification of rivers when acid rain formed in distant locations falls within a local catchment.

### Table 5: The principal categories of human activities affecting river systems [52]

| Supra-catchment effects | • Acid decomposition  
|• Inter-basin transfer  
|• Climate change |
|---|---|
| Catchment land-use change | • Afforestation and deforestation  
|• Urbanisation  
|• Agricultural development  
|• Land drainage/flood protection |
| Corridor engineering | • Removal of riparian vegetation  
|• Flow regulation  
|• Dams  
|• Channelisation  
|• Dredging and mining |
| Instream impacts | • Organic and inorganic pollution  
|• Thermal pollution  
|• Abstraction of water  
|• Navigation  
|• Exploitation of native species  
|• Introduction of alien species |
The conservation status of some key freshwater species groups

**Freshwater fishes**
In the EU 27, 39% of freshwater fishes are described as being threatened with extinction; more specifically, 13% are classified as critically endangered, 11% endangered, and 15% Vulnerable. The major threats to freshwater fishes are identified as water abstraction, alien species, hydropower and water control dams, and water pollution. Water pollution is attributed to a number of sources, including domestic waste, industrial and agricultural effluent, river transportation, and sedimentation.[42]

**Amphibians**
2.4% of amphibians in the EU27 are critically endangered, 6.1% endangered and 13.4% vulnerable; this means a total of around 20% of the EU27’s amphibian species are threatened. Habitat loss, fragmentation, and degradation pose the greatest threats to amphibian species – being dependent of freshwater habitats for their lifecycle, amphibians are particularly vulnerable to changes in the freshwater environment. Agricultural intensification and infrastructure development are amongst the most frequently cited causes of habitat decline and deterioration. Water abstraction is also a significant threat and is noted as having a particularly damaging effect on amphibian populations in the drier southern regions of Europe.[55]

**Freshwater molluscs**
Approximately 40% of EU27 freshwater molluscs are threatened with extinction. In detail, 11.8% are critically endangered, 8.1% endangered and 21% vulnerable. Threatened freshwater mollusc species are suffering as a consequence of declining water quality in rivers and lakes. The intensification of agriculture attributed to affecting 36% of threatened species, with urbanisation (and in particular, poor sewage control) impacting 29% of the species. 33% of threatened species are mostly effected by the over utilisation of water. In contrast invasive species are widely present, but do not play a significant role, impacting less than 5% of threatened freshwater mollusc species.[53]

**Dragonflies**
Around a quarter of European dragonfly species show declining populations, with about half of species exhibiting stable populations, and 10% a trend for population increase; in the EU27, 2.2% are listed as being critically endangered, 4.5% endangered, with 9.7% considered vulnerable. The main threat to European dragonflies is the drying-out of their habitats due to increasingly hot and dry summers and intensified water extraction for drinking and irrigation.[44]

**Anguilla anguilla**, the common eel, may have suffered a decline of stocks as high as 99% since the 1980’s, the damming of rivers and the consequent blocking of migration routes a major contributor.[42]

**Mesotriton alpestris**, the apine newt, is a species of Least Concern in Europe, however, it is experiencing a population decline, largely as a result of habitat loss and fish introduction.[54]

**Radix balthica**, the pond snail, is widespread across Europe and classified as Least Concern, is an abundant species with a stable population.[54]

**Aeshna cyanea**, the blue or southern hawker is mostly found in standing and running waters with a slow current, the species is classified as Least Concern and occurs in habitats that are not threatened in any way.[57]

Pesticides and Freshwater Biodiversity
Water may contain highly toxic bacteria like Cholera, or Salmonella, or protozoa like Giardia.
Ecological disservices: Threats posed by biodiversity

Whilst the benefits of biodiversity are too numerous to list, biodiversity also poses threats that require management in order to maintain and improve our quality of life; indeed, not all of the organisms which inhabit fresh water are good for us; many pose a direct threat to our health and livelihoods. In addition to providing our food and water, nature also harms us, primarily through disease\[^{58}\].

Threats to human health from water-borne organisms

Dipteran insects (possessing two wings as adults) from the families Simuliidae and Culicidae have it in common that the females consume blood from vertebrates. These insects can be a severe nuisance, however the main problem associated with these pests is the pathogens and parasites contained within their saliva. Many of the most disastrous tropical disease originate from aquatic organisms (Table 6).

In Europe the likelihood of contracting a disease transmitted by a waterborne organism is very low, but malaria was once common in large parts of Europe including the coastal plains of Italy and the marshes of England. Malaria has been driven out of Europe by climate change, and by drainage of the marshes and wetlands that once provided the mosquito habitat. However, in 2012, the European Region reported 255 indigenous cases of malaria; so whilst Europe is close to eliminating malaria from the region, continued outbreaks highlight the threat of reintroduction, and the need for continued vigilance \[^{60}\].

At any given time, over half the world’s hospital beds are occupied by people suffering from water-related diseases \[^{59}\].

<table>
<thead>
<tr>
<th>Disease</th>
<th>Transmitter</th>
<th>Figures (worldwide)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Malaria</strong></td>
<td>Anopheles mosquito</td>
<td>190-300 million people infested</td>
</tr>
<tr>
<td></td>
<td></td>
<td>700,000-1,000,000 deaths (2008)</td>
</tr>
<tr>
<td><strong>Onchoceriasis</strong></td>
<td>Black fly</td>
<td>18 million people infested (approx.)</td>
</tr>
<tr>
<td>(aka. River blindness, Robles disease)</td>
<td></td>
<td>3 million people irreversibly blinded</td>
</tr>
<tr>
<td><strong>Schistosomiasis</strong></td>
<td>Freshwater snail</td>
<td>200 million people infested</td>
</tr>
<tr>
<td>(aka. Snail fever, bilharzia, snail fever, Katayama fever)</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Filarialis/Philariahis</strong></td>
<td>Mosquitoes and black fly</td>
<td>120 million people infested</td>
</tr>
</tbody>
</table>
Although water-borne pests present threats to human health and wellbeing, synthetic pesticides play no role in the control of these organisms in Europe. Due to stringent regulations for the use of pesticides in Europe, and efforts to avoid water contamination, non-chemical methods of control are used (Table 7).

It is beyond the scope of this report to provide detailed assessment of the pros and cons of initiatives in place to eradicate or limit waterborne diseases, but it should be mentioned that non-chemical vector control programmes can have impacts on non-target organisms which may be viewed critically from a nature conservation perspective. For example, the use of *Bacillus thuringiensis var. israelensis* to control mosquitoes in the Camargue, France, resulted in localised reductions of several bird species as the mosquito control agent also reduced food availability for birds [66].

