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ESManage Project: Irish Freshwater Resources and Assessment of Ecosystem Services Provision

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Roinn Cumarsáide, Gníomhaithe ar son na hAeráide & Comhshaoil
Department of Communications, Climate Action & Environment

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ENVIRONMENTAL PROTECTION AGENCY

The Environmental Protection Agency (EPA) is responsible for protecting and improving the environment as a valuable asset for the people of Ireland. We are committed to protecting people and the environment from the harmful effects of radiation and pollution.

The work of the EPA can be divided into three main areas:

Regulation: *We implement effective regulation and environmental compliance systems to deliver good environmental outcomes and target those who don't comply.*

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Advocacy: *We work with others to advocate for a clean, productive and well protected environment and for sustainable environmental behaviour.*

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- large scale industrial activities *(e.g. pharmaceutical, cement manufacturing, power plants)*;
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- the contained use and controlled release of Genetically Modified Organisms *(GMOs)*;
- sources of ionising radiation *(e.g. x-ray and radiotherapy equipment, industrial sources);*
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- Working with local authorities and other agencies to tackle environmental crime by co-ordinating a national enforcement network, targeting offenders and overseeing remediation.
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- Prosecuting those who flout environmental law and damage the environment.

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- Monitoring and reporting on the quality of rivers, lakes, transitional and coastal waters of Ireland and groundwaters; measuring water levels and river flows.
- National coordination and oversight of the Water Framework Directive.
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- Monitoring air quality and implementing the EU Clean Air for Europe (CAFÉ) Directive.
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- Office of Environmental Enforcement
- Office of Evidence and Assessment
- Office of Radiological Protection
- Office of Communications and Corporate Services

The EPA is assisted by an Advisory Committee of twelve members who meet regularly to discuss issues of concern and provide advice to the Board.

EPA RESEARCH PROGRAMME 2014–2020

Irish Freshwater Resources and Assessment of Ecosystem Services Provision

EPA Research Report

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Prepared for the Environmental Protection Agency

by

University College Dublin, Blue Island Consulting and Inland Fisheries Ireland

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DISCLAIMER

The EPA Research Programme addresses the need for research in Ireland to inform policymakers and other stakeholders on a range of questions in relation to environmental protection. These reports are intended as contributions to the necessary debate on the protection of the environment.

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Executive Summary

Freshwater is vital for all forms of life and it is a key requirement in almost all human activities. The societal importance of water has been highlighted by the United Nations, with access to clean water and sanitation regarded as a universal human right. Consequently, the sustainable management of freshwater resources has gained importance at regional, international and global scales. However, the activities of humankind affect freshwater resources extensively, in terms of both quantity and quality, through a variety of activities ranging from abstraction of water for drinking and irrigation to waste disposal. Today, worldwide freshwater ecosystems are under great pressure and are one of the most endangered ecosystems. Furthermore, climate change, especially in relation to precipitation patterns and flooding, will result in the traditional norms being replaced with increased variability and unpredictability, with knock-on effects for human societies and well-being.

The benefits society derives from freshwater ecosystems have long been recognised by human societies. As a result, the concept of ecosystem services has evolved and it is now considered an effective means of communicating to all stakeholders, including the general public, the value of protecting our ecosystems, including freshwaters, in order to maintain the flow of benefits (i.e. goods and services) that they provide to human societies. In the simplest of terms, ecosystem services are defined as "the contributions that ecosystems make to human well-being". Application of the ecosystem services framework can optimise the benefits provided by ecosystems and enable improved environmental accounting and practice in the landscape, and provides an opportunity to improve the protection and management of our freshwater resources by relating environmental concerns to social and economic well-being.

Fresh waters, in their entirety, deliver an extensive range of ecosystem services, including provisioning services [clean water for drinking and water for non-drinking purposes (e.g. irrigation, cleaning, industrial use), and provision of food (e.g. fish)], regulating and maintenance services that incorporate those that both directly (e.g. waste assimilation, pathogen control) and indirectly (e.g. regulation of decomposition, climate and flows) sustain environmental quality, and cultural services, which include tangible recreational uses (e.g. kayaking, fishing, walking along a river) and contribute to less tangible benefits, such as aesthetic or spiritual benefits and educational value. It must be noted that not all freshwater habitats have the ability to support all processes and functions and to deliver services and goods equally; the delivery of freshwater ecosystem services and related goods and benefits is highly dependent on the location within the catchment and the service in question, as well as the scale of demand from beneficiaries. More information on freshwater ecosystem services and the ecosystem service framework can be found in Environmental Protection Agency (EPA) Research Reports 187 and 208 available online at: http://www.epa.ie/pubs/reports/research/water/.

Ireland has a broad range of freshwater resources, from the obvious streams, rivers and lakes, to the more ambiguous, such as groundwater, hyporheic zones, turloughs, canals and peatlands. This report highlights and summarises the most up-to-date available information on the extensive variety and distribution of Ireland's freshwater resources. Chapter 4 highlights the biodiversity found within the range of Irish freshwater resources, which includes an extensive list of freshwater taxonomic orders and groups, including algae, macrophytes, micro- and macroinvertebrates, fish and other vertebrates with links to freshwater habitats, such as amphibians, mammals and birds. Overall this section highlights the depauperate nature of Irelands freshwater fauna relative to Britain and continental Europe, owing mainly to the islands glacial history, but equally helps to identify and highlight the diversity of biota that contribute to a healthy functioning freshwater ecosystem in Ireland. The combination of Irish freshwater resources and their biodiversity provides a platform to highlight the broad spectrum of ecosystem services that society derives from them and also the ways in which land management and societal practices may affect their delivery.

Chapter 5 highlights the current ecological status of Irish freshwaters and outlines the multitude of pressures on Irish freshwater resources. The anthropogenic activities relating to agricultural practices and urban wastewater discharges to receiving water continue to result in the loss of nutrients to associated waters and the declining status of our freshwaters, with the dramatic decline in numbers of high status sites, and general loss of many good status sites. Other anthropogenic reasons for poor chemical status and general degradation of Irish freshwaters relate to historical contamination from mining activities, ongoing industrial development, urbanisation, tourism and other factors, such as climate change-related hydrological change and habitat limitations, and the presence of alien species (e.g. zebra mussel, Asian clam, curly waterweed), especially in lakes, canals and other slow-moving waters.

The management of Irish freshwaters is outlined in Chapter 6. The recent move of merging four regional river basin districts (RBDs), namely the Eastern, South-Eastern, South-West and Shannon RBDs, into a single national RBD, and the administrative arrangements in place to deal with cross-border waters of the North-Western and Neagh Bann RBDs to facilitate co-ordination, using a single management plan, with authorities in Northern Ireland, are detailed. Also described is Ireland’s three-tiered governance structure, led by the Department of Housing, Planning, Community and Local Government, as set out in European Union (EU) (Water Policy) Regulations 2014 (S.I. 350 of 2015). The wide range of organisations invested in freshwater catchment management and planning are also highlighted.

The ecosystem services provided by Irish freshwaters are extensive and are currently not well documented. We have undertaken a scoping exercise to identify the range of ecosystem services (i.e. provisioning, regulating and maintenance, and cultural services) derived from the five main categories of water resources [i.e. rivers, lakes, groundwaters, wetlands and heavily modified water bodies (e.g. reservoirs, canals, etc.)] from which Irish society benefits. To do this we have used the Common International Classification of Ecosystem Services (CICES) to categories and define our freshwater ecosystem services. This report also gauges the relative importance of each freshwater ecosystem service to Irish society, with much of the supporting data derived from evidence provided within this report, a stakeholder workshop held in September 2015 by the ESManage project and expert opinion. This qualitative estimation of the relative importance at local, regional and national levels in Ireland was undertaken in order to evaluate and identify the potential for change in ecosystem services in Irish freshwaters in response to selected catchment management options and programmes of measures implemented on behalf of restoring good ecological status and meeting EU Water Framework Directive (2000/60/EC) goals. The catchment management options, mostly relating to reductions in nitrate, phosphate and sediment pressures were chosen following a meeting with the EPA in March 2016. We have also included “intensification” (vis-à-vis Food Harvest 2020 and Food Wise 2025), which will likely increase the nutrient and sediment pressure on some Irish rivers with potentially negative effects on ecosystem services. Thus, the changes to management highlighted may be either positive or negative in response to reduction in contaminant inputs (the latter in the case of further intensification without additional measures to address nutrient and sediment problems).

1 Introduction

Freshwater is vital for all forms of life and it is a key requirement in almost all human activities. The societal importance of water has been highlighted by the United Nations (UN) and access to clean water and sanitation is now regarded as a universal human right (UN, 2003, 2016). Consequently, the sustainable management of freshwater resources has gained importance at regional, international [e.g. Water Framework Directive (WFD) (2000/60/EC), S.I. No. 722 of 2003 (EU, 2000)] and global scales (e.g. UN, 2002, 2006; World Water Council, 2006). Humans can affect freshwaters extensively, in terms of both quantity and quality, through a wide range of activities from abstraction of water to waste disposal. In fact, of all the Earth's ecosystems, freshwaters are under the greatest pressure and are probably the most endangered (e.g. Dudgeon *et al*., 2006). The added effect of climate change, especially in relation to precipitation patterns and flooding, means that traditional norms will be replaced with increased variability and unpredictability.

Degradation of ecosystems affects the delivery and sustainability of ecosystem services (i.e. provisioning, regulating and cultural; see Appendix 1 and Chapter 2). Ecosystem services are defined as "the contributions that ecosystems make to human well-being" by the Millennium Ecosystem Assessment (MEA, 2005). Freshwater ecosystems comprise a combination of rivers, lakes, wetlands and other freshwater habitats that constitute a large part of the natural infrastructure, or so-called natural capital, that underpins human well-being and economic growth (e.g. Postal and Richter, 2003). The ecosystem services derived from freshwaters are underpinned by functions and processes (so-called supporting services or processes), which result from an interaction of physical, chemical and biological components of freshwater systems and the associated drainage landscape to which they are intrinsically linked.

There is a growing interest in the incorporation of the ecosystem services framework into management of water resources. The ecosystem services framework is described as "a strategy for the integrated management of land, water and living resources that promotes conservation and sustainable use in an equitable way" (CBD, 2004). This framework should not be confused with the "ecosystem approach". For example, the ecosystem services framework focuses on understanding how natural systems and the linkages between ecosystem structures and process functioning can lead, directly or indirectly, to valuable benefits for human welfare, whereas the "ecosystem approach" focuses on natural processes and systems (e.g. Turner and Daily, 2008; Waylen *et al*., 2014; Martin-Ortega *et al*., 2015). More information is available in Waylen *et al*. (2014) and Feeley *et al*. (2016a).

The ecosystem services framework is seen as an effective means of communicating to all stakeholders, including the general public, the value of protecting ecosystems in order to maintain the flow of benefits they provide for humans. In theory, estimates of this value provide a rationale to extend conservation efforts to land management through the design and provision of incentives and policies that are proportionate to the contribution of services provided by the ecosystem (Hauck *et al.,* 2013). Before initiating efforts to adopt this framework in Ireland, it is necessary to review the knowledge base on the nature and extent of our freshwater resources and the derived ecosystem goods and services, including some qualitative or quantitative measure of their relative importance. This report commences with an overview of the ecosystem services and related frameworks and approaches before presenting details of the Irish freshwater resource and associated ecosystem services.

2 Freshwater Ecosystem Services – An Introduction

2.1 The Ecosystem Services Framework

The ecosystem services framework, in its simplest terms, is a way of understanding how nature delivers benefits and services for human well-being (Waylen *et al.*, 2014). It also allows a valuation of changes in specific ecosystem service flows and a comparison of previously incomparable resources (Toman, 1998; Salles, 2011); it may also be perceived to have particular power as a support tool for environmental concerns (Costanza *et al.*, 1997). The ecosystem services framework, which is referred to as the "ecosystem services approach" by some authors, is in many respects similar to the "integrated water resource management" (IWRM) approach, the Water–Energy–Food Nexus and the ecosystem approach. IWRM is an umbrella term for water management and is generally applied to the river basin or catchment (and sometimes at country level). It promotes co-ordination, development and management of water, land and related resources in order to maximise economic and social welfare (see Global Water Partnership, 2000). The Water–Energy–Food Nexus (http://www.water-energy-food.org/) enhances water, energy and food security by increasing co-operation, efficiency, reducing trade-offs, building synergies, improving governance across sectors and underpinning policy recommendations (Hoff, 2011; UN Water, 2014). The features that these different approaches have in common are their genesis, underpinning assumptions, objectives and approaches, especially in terms of the sustainable use of natural capital and ecosystems (Niasse and Cherlet, 2015).

2.1.1 Role in catchment services

In Ireland, there is proposal for an overarching catchment services approach that is based on the principle that an absence of joined-up thinking can lead to poor decision making; a catchment services approach essentially promotes IWRM in which the catchment is the major unit of analysis (Daly, 2015a,b). Catchment services underlie the benefits that the people who are living in and/or using the catchment derive from the components of natural capital, ecosystems, geosystems and human/social capital[1] present in the catchment (Table 2.1 and Figure 2.1) (Daly, 2015b); the river catchment is proposed as the land-based unit for water management and for most components of aquatic and terrestrial biodiversity management. However, the links between the natural (living and non-living) and human systems are complex, dynamic and multifaceted (e.g. Patterson *et al.*, 2013). Nevertheless, Daly (2015a) argues that catchment services, as a framework for management, incorporate the perspective of local communities and stakeholders, being both comprehensive and inclusive of the complete mosaic of "physical, ecological,

1 Human/social capital can be further divided into financial, manufacturing, intellectual, human and social capital (see Figure 2.2 for more information). Furthermore, human/social capital is mobile and therefore may not hold true at catchment scale.

Table 2.1. Description and examples of geosystem services and human/social system services

Geosystem services	Human/social system services[a]
The landscape geomorphology; bedrock and gravel; groundwater for drinking water and geothermal energy; soils and subsoils as chemical and physical attenuating media for pollutants; hydrometeorology (rainfall, evapotranspiration, wind); geological heritage sites; minerals; oil/gas; caves; cultural values associated with landscape features; etc.	Housing; farming, both intensive and extensive; mining; quarrying; wind farms; water abstraction facilities; roads; landfills; industry; cultural values associated with historical features and buildings such as ring forts, castles and holy wells; water mills; pathways along streams and canals; other recreational facilities; etc.

Source: adapted from Daly (2015b).

[a]Human/social capital can be further divided into financial, manufacturing, intellectual, human and social capital (see Figure 2.2 for more information). Furthermore, human/social capital is mobile and therefore may not hold true at catchment scale.

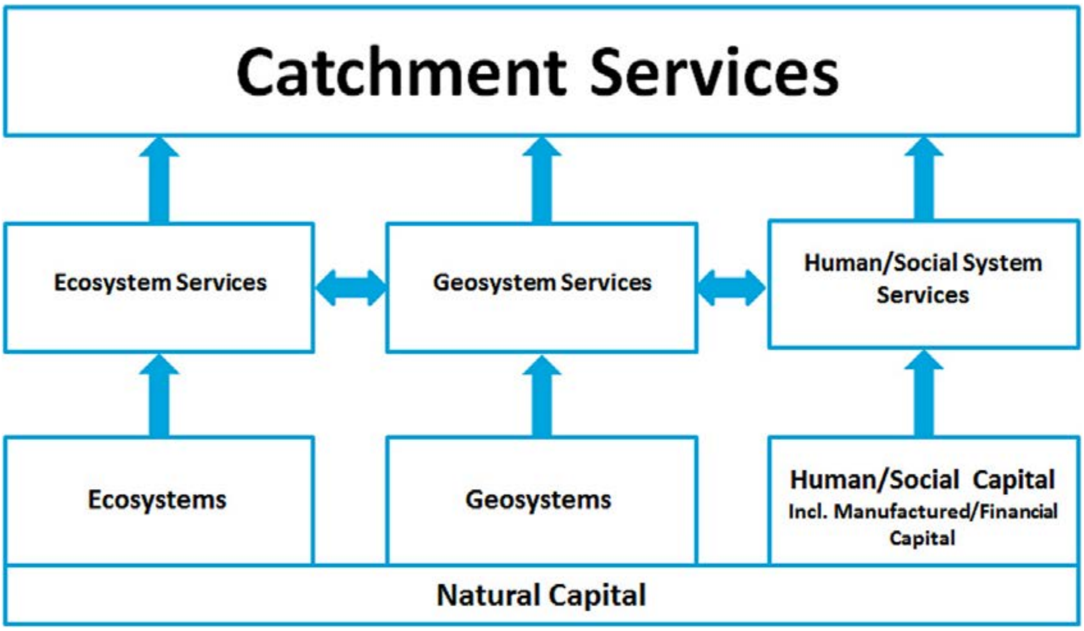

Figure 2.1. Schematic diagram of the different types of services provided to humans within catchments as proposed by Daly (2015a). This encompasses services from the living, non-living and human/social elements, and shows how natural capital, consisting of ecosystem and geosystem services, links with human/social system services to provide the holistic catchment services. Figure reproduced courtesy of Donal Daly, Environmental Protection Agency. Human/social capital can be further divided into financial, manufacturing, intellectual, human and social capital (see Figure 2.2 for more information). Furthermore, human/social capital is mobile and therefore may not hold true at catchment scale.

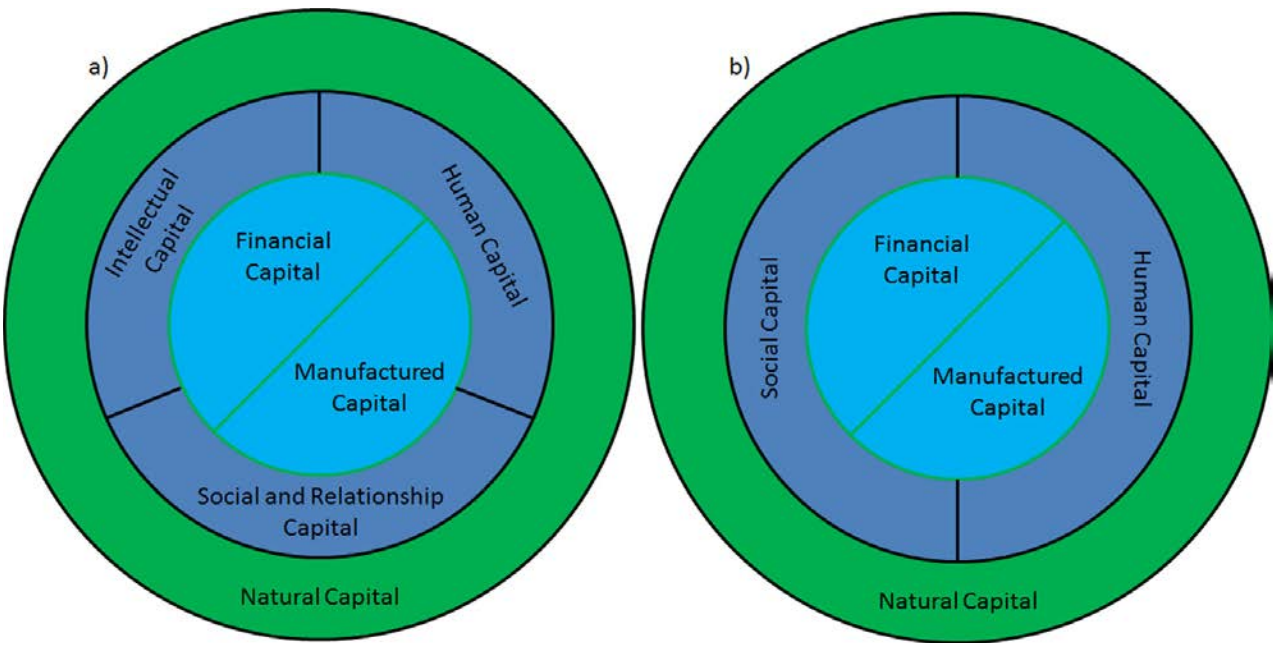

Figure 2.2. The breakdown of human/social capital according to (a) IIRC (2013) and (b) Forum for the Future (2015). Note: Human/social capital is mobile and therefore, may not hold true at catchment scale.

cultural and infrastructural features and functions within a catchment, thereby giving a sense of comfort that no one area is dominating and that the needs of local communities are taken into account". Regardless, consideration of ecosystem services, as one of the three main pillars (i.e. living components) of catchment services, is essential in the overall management of freshwater catchments. Furthermore, use of the ecosystem services framework is an important means of ensuring that the role of ecosystems is prioritised in WFD goals and river basin/catchment planning, management and investment (Daly, 2015a).

2.2 The Use of the Ecosystem Services Framework

Application of the ecosystem services framework can optimise the benefits provided by ecosystems and enable improved environmental accounting and practice in the landscape (e.g. river catchments) (Ormerod, 2014). Fresh waters, in their entirety, deliver an extensive range of ecosystem services (Maltby and Ormerod, 2011) (see Table 2.2 and Appendix 2). The provisioning services include water for drinking and non-drinking purposes (e.g. irrigation, cleaning, industrial use), and provision of food (e.g. fish). Regulating and maintenance services incorporate those that sustain environmental quality both directly (e.g. waste assimilation, pathogen control) and indirectly (e.g. regulation of decomposition, climate and flows) . Regulating and maintenance services regulate water quality and quantity by, for example, removing excess nutrients or moderating water flow (Lautenbach *et al.,* 2012). Climate regulation, through carbon and nitrogen cycling processes, maintains air quality, which influences the greenhouse effect and, as a result, influences climate regulation at both local and global scales (de Groot *et al*., 2002). Cultural services include tangible recreational uses (e.g. kayaking, fishing, walking along a river) and contribute to less tangible benefits such as aesthetic or spiritual benefits and educational value. Tangible uses in Ireland (e.g. extensive recreational freshwater fisheries such as game, pike and coarse angling), depend on less obvious aspects, such as good habitat and good visual appearance (TDI, 2013).

However, it must be highlighted that not all freshwater habitats have the ability to support all processes and functions, or to deliver services and goods equally (Maltby, 1986; Maltby *et al*., 1994; Bullock and Acreman, 2003). The delivery of freshwater ecosystem services and related goods and benefits is highly dependent on their location within the catchment and the service in question (Maltby and Ormerod, 2011). For example, the supply of water in Ireland at present is principally associated with rivers and lakes (71%) and to a lesser extent with groundwater (29%) (Bullock and O'Shea, 2016; and Chapter 7.1). In contrast, wetlands play little or no role in the direct supply of water for consumption in Ireland; however, they do offer a wide range of services, e.g. flood protection (Maltby and Ormerod, 2011).

The distinction between functions, services and benefits is important, especially for economic valuation; however, it is often not possible to make a fully consistent classification, especially for regulating services (TEEB, 2010). Nevertheless, a classification system known as the Common International Classification of Ecosystem Services (CICES) has been adopted by many countries (Haines-Young and Potschin, 2013). This classification is hierarchical in structure so that the categories at each level do not overlap and are not redundant. CICES took the typology of ecosystem services (provisioning, regulating and maintenance, and cultural) suggested in the MEA (2005) as its starting point and refined it to incorporate many of the key criticisms previously discussed in the literature (e.g. Boyd and Branzhaf, 2007; Wallace, 2007, 2008; Constanza, 2008; Fisher *et al*., 2009). At the highest level are the three familiar categories used in the MEA (2005): provisioning, regulating and maintenance, and cultural. Below these major "Sections" are nested a series of "Divisions", "Groups" and "Classes" (see Table 2.2 for more details and examples). The Divisions give the main types of outputs or processes, which are then subdivided into biological, physical or cultural types or processes within the Group division. At Class level, further divisions identify the specific outputs or processes. In this report, this classification has been adopted and modified so that it is appropriate to the Irish context (see Chapter 7).

More detailed information on freshwater ecosystem services is available in Feeley *et al*. (2016a). The range of freshwater resources found in Ireland is outlined in Chapter 3.

Table 2.2. Ecosystem services provided by freshwater ecosystems, based on CICES (version 4.3)

Section	Division	Group	Class	Examples
Provisioning	Nutrition	Biomass	Wild plants and animals and their outputs	Wild fruit/berries, game, freshwater fish (trout, eel, etc.); includes commercial and subsistence fishing and hunting for food
			Plants and animals from *in situ* aquaculture	*In situ* farming of freshwater fish (e.g. trout/salmon) and other products (e.g. cranberry growing)
		Water	Surface water for drinking	Collected precipitation, abstracted surface water from rivers, lakes and other open water bodies for drinking
			Groundwater for drinking	Freshwater abstracted from (non-fossil) groundwater layer or via groundwater desalination for drinking
	Material	Biomass	Fibres and other materials from plants, algae and animals for direct use or processing	Fibres and other products, which are not further processed; chemicals extracted or synthesised from algae, plants and animals; includes consumptive and ornamental uses. Peat/turf for energy use[a]
			Materials from plants, algae and animals for agricultural use	Plant, algae and animal material for fodder and fertiliser in agriculture and aquaculture
			Genetic material from all biota	Genetic material (DNA) from wild plants, algae and animals for biochemical industrial and pharmaceutical processes (e.g. medicines, fermentation, detoxification); bio-prospecting activities (e.g. wild species used in breeding programmes etc.)
		Water	Surface water for non-drinking purposes	Collected precipitation, abstracted surface water from rivers, lakes and other open water bodies for domestic use (washing, cleaning and other non-drinking use), irrigation, livestock consumption, industrial use (consumption and cooling) etc.
			Groundwater for non-drinking purposes	Freshwater abstracted from (non-fossil) groundwater layers or via groundwater desalination for domestic use (washing, cleaning and other non-drinking use), irrigation, livestock consumption, industrial use (consumption and cooling), etc.
Regulation and maintenance	Mediation of waste, toxics and other nuisances	Mediation by biota	Bio-remediation by microorganisms, algae, plants, and animals	Biochemical detoxification/decomposition/mineralisation in freshwater systems including sediments; decomposition/detoxification of waste and toxic materials (e.g. wastewater cleaning)
			Filtration/sequestration/storage/accumulation by microorganisms, algae, plants and animals.	Biological filtration/sequestration/storage/accumulation of pollutants in freshwater biota, adsorption and binding of heavy metals and organic compounds in biota
		Mediation by ecosystems	Filtration/sequestration/storage/accumulation by ecosystems	Bio-physicochemical filtration/sequestration/storage/accumulation of pollutants in freshwater ecosystems, including sediments; adsorption and binding of heavy metals and organic compounds in ecosystems
			Dilution by freshwater ecosystems	Bio-physicochemical dilution of gases, fluid and solid waste, wastewater in lakes, rivers and sediments

Table 2.2. Continued

Section	Division	Group	Class	Examples
Regulating and maintenance	Mediation of flows	Mass flows	Mass stabilisation and control of erosion rates	Erosion/landslide/gravity flow protection; vegetation cover protecting/stabilising terrestrial ecosystems
			Buffering and attenuation of mass flows	Transport and storage of sediment by rivers and lakes
		Liquid flows	Hydrological cycle and water flow maintenance	Capacity of maintaining baseline flows for water supply and discharge (e.g. fostering groundwater, recharge by appropriate land coverage that captures effective rainfall); includes drought and water scarcity aspects
			Flood protection	Flood protection by appropriate land coverage
	Maintenance of physical, chemical and biological conditions	Life cycle maintenance habitat and gene pool protection	Maintaining nursery populations and habitats	Habitats for plant and animal nursery and reproduction (e.g. microstructures of rivers, etc.)
		Pest and disease control	Pest control	Pest and disease control including invasive alien species
			Disease control	Disease control in cultivated and natural ecosystems and human populations
		Water conditions	Chemical condition of freshwaters	Maintenance/buffering of chemical composition of freshwater column and sediment to ensure favourable living conditions for biota (e.g. by denitrification, remobilisation/remineralisation of phosphorus, etc.)
		Atmospheric composition and climate regulation	Global climate regulation by reduction in greenhouse gas concentrations	Global climate regulation by greenhouse gas/carbon sequestration by water columns and sediments and their biota; transport of carbon into oceans (dissolved organic carbon) etc.
			Micro and regional climate regulation	Modifying temperature, humidity, wind fields; maintenance of rural and urban climate and air quality and regional precipitation/temperature patterns
		Energy[b]	Renewables	Various types of energy generated from use of natural water flows and oscillations (e.g. osmotic energy, hydropower)
Cultural	Physical and intellectual interaction with biota, ecosystems and landscapes	Physical	Experiential use of plants, animals and landscapes in different environmental settings	*In situ* wildlife watching
			Physical and experiential interactions	Walking, hiking, boating and leisure fishing (angling)
		Intellectual and representative interactions	Scientific, educational, heritage, cultural, entertainment, aesthetic	Subject matter for research and education both on location and via other media; historic records; cultural heritage (e.g. preserved in water bodies); ex-situ viewing/experience of natural world through different media; sense of place, artistic representations of nature
	Spiritual, symbolic and other interactions with biota, ecosystems, and land-/seascapes (environmental settings)	Spiritual and/or emblematic	Symbolic	Emblematic plants and animals
			Sacred and/or religious	Spiritual, ritual identity (e.g. holy places); sacred plants and animals and their parts
		Other cultural outputs	Existence	Enjoyment provided by wild species, wilderness, ecosystems
			Bequest	Willingness to preserve plants, animals, ecosystems for the experience and use of future generations; moral/ethical perspective or belief

Source: Adapted from CICES. Available online: http://cices.eu/ (accessed 1 July 2016).