### Table 7: Non-chemical pest control methods for the control of mosquitoes in Europe

<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Removal of habitat</strong></td>
<td>The drying of breeding habitats is a simple and effective method. Homeowners can remove plastic ponds and drain areas of standing water. In the open landscape, drainage of water bodies is less neither practical nor economical, and is most likely contrary to efforts to protect biodiversity.</td>
</tr>
<tr>
<td><strong>Introduction of predators</strong></td>
<td>Several species of fish feed on mosquito larvae; the introduction of these predator species can effectively control mosquito populations. The mosquito fish (<em>Gambusia affinis</em>) is a small fish with a high reproduction rate. Originating from southern USA and Mexico, it has been introduced to several regions of Southern Europe where it successfully controls mosquitoes.</td>
</tr>
<tr>
<td><strong>Poisoning</strong></td>
<td>The naturally occurring soil bacterium <em>Bacillus thuringiensis</em> produces a protein which is a highly selective toxin for mosquito larvae. “BTI” (<em>Bacillus thuringiensis israelensis</em>) is widely used in Europe for mosquito control. It can be applied by hand or dispersed by helicopter when large areas require treatment.</td>
</tr>
</tbody>
</table>

Diarrhoea is the leading global cause of illness and death, and the second leading cause of death in children under 5 years old; each year diarrhoea kills around 760,000 children under five. 88% of diarrhoeal deaths are due to a lack of access to sanitation facilities, together with inadequate availability of water for hygiene and unsafe drinking water. The tragedy of these figures is underlined by the fact that diarrhoea is both preventable and treatable [65].

In Europe, water-borne pests are managed with biological control, rather than synthetic pesticides.
Threats to livelihood – agricultural pests

Beyond the often severe impacts that biodiversity can have on our health, there are also significant challenges for the day-to-day functioning of society, most notably threats to our ability to feed ourselves. The terrestrial environment is by far the greater source of agricultural pests, but the freshwater environment provides some notable examples.

Agricultural pests are animals, plants and pathogens that have the potential to compete with the cultivation of food and feed. There are three important categories of agricultural pest organisms:

- **Animal pests** – animals which feed on crops, causing physical damage and transmitting plant disease;
- **Weeds** – plants which compete with crops for resources like water, sunlight, or fertiliser;
- **Pathogens** – microbes (bacteria and viruses) which infest crops and cause plant diseases.

Animal pests

Animal pests inflict most damage whilst they are feeding; the canopy, roots and seeds of crops offering excellent forage. Animal pests can also transmit plant diseases; sucking insects – such as aphids – deliver pathogens to plants through the vomit expelled as part of their feeding process.

Animal pests are not limited to insects, a variety of taxonomic groups qualify, including nematodes, mites, snails, birds and mammals.

According to the principles of Integrated Pest Management (IPM), an animal is considered a pest once the number of organisms per defined area exceeds a numerical threshold of acceptability; therefore, an animal is not automatically considered a pest just because it feeds on crops. These numerical thresholds are specific to pest and crop type.

Weeds

When a plant competes with crops for resources such as soil, sunlight and water, it might be referred to as a ‘weed’. Weeds might also be poisonous, or produce thorns and other defence mechanisms that have the potential to contaminate harvests, and even poison or injure livestock and humans.

Weeds are often well ecologically adapted to agricultural environments. They have developed traits that increase the chances of survival in an environment without long term stability and frequent human intervention. Key weed survival traits include:

- **Seed productivity**: Groundsel (Senecio) produces around 1,000 seeds per plant, whilst mayweed can produce in excess of 30,000 per plant;
- **Seed volatility**: Many seeds have developed highly efficient mechanisms to enable long distance seed dispersal; dandelion (Taraxacum) is a well known example;
- **Seed longevity**: Some plants produce seeds with the trait of extreme longevity, able to survive for long period of time in the soil, only germinating on exposure to light. The poppy (fam. Papaveraceae) is one example, producing seeds that can survive 80 to 100 years before germination.

Plant Diseases

The pathogens that cause plant diseases are often fungi (Table 8), but they may also be bacteria or viruses. These organisms share the characteristics of high reproductive potential and mobile and robust reproductive structures (e.g. spores) to ensure wide distribution of offspring by air, water and soil. Fungal infections reduce crop yields by damaging and killing host plants; in warm and moist weather conditions large fields can be infested within a few days.
The apple snail (fam. Ampullariidae) has become a serious pest for rice farmers in southern Europe.
Agricultural pests from the freshwater environment

Liver fluke
The liver fluke (*Fasciola hepatica*) is worm that parasitises the liver of grazing cattle. This leaf shaped flatworm causes symptoms including a reduction in milk production and fertility. A dairy cow infested with liver fluke yields 0.7 kg per day less milk than a healthy cow, and increases the inter-calving interval [68].

The liver fluke produces up to 25,000 eggs a day; these eggs travel to the pasture in the manure of the dairy cow, but rely on puddles and small ponds for the next stage of their development. Hatching larvae swim and bore into host snails (e.g., *Galba truncatula*), in which the larvae develop. These larvae are finally released by the snail and progress to become encysted in vegetation; where upon the cycle is completed, as cattle ingest the larvae which migrate to the liver [68].

Veterinary medicine can be used to treat infected cattle; to prevent infestation the use of snail habitats for grazing can be avoided [69].

Blackfly
Blackflies (fam. Simuliidae) are amongst a variety of blood-sucking flies and midges that pose a threat to livestock. Blackflies lay their eggs in running water; the hatching larvae attach themselves to solid structures (stones, wood etc.) before emerging as flies. Adult males feed on nectar, but females feed on blood. Swarms of feeding blackfly can cause weight loss in cattle and reduced milk production; in extreme cases cattle may die from toxemia or anaphylactic shock brought on by toxins present in fly saliva. Swarms of blackfly have been known to trigger cattle stampedes resulting in the death of calves [70].

Table 8: Example fungal infections that impact agricultural productivity [67]

<table>
<thead>
<tr>
<th>Fungal infection</th>
<th>Crop/s affected</th>
</tr>
</thead>
<tbody>
<tr>
<td>Powdery mildew</td>
<td>(Erysiphe graminis) Wheat, barley, rye</td>
</tr>
<tr>
<td>Stripe rust</td>
<td>(Puccinia striiformis) Wheat, barley</td>
</tr>
<tr>
<td>Ergot</td>
<td>(Claviceps purpurea) Wheat, barley, rye</td>
</tr>
<tr>
<td>Corn smut</td>
<td>(Ustilago zeae) Maize</td>
</tr>
<tr>
<td>Bakanae</td>
<td>(Fusarium fujikuroi) Rice, cereals</td>
</tr>
<tr>
<td>Common bean rust</td>
<td>(Uromyces appendiculatus) Beans</td>
</tr>
<tr>
<td>Potato blight</td>
<td>(Phytophthora infestans) Potato</td>
</tr>
<tr>
<td>Black leg disease</td>
<td>(Phoma lingam) Rape, cabbage</td>
</tr>
<tr>
<td>Black root disease</td>
<td>(Pleospora bjoerlingii) Sugar beet</td>
</tr>
<tr>
<td>Apple scab disease</td>
<td>(Venturia inaequalis) Apple</td>
</tr>
</tbody>
</table>

Alien Species (AS) are species which are introduced outside their natural distribution area and succeed in surviving and subsequently reproducing; Invasive Alien Species (IAS) are Alien Species whose introduction and/or spread threaten local biological diversity [71]. IAS have affected native biodiversity in almost every type of ecosystem on Earth. As one of the greatest drivers of biodiversity loss, they pose a threat to ecosystem integrity and function and therefore, to human well-being [72].
The apple snail
The apple snail (genus Pomatias) is a large freshwater snail native to tropical and subtropical South America. The snail has been intentionally introduced to several countries; for example, in Japan for the control of aquatic weeds, in Taiwan as a food source, and in Europe sold by pet-shops as an attractive addition to aquariums.

In 2010 the apple snail was found to be living in the wild in Europe, having successfully invaded the rice fields of the Ebro delta, Spain[73]. This Invasive Alien Species (IAS) is a serious pest for rice farmers, and threatens to upset entire freshwater ecosystems through the decimation of aquatic plants important for water quality regulation. Populations of the snail continue to spread, with the risk that it becomes established in the rivers and wetlands of southern Europe[74][75].

While IAS are most commonly cited for their disservices, there are examples where IAS are perceived to have improved local environment. An assessment of perceptions of the impact of dreissenid (zebra and quagga) mussels on coastal ecosystems along Lake Ontario and the western St. Lawrence River in New York State, revealed that local residents valued the clean water resulting from this IAS’s filter-feeding behaviour[76].
Solutions for protecting harvests and water

Safeguarding agricultural productivity with pesticides

When weeds, pests and diseases damage or destroy agricultural goods, they are in direct competition with humans. This competition would be tolerable if the result was a marginal loss of agricultural productivity; however, losses can be catastrophic. Pesticides are used to mitigate the threat of agricultural pests, and to contribute towards the environmental and socioeconomic goal of efficient and sustainable management of natural resources, including biodiversity, soil and water. Table 9 provides an overview of potential crop losses due to pests and disease for several major global crops.

Pesticides are biologically active compounds, designed and formulated to affect target species; they are used for the control of weeds, plant pathogens and animal pests [67]. The biologically active ingredients of pesticides are obtained from a variety of sources, for example:

- Natural compounds;
- Plant extracts;
- Microbial insect pathogens (including bacteria and fungi, or viruses);
- Synthetic compounds.

Nearly all forms of agriculture require pest control, and pesticides are used in both organic and conventional farming. Organic farming relies primarily on naturally occurring inorganic molecules such as copper, sulphur, and microorganisms like bacteria, and viruses. Conventional farming also uses synthetic compounds, which are optimised for efficient and targeted action, and in terms of protecting against crop losses, out-perform low-input agriculture [8] [77] [78] [79].

There are several classes of pesticides, the most relevant for crop protection being:

- **Fungicides** – used for the suppression of fungal infections;
- **Herbicides** – used for the control of weeds;
- **Insecticides** – used for the management of insect pests.

It is a common misconception that organic farming is pesticide free – nearly all forms of agriculture require pest control, and pesticides are used in both organic and conventional farming.

### Table 9: The extent of actual global crop losses to crop pest categories for key crop types, including figures on potential crop losses without crop protection practices [80] [81]:

<table>
<thead>
<tr>
<th>Crop</th>
<th>Actual % crop losses due to:</th>
<th>Total % actual crop loss*</th>
<th>Total % potential crop loss**</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Animal pests</td>
<td>Weeds</td>
<td>Pathogens</td>
</tr>
<tr>
<td>Cotton</td>
<td>12.3</td>
<td>8.6</td>
<td>7.2</td>
</tr>
<tr>
<td>Maize</td>
<td>9.6</td>
<td>10.5</td>
<td>8.5</td>
</tr>
<tr>
<td>Potatoes</td>
<td>10.9</td>
<td>8.3</td>
<td>14.5</td>
</tr>
<tr>
<td>Rice</td>
<td>15.1</td>
<td>10.2</td>
<td>10.8</td>
</tr>
<tr>
<td>Soybean</td>
<td>8.8</td>
<td>7.5</td>
<td>8.9</td>
</tr>
<tr>
<td>Wheat</td>
<td>7.9</td>
<td>7.7</td>
<td>10.2</td>
</tr>
<tr>
<td>Average</td>
<td>10.8</td>
<td>8.8</td>
<td>10.0</td>
</tr>
</tbody>
</table>

* when crop protection measures are employed  
** where crop protection measures are not employed
Without crop protection practices wheat crops are subject to a potential global yield loss of around 50% [80] [81]
Environmental variables such as local temperature and weather conditions have influence over the effectiveness of pesticides; however, the three key factors that determine the effectiveness of a pesticide are:

- The intrinsic properties of its active ingredient;
- The characteristics of the target organism(s);
- The mode of product application and subsequent activities.

Pesticides can have direct or indirect unwanted effects on biodiversity. For example, the effective use of herbicides to remove weeds can have the secondary effect of reducing forage for pollinators; likewise, the use of insecticide to manage aphids (fam. Aphidoidea) reduces the availability of food for ladybirds (fam. Coccinellidae). Direct unintended effects of pesticides may occur for example, when a fungicide drifts into a freshwater body, thereby exposing and potentially damaging aquatic organisms and affecting water quality.

Farmers are faced with a considerable challenge: to safeguard natural resources and to ensure that agriculture continues to produce ecological services; all whilst maintaining the supply of safe and abundant agricultural goods necessary to satisfy markets [82].

The European Union has developed a regulatory framework that aims to ensure the efficacy, safety and suitability of pesticides. This, in combination with other policy and legislative instruments – such as the Sustainable Use Directive – sets rules for the sustainable use of pesticides, to reduce the risks and impacts of pesticide use on people’s health and the environment.

The European Food Safety Authority (EFSA) is the keystone of EU risk assessment regarding food and feed safety. In close collaboration with national authorities and in open consultation with its stakeholders, EFSA provides independent scientific advice on existing and emerging risks. EFSA is an independent European agency which although funded by the EU, operates separately from the European Commission, European Parliament and EU Member States [83].