[a]Note peat is non-renewable in the short to medium term and therefore it is often not considered an ecosystem service.

[b]Although 'Energy' is included in CICES, the authors consider this a geosystem service (see section 1.1) in freshwaters, not an ecosystem service, as it has no biological element.

3 Freshwater Ecosystem Resources in Ireland

Ireland has a broad range of freshwater resources, from the obvious, such as streams, rivers and lakes, to the more ambiguous, such as turloughs, groundwater and peatlands. The following sections summarise the most up-to-date available information for the various freshwater resources in Ireland, which, in turn, will provide a platform to highlight the broad spectrum of ecosystem services that society derives from them and also the ways in which land management and societal practices may affect their delivery.

3.1 Surface Waters

3.1.1 Lakes

Ireland has over 12,200 lakes (Figure 3.1), predominantly located along western coastal areas, a number that is approximately twice the European average. The majority of lakes are very small: 66% are < 1 ha in area. In contrast, < 2% of Irish lakes (e.g. Lough Corrib and Lough Mask) account for more than 80% of the total lake surface area in the country (Figure 3.2).

The six largest lakes in Ireland are located in just two drainage catchments, the Corrib and Shannon systems (Table 3.1), while large (> 1000 ha) lakes are also common in many western and midland counties (Table 3.1). Some areas of the country have an extensive coverage of lakes (e.g. County Galway; Figure 3.3).

In Ireland, 13 lake types are currently defined, with 12 types identified using alkalinity (surrogate for geology), depth and size. The 13th type was defined to include a number of lakes at altitude > 300 m (Tables 3.2 and 3.3). All 13 types were shown to be biologically distinct based on an analysis of phytoplankton, macrophytes and macroinvertebrates (littoral and profundal) (Kelly-Quinn *et al.*, 2009). The risk assessment of Irish lakes in the first WFD planning cycle for Article 5 included all lakes larger than 0.5 km^2 and lakes less than 0.5 km^2 if they were located in protected areas [e.g. in Special Areas of Conservation (SACs) or if they were used for water abstraction for drinking purposes].

3.1.2 Rivers and streams

Ireland has an extensive river network estimated to be 74,000 km in length (McGarrigle, 2014) (Table 3.4). Interestingly, however, less than 5% of this network is made of up of the large rivers that are synonymous within the Irish landscape (Figure 3.4) and urban centres such as the Liffey in Dublin, the Lee in Cork, the Corrib in Galway and, the largest of them all, the Shannon, which is the longest river in Britain and Ireland.

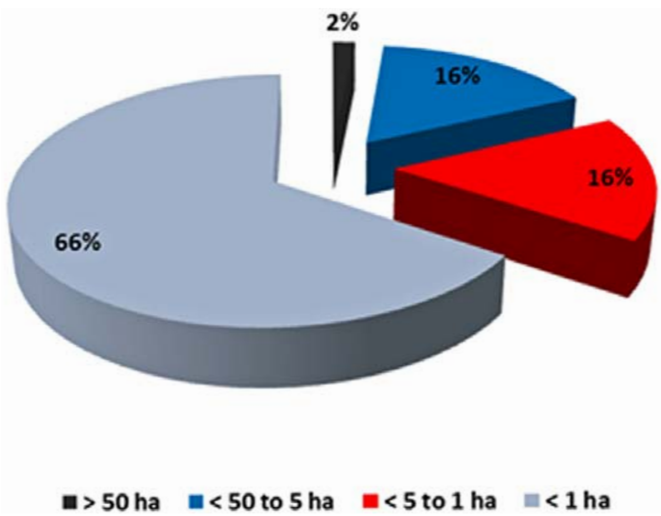

Figure 3.1. Proportional size of lakes in Ireland.

Figure 3.2. The upper lake at Glendalough, Co. Wicklow (photograph: Samuel Kibichii, UCD).

Table 3.1. Fifteen largest lakes in Ireland, by area

Name	Catchment	County	Area (ha)	Area (km²)	Perimeter (km)
Lough Corrib	Corrib	Galway	16,560	165.6	392.2
Lough Derg	Shannon	Clare, Galway, Tipperary	12,510	125.1	257.1
Lough Ree	Shannon	Roscommon, Westmeath, Longford	9980	99.8	192.2
Lough Mask	Corrib	Mayo	7800	78.0	169.4
Lough Conn	Corrib	Mayo	4680	46.8	107.5
Lough Allen	Shannon	Leitrim, Roscommon	3330	33.3	53.1
Lough Melvin	Erne	Leitrim, Fermanagh	2200	22.0	53.8
Lough Leane	Laune	Kerry	1950	19.5	51.4
Lough Sheelin	Inny (Shannon)	Westmeath, Meath, Cavan	1810	18.1	35.6
Lough Carra	Corrib	Mayo	1560	15.6	75.2
Lough Gill	Garavogue	Sligo, Leitrim	1380	13.8	36.0
Lough Arrow	Unshin	Sligo, Roscommon	1240	12.4	40.1
Lough Gara	Boyle (Shannon)	Sligo	1190	11.9	66.2
Lough Ennell	Brosna (Shannon)	Westmeath	1150	11.5	27.3
Lough Gowna	Erne	Longford, Cavan	1150	11.5	80.4

Note: reservoirs not included (see section 3.4).

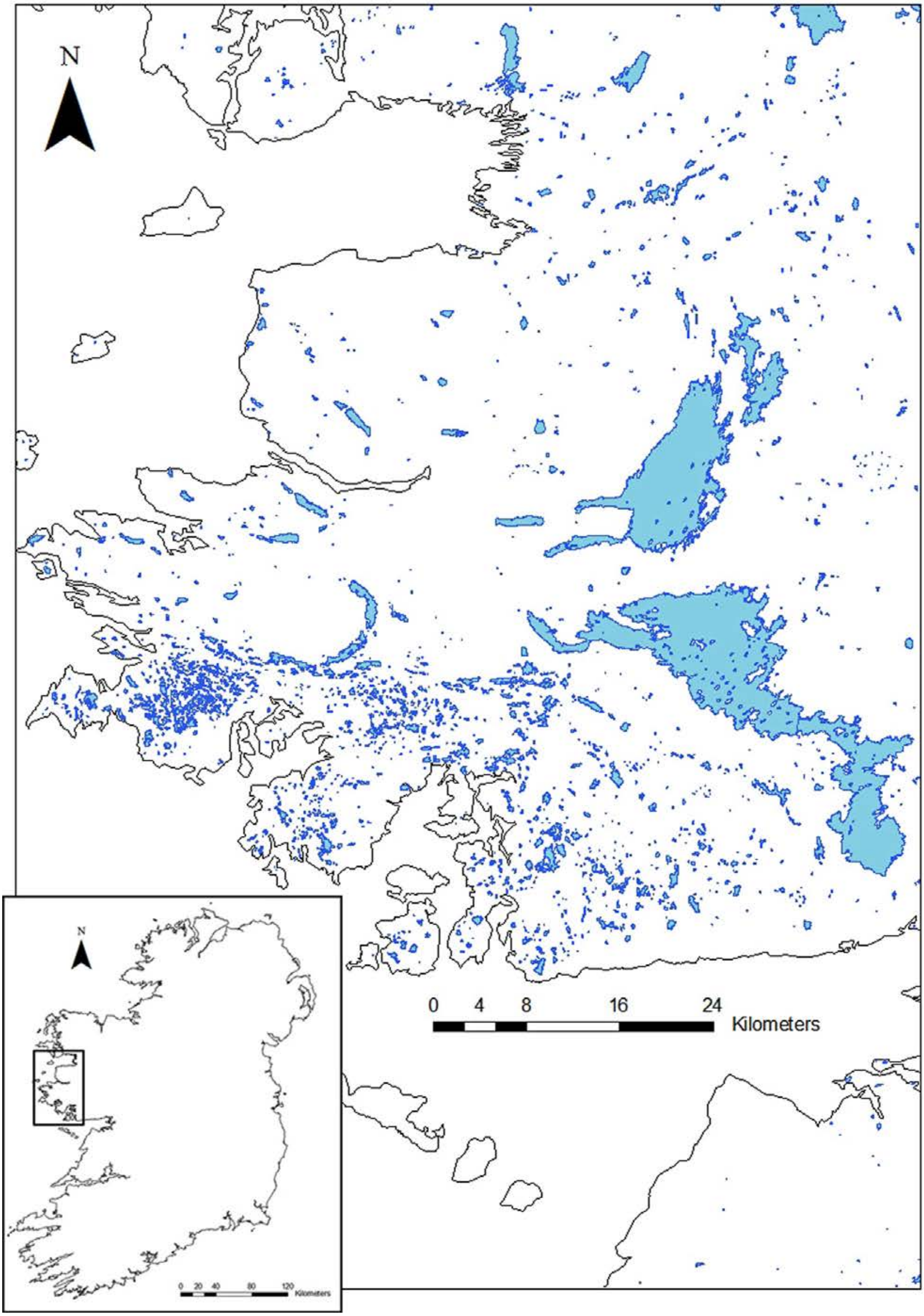

Figure 3.3. The distribution of lakes in the west Galway and south-west Mayo region of Ireland.

Table 3.2. The main descriptors of lake types in Ireland

Descriptor	Level	Concentration/size
Alkalinity	Low	< 20 mg/L $CaCO_3$
	Moderate	20–100 mg/L $CaCO_3$
	High	> 100 mg/L $CaCO_3$
Depth[a]	Shallow	< 4 m (12 m)
	Deep	> 4 m (> 12 m)
Size	Small	< 50 ha
	Large	> 50 ha

Adapted from EPA and RBD co-ordinating authorites (2005).

[a]Mean depth and, in the case of profundal macroinvertebrates, the more relevant maximum depth in parentheses.

$CaCO_3$, calcium carbonate.

Table 3.3. The 13 lake types in Ireland

Type	Alkalinity	Depth	Size
1	Low	Shallow	Small
2	Low	Shallow	Large
3	Low	Deep	Small
4	Low	Deep	Large
5	Moderate	Shallow	Small
6	Moderate	Shallow	Large
7	Moderate	Deep	Small
8	Moderate	Deep	Large
9	High	Shallow	Small
10	High	Shallow	Large
11	High	Deep	Small
12	High	Deep	Large
13	Some lakes > 300 m altitude		

Table 3.4. Breakdown of flowing waters in Ireland

Order[a]	Length (km)	Cumulative length (km)	Total length (%)	Cumulative length (%)
1	38,623	38,623	52.2	52.2
2	18,120	56,743	24.5	76.7
3	9227	65,970	12.5	89.1
4	4909	70,879	6.6	95.8
5	2080	72,959	2.8	98.6
6	973	73,932	1.3	99.9
7	73	74,050	0.1	100.0
Total	74,005		100	

Adapted from McGarrigle (2014).

[a]Based on Strahler stream order classification.

Figure 3.4. Upper River Liffey, Ballyward, Co. Wicklow (photograph: Hugh Feeley, UCD).

The majority (95.8% or >70,000 km) of the river network in Ireland is made up of small streams (first and second order) and small rivers (<5 m wide), which form a hydrological mosaic throughout the island and act as the capillaries of the river network (Table 3.4). As mentioned earlier, the Shannon is the largest catchment in Ireland, making up almost one-fifth of the channel length of all flowing water (Table 3.5, Figure 3.5). Five of the largest river catchments drain the south-east of the country (Figure 3.5).

Rivers and streams are dynamic systems with physicochemical and ecological characteristics that change along the river continuum in response to geology, soil, topography and land use. With respect to the WFD, Irish rivers have been allocated to one of 12 national primary types. The typology is based on geology and its influence on water hardness, and the slope or velocity of water in the channel (Table 3.6). The types are coded according to geology (1–3) and slope (1–4). For instance, a code of 23 indicates mixed geology and a high slope between 2 and 4% gradient, and a code of 31 indicates a calcareous low-slope site. In addition to the basic 12 types of river water bodies, a number of special river types (e.g. highly calcareous, lake outlets) have been treated separately due to their rarity and potentially distinct ecological nature; these are currently the subject of further investigation (Hannigan and Kelly-Quinn, 2016; Hannigan *et al*., 2016; RARETYPE Project, www.ucd.ie/raretype/). The breakdown of the 12 basic Irish river types is outlined in Table 3.7.

River reaches with catchments less than 10 km^2 were not delineated as discrete water bodies. These generally comprised the first-order and some second-order streams in the upper reaches of catchments. However, these river stretches are part of the catchment area of the next downstream river water body and are in this way integrated into the WFD Article 5 characterisation and risk assessment. Coastal streams with catchments less than 10 km^2 were also not delineated.

In terms of habitat management, particularly for fish, O'Grady (2006) assigned the Irish rivers to five of the geomorphological fluvial types described by Rosgen (1996). Channel types B, C and E provide spawning habitat for salmonids, while salmonid angling is general confined to C- and E-type reaches, shown in Figure 3.6 (O'Grady, 2006). A-type channels are considered too steep to be of value to Irish salmonid populations (Figure 3.6). D-type channels, undisturbed estuarine reaches, are not discussed further in this report.

3.2 Groundwater and Hyporheic Zone

3.2.1 Hyporheic zone

The "hyporheic zone" (Figure 3.7) is a three-dimensional and dynamic area that is the interface between surface water and groundwater (Dahm and Valett, 1996), and has been defined hydrologically as

Table 3.5. The top 10 largest river catchments in Ireland

River catchment	Length (km)	Catchment no. in Figure 3.5
Shannon[a]	12,893.7	1
Erne[b]	3717.7	2
Suir	3473.3	3
Blackwater (Munster)	3081.5	4
Corrib	3009.8	5
Moy	2959.6	6
Boyne	2410.7	7
Barrow	2251.5	8
Nore	2228.6	9
Slaney	1839.7	10

[a]Includes Upper and Lower Shannon, Inny and Suck sub-catchments.

[b]Includes area of River Erne catchment in Northern Ireland.

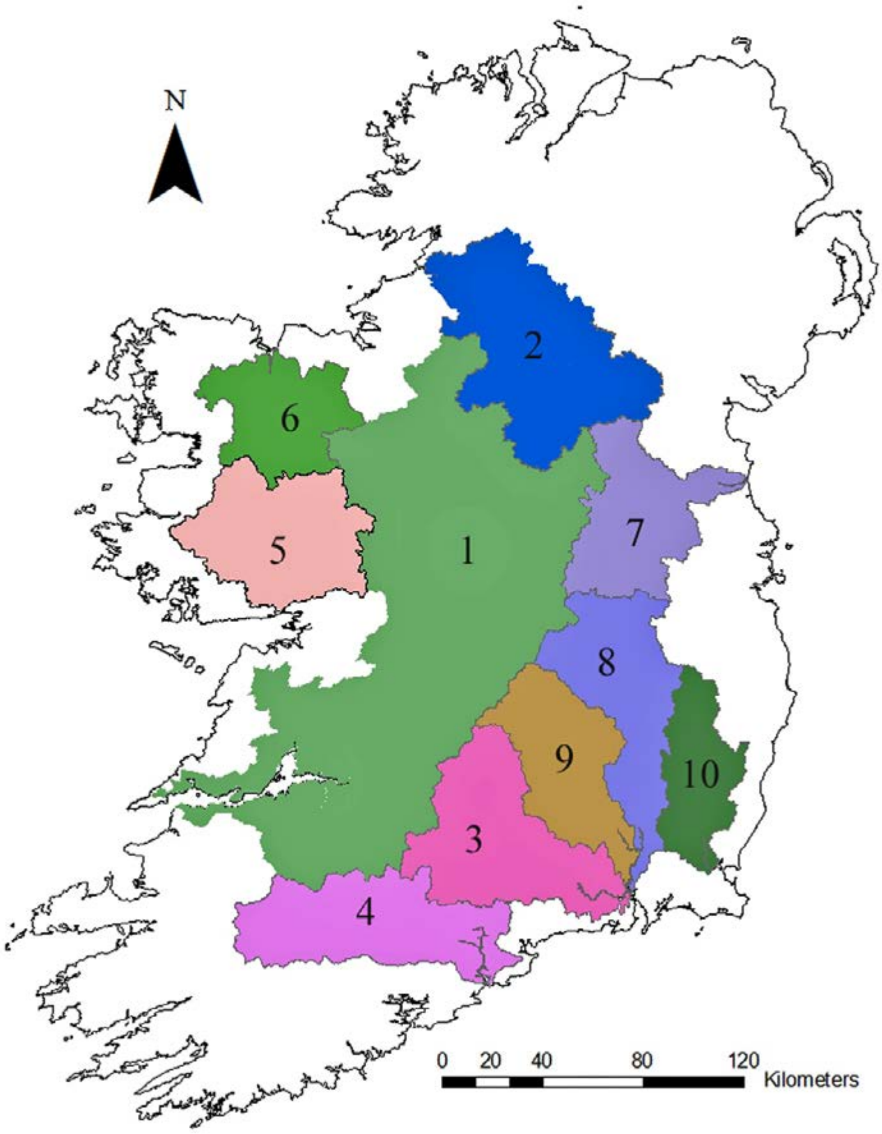

Figure 3.5. Ten largest river catchments in Ireland (includes area of River Erne catchment in Northern Ireland).

Table 3.6. Definition of Irish river types

Code	Catchment geology (% bedrock in upstream catchment by type)	Description	Water chemistry (where data are available)
1	100% Siliceous	Soft water	< 35 mg/L $CaCO_3$
2	1–25% Calcareous (mixed geology)	Medium hardness	35–100 mg/L $CaCO_3$
3	> 25% Calcareous	Hard water	> 100 mg/L $CaCO_3$
Code	**Slope (m/m)**		
1	≤ 0.005	Low slope	–
2	0.005–0.02	Medium slope	–
3	0.02–0.04	High slope	–
4	> 0.04	Very high slope	–

$CaCO_3$, calcium carbonate.

Table 3.7. Breakdown of Irish river water bodies into the 12 principal Irish river water body types by (a) number of water bodies, (b) km of river channel length and (c) percentage of river channel length

			Low slope < 0.005	Medium slope (0.005–0.02)	High slope (0.02–0.04)	Very high slope (> 0.04)	
Geology			1	2	3	4	Water chemistry
Siliceous	1	No.	277	801	361	374	Soft
Siliceous	1	km	1547	2767	849	507	Soft
Siliceous	1	%	7.6	13.5	4.2	2.5	Soft
Mixed	2	No.	152	272	87	58	Medium
Mixed	2	km	1008.26	1271.64	326.18	160.76	Medium
Mixed	2	%	4.93	6.22	1.6	0.79	Medium
Calcareous	3	No.	1247	670	109	58	Hard
Calcareous	3	km	8530	3076	291	113	Hard
Calcareous	3	%	41.7	15.0	1.4	0.6	Hard

Reproduced from EPA and RBD co-ordinating authorities (2005).

"a subsurface flowpath along which water recently from the stream will mix with subsurface water to soon return to the stream" (Harvey and Bencala, 1993). Ecologically the hyporheic zone can be defined as "a spatially fluctuating ecotone between the surface stream and the deep groundwater where important ecological processes and their requirements and products are influenced at a number of scales by water movement, permeability, substrate particle size, resident biota, and the physiochemical features of the overlying stream and adjacent aquifers" (Boulton *et al.*, 1998). Hyporheic waters can be found both beneath the active wetted channel and below the riparian zone of most streams and rivers (Dahm and Valett, 1996; Brunke and Gonser, 1997), as well as below the floodplain of large rivers (Stanford and Ward, 1988). This zone is a mixture of surface water and groundwater (Dahm and Valett, 1996). Therefore, in a broad sense, the hyporheic zone contains elements of both groundwater and surface water. Given Ireland's extensive stream and river network, hyporheic habitats are important but relatively understudied, apart from the work of Kibichii *et al*. (2008, 2009, 2010, 2015).

3.2.2 Groundwater

Ireland has a diverse, complex bedrock and subsoil geology. Consequently, the groundwater flow regime varies from intergranular flow in subsoils to fissure flow in bedrock and karstic (conduit) flow in limestones. This influences not only groundwater abstraction, but also pollutant movement and attenuation, and interaction with surface water. Ireland has extensive groundwater resources in pore spaces and fractures of geologic formations (see Figure 3.8). In contrast to most other European Union (EU) countries, the

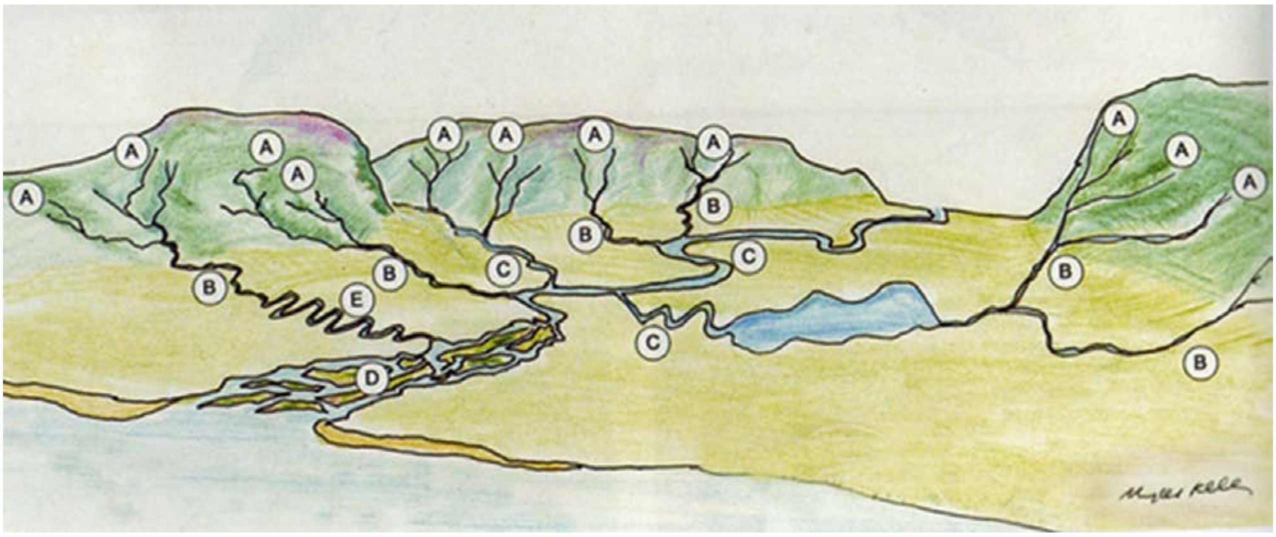

Figure 3.6. Distribution of fluvial hydromorphological zones in a hypothetical Irish catchment. A-type relates to steep channels; B-type channels are high gradient channels with repetitive cascade/pool or riffle/pool sequence (boulder strewn with coarse gravel and cobbles); types C and E are lower gradient channels. C-type channels are considered to be wide, meandering floodplains, while E-type channels are considered to be very sinuous meandering floodplains. D-type channels are undisturbed estuarine reaches. The categories are based on Rosgen (1996). Reproduced from O'Grady (2006).

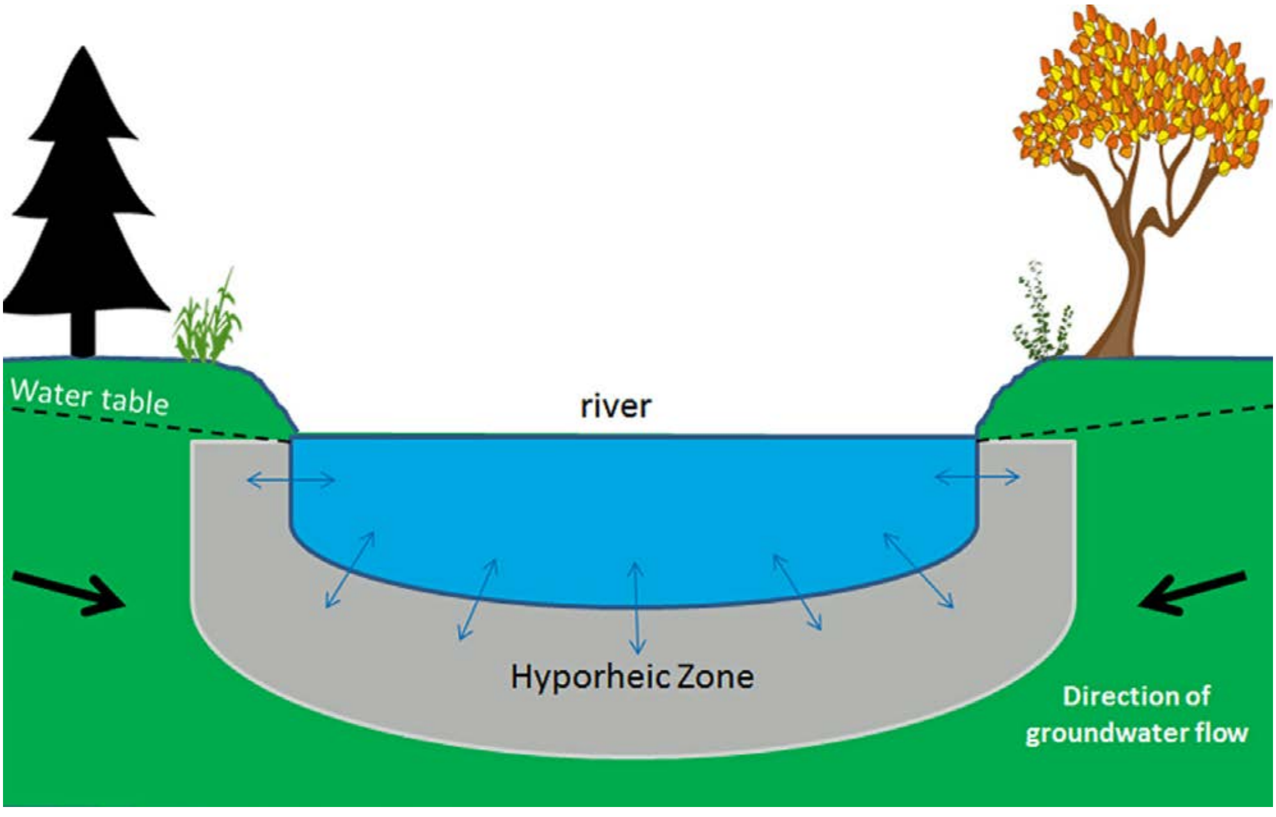

Figure 3.7. A simplified schematic of the hyporheic zones in a river catchment.