Organic farming relies primarily on naturally occurring inorganic molecules, such as sulphur.
Agriculture and the management of fresh water quantity

All crops require fresh water, but the amount of irrigation required depends on several factors, including:

- Crop type;
- Climate;
- Water quality;
- Soil characteristics;
- Cultivation practices.

The complex interaction between these factors and their influences on the management of water quantity, are captured by the DPSIR framework (Figure 6). DPSIR offers a model for describing interactions between society and the environment; the framework’s components in the context of quantitative water management, are:

- **Driving force** (of the demand for water);
- **Pressure** (of the consumptive use of water);
- **State** (A quantification of the water resource situation);
- **Impact** (The impacts of the water resource situation);
- **Response** (Techniques and practices to reduce negative impacts on water).

The DPSIR framework illustrates how responses – including policies, farmers’ initiatives and best management practices – can be used to favourably manage water quantity; efficient production implies a favourable use of natural resources.

---

**Figure 6: Water quantity issues using the DPSIR framework**

- **Driving forces**
  - Climate change
  - Population growth
  - Urbanisation, industrialisation

- **Pressures**
  - Increase of irrigated areas
  - Water efficiency
  - Water losses

- **State**
  - Consumptive uses (agriculture, industry, drinking water etc.)
  - Competitive uses

- **Impacts**
  - Water scarcity and droughts
  - Ecosystem health
  - Human needs
  - Water quality

- **Responses**
  - Policies
  - Farmer initiatives
  - Economic signals
  - Improvement of techniques
  - Better management practices
  - Other water sources
Agriculture, pesticides, and the management of freshwater quality

Agriculture can deliver unwanted effects, these ‘ecosystem disservices’ include the habitat loss associated with agricultural development, the diversion of rivers, groundwater depletion that can result from cropland irrigation, and the potential contamination of surface waters with fertilisers and pesticides [25].

With few exceptions, pesticides are designated for application on terrestrial areas such as fields and orchards; however, pesticides may unfortunately reach freshwater bodies. An understanding of how this might occur is important in order to take steps to help prevent pollution. Water quality is often strongly influenced by the management of agricultural practices at the watershed level [86]. This frames the challenge for the crop protection industry, regulators, advisors and farmers to manage pesticides, and their application, to avoid ecologically unacceptable impacts.

Pesticides can reach water bodies because of mistakes made during application, or the result of a technical deficiency in application equipment; combinations of local environmental, meteorological and geological conditions can also contribute to increased potential for pesticides to reach water (Figure 7).

**Direct exposure routes (referred to as ‘point sources’)**
- **Point sources** are Localised pollution sources which may occur during mixing and loading, the cleaning of application machinery, during transport, or at the point of container disposal.

**Indirect exposure routes (also known as ‘diffuse sources’)**
- **Spray drift**: During spray application, pesticide particles can be transported by wind to nearby water bodies if sufficient care is not taken;
- **Run-off**: After application and in the event of unexpected rainfall, pesticides can be carried away from treated fields and in to water bodies in surface water flows;
- **Drainage**: After application, pesticides might reach water bodies via drainage channels following rainfall.

**Figure 7: Entry points of pesticides to fresh water**
Risk assessment for aquatic organisms

The process of risk assessment for aquatic organisms requires two kinds of data:

- **Exposure data**: To determine the doses to which aquatic organisms may be potentially exposed
- **Ecotoxicity data**: To determine the doses at which aquatic organisms are affected

Exposure is quantified by measuring levels of an active ingredient – or a metabolite – following application, or through modelling based on complex environmental scenarios (for example, pulse exposure in rapidly flowing rivers).

Toxicity data are generated in experiments which are conducted according to accepted scientific principles, many of which follow international guidelines (like those of the OECD).

The standard risk assessment procedure for aquatic organisms requires calculation of the Toxicity-Exposure Ratio (TER) for determining potential risk [(87);]

\[
TER = \frac{\text{Toxicity Statistic}}{\text{Predicted Environmental Concentration}}
\]

In the European Union, the use of pesticides is regulated, and all EU Member States apply the same evaluation procedures and authorisation criteria in order to place a plant protection product on the market. It is the responsibility of the European Food Safety Authority (EFSA) and national authorities to carry out risk assessment for pesticides and to provide the European Commission with scientific support for the decision making processes [(88);]. Reference to the key legislative documents that form the legal framework for the registration of plant protection products can be found in Annex 1.

The testing principles and protection goals of the Plant Protection Product registration process

Testing is carried out with a tiered approach that begins with laboratory tests; based on a system of trigger values, tests potentially culminate in field studies, as illustrated by Figure 8.

Testing schemes and protection goals are closely linked to enable assessment of possible effects on definite protection goals. Tables 10 and 11 respectively provide an overview of scientific protection goals for the ecological threshold option as proposed by EFSA, and an overview of the specific protection goals for the ecological recovery option as proposed by EFSA.

Protection goals for aquatic organisms are divided into two main categories:

- The ‘Ecological Threshold’ option, where only negligible effects on populations are accepted, and
- The ‘Ecological Recovery’ option, where population-level effects are accepted if ecological recovery takes place within an acceptable time period.

The tiered approach allows for a combination of test types (laboratory or field, and acute or chronic) within the scope of specific protection goals. Trigger values are assigned to each tier level which informs the decision to proceed to the next test level.

**Tier 1 tests**

Tier 1 tests employ indicator organisms; i.e. organisms which are representatives of a systematic or ecological group (Table 12). The tests most frequently look for effects in the dose-response curve and can be used for both short (acute) and long-term (chronic) assessments.
Tier 1 tests are conducted in the laboratory under highly controlled conditions.

Figure 8: Schematic presentation of the tiered approach within the acute (left part) and chronic (right part) effect assessment for plant protection products (PPPs) and aquatic organisms [89].

<table>
<thead>
<tr>
<th>Tier 1</th>
<th>Tier 2</th>
<th>Tier 3</th>
<th>Tier 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Core acute toxicity data</td>
<td>Core chronic toxicity data</td>
<td>Population and community level experiments and models</td>
<td>Field studies and landscape level models</td>
</tr>
</tbody>
</table>

Acute risk assessment looks at short-term risk (for example, the occurrence of mortality within 48 hours).

Chronic risk assessment looks at long-term risk (for example, the occurrence of effects on sexual reproduction).

Higher tier levels aim at being more realistic than lower tier levels.
All tiers aim to assess the same protection goal.
In each tier level all available scientific information is used.
Lower tier levels are more conservative than higher tier levels.