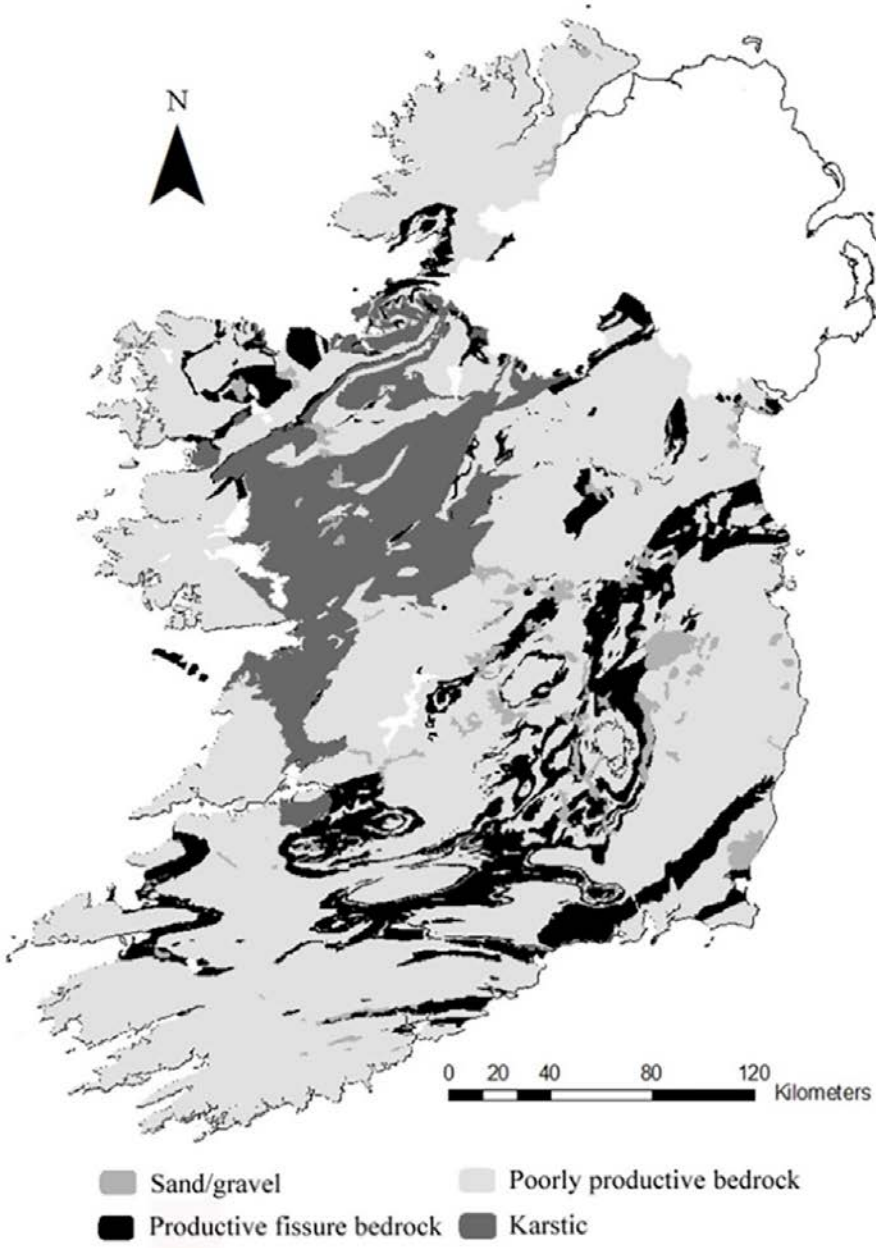

Figure 3.8. Groundwater bodies and flow regime map of Ireland. Northern Ireland not included. Data for map sourced from Geological Survey of Ireland (GSI).

bedrock groundwater or aquifers in Ireland have fissure permeability only. Most of the bedrock aquifers are unconfined. The aquifers have been divided into four groups based on flow regimes, ranging from the low porosity, low transmissivity "poorly fractured" aquifers to the high permeability, long flow path "sand/gravel aquifers" (Figure 3.8). The characteristics of each type are given in Table 3.8. The majority of the "regionally important" aquifers are in karstified limestones, with a high proportion of conduit flow. The sand and gravel aquifers that underlie approximately 2% of the country are the only aquifers with intergranular permeability. These aquifers are usually unconfined and relatively thin, typically between 5 m and 15 m in saturated thickness.

The natural quality of groundwater varies as it flows from recharge areas (e.g. elevated topography) to discharge areas (e.g. springs or rivers). The groundwater chemistry may change as it passes through soils, subsoils or rocks with different mineralogy and is also modified by human activity, whether that is through changes in groundwater flow, caused by groundwater abstraction or by the introduction of anthropogenic substances.

Table 3.8. Groundwater body types in Ireland, subdivided on the basis of flow regime

Body type	Description	Number of water bodies	% of number	Mean (range) groundwater body size (km^2)
Karstified	Generally distinctive karst landforms; drainage largely underground in solutionally enlarged fissures (joints, fractures, bedding planes); variable to high transmissivity; high groundwater velocity; low effective porosity; high degree of interconnection between groundwater and surface water, with sinking streams and large springs; streams often flashy and may be dry in summer; baseflow variable; groundwater level and stream flow hydrographs usually peaky; drainage density low; potentially long groundwater flow paths.	202	26.7	53.0 (0.2–1344.5)
Productive fissured bedrock	Groundwater flow in fissures (joints, fractures, bedding planes); moderate to high transmissivity; low effective porosity; contribute baseflow to streams and maintain dry weather flows; occasional large springs may occur; potentially long groundwater flow paths; confined in places.	109	14.4	45.8 (0.02–681.4)
Sand and gravel	Intergranular flow; high permeability; high effective porosity; tend to be relatively small in area; occasional large springs; contribute substantially to stream baseflow; low drainage density; potentially long flow paths.	70	9.2	17.9 (0.03–126.58)
Poorly productive bedrock	Groundwater flow in fissures; most flow is at shallow depth in the weathered layer at the top of the bedrock; significant flows can occur in widely dispersed deeper fracture zones; low transmissivity; high groundwater gradients; low baseflow contribution to streams; high drainage density; generally short underground flow paths.	376	49.7	142.6 (0.08–1883.7)
Total		757	100.0	

Source: EPA and RBD co-ordinating authorities, 2005.

3.3 Wetlands

Wetlands are diverse and distinctive aquatic habitats that occur in marine, brackish and freshwater biomes. The Ramsar Convention on wetlands, which is the overarching international legislation relating to their protection worldwide, has been adopted in Ireland and defines wetlands as follows:

> Wetlands are natural or artificial areas where biogeochemical functions depend notably on constant or periodic shallow inundation, or saturation, by standing or flowing fresh, brackish or saline water. Marine wetlands occur no more than 6 m below the lowest spring tide level.

or

> Wetlands are a class of heterogeneous but ecologically distinctive habitats characterised by being permanently or periodically inundated with fresh, brackish or saline water or by being saturated by such water at or near the surface of the substrate. Wetlands support characteristic soils, micro-organisms, flora and/or fauna, comprising distinctive ecological communities adapted to such inundation or saturation by surface or ground water. Marine wetlands occur no more than 6 m below the lowest spring tide level.

Three main reviews have attempted to summarise wetland habitats in Ireland; these studies by Reynolds (1998), Fossitt (2000) and Otte (2003) have each defined and categorised freshwater wetlands (see Table 3.9). From this, the following six main categories emerged: wetlands associated with (1) lakes and rivers; (2) marshlands, meadows and wet grasslands; (3) peatlands (bogs and fens); (4) seepages; (5) turloughs; and (6) wet woodlands. Several of the prominent wetland habitats are discussed further in Table 3.9.

3.3.1 Blanket bog and raised bog

Peatlands, which include blanket, Atlantic and raised bogs and fens, cover approximately 16% of the total land area of Ireland (Figure 3.9). Apart from the typical wetland conditions, peatlands may also contain open

Table 3.9. A summary of freshwater wetland habitats found in Ireland as described by Reynolds (1998), Fossitt (2000) and Otte (2003)

Reynolds (1998)	Fossitt (2000)	Otte (2003)
Lakes	Lakes, reservoirs and ponds	Canal, river and lake edges and reed swamps
Rivers	Rivers and canals	–
Marshes	Floodplains and other wet grasslands	Callows, floodplains and freshwater wet meadows
–	Swamps and marshes	–
Peatlands (fens, raised bog, blanket bog)	Peatlands (bogs, wet heath and fens)	Fens and bogs
Springs	Springs and seepages	–
Seepages	–	–
Turloughs	Turloughs	Turloughs
–	Wet woodlands	Wetland woods

Figure 3.9. Various Irish peatlands. Top left: Atlantic blanket bog, Co. Mayo (photograph: Edel Hannigan, UCD); top right: aerial photo of bog pools in an Atlantic blanket bog, Co. Mayo (photograph: Ciara Wögerbauer, Inland Fisheries Ireland); bottom left: mountain blanket bog, Co. Wicklow (photograph: Edel Hannigan, UCD); and bottom right: Clara raised bog, Co. Offaly (photograph: Edel Hannigan, UCD).

water habitats. Blanket bogs are the most extensive of the Irish peatland types and originally covered an area of 774,360 ha. Ireland has two types of blanket bogs: Atlantic blanket bog and mountain blanket bog.

Atlantic blanket bogs are found in low-lying (from sea level to < 200 m) coastal plains and valleys in mountainous areas of western counties, particularly in counties Clare, Donegal, Galway, Kerry, Mayo and Sligo (see Figure 3.10). Here, rainfall is approximately 1200 mm per annum and the acid peat substrate ranges from 2 to 7 m in depth. They are characterised by a grassy appearance due to the occurrence of purple moor grass [*Molinia caerulea* (Linnaeus) Moench] and black bog rush (*Schoenus nigricans* Linnaeus), and often have surfaces patterned with pools, as well as flat and sloped areas, flushes and swallow holes (Figure 3.9).

Mountain blanket bogs occur at relatively higher attitudes (> 200 m) on flat terrain in mountain ranges where rainfall is high and evaporation is low. Their vegetation is characterised by the presence of ericoid shrubs and, in particular, ling heather [*Calluna vulgaris* (Linnaeus) Hull], crowberry (*Empetrum nigrum* Linnaeus) and bilberry (*Vaccinium myrtillus* Linnaeus). Natural drains, lakes, pools and flushes are features of mountain blanket bogs (Figure 3.9)

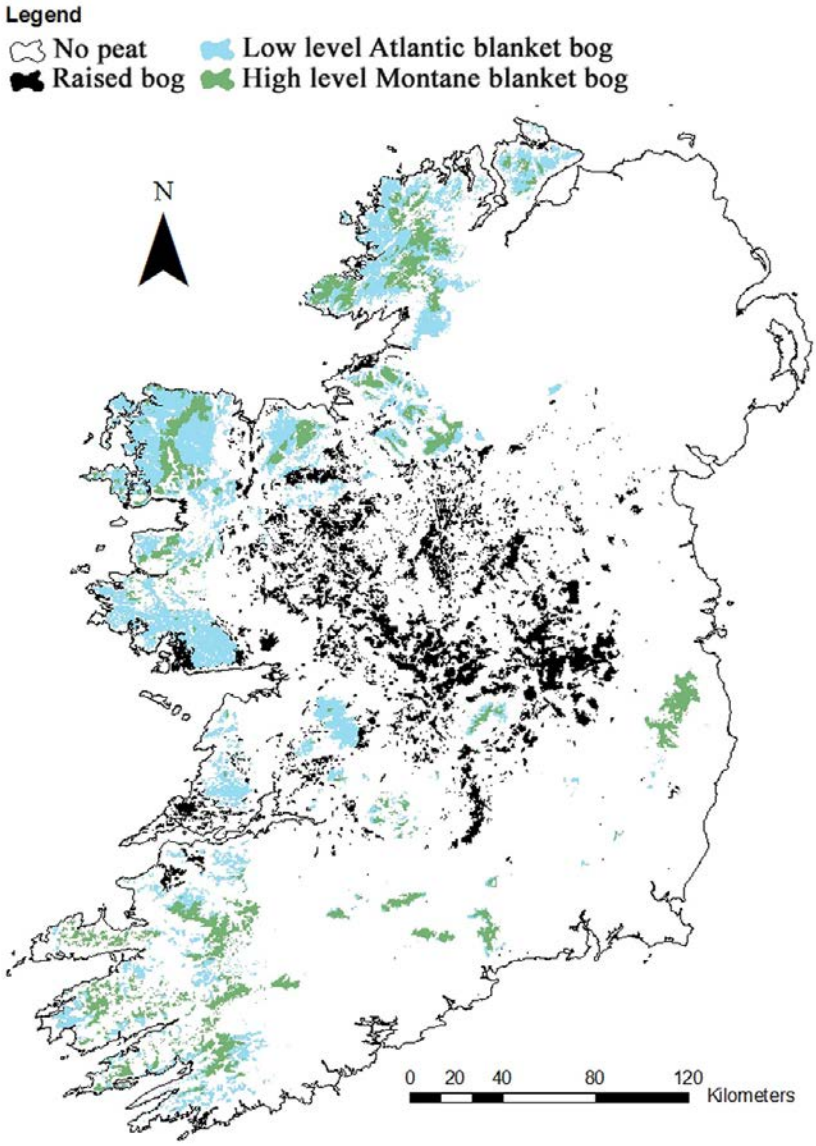

Figure 3.10. Map of Irish peatlands. Data for map taken from Connolly and Holden (2009) and Connolly (2010). Northern Ireland not included.

Raised bogs are discreet, raised, dome-shaped masses of peat occupying former lakes or shallow depressions in the landscape. They occur throughout the midlands of Ireland (Figure 3.10) on land below 130 m and where rainfall is between 800 and 900 mm per annum. Consequently, their principal supply of water and nutrients is from rainfall and the substrate is acid peat soil, which can reach depths of 12 m. Raised bogs are characterised by low-growing, open vegetation dominated by mosses, sedges and heathers, all of which are adapted to waterlogged, acidic and exposed conditions (Figure 3.9).

3.3.2 Fens

A fen is a wetland system with a permanently high water level that is at or just below its surface. Its principal source of nutrients is from surface or groundwater and the substrate is an alkaline to slightly acidic peat soil. The vegetation is usually dominated by sedges. Fens occur throughout the country, but are most common in the west and midlands of Ireland. They tend to occur in limestone regions of Ireland where the water supply is sufficiently rich in minerals (Figure 3.11).

Figure 3.11. Example of a minerotrophic Irish fen habitat at Scragh Fen, Co. Westmeath (photograph: Edel Hannigan, UCD.

3.3.3 Turloughs

Turloughs are karst wetland ecosystems that are almost entirely unique to Ireland (Sheehy Skeffington *et al*., 2006). They are defined as depressions in karst areas, seasonally inundated mostly by groundwater and supporting vegetation and/or soils characteristic of wetlands (GWG, 2004); they usually flood in autumn when rainfall exceeds evapotranspiration, subsequently forming a lake for several months during the winter (Figure 3.12) (Coxon, 1987; Sheehy Skeffington *et al*., 2006). Periodic increases in water level may occur at other times of the year in response to high rainfall (Sheehy Skeffington *et al*., 2006). Although aquatic fauna occur in turloughs, they are not true lakes; this is because most dry up during summer months, revealing fen or grassland vegetation as a result (Figure 3.12). Other studies have described turloughs as ecotones, as they transition between aquatic and terrestrial systems (Reynolds *et al*., 1998). Turloughs are mostly found in the west of the country (Figure 3.13), occurring in areas of thin glacial drift and Carboniferous limestone; they are restricted to areas of grey calcarenite that has a greater degree of karstification than other limestones due to its purity and well-developed bedding (Coxon, 1987).

3.4 Artificial and Heavily Modified Water Bodies

Surface water bodies that have been physically altered by human activity are classified as “heavily modified” whereas water bodies that have been created by human activity (i.e. man-made) are known as “artificial”. Artificial or man-made water bodies in Ireland generally relate to some reservoirs, canals and constructed wetlands. Heavily modified water bodies (HMWB) include most reservoirs and canalised rivers.

Figure 3.12. Various Irish turloughs. Top left: Caranavoodaun, Co. Galway [photograph: Áine O'Connor, National Parks and Wildlife Service (NPWS) Department of Arts, Heritage, Regional, Rural and Gaeltacht Affairs (DAHRRGA)], top right: Keenagh, Co. Roscommon [photograph: Brian Nelson, NPWS (DAHRRGA)], bottom left: a drying Lough Gowra, Co. Sligo [photograph: Áine O'Connor, NPWS (DAHRRGA)]; and bottom right: a dry Lough Gealain in the Burren, Co. Clare [photograph: Áine O'Connor, NPWS (DAHRRGA)].

3.4.1 Reservoirs

There are 15 large and numerous small reservoirs in Ireland, with the majority located in regions surrounding large urban areas. The nine largest reservoirs (see Table 3.10) are located in counties Cork, Dublin, Kildare and Wicklow, and are principally used for hydroelectric power generation, and industrial and domestic water supply. The location of reservoirs in the Dublin region is shown in Figure 3.14.

3.4.2 Canals

Canals are common in Ireland, linking over 1000 km of waterways (Figure 3.15), which includes lakes (e.g. Lough Ree) and canalised rivers (e.g. River Barrow and River Shannon). Most of Ireland's canals were developed for transport in the 18th century in response to industrial development. Some examples of Irish canals are listed in Table 3.11. Canals are instrumental in the movement of freshwater species between water bodies due to their extensive connectivity. See section 4.2 for more details.

3.4.3 Constructed wetlands

Constructed wetlands (Figure 3.16) are fundamentally designed to function as natural wetlands, optimising their water treatment capabilities and providing other functional benefits (Keohane *et al*., 1999). In recent years, Babatunde *et al*. (2008) estimated that there were about 140 constructed wetlands in Ireland (Figure 3.17) and this number has probably increased with time. Constructed wetlands, by virtue of mimicking natural wetlands, have the potential to play a multi-functional role in freshwater landscapes, encompassing water treatment, biodiversity and recreational and educational services (Knight *et al*., 2001; Benyamine *et al*., 2004; Hansson *et al*., 2005; Beccera-Jurado and Kelly-Quinn, 2012). Different

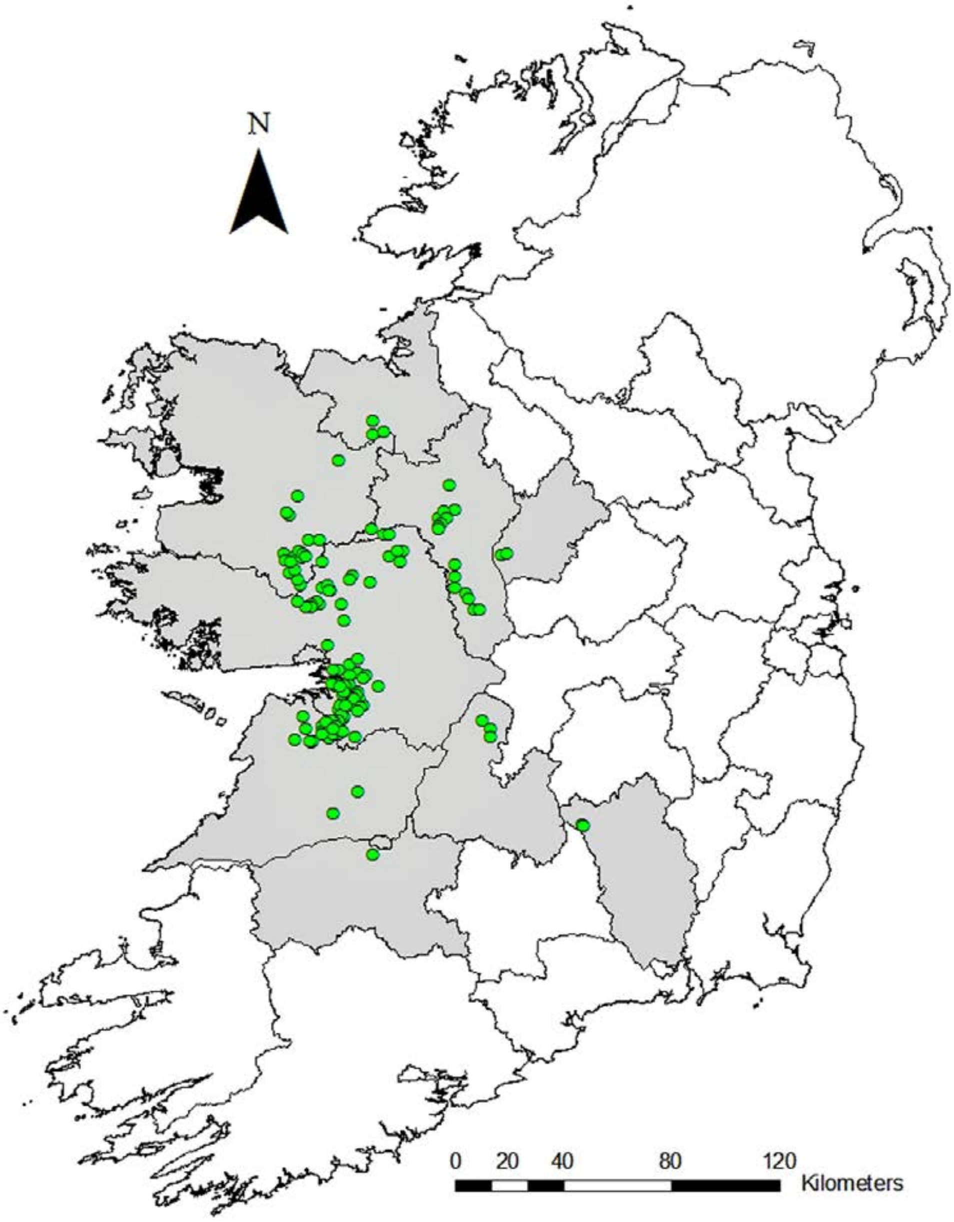

Figure 3.13. The distribution of turloughs in Ireland. Turloughs are indicated by green dots. Administrative counties where turloughs occur are shaded grey. Northern Ireland not included. Data for map taken from Johnston (2007).

Table 3.10. Ten largest reservoirs in Ireland and associated population water supply

Name	Catchment	County	Area (km^2)	Water supply
Pollaphuca Reservoir	Liffey	Wicklow, Kildare	19.5	Dublin
Carrigadrohid Reservoir	Lee	Cork	5.9	Cork
Inniscarra Reservoir	Lee	Cork	4.9	Cork
Vartry Reservoir (Lower)	Vartry	Wicklow	1.6	Dublin
Vartry Reservoir (Upper)	Vartry	Wicklow	1.2	Dublin
Leixlip Reservoir	Liffey	Kildare, Dublin	0.3	Dublin
Glenasmole Reservoirs	Dodder	Dublin	0.2	Dublin
Turlough Hill[a]	n/a	Wicklow	0.1	n/a

[a]Used solely for electricity generation.

n/a, not applicable.

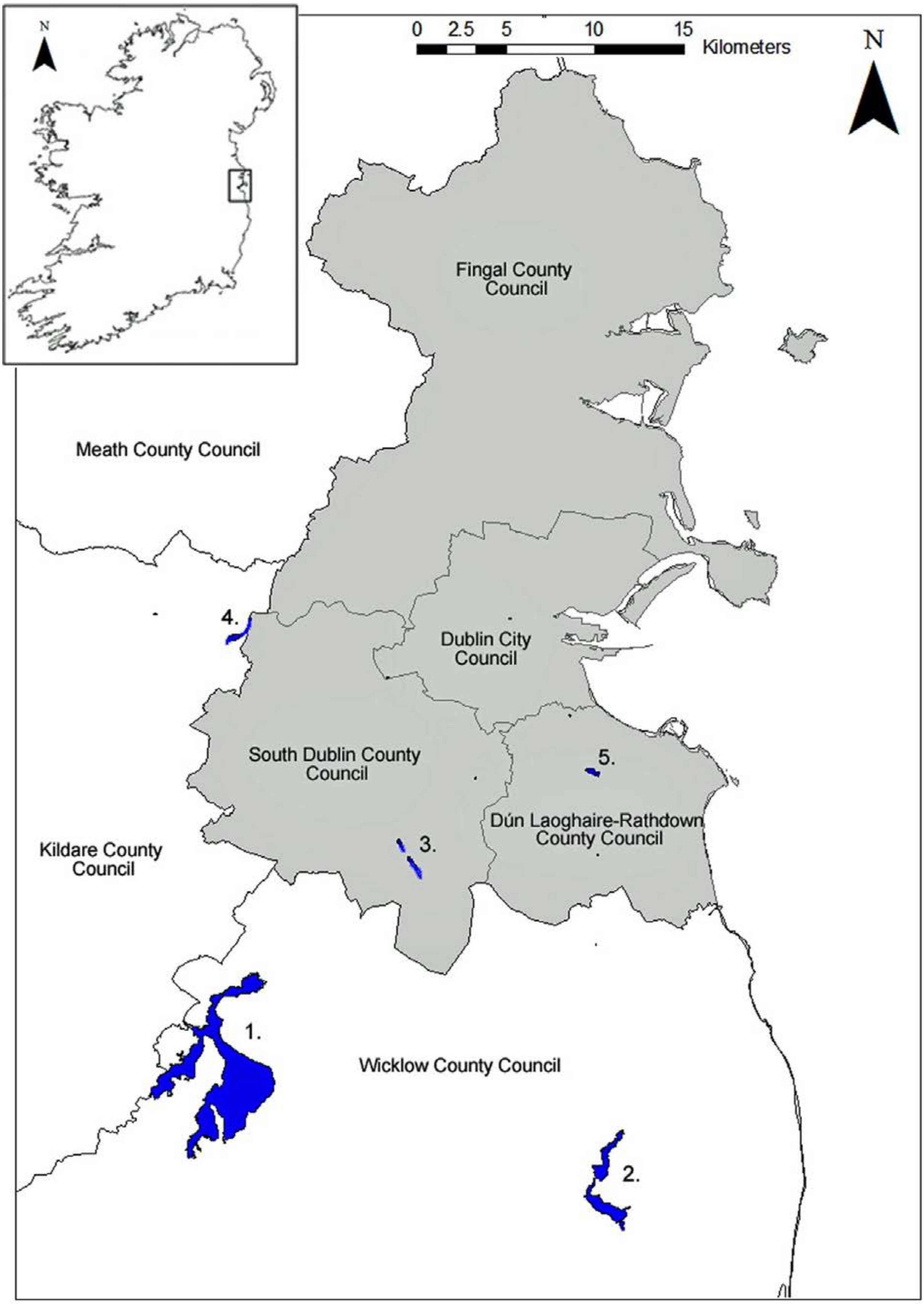

Figure 3.14. Location of major reservoirs (blue) in the Dublin City region: (1) Pollaphuca Reservoir; (2) Vartry Reservoirs (Lower and Upper); (3) Bohernabreena (Glenasmole) Reservoirs; (4) Leixlip Reservoir; (5) Stillorgan Reservoirs. The four major local government areas of Dublin are highlighted in grey.

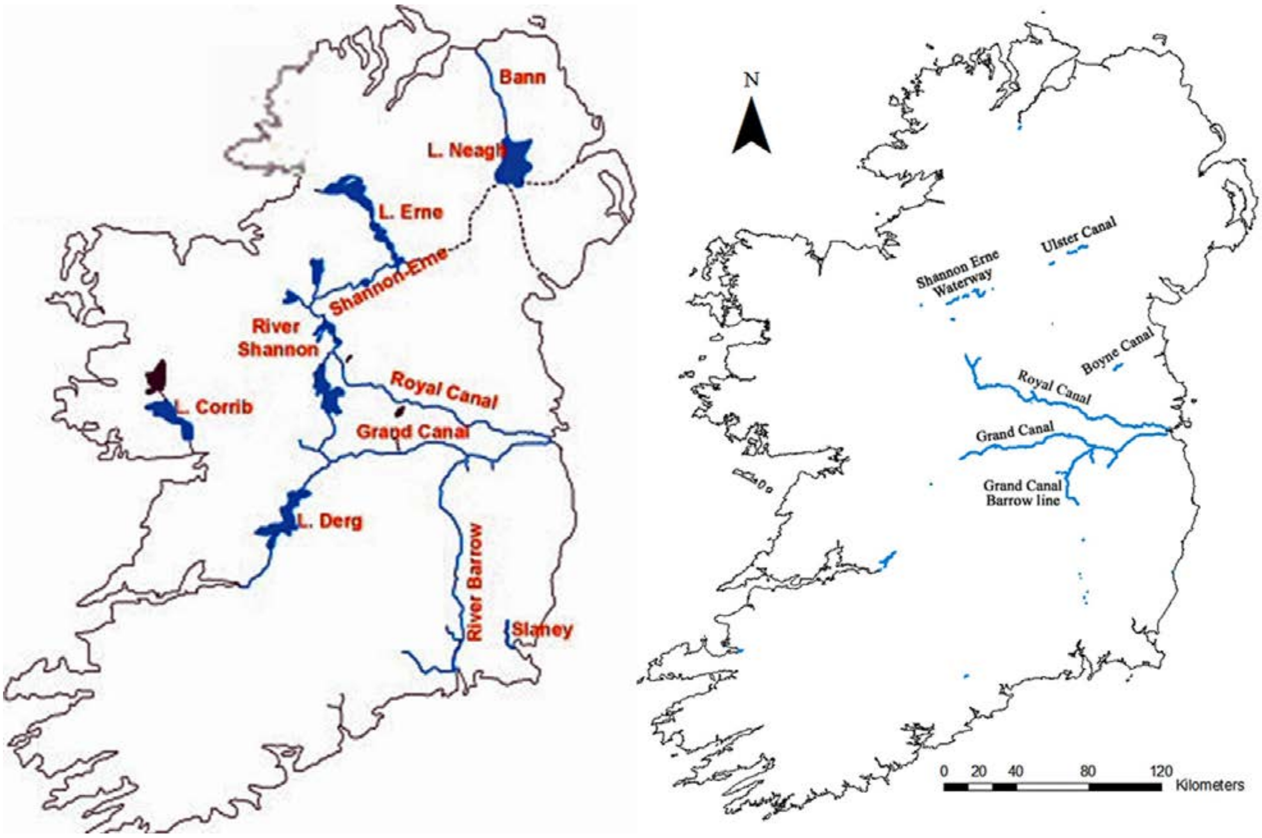

Figure 3.15. Location and names of some major canal and canalised waterways [left: Inland Waterways Association of Ireland (www.iwai.ie; accessed 1 June 2016)] and major artificial Irish canal waterways only (right: data for map from Inland Fisheries Ireland). Northern Ireland not included.

Table 3.11. A selection of canal waterways in Ireland

Name	Description
Grand Canal	144 km connecting Dublin to the Shannon
Royal Canal	146 km connecting the River Liffey in Dublin to the Shannon
Boyne Canal	A series of canals, 31 km, running roughly parallel to the River Boyne from Oldbridge to Navan in County Meath
Shannon–Erne Waterway	63 km linking the River Shannon in the Ireland with the River Erne in Northern Ireland
Barrow Line	45 km linking the Grand Canal to the River Barrow at Athy, Co. Kildare
Ulster Canal	Linking the lowlands around Lough Neagh with the Erne Basin and the River Shannon systems, this waterway is a disused canal running through part of Counties Armagh, Tyrone and Fermanagh in Northern Ireland and County Monaghan in Ireland

types of wetlands are primarily defined on the basis of the movement of the water. In general, they may be free water surface or sub-surface flow systems. Sub-surface flow systems are further divided into those with horizontal and vertical flow. Integrated constructed wetlands are surface-flow systems that comprise a series of interconnected ponds (Figure 3.18) with varying amounts of open water (Beccera-Jurado and Kelly-Quinn, 2012).

3.5 Protected Habitats

The latest list and status of protected habitats and their distribution in Ireland can be found online at http://www.npws.ie/article-17-reports-0/article-17-reports-2013. A list of freshwater habitats included is outlined in Table 3.12.

Figure 3.16. Typical aspect of heavily vegetated constructed wetland ponds where *Lemna minor* Linnaeus thrives in the summer (photograph: Gustavo Becerra-Jurado, UCD).

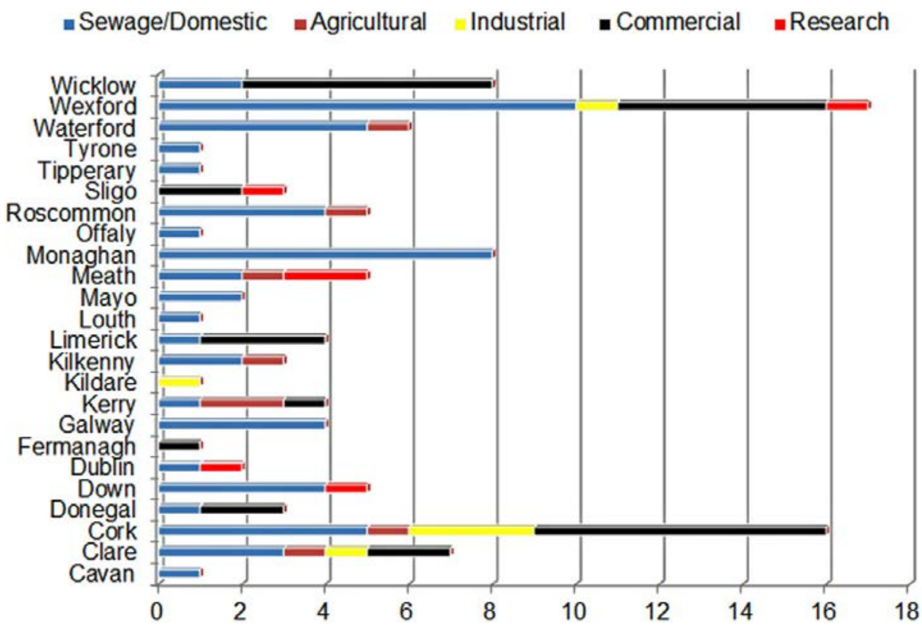

Figure 3.17. Distribution and type of constructed wetlands across Irish counties up to 2008. Adapted from Babatunde *et al*. (2008).

Figure 3.18. Integrated constructed wetland in the Annestown River valley in Co. Waterford showing the four cells (C1 to C4) and the direction (red arrow) of water movement between ponds. The contaminated water enters the first, heavily vegetated, pond (C1) in the system and slowly passes through a number of other ponds (C2, C3 and C4) before being discharged into the Annestown River as purified water, with lowered levels of contamination (photographs: Mary Kelly-Quinn, UCD).

Table 3.12. Protected freshwater habitats in Ireland. Information from NPWS (2013)

Habitat	Brief description
Oligotrophic soft water lakes	Frequently associated with catchments where acid bedrock is overlain by peatland, with soft, nutrient-poor waters
Soft water lakes with base-rich influences	Typically occurs in lowland lakes with circum-neutral waters in catchments on mixed geology. Peatland and acid bedrock is often widespread in these catchments; however, base-rich influences come from basalt, limestone, marble, sedimentary deposits or calcareous coastal sand
Hard water lakes	Strongly associated with lowland lakes over limestone bedrock
Natural eutrophic lakes	Associated with lowland, circum-neutral to base-rich lakes in naturally more productive catchments
Dystrophic lakes	Mainly associated with areas of Atlantic and upland blanket bog, and wet heath
Turloughs	Entirely restricted to well-bedded, relatively-pure karstified Carboniferous limestone
Floating river vegetation	Covers river habitats as diverse as upland, flashy, oligotrophic, bryophyte- and algal-dominated stretches, to tidal reaches dominated by higher plants
Chenopodium rubri	Primarily found in riverine turloughs, in areas where flood water recedes relatively late and that are prone to summer flooding. This dynamic habitat is found on damp, fine, mineral soils (usually alluvial muds)
Wet heath	Generally occurring on gently sloping, poorly-draining ground on shallow or intermediate peat depths (typically 30–80 cm deep)
Raised bog (active)	Accumulations of deep acid peat (3–12 m) that originated in shallow lake basins or topographic depressions. They have a typical elevated surface or dome, which develops as raised bogs grow upwards from the surface. The bog dome is primarily rainwater fed and isolated from the local groundwater table
Degraded raised bogs	Characterised by the complete absence (or a patchy thin cover) of an acrotelm layer, which is defined as the living, actively growing upper layer of a raised bog. The presence of the acrotelm is vital to a raised bog as this is the peat-forming layer and water-storing layer of the bog. The definition of the habitat (still capable of regeneration), indicates that the habitat can be restored to active raised bog habitat
Blanket bog (active)	Occur in areas of consistently high rainfall where the ground surface is waterlogged for much of the time resulting in the development of deep peats. They may be broadly divided into upland and lowland communities. The peat is typically more than 50 cm deep and often 1–2 m deep in the uplands and up to 7 m deep in the lowlands. Blanket bogs generally occur on level ground or gentle slopes, although upland blanket bog can occasionally occur on steeper ground
Transition mires	Also known as quaking bogs and are characterised by a broad range of physically unstable peat-forming vegetation communities floating on surface water
Rhynchosporion depressions	Occur on blanket bogs and raised bogs, both active and degraded. They occur on wet peat on the margins of pools and hollows and a species poor variant occurs as a pioneer community in areas of disturbance such as peat-cuttings
Cladium fen	Occur in a variety of situations including fens found in valleys or depressions, floodplains, overgrown ditches, extensive wet meadows, within tall reed beds, on the landward side of lakeshore communities, calcium rich flush areas in blanket bogs, dune slack areas, fens adjacent to raised and blanket bogs, in turloughs, wet hollows in machair and often in association with alkaline fen
Petrifying springs	Defined as springs and seepages where tufa is actively deposited and where characteristic species of bryophytes are dominant or abundant
Alkaline fens	Typically calcareous basin or flush fen systems with extensive areas of species-rich small sedge communities

4 Irish Freshwater Biological Resources

In recent decades, Purcell (1996) and Ferriss *et al*. (2009) listed the fauna of Ireland, which included most of the freshwater taxonomic orders and groups. These and other sources have been used to compile a list of biota found in, or associated with, Ireland's freshwater (Table 4.1), which includes algae, macrophytes, micro- and macroinvertebrates, fish and other vertebrates with links to freshwater habitats, such as amphibians, mammals and birds.

4.1 Freshwater Invertebrates in Ireland

Ireland has a depauperate freshwater invertebrate fauna compared with Britain and mainland Europe (King and Halbert, 1910; Fahy, 1976; McCarthy, 1986; Murray and O'Connor, 1992). This is mainly owing to the island's isolation and glacial history. There are approximately 2400 known species, which, depending on the taxonomic group, represents between 60% and 80% of the species that occur in Britain. Most species have a patchy distribution and, in terms of riverine species, almost half of macroinvertebrate species occur at less than 5% of sites. Despite this, some groups are relatively diverse, especially the Crustacea and the Insecta. For example, Diptera, has around 40%, and possibly more, of known invertebrates in Irish waters (Table 4.1 and Figure 4.1) and 540 species-level taxa of Chironomidae are currently known for Ireland [Declan Murray, UCD (retired), 7 September 2016, personal communication; see also Murray *et al*. (2013, 2014, 2015)]. However, other taxa that are not usually considered freshwater inhabitants in Ireland, such as Cnidaria (Figure 4.1) and Porifera, can occur in many water bodies. Similarly, at least two Araneidae, the diving bell spider [*Argyroneta aquatica* (Clerck)] and raft spider [*Dolomedes fimbriatus* (Clerck)], have been recorded in Irish freshwaters. See Table 4.1 for more details.

As will be discussed later, many species are heavily impacted by pollution. Red listing has been completed for the Odonata (damselflies and dragonflies) (Nelson *et al*., 2011), Ephemeroptera (mayflies) (Kelly-Quinn and Regan, 2012), aquatic Coleoptera (water beetles), amphibians, reptiles and freshwater fish (King *et al*. 2011), and non-marine molluscs (Byrne *et al*., 2009). The red listing highlights which threatened freshwater species are impacted by (1) poor water quality, such as the pearl mussel (*Margaritifera margaritifera* Linnaeus; see 4.1.2 for more details) and the false orb pea mussel (*Psidium pseudosphaerium* Favre), (2) by drainage [e.g. *Vertigo antivertigo* (Draparnaud)], and (3) by non-native invasive species [e.g. *Anodonta cygnea* (Linnaeus) and *A. anatina* (Linnaeus); the swan and duck mussels are impacted by the invasive zebra mussel, *Dreissena polymorpha* (Pallas)]. More recently, Feeley *et al*. (2016b) published the distribution of Plecoptera (stonefly) in Irish freshwaters and O'Connor (2015) published information on Ireland's 149 species of Trichoptera (caddisfly).

Table 4.1. The biological resources of Irish freshwaters where information is available

Group/division/phylum	Group/subphylum	Group/class/subclass	Group/order	No.	Reference (if available)
Heterokontophyta	Bacillariophyta	Bacillariophyceae	Various[a]	959	www.algaebase.org (accessed 20 May 2016)
Charophyta	(Green algae)	Charophyceae	Charales	17	www.algaebase.org (accessed 20 May 2016)
Chlorophyta	(Green algae)	Chlorophyceae	Chlamydomonadales	6	www.algaebase.org (accessed 20 May 2016)
			Sphaeropleales	5	www.algaebase.org (accessed 20 May 2016)
		Trebouxiophyceae	Trebouxiales	1	www.algaebase.org (accessed 20 May 2016)
			Chlorellales	1	www.algaebase.org (accessed 20 May 2016)
		Ulvophyceae	Ulotrichales	1	www.algaebase.org (accessed 20 May 2016)
Cyanobacteria	–	Cyanophyceae	Chroococcales	3	www.algaebase.org (accessed 20 May 2016)
			Oscillatoriales	6	www.algaebase.org (accessed 20 May 2016)
			Nostocales	2	www.algaebase.org (accessed 20 May 2016)
Ochrophyta	-	Synurophyceae	Synurales	18	www.algaebase.org (accessed 20 May 2016)
		Xanthophyceae	Vaucheriales	6	www.algaebase.org (accessed 20 May 2016)
Rhodophyta	(Red algae)	Bangiophyceae	Bangiales	1	www.algaebase.org (accessed 20 May 2016)
		Florideophyceae	Balbianiales	1	www.algaebase.org (accessed 20 May 2016)
			Batrachosperrmales	9	www.algaebase.org (accessed 20 May 2016)
			Thoreales	1	www.algaebase.org (accessed 20 May 2016)
Other macrophytes	–	Vascular plants	Various[a]	212[b]	Preston (1995); Preston and Croft (2001); Lansdown (2008)
	–	Bryophytes	Liverworts	32[c]	Smith (2004); Hill *et al.* (2007); Atherton *et al.* (2010)
			Mosses	86	Smith (2004); Hill *et al.* (2007); Atherton *et al.* (2010)
Rotifera		Eurotatoria	Bdelloidea	72	Horkan (1981); Ferriss *et al.* (2009)
			Ploima	195	Horkan (1981); Ferriss *et al.* (2009)
			Flosculariaceae	29	Horkan (1981); Ferriss *et al.* (2009)
			Collothecaceae	10	Horkan (1981); Ferriss *et al.* (2009)
Bryzoa	–	Gymnolaemata	Ctenostomatida	1	Smyth (1994); Ferriss *et al.* (2009)
	–	Phylactolaemata	Plumatellida	8	Smyth (1994); Ferriss *et al.* (2009)
Porifera	–	Demospongiae	Spongillidae	5	Stephens (1920); Lucey and Cocchiglia (2014)
Tardigrada		Eutardigrada	Various[a]	35[d]	DeMilio *et al.* (2016)
Cnidaria	–	Hydrozoa	Limnomedusae	1	Inland Fisheries Ireland (2013)
Gastrotricha	–		Chaetonotida	3	d'Hondt (1978); Hansson (1997); Ferriss *et al.* (2009)
Nematomorpha	–	Chordodea	Chordodidae	2	Ferriss *et al.* (2009)
	–	Gordea	Gordiidae	1	Ferriss *et al.* (2009)
Platyhelminthes	–	Turbellaria	Various[a]	26	Southern (1936)

Table 4.1. Continued

Group/division/phylum	Group/subphylum	Group/class/subclass	Group/order	No.	Reference (if available)
Annelida	–	Oligochaeta	Lumbriculidae	3	Trodd *et al.* (2005)
	–		Tubificidae	32	Trodd *et al.* (2005)
	–		Naididae	17	Trodd *et al.* (2005)
	–		Enchytraeidae	23	Trodd *et al.* (2005)
	–		Other Oligochaeta	3	Trodd *et al.* (2005)
	–	Hirudinea	Rhynchobdellida	8	McCarthy (1975); Elliott and Dobson (2015)
			Arhynchobdellida	7	McCarthy (1975); Elliott and Dobson (2015)
Mollusca	–	Gastropoda	Various[a]	33	Byrne *et al.* (2009)
	–	Bivalvia	Various[a]	20	Byrne *et al.* (2009)
Arthropoda	Chelicerata	Arachnida	Araneidae	2	Nolan (2016)
			Hydrachnellae	120	Halbert (1944); Holmes and O'Connor (1990)
	Crustacea[e]	Branchiopoda	Anostraca	1	Thompson (1843, 1844); Huxley (1880); Kane (1903; 1904); Scourfield (1912); Gurney (1932); Grainger (1966, 1979); Moriarty (1973); Hazelton (1974); Holmes (1975, 1998, 2001, 2007); Young (1975); Reynolds (1982, 1985); Ali *et al.* (1987); Duigan (1987, 1988, 1990, 1992); Duigan and Frey (1987); Costello *et al.* (1989); Grainger and Holmes (1989); Holmes and Gotto (1992, 2000); Holmes and O'Connor (1990); Duigan and Kovach (1991); Douglas and McCall (1992); Costello (1993); Karaman *et al.* (1994); de Eyto *et al.* (2001); McLoughlin and Reynolds (2001); Lucy *et al.* (2004); Reynolds *et al.* (2004); Kotov and Stifter (2005); Minchin (2006); Arnscheidt *et al.* (2008, 2012); Hanfling *et al.* (2008); McGavigan (2008); Kibichii *et al.* (2010); Knight and Gledhill (2010); Knight and Penk (2010); Penk (2011)
			Diplostraca	72	
		Malacostraca	Decapoda	2	
			Isopoda	3	
			Amphipoda	13	
		Maxillopoda (Branchiura)	Arguloida	1	
		Maxillopoda (Copepoda)	Calanoida	7	
			Cyclopoida	36	
			Siphonosomatoidea	3	
			Harpacticoida	26	
		Maxillopoda (Ostracoda)	Podocopa	61	
	Hexapoda	Insecta	Coleoptera	244	Foster *et al.* (2009)
			Collembola	17	Ashe *et al.* (1998)
			Diptera	3397	Ashe *et al.* (1998); Chandler (1998, 2015); Murray *et al.* (2013, 2014, 2015)
			Ephemeroptera	33	Kelly-Quinn and Bracken (2000)
			Hemiptera	52v	Ashe *et al.* (1998); O'Connor and Nelson (2012)
			Hymenoptera	17	Ashe *et al.* (1998); O'Connor *et al.* (2009)
			Lepidoptera	5	Bond (1995); Bond and Gittings (2008)
			Megaloptera	2	Ashe *et al.* (1998)
			Neuroptera	4	Barnard *et al.* (1991); Ashe *et al.* (1998)
			Odonata	27[f]	Nelson *et al.* (2011)
			Plecoptera	19	Feeley *et al.* (2016b)
			Trichoptera	149	O'Connor (2015)

Table 4.1. Continued

Group/division/phylum	Group/subphylum	Group/class/subclass	Group/order	No.	Reference (if available)
Chordata	(Amphibians)	Amphibia	Anura	2	King *et al.* (2011)
			Caudata	1	King *et al.* (2011)
	(Lamprey)	Hyperoartia	Petromyzontiformes	3	King *et al.* (2011)
	(Fish)[g]	Actinopterygii	Acipenseriformes	1	King *et al.* (2011)
			Anguilliformes	1	King *et al.* (2011)
			Clupeiformes	4	King *et al.* (2011)
			Cypriniformes	9	King *et al.* (2011)
			Esociformes	1	King *et al.* (2011)
			Gasterosteiformes	2	King *et al.* (2011)
			Osmeriformes	1	King *et al.* (2011)
			Perciformes	1	King *et al.* (2011)
			Pleuronectiformes	1	King *et al.* (2011)
			Salmoniformes	5	King *et al.* (2011)
	(Bird)	Aves	Various[a]	60[h]	Birdwatch Ireland (2011); Wilson and Carmody (2011, 2013)
	(Mammals)	Mammalia	Carnivora	2	Marnell *et al.* (2009)

Note the authors have attempted to include all groups; however the information in this table may be incomplete due to the difficulty locating up-to-date data. Estuaries and brackish waters not included.

[a]Too many orders to list – see related references for more information.

[b]Based on ≥9 Ellenberg value for moisture (Hill *et al.* 2004).

[c]Based on >9 Ellenberg value for moisture (Hill *et al.* 2007).

[d]May contain marine species.

[e]References pooled.

[f]Resident (non-migratory) species.

[g]See Table 4.3 for a list of native and non-native fish.

[h]Birds known to inhabit rivers, lakes, pools, reservoirs, fens, marshes, turloughs and bogland.

Figure 4.1. Various invertebrates found in Irish freshwater ecosystems. Top left: a zooplankton *Chydorus sphaericus* (Müller) found in Irish lakes (photograph: Elvira de Eyto, Marine Institute); top middle: the jellyfish, or medusa stage of *Craspedacusta sowerbii* Lankester, an invasive freshwater jellyfish found in Lough Derg [photograph: © Inland Fisheries Ireland (http://www.fisheriesireland.ie/Press-releases/freshwater-jellyfish-in-lough-derg-surely-not.html, accessed 1 June 2016)]; top right: a group of simuliid (Diptera) larvae on vegetation, a common taxon in Irish rivers (photograph: Jan Robert Baars, UCD); middle left: a mayfly (Ephemeroptera) nymph *Ecdyonurus venosus* Fabricius (photograph: Siobhan Atkinson, UCD); middle right: the caddisfly (Trichoptera) larvae, *Rhyacophila dorsalis* (Curtis); bottom left: an adult male damselfly (Odonata), the beautiful demoiselle [*Calopteryx virgo* (Linnaeus)] (photographs: Jan Robert Baars, UCD); bottom right: an adult male stonefly (Plecoptera), *Perla bipunctata* Pictet, recently emerged from the upper River Liffey, Co, Wicklow (photograph: Siobhan Atkinson, UCD).

4.1.1 Groundwater and hyporheic fauna

As noted by Arnscheidt *et al*. (2012), the ecosystem nature of groundwaters is poorly researched. The same report documented the crustacean fauna of Irish groundwaters and some hyporheic sites in Ireland (Table 4.2). Kibichii *et al*. (2008, 2009) also carried out studies on hyporheic fauna of the Delour River, Co. Laois. Four spatial assemblages were identified. First, a “shallow substream” assemblage, dominated by insect larvae and nymphs with a few microcrustacean species, was found in the upper 0.2 m below the wetted channel. Second, an “ecotonal” assemblage, dominated by microcrustacean species, was found in the hyporheic habitat 0.2 m below exposed gravels of the parafluvial zone. Third, a “deep substream” assemblage with a taxonomic composition showing a mixture of the above two

Table 4.2. Crustacean taxa recorded from groundwaters by Arnscheidt *et al*. (2012)

Taxa	Family	Species
Amphipoda	Asellidae	*Asellus aquaticus* Linnaeus, 1758
		Proasellus meridianus (Racovitza, 1919)
	Gammaridae	*Gammarus duebeni celticus* Stock and Pinster, 1970
		Gammarus lacustris[a] Sars, 1863
		Gammarus pulex Linnaeus, 1758
	Niphargidae	*Microniphargus leruthi* Schellenberg, 1934
		Niphargus kochianus irlandicus Schellenberg, 1932
		Niphargus wexfordensis Karaman, Gledhill and Holmes, 1994
Copepoda (cyclopoid)	Cyclopidae	*Acanthocyclops robustus* (Sars, 1863)
		Acanthocyclops venustus (Norman and Scott, 1906)
		Acanthocyclops vernalis (Fischer, 1853)
		Cyclops furcifer Claus, 1857
		Cyclops strenuus (laevis) Fischer, 1853
		Cyclops sp.
		Diacyclops bicuspidatus s.str. (Claus, 1857)
		Diacyclops bisetosus (Rehberg, 1880)
		Diacyclops languidus (Sars, 1863)
		Eucyclops serrulatus (Fischer, 1853)
		Megacyclops latipes group
		Megacyclops viridis (Jurine, 1820)
		Microcyclops sp.
		Paracyclops affinis (Sars, 1863)
		Paracyclops fimbriatus (Fischer, 1853)
		Paracyclops sp.
Copepoda	Parastenocarididae	*Parastenocaris vicesima* Klie, 1935
(harpacticoid)	Phyllognathopodidae	*Bryocamptus pygmaeus* (Sars, 1863)
		Moraria nov. sp.
Ostracoda	Candonidae	*Candona candida* (Müller, 1776)
		Cyclocypris globosa Sars, 1863
		Cyclocypris serena (Koch, 1867)
		Fabaeformiscandona breuili (Paris, 1920)
	Cyprididae	*Herpetocypris* chevreuxi (Sars, 1896)
		Potamocypris sp.
		Potamocypris villosa (Jurine, 1820)
	Darwinulidae	*Darwinula stevensoni* (Brady and Robertson, 1870)

[a]Hyporheic survey only.

assemblages was found at 0.5 m below the sub-stream zone. Finally, a “marginal” assemblage, characterised by the presence of true groundwater specialists *Niphargus kochianus irlandicus* Schellenberg (Figure 4.2) and *Parastenocaris* sp., was found at 0.5 m of the parafluvial zone and both depths of the terrestrial margins beyond the highest water level. The exact locations of these assemblages varied seasonally, with the groundwater specialists moving closer to the stream in summer when the surface water was dominated by groundwater seepage. These assemblages represent a transition from the surface-water-affiliated insect taxa to groundwater-affiliated taxa. Overall, a total of 86 taxa were recorded; this included 50 insect taxa (most common in river habitats of rivers), 18 crustaceans and 18 other taxa including molluscs, oligochaetes, nematodes, mites and leeches, in addition to low occurrences of hydrozoans, tardigrades, gastrotriches and rotifers. Kibichii *et al*. (2015) found that total invertebrate

Figure 4.2. The endemic specialist *Niphargus kochianus irlandicus* found in Irish groundwaters (photographs: Marcin Penk, TCD).

densities and richness, crustacean densities and richness, and densities of Ephemeroptera, Plecoptera and Trichoptera (EPT) were significantly reduced in polluted hyporheic and parafluvial habitats. Boulton *et al*. (2008) reported that subterranean invertebrate biodiversity probably sustains high levels of valuable ecosystem services, such as water purification, bioremediation and water infiltration and transport.