Specific protection goal

Acute effect assessment

Chronic effect assessment

Acute lab tests with additional species and/or refined exposure

Chronic lab tests with additional species and/or refined exposure

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Tier 1 tests are conducted in the laboratory under highly controlled conditions – where factors including temperature, water quality, the age of test organisms, illumination regime, and the exposure of test organisms to test compounds, are all carefully controlled. The high level of standardisation that characterises Tier 1 tests ensures that tests can be reproduced, and results corroborated in different laboratories.

The long-term and constant exposure of test organisms achieved at Tier 1 ensures that worst-case and complex exposure scenarios can be tested. The controlled conditions allow for analysis of exposure to compounds during their degradation, and in scenarios that bring rapidly changing exposure, which is possible in fast flowing water bodies (pulse exposure).

The limitations of lab tests are to be found in the number of species tested, the trophic level occupied by test species, and the assessment of impact on ecological interactions. Lab tests are conducted on considerably fewer species than are found in a natural ecosystem, and tests do not examine effects on ecological interactions or on groups such as top level predators.

**Higher tier tests**

There is no testing system available that can accommodate the specific complexity of all aquatic ecosystems in Europe. The aim of higher tier risk assessment is to achieve an approximation of ecological reality in order to deliver a satisfactory degree of confidence for risk management ‘in the field’. Some of the methods used for higher tier tests include mesocosm, bioconcentration and biomagnification studies, and Species Sensitivity Distribution (SSD) curves.

**Mesocosm studies**

Mesocosm studies use an artificial pond, normally containing natural water, sediment, and a community consisting of at least microorganisms, plankton, macrophytes and macroinvertebrates, and sometimes small fish. A mesocosm allows for the study of effects of test compounds on communities of organisms.

Table 10: Overview of scientific protection goals for the ecological threshold option as proposed by EFSA

<table>
<thead>
<tr>
<th>Organism group</th>
<th>Ecological entity</th>
<th>Attribute</th>
<th>Magnitude</th>
<th>Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Algae</td>
<td>Population</td>
<td>Abundance/biomass</td>
<td>Negligible effect</td>
<td>Not applicable</td>
</tr>
<tr>
<td>Aquatic plants</td>
<td>Population</td>
<td>Survival/growth Abundance/biomass</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Aquatic invertebrates</td>
<td>Population</td>
<td>Abundance/biomass</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vertebrates</td>
<td>Individual</td>
<td>Survival</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Population</td>
<td>Abundance/biomass</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Aquatic microbes</td>
<td>Functional group</td>
<td>Process (e.g. litter breakdown)</td>
<td>Risk Assessment will not be developed since tier 1 data requirements are not defined</td>
<td></td>
</tr>
</tbody>
</table>
Table 11: Overview of the specific protection goals for the ecological recovery option as proposed by EFSA[89]

<table>
<thead>
<tr>
<th>Organism group</th>
<th>Ecological entity</th>
<th>Attribute</th>
<th>Effect allowable on most sensitive/vulnerable population</th>
<th>Magnitude (effect)*</th>
<th>Duration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Algae</td>
<td>Population</td>
<td>Abundance/biomass</td>
<td>Small Medium Large</td>
<td>Months Weeks Days</td>
<td></td>
</tr>
<tr>
<td>Aquatic plants**</td>
<td>Population</td>
<td>Survival/growth Abundance/biomass</td>
<td>Small Medium</td>
<td>Months Weeks Days</td>
<td></td>
</tr>
<tr>
<td>Aquatic invertebrates*</td>
<td>Population</td>
<td>Abundance/biomass</td>
<td>Small Medium Large</td>
<td>Months Weeks Days</td>
<td></td>
</tr>
<tr>
<td>Vertebrates</td>
<td>No recovery option</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Aquatic microbes</td>
<td>Functional group</td>
<td>Processes</td>
<td>RA will not be developed since Tier 1 data requirements are not defined</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* None of the direct effects should lead to unacceptable indirect effects
** The recovery option will not be applicable in case organisms with a long life cycle could be affected and short-term (days) large effects generally will be acceptable only for short-cyclic organisms that have a high reproduction capacity.

Table 12: The aquatic key drivers and their ecological entity to be protected as proposed by EFSA and the current standard aquatic test species related to these key drivers[89]

<table>
<thead>
<tr>
<th>Key Driver</th>
<th>Ecological entity to be protected</th>
<th>Tier 1 taxa mentioned in data requirements (EC Regulation 283/2013)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aquatic algae</td>
<td>Populations</td>
<td>• Green algae (e.g. Pseudokirchneriella subcapita)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Other taxonomic groups (e.g. the diatom Navicula pelliculosa)</td>
</tr>
<tr>
<td>Aquatic vascular plants</td>
<td>Populations</td>
<td>• Monocotyledons, e.g. Lemna gibba/minor (Lemna is a genus of free-floating aquatic plants from the duckweed family), Glyceria maxima (a perennial grass)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Dicotyledons, e.g. Myriophyllum (a genus of aquatic plants, sometimes referred to as water weeds)</td>
</tr>
<tr>
<td>Aquatic invertebrates</td>
<td>Populations</td>
<td>• Crustaceans: Daphnia magna/pulex, Americamysis bahia</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Insects: Chironomus riparius</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Oligochaets: Lumbriculus spp. (worm species within the order Lumbriculidae, of the Annelida subclass, Oligochaeta)</td>
</tr>
<tr>
<td>Aquatic vertebrates</td>
<td>Individuals (In acute risk assessment to avoid possible mortality)</td>
<td>• Fish, e.g. Oncorhynchus mykiss (trout)</td>
</tr>
<tr>
<td></td>
<td>Populations (In chronic risk assessment)</td>
<td></td>
</tr>
<tr>
<td>Aquatic microbes</td>
<td>Functional groups</td>
<td>• No standard test species</td>
</tr>
</tbody>
</table>
and takes into account indirect effects such as those experienced by predators where prey populations are reduced, and the potential effects on water pH where the pH regulating services of plants and microorganisms might be affected.

Mesocosm studies can be run for more than a year to determine long-term effects, and they can be managed as static or ‘flow’ water bodies in order to mimic still water and stream or river conditions.

Bioconcentration and biomagnification tests
Bioconcentration is the process in which the chemical concentration in an aquatic organism exceeds that in water as result of direct exposure to waterborne chemical; bioconcentration occurs because of absorption of chemicals through respiratory surfaces and skin [91].

Biomagnification is the process in which the chemical concentration in an organism achieves a level that exceeds that in the organism’s diet due to dietary absorption [91]. Biomagnification is exhibited through the detection of higher chemical concentrations with the increased trophic status of organisms sampled [92]. Tissue concentrations of bioaccumulated chemicals increase as these materials pass up the food chain [93] (Figures 9 and 10). In risk assessment for aquatic organisms, EFSA defines the biomagnification factor (BMF) as the relative concentration (of a relevant compound) in a predatory animal compared with the concentration in its prey [89].