4.1.2 Freshwater pearl mussel

The freshwater pearl mussel (*M. margaritifera*; Figure 4.3) is found in many clean, low-nutrient, fast-flowing, well-oxygenated rivers throughout the country and occurs in more than 160 rivers and a handful of associated lakes (e.g. Byrne *et al*., 2009). A hard-water form of the freshwater pearl mussel [*M. durrovensis* (Phillips); Figure 4.3] is endemic to Ireland, but is now only found in the main channel of the River Nore. Clean gravel and sand are essential to a healthy population of both pearl mussel species in Ireland. Moorkens (2006) reported that within the remaining Irish populations only a handful are recruiting young and at least 90% are so badly impacted by poor water quality and river bed conditions that they will probably never breed successfully again.

4.1.3 White-clawed crayfish

The white-clawed crayfish, *Austropotamobius pallipes* (Lereboullet) (Figure 4.4), is the only species of crayfish to occur naturally in Ireland (e.g. Reynolds, 1997). It is the largest non-marine invertebrate found in Ireland, with adults reaching approximately 11 cm in length and living up to 10 years (NPWS, 2013). White-clawed crayfish populations in Ireland are considered healthy and they remain widespread in many lakes, rivers and streams in limestone areas (Reynolds, 1997). This is in contrast to populations elsewhere in Europe, which are affected by the impact of introduced, mainly American, species and disease (i.e. crayfish plague). Consequently, the white-clawed crayfish was listed on Annex II and Annex V of the Habitats Directive and the species is protected in Ireland under the Wildlife Act (NPWS, 2013). Furthermore, owing to Ireland's unique situation (i.e. no introduced species of crayfish and low incidence of crayfish plague) it has international responsibility for the protection and maintenance of white-clawed crayfish populations (NPWS, 2013).

4.2 Freshwater Vertebrates in Ireland

A range of vertebrate taxa are associated with freshwaters in Ireland (Table 4.1); some of the most important groups are discussed below.

4.2.1 Freshwater fish in Ireland

Ireland has a depauperate and distinctly young fish community compared with the rest of Europe (Kelly *et al*., 2012a). Twenty-eight species of fish are known to occur in Irish freshwaters (Went and Kennedy, 1976; Maitland and Campbell, 1992; Kelly *et al*., 2007a). A full list of fish that are known to occur in

Figure 4.3. Ireland's freshwater pearl mussels *Margaritifera margaritifera* (left) and *M. durrovensis* (right). Note photographs at different scales [source: Áine O'Connor, NPWS (DAHRRGA)].

Figure 4.4. A white-clawed crayfish (photograph: Jan-Robert Baars, UCD).

Irish freshwaters is provided with observations on their current status (Table 4.3).

Brown trout, Atlantic salmon (Figure 4.5) and eel (Figure 4.6) are ubiquitous in Ireland and occur in all waters to which they are able to gain access (McGinnity *et al*., 2003). Brown trout occur in almost every rivulet, brook, stream, river and lake in Ireland (Kennedy and Fitzmaurice, 1971). Some Irish lakes are more suitable for coarse fish than for trout (e.g. shallow, sheltered, reed-fringed inter-drumlin lakes with limited salmonid spawning availability); however, it is clear that there are few Irish lakes or rivers in which brown trout cannot live (Kennedy and Fitzmaurice, 1971). A migratory component of the trout population (sea trout) may also be present (see "Brown trout varieties" for more details). In the absence of large catchment areas upstream of lakes (i.e. where efferent streams are very small) or where barriers exist downstream, salmon will probably be absent and trout populations may be naturally small. There are examples of lakes in which trout stocks are also maintained by lake-shore spawning (e.g. Lough Salt, Co. Donegal). It is in these waters that native trout stocks are most vulnerable to the adverse impacts of

Table 4.3. List of freshwater fish species of Ireland[a] (scientific and common names)

Common name	Scientific name	Status	
Species that spend their entire life, or the major part thereof, in freshwater			
River lamprey*	*Lampetra fluviatilis* (Linnaeus, 1758)	W	A
Brook lamprey*	*Lampetra planeri* (Bloch, 1784)	L	C/R
Sea lamprey*	*Petromyzon marinus* (Linnaeus, 1758)	L	C/R
Killarney shad*	*Alosa fallax killarnensis* (Regan)	L	R
Atlantic salmon*	*Salmo salar* Linnaeus, 1758	W	A
Brown trout/sea trout*	*Salmo trutta* Linnaeus, 1758	W	A
Rainbow trout	*Oncorhynchus mykiss* (Walbaum, 1792)	L	R
Arctic char*	*Salvelinus alpinus* (Linnaeus, 1758)	L	R
Pollan*	*Coregonus autumnalis* (Pallas, 1776)	L	R
Pike	*Esox lucius* Linnaeus, 1758	W	A
Common carp	*Cyprinus carpio* Linnaeus, 1758	L	C
Gudgeon	*Gobio gobio* (Linnaeus, 1758)	W	A
Tench	*Tinca tinca* (Linnaeus, 1758)	L	C
Common bream	*Abramis brama* (Linnaeus, 1758)	W	A
Minnow	*Phoxinus phoxinus* (Linnaeus, 1758)	W	A
Rudd	*Scardinius erythrophthalmus* (Linnaeus, 1758)	W	C
Roach	*Rutilus rutilus* (Linnaeus, 1758)	W	C
Dace	*Leuciscus leuciscus* (Linnaeus, 1758)	L	R
Stone loach	*Noemacheilus barbatulus* (Linnaeus, 1758)	W	A
European eel*	*Anguilla anguilla* (Linnaeus, 1758)	W	A
Three-spined stickleback*	*Gasterosteus aculeatus* Linnaeus, 1758	W	A
Ten-spined stickleback*	*Pungitius pungitius* (Linnaeus, 1758)	L	C
Perch	*Perca fluviatilis* Linneaus, 1758	W	A
Species that enter freshwater to spawn near the upstream limit of tidal influence			
Twaite shad*	*Alosa fallax* (Lacepede, 1803)	L	R
Smelt*	*Osmerus eperlanus* (Linnaeus, 1758)	L	R
Species that may enter freshwater for variable periods but which principally occur in marine or estuarine waters			
Allis shad	*Alosa alosa* (Linnaeus, 1758)	L	R
Sturgeon	*Acipenser sturio* (Linnaeus, 1758)	L	R
Flounder*	*Platichthys flesus* (Linnaeus, 1758)	W	C

After Kelly *et al.*, 2007a and King *et al.*, 2011.

Native species indicated by asterisk.

[a]Chub [*Leuciscus cephalus* (Linnaeus, 1758)] was previously recorded in the Inny catchment but subsequent surveys in recent years have failed to record any individuals (Fiona Kelly, Inland Fisheries Ireland, unpublished information, September 2016).

A, abundant; C, common; L, local; R, rare; W, widespread.

introduced species, especially of pike or perch. Eels (Figure 4.6) are thought to exhibit a similar distribution to brown trout (Moriarty and Dekker, 1997) but are affected by access issues in a number of catchments.

In terms of distribution of fish species in Ireland, diversity is limited in many of the rivers and lakes of Counties Donegal, Kerry, west County Cork, west County Mayo, west County Galway and the Connemara region. Fortunately, native species continue to dominate the ichthyofauna in these areas where cyprinids have been introduced to very few waters (Kelly *et al.*, 2009, 2010, 2011, 2012b, 2013, 2014, 2015). The Arctic char and Killarney shad are mainly confined to lakes (see “Lake specific species”). Current knowledge indicates that all populations of Irish char are non-migratory and viable populations exist in lakes where suitable spawning gravels occur in shallows. They are mainly restricted to oligotrophic

Figure 4.5. Brown trout common in Irish freshwaters (top) and Atlantic salmon found in Irish waters (bottom). Note photographs at different scales [photographs: ©Inland Fisheries Ireland (http://www.fisheriesireland.ie/; accessed 1 September 2016)].

and mesotrophic lakes where oxygen reserves in the hypolimnion are not depleted by the decomposition resulting from intensive organic production (Kennedy and Fitzmaurice, 1971). Killarney shad, or goureen, is derived from a population of twaite shad that became landlocked after the last glaciation. The species is unique to Ireland and only found in one location, Lough Leane, and is rated as critically endangered by the International Union for Conservation of Nature (IUCN).

Three species of lamprey are found in Irish freshwaters: the river lamprey, the brook lamprey and the sea lamprey. The river lamprey (Figure 4.7) reaches a maximum length of approximately 30 cm and the brook lamprey, which is the smallest of the three lampreys recorded in Ireland, typically reaches no more than 15–18 cm in length. Both river and brook lamprey breed in freshwater rivers and streams by excavating shallow nests in gravels and stones. Their larvae, or ammocoetes, drift or swim downstream to areas of river bed with a fine silt composition where they burrow into the river bed and live as filter feeders for several years. Unlike the river lamprey, which is parasitic, attaching to and feeding on larger fish in coastal waters, the brook lamprey is non-parasitic and non-migratory as an adult, living its entire life in freshwater. Interestingly, river and brook lamprey are indistinguishable as larvae. The adults, in contrast, are clearly distinguishable but are considered by many in the same context as the brown trout and sea trout pairing, with a similar absence of genetic discriminators (see “Brown trout varieties”) (NPWS, 2013). Both these species of lamprey have extensive

Figure 4.6. Eels taken from Irish waters (top). A pike (*Esox lucius* Linnaeus, 1758) from an Irish lake (bottom). Note photographs at different scales [photographs: ©Inland Fisheries Ireland (http://www.fisheriesireland.ie/; accessed 1 September 2016)].

Figure 4.7 Brook (top) and river (bottom) lamprey. Note photographs at different scales (photographs: Fiona Bracken, UCD).

areas of available habitat and, at present, experience no significant pressures influencing populations (NPWS, 2013).

Sea lamprey have both a marine phase and a freshwater phase, and reach 60–100 cm in length. The adults live as external parasites to host fish at sea but return to freshwater to breed. Larvae remain in freshwater, burrowing in fine-grained sediment, as a filter feeder, over a period of several years before migrating to estuarine and marine waters. Interestingly, non-migratory or "land-locked" sea lamprey have been reported in Lough Conn, Lough Corrib, Lough Derg and Lough Gill (NPWS, 2013). Low levels of occurrence and abundance of sea lamprey in many catchments throughout Ireland gives rise to concern for their long-term future (King *et al*., 2011). The main threats to sea lamprey are pollution, dredging or desilting operations in rivers, which can lead to loss of juvenile habitat. Weirs are seen as a major factor in impeding upriver penetration and this has adverse consequences on dispersal and resource use in any catchment (King *et al*., 2011).

Cyprinid species (Figure 4.8) commonly occur in most moderate/high alkalinity catchments draining the central limestone plains. This is perhaps not surprising considering the presence of the two artificial water bodies that traverse this region (i.e. the Royal and Grand canals). The canals have overflow facilities to most/any rivers over which they cross and fish species that occur in the canals therefore have ready access to these catchments. Pike, perch, bream (Went, 1950; Kennedy and Fitzmaurice, 1968), rudd (Kennedy and Fitzmaurice, 1974) and tench (Kennedy and Fitzmaurice, 1968) are known to be widespread in the Shannon system (some have been for several centuries). Rudd, tench and bream (Figure 4.8) are non-native species that have a limited distribution, dependent on when and where these species were introduced. They are primarily species of standing waters but also occur in slow-flowing, deep waters in some rivers (Kelly *et al*., 2007a). A water temperature of approximately 15ºC is sufficient to meet the spawning requirements of bream and rudd; however, a water temperature of 20ºC is required for tench and in Ireland reproduction may be dependent on the occurrence of warm summer anticyclones (Kennedy and Fitzmaurice, 1970). In some years, tench may fail to spawn. Tench were originally concentrated in the Shannon catchment and in some lakes and ponds. Since 1956, tench have been transferred to other waters for angling purposes. In recent years (post 1990) tench have become widespread in the River Erne system (Inland Fisheries Ireland, unpublished data). They also occur in many lakes throughout the midlands where they have been stocked for angling purposes. This is thought to be linked to increased water temperatures. Rudd are more widespread and have been introduced to many waters for angling purposes. However, they are particularly susceptible to hybridisation with roach. Recent fish monitoring for the WFD has revealed that their populations have become quite scarce (Fiona Kelly, Inland Fisheries Ireland, unpublished data). Prior to 1955, bream were mainly present in large lake catchments situated in the centre of Ireland. However, with the growth in the popularity of coarse angling, bream were transferred to waters they did not previously occupy and in some of these waters the subsequent arrival of roach and hybridisation has diminished bream numbers.

Other fish species found in Ireland's freshwaters include the native three-spined stickleback, ten-spined stickleback and flounder (Figure 4.9). Ireland's freshwaters also include the non-native rainbow trout and carp, which are considered "domesticated" species (i.e. requiring human interference and inputs in order to maintain the species in Ireland) as well as the non-native dace, which is considered to require management.

Lake-specific species

Arctic char, pollan, Killarney shad (see Figure 4.10) and ferox trout are restricted to lakes (Kelly *et al*., 2009, 2010, 2011, 2012b, 2013). They are sensitive to anthropogenic degradation, particularly to eutrophication, reduction in dissolved oxygen levels and changes to habitat structure. Currently, Arctic char populations are mainly present in the north-west, west and south-west of Ireland. There are, however, some historical records of Arctic char populations occurring in the midlands and the east of the country (Went, 1945), but the majority of these populations are now extinct (Went, 1971; Igoe *et al*., 2003; Kelly *et al*., 2009, 2010, 2011, 2012b, 2013). Igoe *et al*. (2003) carried out a review of the distribution of Arctic char in Ireland and identified 76 lakes where there are records of populations being present. Subsequently, Inland Fisheries Ireland (IFI) and the Irish Char Conservation

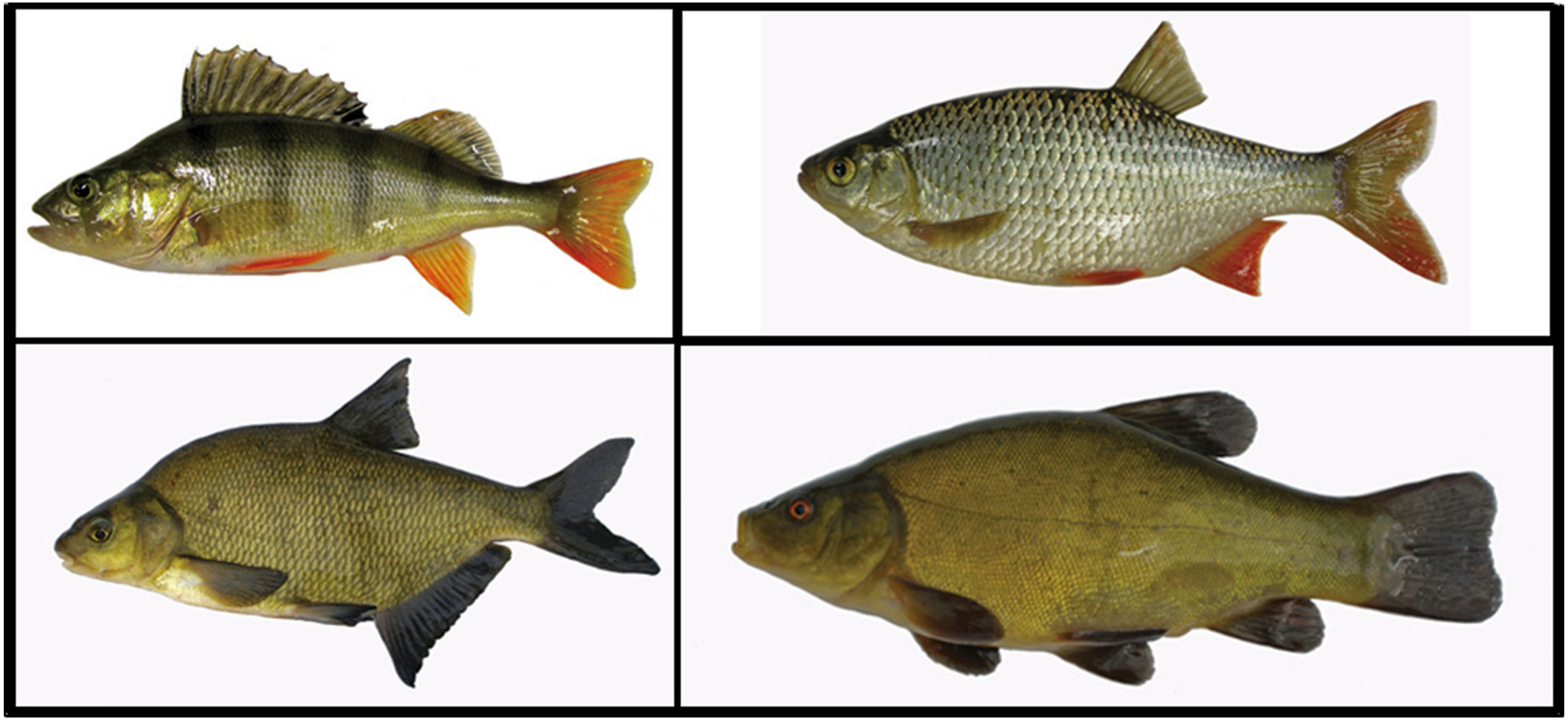

Figure 4.8. Perch (top left), rudd (top right), bream (bottom left) and tench (bottom right), found in Irish waters. Note photographs at different scales [photographs: ©Inland Fisheries Ireland (http://www.fisheriesireland.ie/; accessed 1 September 2016)].

Figure 4.9. Three-spined stickleback (top left), ten-spined stickleback (top right) and flounder (bottom). All three species are considered native to Irish freshwaters. Note photographs at different scales [photographs: ©Inland Fisheries Ireland (http://www.fisheriesireland.ie/; accessed 1 September 2016)].

Group (ICCG) have undertaken a programme to establish the status of the species (Kelly *et al*., 2007b, 2009, 2010, 2011, 2012b, 2014, 2015; Rooney *et al*., 2014). During this time, IFI and the ICCG have located and confirmed the presence of nine previously unrecorded populations of the species in the following locations: Lough Akibbon, Co. Donegal (Kelly *et al*., 2007b), Lough Arderry, Co. Galway (Kelly *et al*., 2009), Loughs Namona, Cloonaghlin and Derriana in the Cummeragh catchment (Lough Currane), Lough Cloon in the Lough Caragh catchment, Co. Kerry (Igoe and Hammar, 2004), Lough Altan, Co. Donegal (Igoe and Greer, 2005) and Coomaglaslaw in the Behy catchment, Co. Kerry (Fran Igoe, ICCG, 2007, personal communication). In Northern Ireland, one new population was discovered in 2006 in Lough Formal, Co. Fermanagh (Girvan *et al*., 2006). It is now estimated that there are at least 84 lakes on the island of Ireland where Arctic char are present (Went, 1945, 1971; Igoe and Hammar, 2004; Kelly *et al*., 2007a, 2007b, 2009, 2010, 2011, 2012b, 2013, 2014, 2015; Rooney *et al*., 2014) and their presence has been confirmed in at least 42 of these (Igoe and Hammar, 2004; Igoe and Greer, 2005; Kelly *et al*., 2009, 2010, 2011, 2012b; Rooney *et al*., 2014), although many of these populations are currently at risk.

Pollan is a unique and threatened land-locked relict of post-glacial colonisation of the anadromous Arctic cisco that still occurs in North America and northern Eurasia (Maitland and Campbell, 1992; Harrod *et al*., 2001; Harrison *et al*., 2012). They are a pelagic species and are known to exist in only five lakes in the island of Ireland: Lough Neagh and Lower Lough Erne in Northern Ireland and Lough Derg, Lough Ree and Lough Allen in Ireland (Harrison *et al*., 2010, 2012). Due to their restricted geographic range and decline in numbers, pollan are afforded a high conservation

Figure 4.10. A small Arctic char found in Ireland (top), a pollan found in Irish freshwaters (middle) and a Killarney shad unique to Ireland (bottom). Note photographs at different scales (photographs top and bottom: ©Inland Fisheries Ireland (http://www.fisheriesireland.ie/; accessed 1 September 2016), middle: Fiona Kelly, Inland Fisheries Ireland).

status; they are listed in Annex V of the EU Habitats Directive [(92/43/EEC) EU, 1992].

Brown trout varieties

Virtually every small stretch of stream or river plays host to its own family of genetically distinguishable brown trout, each of which displays strong fidelity to its spawning place. Thus, genetic isolation is maintained and it would be more accurate to consider brown trout as a mosaic of family units rather than as one amorphous species grouping (Fahy, 1995). A series of genetic studies on Irish trout populations has confirmed this and has revealed a heretofore unknown complexity to the brown trout and its spawning rituals (O'Grady and Delanty, 2013; Delanty *et al*., 2016a,b,c).

Many different varieties of brown trout have been identified in lake and river catchments (e.g. nine varieties have been identified in the Lough Corrib catchment, while many more have been identified in other lake and river catchments such as Loughs Mask, Sheelin and Ennell and the Rivers Suir and Boyne) each with its own discrete genetic make-up and spawning ritual (O'Grady and Delanty, 2013).

In addition to the above mentioned genetic strains, there are a number of more well-known strains present in some Irish lakes. The "ferox" trout is a piscivorous strain of lake-dwelling brown trout; it represents a remnant of a once widespread type of trout which colonised areas of freshwater in immediately post-glacial times (Ferguson, 1986). This piscivorous strain of brown trout may have evolved to occupy the fish-feeding niche in Irish lakes (IFI, unpublished data) before pike were introduced to certain areas of Ireland. These ferox trout appear to be present in small numbers in low alkalinity lakes (e.g. Lough Caragh, Co. Kerry), but are more common in large lakes (moderate to high alkalinity and > 1000 ha) in the west (e.g. Lough Corrib and Lough Mask), north-west (Lough Melvin and Lower Lough Erne) and south-west (Lough Leane). Ferox trout are regularly captured on these lakes by anglers trolling baits. Because of their exceptional size and growth rate they are regarded as a distinct strain of brown trout and have been allocated a specific category in the Irish Specimen Fish Listings (ISFC, 2006). All of these lakes contained populations of Arctic char, though they are thought to have disappeared from Lough Corrib prior to 1996. Lough Conn, which also lost its char population in the late 1980s, although very similar in many respects to the other western lakes, does not contain the ferox strain of trout. The lake is fished heavily by anglers, many of whom troll for salmon, and if ferox trout were present they would have been noted. IFI found that trout in Lough Conn only adopted a fish diet for a few years after the Moy arterial drainage scheme, when the lake level was lowered by about 2 m (IFI, unpublished data). Between 1965 and 1967, trout weighing 4.25 lb (1.9 kg) to just under 10 lb (4.5 kg) (the latter had two char in its stomach) were captured in gill nets and these fish were described as ferox (Kennedy and Fitzmaurice, 1971). At that time, extensive areas of the littoral zone were dewatered with a serious reduction in macroinvertebrate fish food. This event also impacted significantly on the pike population, which was deprived of spawning substrate in the 1960s (Inland Fisheries Trust, 1967). Ferox trout are not a normal component of the fish community in high alkalinity waters (Kennedy and Fitzmaurice, 1971) where macroinvertebrates are in plentiful supply. However, some trout changed to a fish diet (feeding on roach and perch) and grew to unusually large sizes in Lough Sheelin (O'Grady, 1981; Gargan, 1986) when the lake switched from macrophyte to phytoplankton dominance alongside a loss of submerged flora (charophytes) and associated invertebrates (Champ, 1993). The Irish record brown trout [a fish of over 28 lb (12.7 kg)] was captured in Lough Ennell, a high alkalinity lake, in 1894. While this lake held Arctic char prior to 1925 (Went, 1945), this exceptionally large trout is thought not to be of the true ferox strain (IFI, unpublished data).

A number of other strains of brown trout exist in Irish lakes, namely gillaroo, sonaghan (Figure 4.11) and croneen. Gillaroo feed mainly on molluscs and caddis flies, a diet that has resulted in this strain developing a distinctive heavy muscular stomach with which to crush shells (Kennedy and Fitzmaurice, 1971), and is present in Lough Melvin. Sonaghan, a pelagic strain that feeds mainly on zooplankton, is also present in Lough Melvin (Ferguson, 1986) and is also thought to be present in Lough Mask (IFI, unpublished data). Ferguson (2004) is satisfied that ferox, gillaroo and sonaghan in Lough Melvin are sufficiently genetically distinct to be regarded as three separate species of brown trout.

Croneen trout are a pelagic fish, designed to swim long distances to spawn and commencing their spawning migration in July or August. They behave like sea trout and feed only spasmodically. The croneen population in the Lough Derg catchment of the Shannon's main stem migrate to the small Camcor river in County Offaly, 50 km away, to spawn. A similar trout in Lough Neagh is the dollaghan (Kennedy and Fitzmaurice, 1971). Another trout variety in the river Suir, which has not yet been named, was found to travel 78 km from the River Nier in County Waterford, where it is born, down to the main stem of the Suir (IFI, unpublished data).

Sea trout (Figure 4.11) are an anadromous form of brown trout that spend periods of their life feeding at sea before returning to their natal river to spawn (Gargan *et al.*, 2003) and are present in most Irish

Figure 4.11. Brown trout varieties: a sonaghan (top), a gillaroo (middle) and a sea trout (bottom). Note photographs at different scales [photographs: ©Inland Fisheries Ireland (http://www.fishinginireland.info/; accessed 1 September 2016)].

rivers where they can gain access to the sea. Currently it is thought that a combination of multiple genetic factors, interacting with environmental influences, triggers anadromy in brown trout (O'Grady *et al*., 2008).

4.2.2 Amphibians in Ireland

King *et al*. (2011) reported that there are three amphibians established in Ireland. All three species are thought to be native, with two confirmed using genetics, natterjack toads [*Epidalea (Bufo*) *calamita* (Laurenti)] (Beebee and Rowe, 2000; Beebee, 2002; Rowe *et al*., 2006; May and Beebee, 2008) and common frogs (*Rana temporaria* Linnaeus) (Teacher *et al*., 2009), although some later introductions may also have occurred in some areas. There are no molecular studies or fossil records to support the native status of the smooth newt [*Lissotriton* (*Triturus*) *vulgaris* (Linnaeus)] (Figure 4.12) in Ireland, but this is a cold-tolerant species, found within the Arctic Circle, and it is generally considered to have been capable of re-colonising naturally in the wake of the retreating ice (Marnell, 1996). The common frog is widespread and common throughout Ireland, while the smooth newt has a widespread distribution with local populations (King *et al*., 2011). The natterjack toad, on the other hand, is restricted to the Dingle and Iveragh peninsulas in west County Kerry and a small introduced population in the Raven area of County Wexford (Beebee, 2002; King *et al*., 2011).

4.2.3 Birds associated with freshwaters in Ireland

Wilson and Carmody (2011, 2013) and BirdWatch Ireland (2011 and http://www.birdwatchireland.ie/) list 60 bird species that occur in, or are associated with, various Irish freshwaters (e.g. rivers, lakes, fens, boglands, etc.). Many utilise freshwaters for shelter, breeding, nesting and feeding throughout the year (e.g. Figure 4.13), while others are seasonal or intermittent and only occur from time to time. A full list of other bird species and their associations to Irish freshwaters is provided in Table 4.4. BirdWatch Ireland compiles records of birds associated with Irish freshwaters from a range of surveys; of particular relevance are the Irish Wetland Bird Survey and the Waterways Survey. The distribution of one iconic species, the kingfisher [*Alcedo atthis* (Linnaeus)] (Figure 4.14), is shown in Figure 4.15. Wilson and Carmody (2011, 2013) also list 13 "ornamental" wildfowl that have been introduced to Ireland, mostly during the 18th and 19th century by collectors and explorers; these include birds such as the black-necked swan [*Cygnus melanocoryphus* (Molina)], greylag goose [*Anser anser* (Linnaeus)], mandarin

Figure 4.12. A smooth newt (photograph: Mary Kelly-Quinn, UCD).

Figure 4.13. A white-tailed sea eagle [*Haliaeetus albicilla* (Linnaeus)] (left) and a grey heron (*Ardea cinerea* Linnaeus) (right) in flight [photographs: ©Mark Carmody (www.markcarmodyphotography.com and http://flickr.com/photos/drcarmo/; both accessed 16 September 2016)].

Figure 4.14. A selection of Irish freshwater birds. Top left: mute swans [*Cygnus olor* (Gmelin, 1789)]; top right: a whooper Swan [*Cygnus cygnus* (Linnaeus)]; middle left: a dipper [*Cinclus cinclus* (Linnaeus)]; middle right: a kingfisher [*Alcedo atthis* (Linnaeus)]; bottom left: a tufted duck [*Aythya fuligula* (Linnaeus, 1758)] and bottom right: a Mallard (*Anas platyrhynchos* Linnaeus) [photographs: ©Mark Carmody (www.markcarmodyphotography.com and http://flickr.com/photos/drcarmo/; both accessed 16 September 2016)]. Also see Wilson and Carmody (2011, 2013) for more information and photography.

Table 4.4. Sixty common and charismatic bird species associated with freshwater habitats in Ireland[a]

Common name	Scientific name	Association with freshwater habitats in Ireland
Kingfisher	*Alcedo atthis* (Linnaeus, 1758)	Resides on Irish streams, rivers and canals throughout the country. Diet consists of various species of small fish (stickleback, minnow, and chub) and larger aquatic insects caught by plunge-diving from a perch or while hovering. Breeds in tunnels dug in vertical banks along streams and rivers
Dipper	*Cinclus cinclus* (Linnaeus, 1758)	A widespread resident along rocky streams and rivers. Feeds on aquatic invertebrates, such as the larvae of caddisflies and mayflies. Breeds along fast-flowing streams and rivers with plenty of exposed rocks. In Ireland, the majority of breeding pairs are found in the uplands
Grey wagtail	*Motacilla cinerea* Tunstall, 1771	A widespread resident along fast-flowing streams and rivers throughout Ireland. Feeds mainly along streams and rivers, frequently building its nest under a bridge
Swallow	*Hirundo rustica* (Linnaeus, 1758)	Often seen hunting over watercourses
White-tailed sea eagle	*Haliaeetus albicilla* (Linnaeus, 1758)	Associated with the lakes in Killarney, Co. Kerry, often seen feeding on fish
Mute swan	*Cygnus olor* (Gmelin, 1789)	Breeds on lakes, ponds and rivers. Nest is constructed from reed stems and other aquatic vegetation. Diet includes aquatic plants and occasionally amphibians and invertebrates
Bewick's swan	*Cygnus columbianus* (Ord, 1815)	Uses water bodies near suitable grazing areas; particularly favoured flooded grasslands in the past
Whooper swan	*Cygnus cygnus* (Linnaeus, 1758)	Winters on lakes, marshes, lagoons and sheltered inlets. Diet includes aquatic vegetation within 1 m of the surface
Greenland white-fronted goose	*Anser albifrons flavirostris* Dalgety and Scott, 1948	Historically found on bog habitats, but in recent years favours more intensively managed farmland. Often associates with nearby water bodies
Greylag goose	*Anser anser* (Linnaeus, 1758)	Can be found feeding in shallow waters. Diet includes aquatic plants
Canada goose	*Branta canadensis* (Linnaeus, 1758)	Nests in areas free of disturbance and near to water, always well hidden
Wigeon	*Anas penelope* Linnaeus, 1758	Often found in various freshwaters. Diet includes aquatic plant material (e.g. grasses, eel-grass and algae)
Gadwall	*Anas strepera* Linnaeus, 1758	Winters in a variety of wetlands. Diet includes aquatic vegetation and insects
Teal	*Anas crecca* Linnaeus, 1758	Usually nests near small freshwater lakes or pools and small upland streams preferring thick cover. Found in a variety of well-vegetated wetlands in the winter
Mallard	*Anas platyrhynchos* Linnaeus, 1758	Occurs in almost all available wetland habitats in Ireland. Also associated with rivers
Pintail	*Anas acuta* Linnaeus, 1758	Can be found in large flocks on large lakes. Diet includes aquatic plants and some invertebrates
Garganey	*Anas querquedula* Linnaeus, 1758	Only occasionally breeds in Ireland on well-vegetated ponds and small lakes. Diet includes aquatic grasses and some invertebrates
Shoveler	*Anas clypeata* Linnaeus, 1758	Prefers shallow eutrophic waters rich in plankton and occurs in a variety of habitats, including coastal inland lakes and callows. Feeds on invertebrates, zooplankton and some plant material
Pochard	*Aythya ferina* (Linnaeus, 1758)	Prefers large shallow freshwater lakes in winter that are well vegetated and ideally have slow flowing rivers. Feeds on plant material but also chironomid larvae
Tufted duck	*Aythya fuligula* (Linnaeus, 1758)	Prefers large open lakes in lowland areas but are also found in ponds, canals and slow moving rivers. Diet consists primarily of animal matter (mussels, crustaceans and small invertebrates) but also some plant material
Scaup	*Aythya marila* (Linnaeus, 1761)	Nests on the ground near freshwater lakes. Chironomid larvae form part of the diet in Lough Neagh
Common scoter	*Melanitta nigra* (Linnaeus, 1758)	During the breeding season they occur on large inland lakes where there is sufficient scrub and tree cover under which to nest. Feeds on aquatic plants, insect larvae and crustaceans

Table 4.4. Continued

Common name	Scientific name	Association with freshwater habitats in Ireland
Goldeneye	*Bucephala clangula* (Linnaeus, 1758)	Found in both freshwater lakes in winter, feeds on insects and, less often, on molluscs and crustaceans in freshwater habitats
Goosander	*Mergus merganser* Linnaeus, 1758	Found on freshwater lakes, pools and rivers. Feeds on small fish
Ruddy duck	*Oxyura jamaicensis* (Gmelin, 1789)	American species introduced into Ireland. Breeds by open freshwater lakes with fringe vegetation in which nests are hidden
Little grebe	*Tachybaptus ruficollis* (Pallas, 1764)	Found on small shallow lowland lakes, ponds, marshes, canals and on the fringes of larger lakes. Can nest on floating vegetation and feeds on a range of invertebrates, especially insect larvae, and small fish. Also associated with rivers
Great crested grebe	*Podiceps cristatus* (Linnaeus, 1758)	Found in lakes and large rivers, generally breeds on inland lakes, with nests consisting of a floating mass of aquatic vegetation, which is usually hidden within dense reeds. Feeds mainly on fish, sometimes supplemented with aquatic invertebrates
Black-necked grebe	*Podiceps nigricollis* Brehm, 1831	Found in small well-vegetated shallow eutrophic pools and lakes. Nests on floating aquatic plant material anchored to emergent vegetation and feeds on small fish and crustaceans
Red-necked grebe	*Podiceps grisegena* (Boddaert, 1783)	Occasionally found on large lakes inland from October to March
Cormorant	*Phalacrocorax carbo* (Linnaeus, 1758)	Occurs on lakes and rivers with sufficient areas for nesting (generally in trees and scrub) and sufficient food resources. Avoids very shallow or deep waters. Diets consists mainly of fish, but they will also take invertebrates
Grey heron	*Ardea cinerea* Linnaeus, 1758	Common resident at wetlands and along rivers throughout Ireland
Little egret	*Egretta garzetta* (Linnaeus, 1766)	Prefers shallow inland waters and slow-flowing rivers, feeding on small fish and invertebrates
Hen harrier	*Circus cyaneus* (Linnaeus, 1766)	Often roosts in reed beds in freshwater wetlands in winter
Marsh harrier	*Circus aeruginosus* (Linnaeus, 1758)	Overwintering birds are usually found in reed beds, swamps, marshes and flooded grasslands
Osprey	*Pandion haliaetus* (Linnaeus, 1758)	Chooses territories near lakes, rivers or other suitable water bodies with sufficient medium-sized fish and clear water, feeding on fish caught near the surface
Water rail	*Rallus aquaticus* Linnaeus, 1758	Found in wetlands with still or slow moving water with plenty of tall, dense vegetation around the margins. Nest consists of aquatic vegetation on or near water
Corncrake	*Crex crex* (Linnaeus, 1758)	Only present in small numbers in the Shannon Callows, north Donegal and western parts of Mayo and Connaught
Spotted crake	*Porzana porzana* (Linnaeus, 1766)	Found in shallow freshwater lakes or ponds with plenty of low plant cover and food. Nests above or near water, feeding on invertebrates and plant material
Moorhen	*Gallinula chloropus* (Linnaeus, 1758)	Nests near water, usually in emergent vegetation or on a floating raft. It is widespread throughout the country, only being absent or rare in parts of the west. Can be found on any freshwater habitat with abundant emergent vegetation, including town canals, muddy ditches and large lakes
Coot	*Fulica atra* Linnaeus, 1758	Prefers large shallow nutrient-rich freshwater bodies with plenty of submerged vegetation for feeding and nest anchorage. Feeds on plant material but also eats invertebrates, small fish and fish eggs
Golden plover	*Pluvialis apricaria* (Linnaeus, 1758)	Can be found in or near wetlands
Lapwing	*Vanellus vanellus* (Linnaeus, 1758)	Can be found in or near wetlands
Dunlin	*Calidris alpina* (Linnaeus, 1758)	Sometimes found in low numbers inland by freshwater. Prefer to breed on machair and upland blanket bog
Snipe	*Gallinago gallinago* (Linnaeus, 1758)	Forages over a variety of wetland and damp habitats, including fens, turloughs, lakes, coastal sites and rivers
Black-tailed godwit	*Limosa limosa* (Linnaeus, 1758)	Breeds in lowland wet grassland and marshes
Curlew	*Numenius arquata* (Linnaeus, 1758)	Often nests on meadows
Common sandpiper	*Actitis hypoleucos* (Linnaeus, 1758)	Breeds on the shores of inland lakes and fast-flowing rivers. Diet includes small fish and amphibians

Table 4.4. Continued

Common name	Scientific name	Association with freshwater habitats in Ireland
Red-necked phalarope	*Phalaropus lobatus* (Linnaeus, 1758)	Breeds in wetlands with dense vegetation
Black-headed gull	*Chroicocephalus ridibundus* (Linnaeus, 1766)	Mainly breeds in wetlands and lakes
Common gull	*Larus canus* Linnaeus, 1758	Often breeds on lakes. Diet includes fish
Lesser black-backed gull	*Larus fuscus* Linnaeus, 1758	Often breeds on islands on inland lakes
Common tern	*Sterna hirundo* Linnaeus, 1758	Often breeds on lake islands. Diet consists of fish
Arctic tern	*Sterna paradisaea* (Pontoppidan, 1763)	Often found inland on large lakes. Feeds mainly on fish but also on crustaceans and insects
Sand martin	*Riparia riparia* (Linnaeus, 1758)	Often found in wetlands. Also associated with rivers
Grasshopper warbler	*Locustella naevia* (Boddaert, 1783)	Often found on the edges of bogs and in reed beds. Also associated with rivers
Reed warbler	*Acrocephalus scirpaceus* (Hermann, 1804)	Often found in reed beds. Also associated with rivers
Sedge warbler	*Acrocephalus schoenobaenus* (Linnaeus, 1758)	Breeds on the edge of wetlands, especially in areas of wet grassland
Reed bunting	*Emberiza schoeniclus* (Linnaeus, 1758)	Widespread resident of wetlands throughout Ireland. Breeds in wetlands with some reed bed areas or in peatlands
Starling	*Sturnus vulgaris* Linnaeus, 1758	Roosts in reed beds in large aggregations during the winter
Red grouse	*Lagopus lagopus scoticus* (Latham, 1787)	Found on moorland and lowland blanket bogs and raised bogs, where it is associated with heather, which it requires for food, shelter and nesting

[a]For references and more information see Wilson and Carmody (2011, 2013) and BirdWatch Ireland (2011) and www.birdwatchireland.ie (accessed 1 June 2016).

duck [*Aix galericulata* (Linnaeus)] and red-crested pochard [*Netta rufina* (Pallas)].

4.2.4 Mammals associated with freshwaters in Ireland

The otter and the American mink are associated with freshwaters in Ireland (Marnell *et al*., 2009). The invasive American mink [*Neovison vison* (Schreber)] is now well established in Ireland as a result of escapes from fur farms, some of which still operate. They are important predators of globally threatened seabirds and waders. The native otter [*Lutra lutra* (Linnaeus), Figure 4.16] is found in many freshwater habitats and, even when resident in coastal areas, requires a nearby source of freshwaters to drink from and bathe in (Marnell *et al*., 2009; Reid *et al*., 2013). Research suggests that the occurrence of otters in Ireland is negatively associated with altitude, urbanisation, bank height, water depth and bankside vegetation density (Bailey and Rochford, 2006). Generally, otters are thought to be impacted by poor water quality, but only a few studies have indicated a relationship with pollution and human disturbance (Mason and Macdonald, 1986; Delibes *et al*., 1991; Bailey and Rochford, 2006). Otters feed principally on salmon and trout, but eels, frogs, invertebrates (especially crayfish), birds and small mammals may also form part of their diet (e.g. Bailey and Rochford, 2006).

4.3 Protected Freshwater Species in Ireland

Ireland has 18 freshwater species that are protected under Annex II (i.e. they must be protected under the Natura 2000 network and the sites managed in accordance with the ecological requirements of the species) and IV (i.e. a strict protection regime must be applied across their entire natural range within the EU, both within and outside Natura 2000 sites) of the EU Habitats Directive (Council Directive 92/43/EEC of

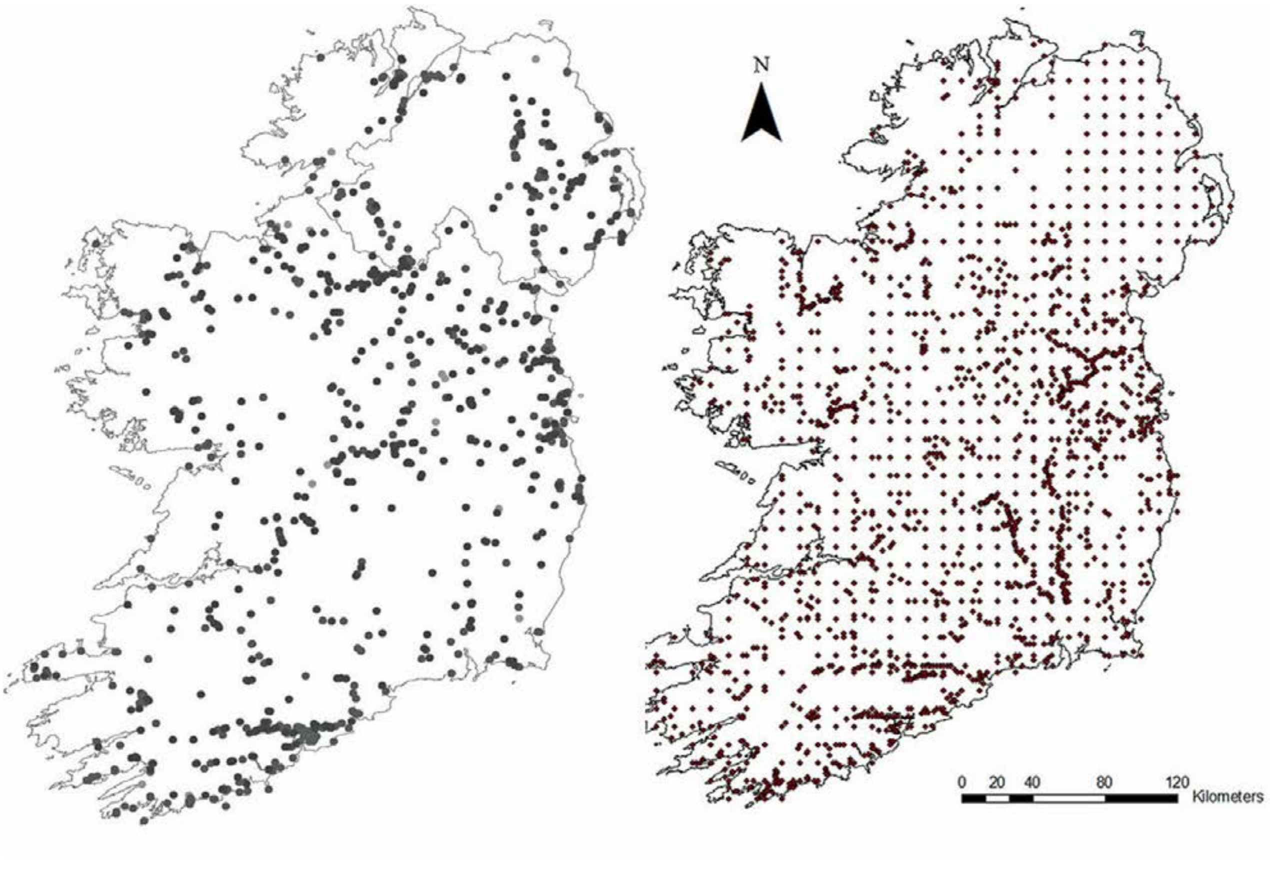

Figure 4.15. Records of kingfishers in Ireland between 1998 and 2007 (left-hand map) [source: https://goo.gl/gZYo8O (accessed 1 June 2016)] and all records of kingfishers for Ireland held by the National Biodiversity Data Centre (right-hand map).

Figure 4.16. An otter, synonymous with Irish freshwaters [photograph: Eddie Dunne, ©NPWS (DAHRRGA)].

21 May 1992 on the conservation of natural habitats and of wild fauna and flora). The species are listed in detail in Table 4.5. Some taxa, such as the Killarney fern [*Trichomanes speciosum* Willd.], have not been included, although they may well be found close to humid habitats, including stream gullies, waterfalls and damp woodlands. More details can be found in NPWS (2013).

Ireland also has several Annex V species (i.e. Member States shall, if deemed necessary as a result of surveillance work, take measures to ensure that their exploitation and taking in the wild is compatible with maintaining them in a favourable conservation status), which include the common frog (see section 4.2.2), pollan (see "Lake specific species") and non-animal species such as the *Sphagnum* species and clubmoss, *Lycopodium clavatum* Linnaeus. Similarly, peatlands host a range of taxa, such as the white cushion moss [*Leucobryum glaucum* (Hedw.) Ångstr.], which requires wet habitat to survive. Many of the Annex II taxa highlighted in Table 4.5 are also listed as Annex V taxa. More details can be found in NPWS (2013).

Table 4.5. Annex II and IV species associated with freshwater habitats in Ireland

Common name	Scientific name	Annex	Brief description
Marsh saxifrage	*Saxifraga hirculus* Linnaeus	II, IV	Restricted to mineral flushes in blanket bogs near small streams and seepage areas
Slender naiad	*Najas flexilis* (Willd.) Rostkovius and Schmidt	II, IV	A fragile, annual plant that grows in clear-water, lowland lakes. It is a glacial relict species and it has occupied the same lakes continuously for almost 10,000 years. Occurs in lakes in peatland-dominated catchments, but with some base-rich influences. In Ireland, the lakes typically overlie calcareous sand (often in machair), marble or sometimes limestone. The species, in Ireland at least, appears to be strongly associated with naturally oligotrophic lakes
Slender green feather moss	*Hamatocaulis vernicosus* (Mitt.) Hedenäs	II	Slender green feather moss is found in intermediate fens and flushes where there is an influence of mineral-rich, but not calcium-rich, groundwater. In Ireland, it is found in somewhat base-rich springs in upland districts, while in the lowlands it generally occurs in spring-influenced sites in mildly basic small-sedge fens
Geyer's whorl snail	*Vertigo geyeri* Lindholm, 1925	II	Found in small wetlands. Can also be found in raised bog lags and lake shores. Habitat needs to be open and have stable hydrology
Narrow-mouthed whorl snail	*Vertigo angustior* Jeffreys, 1830	II	Favours damp or wet habitats where it lives among moss, leaves and decaying vegetation. Mainly found on the Atlantic-facing dune systems from Counties Kerry to Donegal. Inland populations are rarer and more scattered but it once occurred as far east as County Kildare in fens and floodplains
Desmoulin's whorl snail	*Vertigo moulinsiana* (Dupuy, 1849)	II	Found principally in calcareous lowland wetlands, including swamps, fens and marshes bordering river, lakes and ponds
Freshwater pearl mussel	*Margaritifera margaritifera* Linnaeus, 1758	II	Found in clean, fast-flowing rivers. Freshwater pearl mussels are widespread in Ireland, occurring in more than 160 rivers and a handful of associated lakes
Irish freshwater pearl mussel	*Margaritifera durrovensis* (Phillips, 1928)	II	Also known as the Nore pearl mussel, it is a hard water form of the freshwater pearl mussel. It does not occur outside of Ireland, where it is now only found in the main channel of the River Nore
White-clawed crayfish	*Austropotamobius pallipes* (Lereboullet, 1858)	II	Occurs in small and medium-sized lakes as well as rivers and streams; this is considered to be due to the lack of competition from other crayfish species
Sea lamprey	*Petromyzon marinus* Linnaeus, 1758	II	Adult lamprey migrate in spring into freshwater to excavate redds or spawning nests in gravelled areas of large rivers
Brook lamprey	*Lampetra planeri* Bloch, 1784	II	Breeds and spawns in freshwater rivers and streams
River lamprey	*Lampetra fluviatilis* (Linnaeus, 1758)	II	Non-parasitic and non-migratory as an adult, lives its entire life in freshwater
Killarney shad	*Alosa fallax killarnensis* Regan, 1916	II	Unique to Ireland and is only known from Lough Leane in Killarney
Allis shad	*Alosa alosa* (Linnaeus, 1758)	II	This species enters freshwater to breed, with significant penetration of large rivers reported on the continent. There is some evidence of Allis shad entering Irish rivers, with one fish recorded some 40 km from the sea on the Slaney. However, only a small number of Allis shad have ever been recovered from Irish freshwaters and there is no concrete evidence for breeding populations. No juveniles have been found in Irish rivers systems and so it is assumed that the Allis shad is an opportunistic spawner in Irish waters and is considered a vagrant
Twaite shad	*Alosa fallax* Lacépède, 1800	II	Spends most of its life in estuaries and coastal waters, but migrates upriver to spawn in late spring. Spawning has been confirmed only in the major river systems of the south-east and even there only limited evidence exists for any recent spawning outside the Barrow and the Blackwater
Atlantic salmon	*Salmo salar* Linnaeus, 1758	II	Uses rivers to reproduce and as nursery areas. The Irish population generally comprises fish that spend two winters (small numbers spend one or three winters) in freshwater before going to sea, in spring, and smolts measure around 10–25 cm in length. Individuals return to freshwater after 1 to 3 years at sea before returning to freshwater to breed
Natterjack toad	*Bufo calamita* (Laurenti, 1768)	IV	Males take up residence in traditional breeding ponds where, in the evenings, they call to females. Eggs are laid in strings. In warm weather, tadpoles can develop quickly and emerge onto land within 8–10 weeks. The toad is adapted to temporary water bodies; while dry years lead to mass mortalities of tadpoles, good years can see thousands of juveniles emerge successfully
Otter	*Lutra lutra* (Linnaeus, 1758)	II	Populations are found along rivers, lakes and coasts, where fish and other prey are abundant, and where the bank-side habitat offers plenty of cover

Source: NPWS (2013).

5 Current Status of Irish Freshwaters

The WFD (2000/60/EC) requires EU Member States to categorise water quality on a five-point ecological status scale of high, good, moderate, poor and bad. It also requires that Member States identify and protect water bodies that have been minimally impaired (at high status) by anthropogenic pressure. The latest report on the status of Irish freshwaters by Bradley *et al*. (2015) highlights how the health and quality of groundwater and surface water in Ireland is among the best in Europe. However, there are still many issues in bringing all waters up to a satisfactory level, in addition to protecting the waters already at good or high status. Some 48% of rivers and 57% of lake water bodies assessed have been rated as impacted (Table 5.1). In contrast, only 1% of groundwater bodies are at poor chemical status (Table 5.1). Artificial and modified water bodies such as the Grand and Royal Canals and the canalised section of the Shannon–Erne Waterway achieved good ecological potential and were compliant with all water quality standards. However, the ecology of the canal was compromised by its hydromorphology (i.e. box-shaped profile), which limits the development of macrophyte and macroinvertebrate communities. Six of the nine monitored lake HMWBs were at maximum or good ecological potential (Bradley *et al*., 2015).

5.1 Trends in High Status Sites

The historical low intensity land use and low density human population means that Ireland had, until recently, a large number of high status water bodies (Irvine *et al*., 2011). However, White *et al*. (2014) highlighted that, between 1998 and 2006, the percentage of high status monitored sites decreased from 41%, of all sites monitored (approximately 1800 sites nationally), to 31% in 2004 to 2006, an approximate degradation of 210 high status river sites. In the current reporting period, the number of the highest quality "Q5" sites continues to decline [from 38 (2007–2009) to 27 (2010–2012)]. High status rivers are considered to have a high (healthy) ecological status with largely undisturbed conditions and they reflect natural background status or show only a minor distortion by anthropogenic influences (White *et al.,* 2014). Therefore, they tend to occur in areas with low intensity agriculture [i.e. associated with low inputs of nutrients and sediment (Irvine *et al*., 2011; White *et al*., 2014) and represent the best quality habitat, which is important for the protection of sensitive species, such as juvenile salmonids and the endangered freshwater pearl mussel (*M. margaritifera*), but also in maintaining high levels of aquatic biodiversity (White *et al*., 2014). One of the driving principles behind conservation of biodiversity and protection of high status sites is that it will ensure that the ecosystem functions, which in turn secures the sustainable provision of ecosystem services, ultimately benefiting society (Naeem *et al*., 2012). Several studies have highlighted how protected areas can supply higher levels of some regulating (e.g. erosion control, water-flow maintenance and water quality) and cultural (e.g. aesthetics, education and tourism) services than non-protected areas (e.g. Maes *et al*., 2012; Castro *et al*., 2015; Eastwood *et al*., 2016).

5.2 Pressures on Irish Freshwaters

Worldwide, freshwaters are probably the most endangered ecosystems and, in general, are under a multitude of pressures as outlined in Figure 5.1 (Dudgeon *et al*., 2006). These pressures include

Table 5.1. Summary of WFD water quality status for groundwater (chemical status) and surface waters (ecological status) during 2010–2012

Status of Irish waters (2010–2012)	High	Good	Moderate	Poor	Bad
Groundwater (% area) (interim status)	n/a	99	n/a	1	n/a
Rivers (% water bodies)	11.8	41	28.6	17.9	0.7
Lakes (% water bodies)	11	32	33	15	9

n/a, not applicable.