The bioaccumulation of a substance is not an adverse effect or hazard in itself; however bioaccumulation and biomagnification can lead to unacceptable environmental impact within food chains. Therefore, the challenge for industry and regulators during the risk assessment process is to screen for the potential of substances to bioconcentrate and/or bioaccumulate, and in a next step to assess if effects due to bioaccumulation or biomagnification after prolonged exposure occur [94]. As bioaccumulation processes often are slow and substances may be persistent, a long-term assessment is appropriate [95].

Testing and assessment for bioconcentration follows a stepwise approach. At first, compounds are evaluated for their potential to bioconcentrate; if bioconcentration potential is confirmed, then a second stage of testing sees the controlled

In July 2013 EFSA issued revised guidance for assessing the risks posed by pesticides to aquatic organisms – such as fish, amphibians, invertebrates and plants – living in ponds, ditches and streams next to fields that are treated with these substances. The guidance document outlines methods to evaluate the extent to which exposure to pesticides affects populations of aquatic organisms, including aquatic plants and algae. This risk assessment scheme is designed to help risk assessors and decision-makers at national and EU level ensure that aquatic organisms are protected when pesticides are placed on the market [96].
exposure of fish to the compound to determine the effects of exposure to the compound at different concentration levels. Several parameters are measured, including compound uptake rate, excretion, and the formation of metabolites.

Both bioconcentration and biomagnification have relevance for pesticide risk assessment; however, as top level predators (e.g., eagles, otters) are often rare or endangered, direct testing is neither desirable nor practical. Therefore, data is required which shows the extent to which a compound has the potential to bioaccumulate (compound specific factors) and other data are required (by comparing concentration levels found within test fish compared to concentrations found within surrounding water\cite{89}) for risk assessment for some fish, and for fish-eating predators.

**Bioconcentration** refers to the uptake and accumulation of a substance from water alone.

**Bioaccumulation** refers to uptake from all sources (dietary and other environmental exposure).

**Biomagnification** is the process in which the chemical concentration in an organism achieves a level that exceeds that in the organism’s diet due to dietary absorption.
Species Sensitivity Distribution (SSD)

Species sensitivity distributions (SSDs) are used in ecological risk assessment; when used correctly they can give a greater statistical confidence to the risk assessment process as compared to traditional quotient and assessment factor approaches. SSD curves make use of data from laboratory tests which provide specific endpoints for individual species; the species specific endpoints can be plotted to an SSD curve for each tested compound. The aim of a SSD analysis is to establish the dose-related risk-potential of exposure of particular species to particular compounds, it allows for the extrapolation of effects on non-tested species, based upon the known effects on tested species.

An SSD curve can be used to describe the marked differences in sensitivity to test compounds exhibited between species. SSD curves make use of data from laboratory tests which provide specific endpoints for individual species; the species specific endpoints can be plotted to an SSD curve for each tested compound. The aim of a SSD analysis is to establish the dose-related risk-potential of exposure of particular species to particular compounds. It allows for the extrapolation of effects on non-tested species, based upon the known effects on tested species.

The specific end point may, for example, be set to the ‘ED50’, i.e. the amount of agent required to produce a pre-determined response in test organisms at the median (50%) level. Based on ED50 data, the ‘HC5’ (Hazardous Concentration for 5% of the species) value is frequently estimated, and used to represent a concentration that would materially impact 5% of the species while not seriously impacting the other 95%.

HC5 offers a conservative assessment of risk, and with a high degree of confidence it is often used to determine safe exposure scenarios for pesticides in relation to specific species. HC5 is not intended as an ‘all or nothing’ threshold. The conservative nature of HC5 is also to be found in the fact that ecological community structures would likely sustain structure with a higher proportion of loss – than experienced in a HC5 scenario – through ecological processes such as adaptation and immigration.

Complex exposure scenarios

The constant exposure scenarios normally used during 1st tier tests do not reflect the kind of exposure that is perhaps experienced out in the real world. For example, compounds will degrade over time and produce metabolites which may themselves possess toxicological profiles of interest for risk assessment. It is possible for compounds and their metabolites to become enriched in the sediment of water bodies before finally entering the food chain.

In Europe, complex exposure scenarios in surface water are modelled using FOCUS (FORum for the Co-ordination of pesticide fate models and their Use) modelling tools which were developed specifically for this purpose.

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**Figure 11**: Graphical presentation of a species sensitivity distribution curve with example lower, median and upper species sensitivity curve and lower, median and upper limit hazardous concentration to 5% of the species (HC5).
Risk management and best management practices for the use of Plant Protection Products

The risk assessment process may identify the need for specific risk mitigation measures to be applied during the use of a product in order to protect surface water. A high degree of knowledge of exposure routes and exposure reduction measures means that today European farmers have access to technical solutions, products, and application strategies that deliver a high degree of safety and protect aquatic organisms.

Risk mitigation measures are described on pesticide product labels and it is obligatory for pesticide users to follow these approved safety instructions. In addition to safety instructions, best management practices can contribute to the protection of surface water, including measures to reduce diffuse source losses such as spray drift, run-off and point source pollution which can result for example from a spillage or during the cleaning of equipment.

Many farmers – aware of the risks associated with crop protection products and the importance of maintaining water quality – utilise various best management practices and adhere to product label requirements.

Figure 12: Direct and indirect measures to protect surface water from drift [101]

- **Direct measures** (reducing drift at source)
  - Use of Spray Drift Reduction Technology (SDRT)
  - No-spray zones
- **Indirect measures** (reducing exposure to drift)
  - Fixed buffer zones
  - Adjustable buffer zones (depending on spray application technology)
  - Natural vegetation, windbreaks, hail nets, etc.
  - Water body
Spray drift reduction
Spray drift occurs when air currents move pesticides outside of the treatment area during their application. To prevent spray drift reaching surface waters, direct and indirect measures can be taken (Figure 12). Direct measures include the use of spray drift reducing nozzles that minimise the quantity of super-fine droplets which are vulnerable to drift. Indirect measures include the use of buffer strips to enlarge the distance between treated areas and water bodies, and the addition of structural elements such as hedges, windbreaks or high vegetation which help capture drifting spray.

Local weather conditions – and in particular wind speed and wind direction – are important parameters to consider in any effort to minimise spray drift; some EU countries include wind speed limits in their management guidance.