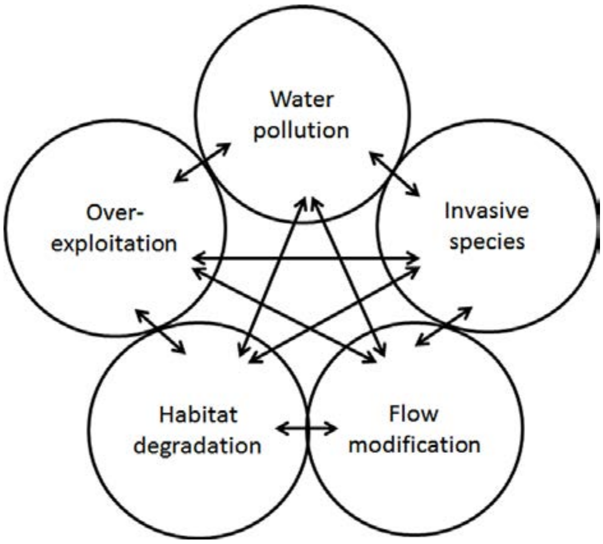

Figure 5.1. The five major threats (and their interactions) to freshwater ecosystems worldwide, according to Dudgeon *et al*. (2006).

overexploitation (e.g. abstraction), water pollution (e.g. nutrient enrichment), flow modification, destruction or degradation of habitat (hydromorphological change) and invasion by alien (invasive) species (Dudgeon *et al*., 2006). In Ireland, anthropogenic activities, relating to agricultural practices and urban wastewater discharges to receiving water, continue to result in the loss of nutrients to associated waters (see section 5.2.1 for further details) and the declining status of our freshwaters (White *et al*., 2014; Bradley *et al*., 2015). The dramatic decline in numbers of high status sites (see section 5.1) suggests that small-scale intensification and other, quite localised, impacts are continuing to affect the status of Irish freshwaters (White *et al*., 2014). In relation to high status sites, the input of low concentrations of phosphorus will have a much more damaging impact on the ecology than the same addition to systems that have already been influenced by nutrient enrichment (White *et al.,* 2014) (see section 5.2.1 for more details). Similarly, small increases in sediment and silt inputs (see section 5.2.2), hydromorphological pressures or priority substances (e.g. pesticides; see section 5.2.5) will have a disproportionate impact on a high status system relative to the impact of the same input to an already degraded system. Nevertheless, these pressures, namely nutrient enrichment, increased sediment load, alterations in drainage and chemical pollution (e.g. White *et al*., 2014), as well as acidification (i.e. low pH) from conifer forestry in areas with low buffering capacity (e.g. Kelly-Quinn *et al*., 1996, 2008; Feeley *et al*., 2011, 2013; Feeley and Kelly-Quinn, 2014; Harrison *et al*., 2014), can alter aquatic ecology, biodiversity and salmonid survival in all water bodies, depending on the magnitude of the pressure. Other anthropogenic reasons for poor chemical status and general degradation of Irish freshwaters relate to historical contamination from mining activities, industrial development, urbanisation, tourism and other factors, such as climate change-related hydrological change and habitat limitations, and the presence of alien species (e.g. zebra mussel, Asian clam, curly waterweed; see section 5.2.6 for more details), especially in lakes, canals and other slow-moving waters. Tables 5.2 and 5.3 provide examples of drivers, pressures and issues in Irish freshwater catchments, as highlighted by Irish water resource management bodies and stakeholders.

5.2.1 Nutrient enrichment

Bradley *et al*. (2015) indicated that elevated nutrients are the single largest factor in water quality degradation in Ireland. For example, of the 11 groundwater bodies at poor chemical status, three were at poor chemical status due to phosphate contribution to rivers (Bradley *et al*., 2015). In rivers, the two most important suspected causes of pollution are agriculture and municipal sources, which account for 53% and 34% of cases, respectively (Bradley *et al*., 2015). More worryingly, in the future, nutrient pressures are likely to increase with the planned expansion in the agricultural sector (e.g. Food Harvest 2020 and Food Wise 2025; DAFM, 2010, 2015) and the increased nutrient loadings to waters from municipal wastewater discharges due to projected population growth and other factors (Bradley *et al*., 2015).

Nutrients occur in two forms: organic and inorganic. Organic forms are the source of most pollution problems in water bodies and originate from both animal (e.g. livestock) and human waste, and to a lesser extent plant debris. Inorganic fertilisers that are not taken up by plants are also a major direct source of nutrient input. Phosphorus and nitrogen are the principal nutrients. Under natural conditions, these nutrients are usually scarce and are quickly assimilated by biological activity. This primary productivity provides the base to a food chain that supports higher order taxa, such as fish, birds and mammals, of ecosystem services value. The removal of nutrients by aquatic flora and fauna represents an ecosystem service (see section 7.2.1) and, under natural conditions, is sufficient to maintain a high level of water quality. However, these conditions can be rapidly undermined by excess nutrients, although other communities of existing and replacement species may continue to contribute to providing an ecosystem service by reducing nutrient levels. In freshwaters, excess nutrients lead to the rapid growth of plants and, in particular, algae. Oxygen depletion occurs at night when photosynthesis ceases and the respiration of excessive plant biomass exceeds the re-oxygenation rate from the atmosphere. Oxygen depletion may also occur when these algae are decomposed by microorganisms, especially in the hypolimnion of lakes.

Nutrient pollution can originate from point sources and diffuse sources. Two of the principal point sources in Ireland are from urban wastewater treatment plants (WWTPs) and IPPC (International Plant Protection Convention) registered agribusiness or industrial facilities. The latter includes certain manufacturing plants, pig farms, poultry farms, pharmaceuticals businesses and extraction businesses. Non-point sources include septic tanks and run-off from agricultural and urban areas. In some counties, such as Roscommon and Cavan, around half of rural households depend on septic tanks, with the figure being as high as 80% in some areas. To function properly, septic tanks must be regularly emptied; however, this is thought to be done by less than one-third of households (DEHLG, 2000). The waste should be transported to a WWTP, although much is informally spread onto farmland along with animal slurry. As highlighted by Bradley *et al*. (2015), agriculture is also a significant contributor to both point and diffuse nutrient pollution in Ireland and is discussed in “Agriculture”.

Table 5.2. Significant water management issues in Irish freshwaters, as highlighted by DECLG (2015)

Societal factors
Affordability and prioritisation
Public engagement
Organisational co-ordination
Co-ordination of plan implementation
Land use planning and water
Floods and water
Biodiversity management and water
Environmental pressures
Pollution from nutrient enrichment
Water and health
Fine sediment
Physical changes
Abstractions and flows
Hazardous chemicals
Climate change
Invasive alien species
Loss of high status waters

Wastewater treatment[2]

There are 530 licensed WWTPs serving catchments of over 500 population equivalent (pe) and there are at least another 1000 certified WWTPs for agglomerations below 500 pe (as of July 2015). Of the former, 83% discharge to a freshwater environment, 8% to a transitional environment and 9% to coastal waters. In 20% of cases, this is to a “sensitive environment”, namely one that is already eutrophic or polluted and in need of protection from further nitrogen and/or phosphorus inputs (O’Neill *et al*., 2016).

Primary treatment typically involves only gravity separation of solids. Secondary treatment involves the biochemical removal of organics that would otherwise impact adversely on the environment. However, different levels of secondary treatment have

2 Most of the information in this section comes from data and discussion with the Environmental Protection Agency and Irish Water.

Table 5.3. Summary of drivers and pressures on Irish freshwaters and ecosystem services listed by the stakeholders at the ESManage workshop at University College Dublin, August 2015

Drivers	Pressures
Agriculture/agri-policy (e.g. Food Harvest 2020 and Food Wise 2025)	Nutrients (e.g. increase in stocking densities)
	Sediment/erosion
	Various other pollutants [e.g. pesticides, (cypermethrin) sheep dipping, etc.]
	Water abstraction
	Physical habitat damage
	Habitat loss (e.g. infilling of wetlands)
	Hydromorphological change
	Pathogens (e.g. *Cryptosporidium*)
Food production industry	Water demand
	Wastewater
	Fish lice
Human habitation/urbanisation	Inadequate wastewater treatment
	Septic tank legacy issues
	Municipal waste
	Water demand/population growth
	Physical habitat damage
	Road/hard/artificial surface run-off/discharge (range of pollutants)
	Various other pollutants (e.g. micro/nano plastics)
	De-icing of growing road network
	Illegal dumping
	Disease potential (e.g. trihalomethanes)
	Habitat loss
	Hydromorphological change (e.g. flood defences, HEP, etc.)
Climate change	More intense flooding/precipitation
	Changes in temperature regimes
	Physical habitat damage
	DOC release (i.e. coloured water/carbon loss)
Forestry (and its operations)	Nutrients
	Sediments
	Various chemicals
	Hydromorphological change (e.g. catchment water balance)
	Carbon loss (DOC in water)
Mining	Sediment/erosion
	Physical habitat damage
	Various pollutants (e.g. tailings)
Invasive/alien species	Ecosystem changes
Tourism/recreation	Water demand
	Physical habitat damage
	Recreational infrastructure (e.g. irrigation of golf courses)

DOC, dissolved organic carbon; HEP, hydroelectric power.

different levels of effectiveness and a basic secondary treatment may lead to higher labile nutrients with an associated eutrophication risk. Disinfection to kill pathogenic bacteria may be used primarily to protect human health and is normally applied in plants that have higher than primary treatment, in particular where shellfish or bathing waters will probably be impacted. Ultraviolet (UV) disinfection is most effective where effluent is relatively clear with low suspended solids and colour. Under natural conditions, particularly in well-oxygenated waters, harmful bacteria are killed off by predation or sunlight. The former represents an ecosystem service, particularly as regards human health.

Further treatment may be required to remove a higher proportion of nitrogen or phosphorus. At present, only 3% of registered plants now provide only primary treatment, whereas 40% provide secondary treatment, 51% provide tertiary removal of phosphorus and 6% provide tertiary removal of both phosphorus and nitrogen. In 2000–2001 only 21% of Ireland's WWTPs had secondary treatment.

The removal of algae presents a significant cost for wastewater treatment in itself. Nitrogen can contribute to eutrophication and some forms can be toxic to aquatic fauna, particularly in the transitional or marine environment. Unionised ammonia is toxic when concentrated, but is relatively inexpensive to remove. The more environmentally troublesome nitrates require higher levels of treatment. In comparison, phosphates have a more significant impact on freshwater resources, although many transitional waters around the coast are also phosphate limited. Phosphate discharges have reduced in many catchments due to improved agricultural practice. Nitrate concentrations have also decreased, but to a lesser extent.

In the latest national wastewater report (EPA, 2016a) 10 of 171 large urban areas did not meet national and EU requirements to provide secondary treatment, with a total 45 wastewater works linked to river pollution. While this was a reduction from 56 in 2009, untreated wastewater from 43 areas was routinely discharged into our rivers, estuaries and coastal waters (EPA, 2016a), highlighting an ongoing significant problem with wastewater and its treatment in Ireland. Another major challenge for wastewater treatment is the country's capacity to deal with storm water flows (EPA, 2016a). Few of Ireland's drainage or sewage systems separate wastewater from storm water run-off. When rainfall is heavy, too much water enters these combined sewers, with the result that influent to WWTPs would be diluted and treatment processes would fail. Consequently, much drainage water is diverted through combined sewer overflows at these times. The Department of the Environment, Community and Local Government [DECLG; now Department of Housing, Planning, Community and Local Government DHPCLG)] has requirements for storm water, which, in principle, should be held in holding tanks, but is frequently discharged directly to watercourses. Significant investment will be needed to separate sewage systems from storm water run-off. Storm water outflows (SWOs) are mapped in the EPA's geographical information system (GIS) and WWTP annual environmental reports (AERs) are required to include assessments of these (e.g. the frequency and quantity of discharge). However, the full extent of the problem is unknown and reliable data are not expected for another 4 years.

Domestic septic tanks[3]

Septic tanks are required to meet certain standards and are now being inspected under the Domestic Waste Water Treatment System inspection regime. As of February 2014, 53% of sampled households failed their first inspection. The high rate of failure reflects the absence of previous implementation measures, the simple construction of many tanks, the old age of others and prolonged lack of maintenance. Householders are allowed to avail themselves of grants towards a proportion of the cost of new facilities or an upgrade, but for many there will be a need to install new facilities and the balance will still represent a substantial sum. Conformance will probably take some time because of a continuing reluctance among some people to register their tanks, although the EPA is working on new communication strategies. Inspections are targeting the most vulnerable areas in the first instance.

Agriculture[4]

Most true non-point or diffuse pollution in Ireland derives from agricultural practices. Diffuse agricultural

3 Most of the information in this section comes from data and discussion with the EPA and Irish Water.

4 Most of the information in this section comes from data and discussion with the EPA and Irish Water.

pollution is associated with livestock farming, the spreading of winter slurry and the leaching of fertilisers from intensive grassland. Both grazing and slurry spreading are, in principle, subject to a National Code of Good Practice. Millions of tonnes of slurry from livestock require spreading each year (Carton and Magett, 1999; Hennessy et al., 2011). On average, the nutrient value of cattle slurry is 15% nitrogen, 17% is phosphorus and 68% is potassium, amounting to an annual discharge of 146,000 tonnes, 22,450 tonnes and 126,000 tonnes, respectively, across Ireland. Pig slurry is more nutrient concentrated and contains, on average, 43% nitrogen, 22% phosphorus and 35% potassium.

Dairy farms tend to be more intensive with higher livestock densities than other grass-based systems, and in turn must apply higher levels of phosphorus and have higher farm phosphorus imports in feed and fertiliser, thus becoming a greater nutrient source pressure (Murphy *et al*., 2015). It is argued that Ireland has the capacity to accept these additions of nutrients, given that they are taken back up by animals in grazing fodder. However, this requires farmers to balance their application of nutrients carefully. Most dairy or beef farms include areas for summer grazing and winter silage. Most slurry, around 60%, is spread back onto land. There may be some top-up fertilising during the winter, especially for dairy farms, but as milk and meat are exported through the farm gate, significant amounts of phosphorus and nitrogen leave the farm. This outflow should be replaced with input from artificial fertiliser, but balancing of inputs and outputs is vulnerable to some losses that occur via diffuse pathways to watercourses. Pig slurry is more problematic in that it is not linked to the area of land used to produce the feedstuffs. This slurry is typically exported to beef and sheep farms and amounts to 652,000 tonnes and 25,500 tonnes per annum (in 2009), respectively, of slurry and farm-yard manure (Hennessy *et al*., 2011). Larger pig and poultry units are subject to IPPC licences.

Commercial forestry

In Ireland, the recent HYDROFOR project (Kelly-Quinn *et al*., 2016) highlighted the role of commercial plantation forestry operations in nutrient loss to Irish freshwaters (Figure 5.2). This research indicated that tree harvesting and windrowing, in preparation for replanting, resulted in elevated episodic inputs of nutrients (mainly phosphorus) and sediment to watercourses that exceeded water quality standards, with the largest releases near the end of the operations (Drinan *et al*., 2013; Finnegan *et al*., 2014b; Clarke *et al*., 2015; Kelly-Quinn *et al*., 2016). The transportation of nutrients is typically associated with elevated levels of sediment, heavy metals and dissolved organic carbon (DOC), which in turn reduces

Figure 5.2. Felling operations in the Annalecka Brook catchment, Co. Wicklow (photograph: Hugh Feeley, UCD).

concentrations of dissolved oxygen and increases the toxic effects on freshwater biodiversity. Sediment (section 5.2.2) and DOC (section 5.2.4) are discussed further below.

5.2.2 Sediment

Natural erosion processes transport small quantities of sediment into freshwaters systems on an annual basis and are essential physical processes that promote the development of habitats and transport of nutrients, providing healthy, functioning freshwater ecosystems. However, anthropogenic activities are known to markedly increase this load (e.g. Cocchiglia *et al*., 2012). Cattle access to streams (Figure 5.3) is one of the localised contributors of elevated sedimentation of Irish streams and rivers (Bradley *et al*., 2015; Kibichii *et al*., 2015; Conroy *et al*., 2016), especially owing to

Figure 5.3. Overwintered cattle along the Boycetown River, Co. Meath, drinking directly from river in foreground, while in the background a very heavily poached field is clearly visible (top) and cattle with direct access to the Yellow River, a tributary of the River Boyne. The bankside is clearly impacted by erosion (bottom) (photographs: Liz Conroy, UCD).

the extensive network of small streams (74,000 km or 77% of the river network; McGarrigle, 2014) and known interaction between livestock and these systems in Ireland. Kibichii *et al*. (2015) highlighted noticeable trampling of the bankside and soil compaction by livestock and machinery along rivers, which can have a significant effect on the hyporheic fauna. Evans *et al*. (2006), on the other hand, found that bank erosion, as a result of livestock poaching and farm machinery, led to the compaction and addition of large amounts of fine sediments (between 0.196 and 4.98 tonnes per year) to associated waterways, increasing the bedload by up to 60%. Sediment loss is also a problem with tillage farms and following forestry operations such as harvesting and windrowing (Finnegan *et al*., 2014a; Clarke *et al*., 2015; Kelly-Quinn *et al*., 2016). The loss of excess sediment increases the risk of impact on aquatic ecology, especially the survival of salmonid eggs and alevins (e.g. Cocchiglia *et al*., 2012), and micro- and macroinvertebrates (e.g. Kibichii *et al*., 2015; Conroy *et al*., 2016); this will have knock-on effects on the delivery of freshwater ecosystem services (e.g. fish angling, decomposition, nutrient cycling, visual aesthetics, etc.). Increased sedimentation can also lead to physical impacts, e.g. river and stream channels can become "clogged", while lake depth can be reduced, which would potentially affect navigation, increase erosion and flooding, and reduce habitat for biota within a catchment.

5.2.3 Water abstraction

Domestic and non-domestic

Other anthropogenic pressures, such as water abstraction (see Figure 5.4), can potentially lead to reduced water quality. In Ireland, 81.5% of drinking water is sourced from surface water (i.e. river and lakes), while 11.5% is sourced from groundwater and 7% is sourced from springs (EPA, 2014a; EPA, 2016b). Exact figures are difficult to source; the data sources used to compile the maps in Figure 5.3 are given in Table 5.4. Regionally, there is considerable variation, for example groundwater sources in County Roscommon supply 75% of its total water consumption (EPA, 2007). Currently two out of 336 groundwater bodies were classified at poor quantitative status due to impacts of water abstractions. In Ireland, more than 1.7 million litres of drinking water are treated per day (584 million litres per year) (Ervia, 2015), which is well below the estimated domestic usage in Ireland at 111.4–125.5 litres per head per day (Irish Water, 2015a).

Non-domestic water use (excluding non-tillage agriculture – see "Dairy and livestock agriculture") includes using water for purposes such as tillage farming and food production, product manufacturing (e.g. computer chip manufacturing), product processing (e.g. paper, chemicals, etc.), washing, diluting, cooling and sanitation within the manufacturing industries. Even within other less obvious industries, some elements of non-domestic usage can be very water intensive (e.g. car-wash services and swimming pools). Recent non-domestic demand for water in the east of the country (Counties Dublin, Kildare and Wicklow) was estimated at 126.5 million litres per day (46.2 billion litres per year) and is projected to reach between 142 and 146 million litres per day (51.8 and 53.3 billion litres per year) by 2026 under various scenarios (Irish Water, 2015a).

Dairy and livestock agriculture

The abstraction of water for drinking by livestock in Ireland is also significant, although national figures are currently unavailable. As of June 2015, the number of cattle in the country stood at just under 7 million (4.719 million female cattle and 2.244 million male cattle) (CSO, 2015). Of these, 1.3 million cattle are in dairy production. The amount a cow will drink depends on the yield of milk, but in general dairy cows drink up to a total of 140 litres of water per cow per day (Kavanagh, 2015), which equates to a total of over 66.4 billion litres of water per year. Other non-dairy cattle drink approximately 20 litres of water per day (Kavanagh and McGee, 2015) which equates, conservatively, to 41.6 billion litres in total per year. While a proportion of livestock water use is accounted for in domestic and non-domestic water usage, the majority of it is not; this is a result of cattle accessing waterways via banksides. Several studies have highlighted the high potential for interaction between livestock and surface water in Ireland (e.g. Conroy *et al*., 2016). In addition to current estimates, meeting the ambitious agriculture growth targets (e.g. Food Harvest 2020 and Food Wise 2025; DAFM, 2010, 2015) will put additional pressures on freshwaters in the future, especially on abstraction for livestock production (Figure 5.4).

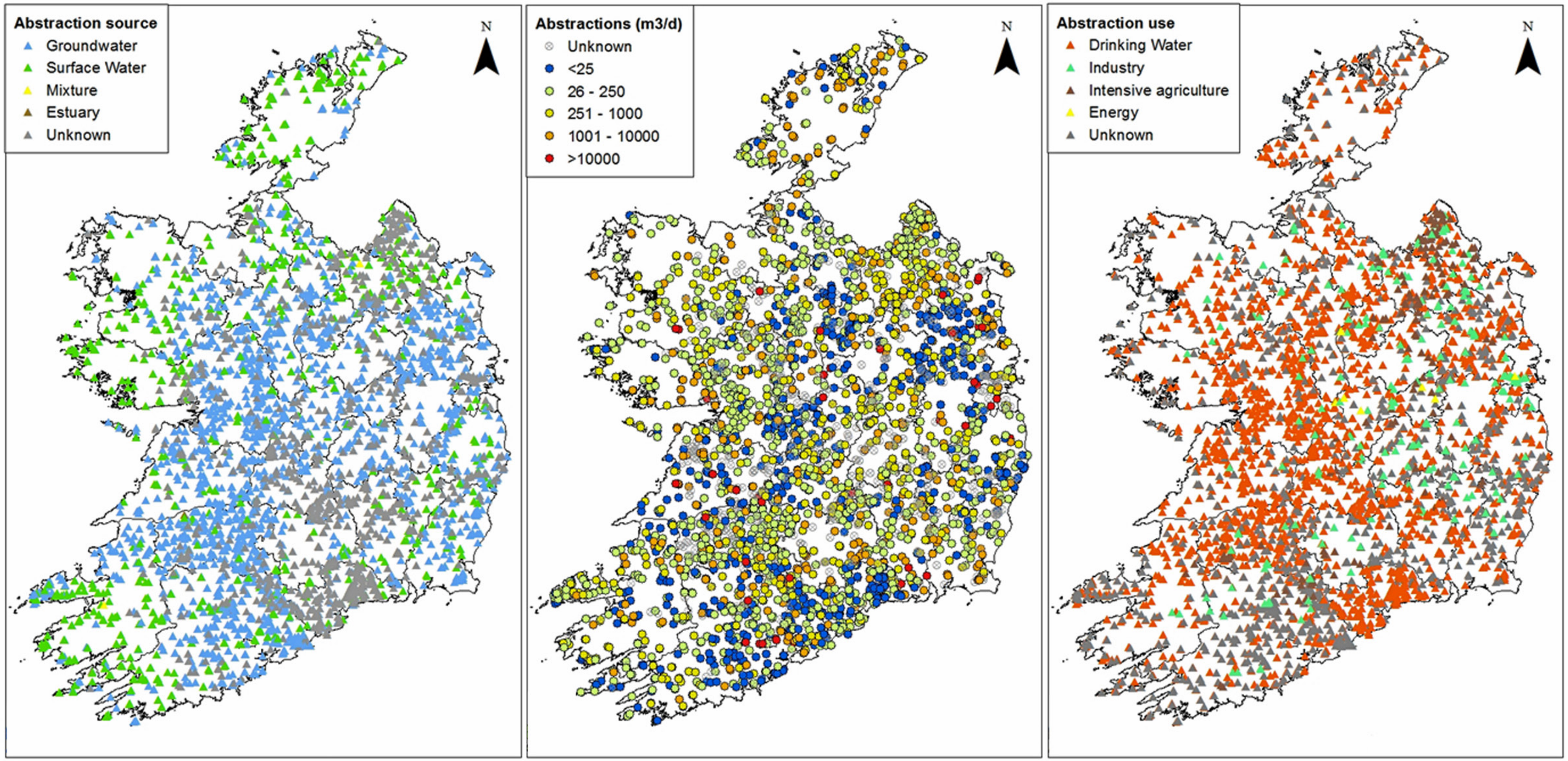

Figure 5.4. Freshwater abstraction in Ireland. Source: Webster *et al*. (2017)

Table 5.4. Sources, features and limitations of data used to compile the maps in Figure 5.3 by Webster *et al*. (2017)

Layer name	Source	Features	Limitations
National abstraction inventory	DECLG	Good national summary	Many abstractions unknown; often no XY data
Catchments team SE pilot project	EPA	Regional register including different sources	Many abstractions unknown; often no XY data
IPPC register	EPA	Includes industrial abstractors	Abstraction information is rare; proxy data in licence documents; time consuming
Power generators	ESB/IPPC	Includes abstractions for power generation	Abstraction (proxy) data is limited to licence details; limited XY data
GIS abstractions	EPA	National coverage	No abstraction information; unknown source
CDM national abstraction register	EPA/GSI	National register including different sources	Many abstractions unknown; now out of date
Irish Water Public Water Supply	Irish Water/GSI	Most up to date Public Water Supply data set	Many abstractions unknown
National Federation of Group Water Schemes	NFGWS/GSI	Most up to date Group Water Scheme data set	Many abstractions unknown; limited dataset
Other projects:			
EPA catchments team National Abstraction and Discharge Project			
Department of Environment Abstraction Working Group			
Irish Water Abstraction Project			

CDM, Camp Dresser and McKee; ESB, Electricity Supply Board; GSI, Geological Survey of Ireland; NFGWS, National Federation of Group Water Schemes.

5.2.4 Organic matter and carbon loss

DOC is the soluble carbon contained within organic matter (e.g. Koehler *et al*., 2009). Organic carbon derives from many sources including plant litter, root exudates, microbial biomass and soil organic matter, and is an important component of the global carbon cycle (e.g. Meybeck, 1993). The loss of organic material and dissolved organic carbon is associated with organic soils, especially with peatlands. Several Irish studies have highlighted the loss of DOC from Irish freshwaters (e.g. Koehler *et al*., 2009; Burton and Aherne, 2012; Feeley *et al*., 2013; Liu *et al*., 2014) which can range from as low as 1 mg/L to as high as 34 mg/L. In addition, both Burton and Aherne (2012) and Feeley *et al*. (2013) have highlighted the increases in DOC loss to freshwaters in Ireland, which is in line with findings elsewhere (e.g. Skjelkvåle *et al*., 2003; Davies *et al*., 2005; Monteith *et al*., 2014). While the cause is still being debated, the most likely driver is climate change (e.g. Clark *et al*., 2005; Evans *et al*., 2005), as well as changes in hydrology (i.e. lowering of the water table) and changes in land use (i.e. peatland to conifer forest plantation) (Evans *et al*., 2005; Feeley *et al*., 2013). The consequences of increased DOC loss in freshwaters is lower pH, higher colour and increased trihalomethanes (THMs) in treated water (described in "Organic matter in Irish drinking water"), which will directly affect aquatic ecology (e.g. decomposition and fish recruitment), drinking water quality, human health (see "Organic matter in Irish drinking water") and the associated ecosystem services. Similarly, the loss of carbon from peatland wetlands has implications for the regulation of climate (e.g. Wilson *et al*., 2016). Rewetting, which is described as the deliberate action of raising the water table on drained soils to re-establish water saturated conditions, is considered an important climate change mitigation tool to reduce emissions and create suitable conditions for carbon sequestration (Wilson *et al*., 2016).

Organic matter in Irish drinking water

One of the most important ecosystem services provided by Irish freshwaters is safe drinking water. Elevated natural organic matter (NOM) is one of the main sources of environmental pollution to surface drinking water supplies in Ireland (e.g. EPA, 2014a).