Run-off (and erosion) reduction
Run-off occurs when rain intensity exceeds the water infiltration capacity of a soil. Run-off is relevant for erosion prevention, and should be considered as a potential route for the translocation of pesticides outside of fields. There are several factors which can be taken into account when considering mitigation of the problems associated with run-off (and the associated erosion of soil), including:

- The characteristics of the soil, including water holding capacity;
- Knowledge of normal rain intensity and average rainfall levels, and the likelihood of severe weather events with high precipitation;
- The characteristics of the field, including information on field slope and distance between the field and surface water;
- The particular management practices that take place within or near the field, and adjacent to water bodies.

While many of the factors which influence run-off and erosion are not under the control of farmers, there are certain practices which if adopted can reduce the likelihood and/or impact of run-off and erosion (Table 13).

Table 13: Example best management practices to prevent or minimise run-off and/or erosion

<table>
<thead>
<tr>
<th>Type of management practice</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soil management</td>
<td>Contour tilling</td>
</tr>
<tr>
<td></td>
<td>Reduced tillage</td>
</tr>
<tr>
<td></td>
<td>Reduced soil compaction</td>
</tr>
<tr>
<td></td>
<td>Increased organic matter</td>
</tr>
<tr>
<td>Cropping practices</td>
<td>Crop rotation</td>
</tr>
<tr>
<td></td>
<td>Cover crops</td>
</tr>
<tr>
<td></td>
<td>Strip cropping</td>
</tr>
<tr>
<td>Vegetative buffers</td>
<td>Edge of field and riparian buffer</td>
</tr>
<tr>
<td></td>
<td>Hedge and woodland buffers</td>
</tr>
<tr>
<td>Retention structures</td>
<td>Edge of field bunds</td>
</tr>
<tr>
<td></td>
<td>Artificial wetlands/ponds</td>
</tr>
<tr>
<td>Adapted use of PPPs</td>
<td>Adapted timing of use</td>
</tr>
<tr>
<td></td>
<td>Product rotation</td>
</tr>
<tr>
<td></td>
<td>Modified rate of application</td>
</tr>
<tr>
<td>Optimised irrigation</td>
<td>Use of modern technologies</td>
</tr>
</tbody>
</table>
Clover is an excellent cover crop with high nitrogen fixing potential

Vegetative buffers help to prevent and minimise run-off and erosion to water bodies

Evidence of soil erosion on a wheat field following snow-melt and heavy rain

Woodland buffer

Overuse of heavy farm machinery can result in soil compaction which elevates the risk of run-off and erosion
Reducing point source pollution

Point source pollution is entirely manageable by farmers, and has until relatively recently been overlooked as a significant source of water pollution. In fact, point sources typically contribute between 50-80% of total pesticide pollution of surface waters [102].

Point source pollution is usually the result of failure to carefully handle the product and because of the use of inappropriate or malfunctioning equipment. Point source pollution can occur at any point during the working process, beginning with transportation of the product, through the mixing and loading stages, and ending in the disposal of remnants and the cleaning of machinery and used containers (Figure 13).

Whilst mandatory regulations exist to minimise the occurrence of point source pollution, there are also voluntary initiatives that can provide farmers with training and guidance on best practices, and advice on the selection and use of pesticide application and cleaning equipment.

Out of care for their land, many farmers and land managers are engaged in initiatives that aim to prevent pollution.

Figure 13: Key stages in the use-phase of a crop protection product with potential to generate point source pollution [102]

For more than 10 years, ECPA has been engaged stewardship projects to prevent pesticide pollution of water. Focusing on the prevention of point source pollution and minimising drift, run-off and erosion, ECPA currently works with 22 partner organisations in 24 European countries to roll-out guidance for best management practices during the use of pesticides to safeguard freshwater resources. For more information about the ‘TOPPS’ projects, visit www.ecpa.eu and www.topps-life.org
Home, garden and amenities – a brief look at non-agricultural pesticide uses

Certain plant protection products are made for non-agricultural use; for example, for use in private gardens and amenities, and for municipalities in order to maintain public spaces such as parkland and transport infrastructure including roads and railways.

In most EU countries plant protection products authorised for amateur use must have low human and environmental toxicological profiles, and easy-to-follow label instructions, including recommendations for buffer zones to protect water; they are also sold in small pack sizes to discourage excessive use. In general, the non-professional use of commonly used pesticides around the home and garden is found to have relatively minor contribution to the contamination of drain flow[103].

Non-agricultural pesticide use also offers an important means to manage invasive alien species. The controls of IAS around homes, in gardens and public spaces can help protect biodiversity by preventing the dominance of aggressively invasive species.

Municipalities typically use herbicides to control weeds on hard surfaces, including roadsides, pavements, parking lots and public squares. Characterised by their efficient drainage of rainwater, these hard surfaces present an additional challenge in the avoidance of contamination of drainage waters. To compliment label instructions and best management practices, in 2002 a sustainable weed management system for pavements (SWEEP) was first developed, and extensive field tests have demonstrated that pesticide use guidelines are effective at reducing hard surface run-off to drainage flows. Tailored for policy makers and pesticide users, SWEEP provides information and guidance on herbicide selection and appropriate control methods, and if applicable, herbicide use registration[104].
The Water Framework Directive and the Common Agricultural Policy

The EU has some of the strictest water protection legislation to be found anywhere in the world, the backbone of which is the Water Framework Directive (WFD) which protects water resources for human use and the environment. Adopted in the year 2000, this directive is in part a European Commission response to public concern over water pollution [105]. Furthermore, the new Common Agricultural Policy and Rural Development programme include cross compliance and other methods that will help ensure the quality and quantity of Europe's freshwater systems.

Setting out a precise timetable for action – with 2015 as the target date for getting all EU surface waters into good condition – the WFD adopts an innovative approach to water management, based on natural geographical and hydrological formations: river basins; rather than national administrative or political boundaries [106].

Under the WFD, Member States of the EU are required to draw up River Basin Management Plans (RBMP) that serve as the coordinated plan for each River Basin District. Where these River Basins cross national borders, the responsibility becomes shared among the different member states who must draw up these plans with extensive consultation from the public. As the different RBMPs are created on the basis of the great variety that exists within Europe's waterways, these 6-year plans will be able to take regional variety and agricultural needs into account.

The main goal of the new Water Framework Directive will be the achievement of ‘good ecological status’ and ‘good chemical status’. Good ecological status is defined in terms of the quality of the biological community that can be expected under conditions of minimal human impact. Under these guidelines, Member States must construct their RBMP in such a way as to establish the particular chemical and hydro-morphological standards that will ensure the right quality.

Good chemical status is defined as compliance with existing European quality standards for chemical substances such as crop protection products – there can thus be no lessening of the protection of water quality.

With regards to the Common Agricultural Policy, the main mechanism that protects surface water is cross-compliance, under which farmers and Member States are required to pay special attention to water quantity and quality. Both the Water Framework Directive as well as the Sustainable Use of Pesticides Directive are part of the compliance required for farmers to receive CAP funding. To further protect surface water, the EU has implemented the Nitrates Directive to prevent the eutrophication of water through fertiliser and other nitrate runoff.

Additionally, under the new CAP’s greening measures, farmers will be required to maintain Ecological Focus Areas (EFA), which may consist of managing buffer strips in riparian zones as well as implementing additional management practices that help shield surface water from accidental contamination by crop protection products or nitrates.

The EU’s renewed efforts under both the WFD and the CAP show that there is a commitment on part of regulators as well as farmers and other parties to improve and maintain the status of Europe’s waterways and water bodies.

Directive 2000/60/EC of the European Parliament and of the Council establishing a framework for the Community action in the field of water policy or, in short, the EU Water Framework Directive (or WFD) was adopted on the 23rd of October, 2000. The WFD aims for good condition for all EU surface waters by 2015, which includes achieving ‘good ecological status’ and ‘good chemical status’ [107].
Ways forward

Meeting the challenge

Global agriculture is faced with many challenges. It has to produce more raw materials to satisfy the increasing and diversifying demands of a growing world population, it has to contribute to economic prosperity and social wellbeing in rural areas, and it has to preserve natural resources such as land, biodiversity and fresh water.

A more productive and resource efficient agriculture mitigates the problems associated with these challenges, because it enables us to have more of everything – more food, more feed, more non-food crops, more biodiversity and natural habitats [8].

Bio-physical improvements to reduce the impact of food production on local and global biodiversity include reducing pressure on global land use, reducing losses of inputs (including pesticides) and emissions, and improving local biodiversity and land and water management.

Likewise, by increasing the output of crop products per hectare, improvements in food security and natural area protection can be combined [10].

If we wish to maintain and improve yields, make efficient use of natural resources and feed the planet, the use of plant protection products must be part of a toolbox of agricultural technologies and best practices that is readily accessible for farmers. When the global need for agricultural productivity is considered, there are currently no practical alternatives to pesticide use in either conventional or organic farming.

Efficient production technologies are imperative to allow us to close yield gaps and ensure productivity; however, society must use these technologies in an appropriate way to ensure that agriculture plays a central role in delivering sustainable solutions. These can be achieved through risk management, innovation, and best management practices.
Managing the risks

Science, research and development have given us sophisticated crop protection solutions. Used professionally, pesticides play a key role in delivering an abundant supply of safe, healthy and affordable food. While their use is certainly not without risk, a sensible, risk-based approach to EU legislation ensures a safe, healthy environment in addition to the reliable supply of food and other agricultural goods.

The biologically active characteristics of pesticides that can pose risk to non-target species are acknowledged and accommodated in European pesticide regulation; in fact, pesticides are one of the most regulated product classes on the European market.

Pesticide regulations are designed to ensure the safety and safe use of pesticides, so that farmers are equipped with the right tools for sustainable productivity. In addition, EU pesticide regulation allows European consumers a high degree of confidence in the safety, availability and affordability of food.
Improving through science and innovation

Technical developments and innovative solutions – such as satellite guided precision agriculture – continue to help minimise the exposure of surface water to pesticides.

There are also down-to-earth technical solutions, such as filters for application devices which guard against the release of dust when drilling treated seeds. Application nozzles have been developed which optimise drift reduction; and, orchards and vineyards often make use of physical barriers – such as hail nets – to prevent drift reaching water bodies. Agricultural innovations equip farmers with new possibilities and greater flexibility in decision making.

Supporting Best Management Practices, working together

To protect freshwater biodiversity in the long term, a mixture of strategies is recommended; strategies that include measures to protect key, biodiversity-rich water-bodies and their catchments, as well as species or habitat based plans that reconcile the need to protect biodiversity and the need for societal use of water[^9].

More generally, sustainable agricultural practices can contribute to protecting and preserving the freshwater resource. For agriculture to be sustainable it must be efficient, productive and contribute to a resilient natural environment. Society’s demands challenge farmers to ‘produce more, with less’, but this can only be achieved if farmers have access to appropriate technology and best management practices.

At the global scale, lack of access to markets, inputs, capital, technology, and limited exposure to the best agronomic practices, results in large regional differences in crop yields[^10].
Even in the prosperous EU the latest technological developments take time to be widely adopted; however, a range of easy-to-implement Best Management Practices (BMPs) offer scope to improve pesticide risk management and provide solutions that protect human health and the environment – including water – without jeopardising essential agricultural productivity.

Farmers and landowners engage in the management of agricultural land, and stewardship initiatives from industry and farmers’ associations provide outreach and expert support to European farmers. These initiatives help with crop protection, risk management, and biodiversity protection.

Strong public support for biodiversity protection, a knowledgeable and passionate community of farmers, and the engaged expertise of industry can be combined to make the rural environmental ‘greener’ and more productive. With careful management and reasoned discussion between land managers, public, and policy makers, we can help ensure a sustainably productive future.
Annex I.
Legislative framework for Plant Protection Products

The PPP registration process comprises both EU-wide and national legislation and guidance documents; some of the key EU references are listed below.

These documents – together with others to which they refer – detail requirements for product registrations. This includes information on requirements for study design, validity criteria, and test organism specifications. Different categories of compounds are also addressed, such as active ingredients (the primary active molecules in a product), products (which may contain more than one active ingredient), and metabolites (the products of the degradation of active ingredients in the natural environment).

**PPP registration in the EU in general:**
  

**Details for PPP registrations in EU:**
  

  

**EU Guidance document for the risk assessment of aquatic organisms:**
- Guidance on tiered risk assessment for plant protection products for aquatic organisms in edge-of-field surface waters
  

**Sustainable Use Directive**
  
References


The European Crop Protection Association (ECPA) represents the crop protection industry at the European level. Its members include all major crop protection companies and national associations across Europe.

ECPA promotes modern agricultural technology in the context of sustainable development; to protect the health of humans and the environment, and to contribute towards an affordable healthy diet, competitive agriculture and a high quality of life.

ECPA members support fair, science-based regulation as a guarantee to the consumer, and the crop protection user, of high standards and safe products.

The ELO is a European organization representing more than 54 national associations of private landowners across the EU 27. It is a non-profit organization committed to promoting a sustainable and prosperous countryside and to increase awareness relating to environmental and agricultural issues.

By engaging various stakeholders, ELO develops policy recommendations and programmes of action targeted to European policy makers.

ELO also organizes interdisciplinary meetings, gathering together key actors from the rural sector and policy makers at local, regional, national and European level.