During the drinking water treatment process, NOM contributes to the fouling of membranes, serves as a precursor for the formation of disinfection by-products and increases the exhaustion and usage rate of coagulant and disinfectant dosages (O'Driscoll, 2016). Disinfection by-products (DBPs) are formed when natural water is treated to control microbial presence during the drinking water treatment process. They are the most prominent class of DBPs in treated water (O'Driscoll, 2016). THMs are by-products of the chlorination (i.e. disinfection) process (EPA, 2014b) and have been identified as a potential health hazard as a result of their possible carcinogenic properties and possible impacts on reproductive outcomes (EPA and HSE, 2011). THMs are formed when chlorine reacts with NOM. In recent years, successive EPA reports (e.g. EPA, 2014b) have shown that an unacceptably high number of drinking water supplies exceeded the EU Drinking Water Regulations (2014; S.I. No. 122/2014) parametric value of 100 μg/L for THMs (e.g. EPA and HSE, 2011), while many more drinking water supplies recorded total organic carbon levels above 2 mg/L, suggesting a risk of THM formation (O'Driscoll, 2016). Recently, the EPA (2016b) found that THMs exceedance in drinking water supplies occurred in 59 supplies nationally.

5.2.5 Pesticides

In Ireland, pesticides (see Table 5.5 for more details) can enter surface or groundwater bodies via direct application, run-off, spray drift, volatilisation, by seeping through soils or through spillage and leakage (EPA, 2013). Pesticides and their metabolites can

Table 5.5. Current common pesticides legally used in Ireland

Substance name	Use/function
Chlorothalonil	Fungicide
Bentazone	Contact herbicide
Bromoxynil	Herbicide
Chlorpropham	Herbicide and plant regulator
Chlorotoluron	Herbicide
Clopyralid	Herbicide
Cypermethrin	Insecticide
Deltamethrin	Insecticide
Demeton-*S*-methyl	Acaricide and insecticide
Diuron	Herbicide
Epoxiconazole	Fungicide
Fenvalerate	Insecticide
Glyphosate	Broad-spectrum herbicide used in both agriculture and forestry and for aquatic weed control
Isoproturon	Selective, systematic herbicide used in the control of annual grasses and broad-leaved weeds in cereals
MCPA or 4-(2-methyl-4-chlorophenoxy) acetic acid	Post-emergence herbicide
Mecoprop	Herbicide
Metaldehyde	Molluscicide used against slugs, snails and other gastropods. Usually in the form of pellets for ingestion
Pendimethalin	Herbicide
Propyzamide	Herbicide
Terbuthylazine (TBA)	Herbicide used for pre-emergence and post-emergence treatment of a variety of crops in agriculture and forestry
Triazines	Herbicide used for weed control
Triclopyr	Herbicide
2,4-D (2,4-dichlorophenoxyacetic acid)	Systematic herbicide used for the control of broad-leaved weeds, including aquatic plants
2,4-DB (2,4-dichlorophenoxybutyrio acid)	Herbicide

Adapted from EPA (2013).

enter freshwaters in solution, emulsion or by being bound to soil particles and can originate from agriculture, forestry, horticulture and recreational areas, such as golf courses, residential gardens, parks and sports pitches; the use of pesticides on hard surfaces (e.g. roadside verges) can be an important pathway for entry into surface waters (EPA, 2013). One of the most toxic pesticides in use in Ireland is the active ingredient cypermethrin, a synthetic pyrethoid, which is used in sheep dip and in forestry. This pesticide is extremely toxic to aquatic environments (SWAN, 2014). Many studies have highlighted its toxic effects on aquatic biota (e.g. invertebrates, fish, amphibians) (Saha and Kaviraj, 2008; Antwi and Reddy, 2015) and it has been associated with the degradation of some previously high status rivers in Ireland (SWAN, 2014). In addition to sheep dip, this pesticide is associated with commercial forestry and has, up until recently, been sprayed on young trees (post planting) and on dipping saplings (pre-planting) to prevent and control pine weevil attack on non-native spruce and pine trees. In 2015, Coillte issued a consultation document on derogation for its continued use in forestry in Ireland (Coillte, 2015) and the Forest Stewardship Council (FSC) granted a new 5-year licence to use cypermethrin up to March 2021. Its use in forestry may affect associated waterways (http://www.irishexaminer.com/ireland/coillte-facespressure-over-hazardous-pesticide-348951.html). More recently, the pesticide MCPA [4-(2-methyl-4-chlorophenoxy) acetic acid] has emerged as a significant water quality issue, while 61 public water supplies detected pesticide exceedances in 2015, a significant increase on the 28 supplies in which pesticide exceedances were reported on in 2014 (EPA, 2016b).

5.2.6 Invasive species

Aquatic invasive species (Figure 5.5) have a wide range of impacts on aquatic biodiversity and ecosystem services (Charles and Dukes, 2007; Gillardo and Aldridge, 2013; Katsanevakis *et al.*, 2014). Ireland's freshwaters already host several invasive species (examples of invasive species and ecosystem services most at risk are available in Table 5.6), potentially affecting a wide range of ecosystem services, from habitat provision to bio-accumulation of nutrients and from hazardous substances to recreation, tourism and cultural heritage (Charles and Dukes, 2007). A list of potential threats from non-native taxa is available in Table 5.7.

Figure 5.5. The invasive curly waterweed (*Lagarosiphon major* (Ridl.) Moss ex Wager) in Lough Corrib. The natural range of this plant is southern Africa (photograph: Hugh Feeley, UCD).

5.2.7 Climate change

Freshwaters are particularly susceptible to the effects of climate change, which is directly associated with changes in seasonal rainfall and temperature patterns. Changes in rainfall patterns affect flow regimes, which in turn affect biodiversity, ecological function and ecosystem services provision (e.g. water abstraction). Examples include the detrimental effect of increased storm flow on stream and river ecology (e.g. Feeley *et al.*, 2012; Woodward *et al.*, 2015), with recovery potentially taking decades (Woodward *et al.*, 2015). Temperature changes similarly affect biodiversity through alterations to invertebrate and vertebrate life histories, ecological function and ecosystem services (e.g. fish for angling). For example, de Eyto *et al.* (2016) highlighted the effect of warm, wet winters, which reduce the survival of freshwater salmonids in the west of Ireland.

Table 5.6. Examples of invasive species in Irish freshwaters and ecosystem services most at risk

Invader types	Example of invader	Scientific name	Associated impact on ecosystems[a]	Examples of ecosystem services at risk[a]	Ecosystem/habitat most at risk
Aquatic plants	Curly waterweed	*Lagarosiphon major (*Ridl.) Moss ex Wager	Significant changes to the ecology of the invaded habitat for native plants, insects and fish	Habitat provision, recreation/ tourism, supporting services	Lakes, wetlands, reservoirs, canals
	Water fern	*Azolla filiculoides* Willd.	Reduction of surface light reaching the benthos	Habitat provision, decomposition, supporting services	Rivers, lakes, wetlands, reservoirs, canals
	Parrots feather	*Myriophyllum aquaticum* (Vell.) Verdc.	Competition with native macrophytes. Clogging of waterways	Flow regulation, flood regulation, recreation/tourism, supporting services	Rivers, lakes, wetlands, reservoirs, canals
Invertebrates	Asian clam	*Corbicula fluminea* (O.F. Müller, 1774)	Competition with native species. Biofouling	Water purification, nutrient regulation, habitat provision, supporting services	Rivers, lakes, reservoirs, canals
	Zebra mussel	*Dreissena polymorpha* (Pallas, 1771)	Fouling, negative impacts on native species and local extinction of unionids	Water purification, nutrient regulation, supporting services	Lakes, reservoirs, canals
	Bloody-red shrimp	*Hemimysis anomala* G.O. Sars, 1907	Alteration of ecosystem dynamics. Competition with native species	Bio-remediation, decomposition, supporting services	Rivers, lakes, reservoirs, canals
Fish	Chub	*Squalius cephalus* (Linnaeus, 1758)	Negative impacts on native salmonid species. Associated economic impacts	Recreation/tourism, heritage, cultural, supporting services	Rivers, lakes, reservoirs, canals
	Dace	*Leuciscus leuciscus* (Linnaeus, 1758)	Negative impacts on native salmonid species. Associated economic impacts	Recreation/tourism, heritage, cultural, supporting services	Rivers, lakes, reservoirs, canals

Source: information taken from Invasive Species Ireland; http://invasivespeciesireland.com/most-unwanted-species/established/freshwater/?pg=1 (accessed 3 May 2016).

[a]Supporting services affected through alterations to competition, top-down and bottom-up trophic pressures and/or habitat change. Alterations to supporting services may have direct and indirect effects on sustainable ecosystem service delivery.

Table 5.7. Potential threats to Irish freshwaters from non-native taxa according to Invasive Species Ireland[a]

Prevalent invader types	Invader	Scientific name	Associated impact on freshwater ecosystems[a]
Aquatic plants	Fanwort	*Cabomba caroliniana* Gray	Competition with native species. Clogging of waterways
	Water primrose	*Ludwigia grandiflora* (Michaux) Greuter and Burdet	Competition with native species
Invertebrates	Fishhook waterflea	*Cercopagis pengoi* (Ostroumov, 1891)	Competition with native invertebrates. Negative impacts on native fish
	Salmonid ectoparasite	*Gyrodactylus salaris* Malmberg, 1957	Serious negative impacts on salmonid stocks
	North American signal crayfish	*Pacifastacus leniusculus* (Dana, 1852)	Detrimental impacts on white-clawed crayfish. Human health impacts
	Quagga mussel	*Dreissena bugensis* Andrusov, 1897	Fouling, negative impacts on native species and local extinction of unionids
Fish	Brown bullhead catfish	*Ameiurus nebulosus* Lesueur, 1819	Negative impacts on native fish species
	Ruffe	*Gymnocephalus cernuus* (Linnaeus, 1758)	Negative impacts on native fish communities
	Topmouth gudgeon	*Pseudorasbora parva* Temminck and Schlegel, 1846	Negative impacts on native fish and vegetation species
	Zander	*Stizostedion lucioperca* (Linnaeus, 1758)	Competes with native fish species. Transmits fish disease and parasites

[a]http://invasivespeciesireland.com/most-unwanted-species/potential/freshwater/?pg=1 (accessed 3 May 2016).

5.2.8 Hydromorphological pressures

Freshwater hydromorphology [i.e. physical characteristics of the shape, boundaries and content of a water body (EU, 2000)] in Ireland is a much under investigated aspect of water quality and WFD to date. In general, good hydromorphological conditions, namely the quantity and dynamics of water flow, connection to groundwater, substrate condition and composition, bankside integrity and connectivity, support aquatic ecosystems by providing the physical habitat for biota such as fish, invertebrates and aquatic flora. Hydromorphological pressures comprise all physical alterations and modifications of shorelines, riparian/littoral zones, water level and flow (except water abstraction) of water bodies, with examples encompassing pressures such as damming, channelisation, embankment and non-natural water level fluctuations (Fehér *et al.*, 2012). In the latest "Water Quality In Ireland 2010-2012" report, Bradley *et al.*, (2015) highlight that the assessment of hydromorphological condition was responsible for the downgrade of four otherwise high status lakes; Doo Lough, Guitane, Nahasleam, and Pollacappul. Similarly, the canalised Shannon-Erne Waterway was classified as less than good due to poor hydromorphological condition (Bradley *et al*., 2015). Hydromorphological pressures in reducing the physical habitat for biota such as fish, invertebrates and aquatic flora potentially affecting a wide range of ecosystem services, from habitat provision to tourism and cultural heritage.

6 Management of Freshwaters in Ireland

There are numerous bodies involved in the management of various aspects of Irish freshwaters (Table 6.1). Interests are wide and range from resource exploitation to resource protection. A list of stakeholders with an interest in Irish freshwaters can be found in Appendix 3.

6.1 WFD Governance

In the first WFD management cycle, the island of Ireland had eight river basin districts (RBDs). Following review, this arrangement was considered overly complex and as a result the number of RBDs has been reduced. The Eastern, South Eastern, South West and Shannon RBDs have been merged into a single national RBD (Figure 6.1). Administrative arrangements are in place to deal with cross-border waters of the North Western and Neagh Bann RBDs and to facilitate co-ordination with authorities in Northern Ireland. The aim is to prepare a single management plan for these international waters that are shared with Northern Ireland.

A new three-tiered governance structure (Figure 6.2) has been established with national oversight led by DHPCLG (formally DECLG), as set out in EU (Water Policy) Regulations 2014 (S.I. 350 of 2015). A Water Policy Advisory Committee (WPAC), with membership from government departments, EPA and other agencies, advise the Minister and facilitate co-ordination across sectors. Technical support, implementation and reporting are the responsibility of the EPA with the assistance and support of local authorities, whereas regional implementation, including implementation of Programmes of Measures (POMs), is to be led by a lead co-ordinating authority in consultation with the EPA. Local authorities, led by the newly established Local Authorities Water and Communities Office (LAWCO), have the role of carrying out and enforcing these measures on the ground. They also have key responsibility for ensuring

Table 6.1. Bodies and organisations involved in water management in Ireland[a]

Body/organisation	Responsibilities
Government bodies	
Department of Housing, Planning, Community and Local Government	WFD governance[b]
EPA	WFD governance[b]
County and City Councils	WFD governance[b]
National Parks and Wildlife[c]	Designation and protection of habitats and species
Office of Public Works[d]	Flood risk management
IFI[e]	Management, protection, conservation, development and improvement of the inland fisheries resource
Waterways Ireland[f]	Management, maintenance, development and restoration of the inland navigable waterways, principally for recreational purposes
Utilities	
Irish Water	Domestic and non-domestic water supply and wastewater services
ESB	Hydroelectric power

[a]As of August 2016.

[b]See section 6.1 for more details.

[c]Under the Department of Arts, Heritage, Regional, Rural and Gaeltacht Affairs.

[d]Under the Department of Finance.

[e]Under the Department of Communications, Climate Action and Environment.

[f]Under the Department of Arts, Heritage, Regional, Rural and Gaeltacht Affairs (DAHRRGA) in Ireland, and the Department for Infrastructure in Northern Ireland.

ESB, Electricity Supply Board.

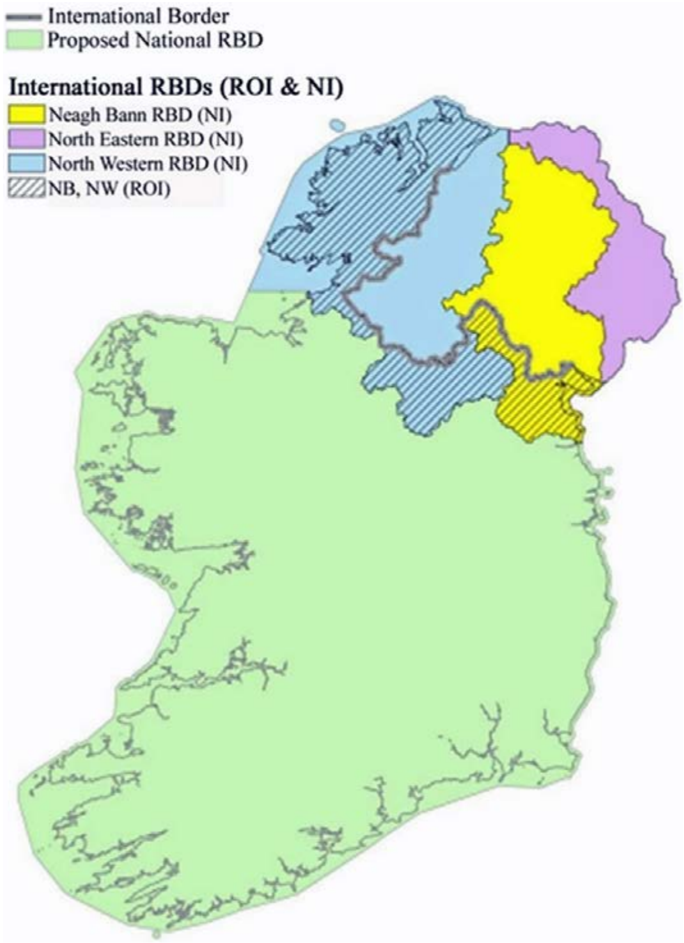

Figure 6.1. Layout of the current RBDs on the island of Ireland. Reproduced from DECLG (2015). NB, Neagh Bann; NI, Northern Ireland; NW, North Western; ROI, Republic of Ireland.

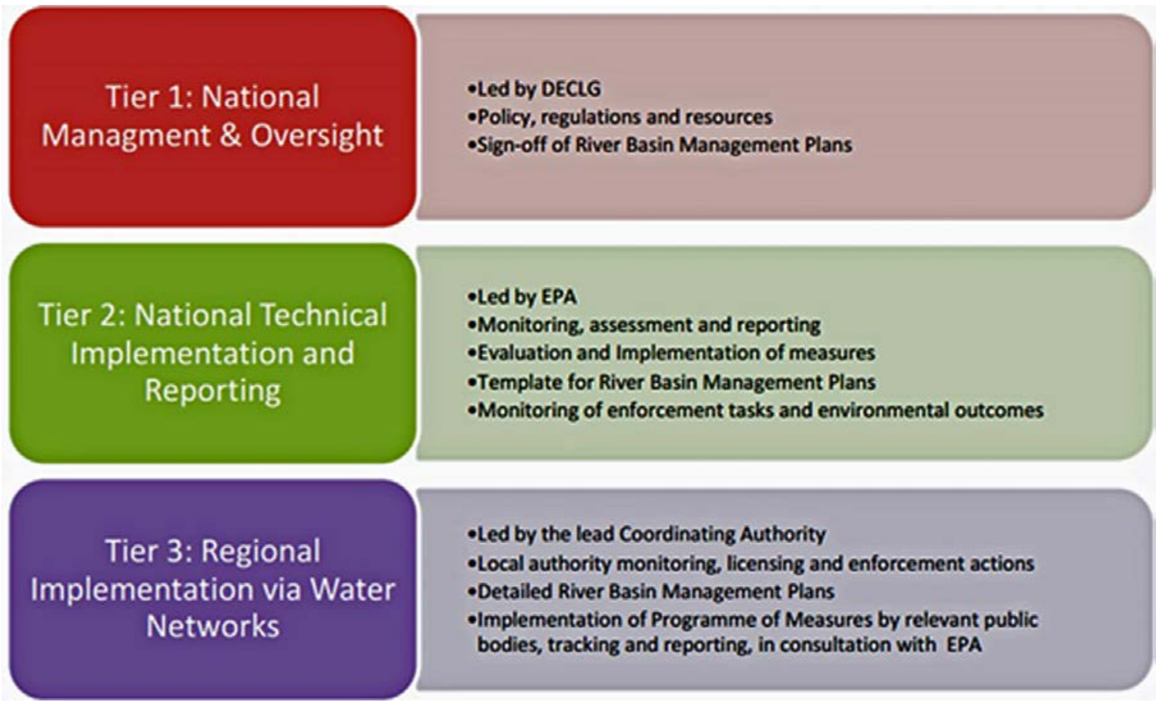

Figure 6.2. New three-tiered governance structure of DECLG (now DHPCLG). Reproduced from DECLG (2015).

effective public participation, including consultation on draft river basin management plans.

A national river basin plan is to be produced in the second WFD planning cycle, with sub-plans at sub-regional scale (DECLG, 2015). The country has been divided into 46 sub-catchments (Figure 6.3) for assessment of pressures and targeting of actions. The EPA has established a WFD Implementation Group and Catchment Management Network. Members of the network include:

- EPA;
- Irish Water;
- 31 local authorities;
- RBDs;
- County and City Management Association;
- DECLG;
- Department of Agriculture, Food and the Marine (DAFM);
- Department of Arts, Heritage, Regional, Rural and Gaeltacht Affairs (DAHRRGA);
- Department of Communications, Climate Action and the Environment;
- Department of Jobs, Enterprise and Innovation;
- Commission for Energy Regulation;
- IFI;
- Marine Institute;
- GSI;
- NPWS;
- Teagasc;
- Health Service Executive (HSE);
- Electricity Supply Board (ESB);
- Office of Public Works;
- Health and Safety Authority;
- Local Government Management Agency;
- Met Éireann;
- regional authorities;
- Northern Ireland Environment Agency (NIEA);
- Waterways Ireland;
- the Heritage Council;
- Tourism Ireland;
- Coillte;
- Bord na Móna;
- Sustainable Water Network (SWAN); and
- the National Federation of Group Water Schemes.

This second planning cycle aims for better integration between the WFD and land use planning, as illustrated in Figure 6.3.

Figure 6.3. Hierarchical structure of river basin management plans and interaction with development plans. Reproduced from DECLG (2015).

7 Identification of Ecosystem Services from Irish Freshwaters

The ecosystem services provided by Irish freshwaters are extensive and currently not well documented. We have undertaken a scoping exercise to identify the range of services derived from the five main categories of water resources using the CICES (2013) framework (see provisioning services in Table 7.2; regulating and maintenance in Table 7.3; cultural services in Table 7.4). In each of these tables, as will be outlined later, we have also attempted to gauge the relative importance of each to beneficiaries (section 7.4). This will aid in the identification of potential ecosystem services for valuation. Much of the data for these compilations have been derived from the information in this report and the ESManage Stakeholder Workshop that was run in September 2015.

7.1 Provisioning Services

7.1.1 Domestic and non-domestic water supply

There are over 58,000 km of mapped water pipelines in Ireland at present (Ervia, 2015). The principal provisioning service is supplying water for drinking and non-drinking purposes, agriculture and industry (Bullock and O'Shea, 2016). In Ireland, both surface water (71%) and groundwater (29%) are used extensively for both domestic and non-domestic water use (Bullock and O'Shea, 2016). More recent figures from the EPA (2014a) state that 81.5% of drinking water is sourced from surface water (i.e. river and lakes), while 11.5% is sourced from groundwater and 7% from springs. The extent, uses and sources of abstraction in Ireland are summarised in Figure 5.3.

In Ireland, 83% of people get their drinking water from 963 public supplies provided by Irish Water, 7% of people are supplied by public or private group water schemes, while 11% of people have their own private well (EPA, 2016b). Recent estimates by Irish Water suggest that each person consumes approximately 150 litres per day, which equates to 54,750 litres per person per year (http://www.water.ie/news/tapping-into-the-water-us/). Urban water demand is estimated to account for approximately 39% of total water use in Ireland (EEA, 1999), although these figures were taken from 1994. Industrial water use (21% of total use in Ireland) is needed to produce goods such as food, paper, chemicals, refined petroleum and primary metals, and is also needed for computer chip manufacturing and brewing. Worldwide, agriculture accounts for over 70% of all water use, with the majority used for irrigation. However, livestock also need to be supplied with water to survive and in some areas this constitutes significant amounts. Farming, as an industry, in Ireland accounts for approximately 15% of the total water use (EEA, 1999). Additionally, the aim of targeting a 50% rise in agricultural output by the year 2020 (Food Harvest 2020; DAFM, 2010) will increase water demand. Another significant user of water is the energy sector (during electricity generation water is used either for cooling purposes or for hydro-power generation), which is estimated to account for 23% of the total water use at present (EEA, 1999). For a more comprehensive review of water usage in Ireland, see Bullock and O'Shea (2016).

The security of the supply of water services is weak in many areas of Ireland. These areas of Ireland are reliant on a single source, treatment plant or storage reservoir and do not have much available headroom (i.e. spare capacity above normal demand) to cater for emergencies, planned maintenance or system failures (e.g. Kelly-Quinn *et al*., 2014). For example, frequently, there is just 2% headroom available to supply water to the Greater Dublin Area. The vulnerability of this supply was seen in 2013 when water restrictions impacted many areas of Dublin due to a production problem at the Ballymore Eustace water treatment plant, which delivers over 50% of the supply to Dublin (Irish Water, 2015b). A recent paper by Kelly-Quinn *et al*. (2014) reviewed the supply of water to Dublin city and the wider area (see Figure 7.1) and found that the challenges facing Dublin are still being addressed on an ad hoc basis, and this is probably also the case for other areas of Ireland. Irish Water has recently released proposed plans to pipe water from the Shannon catchment to resolve

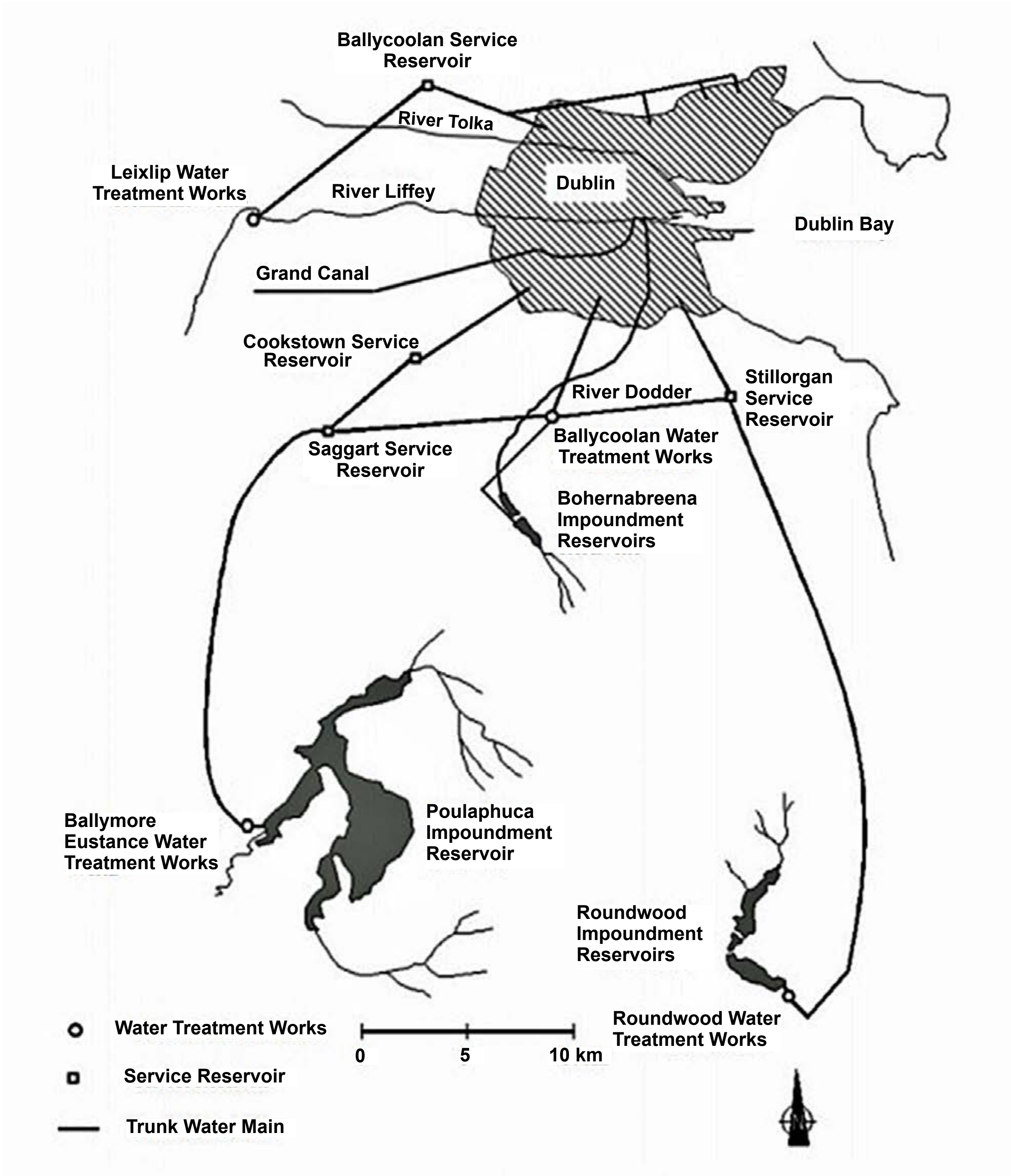

Figure 7.1. Schematic layout of Dublin City Council's water supply system. Reproduced from Kelly-Quinn *et al*. (2014), with permission from the authors and the Resilience Alliance.

the issues in Dublin (Irish Water, 2015c). While the establishment of Irish Water is a positive step, water supply issues will probably still remain in the long term. Interestingly, Kelly-Quinn *et al*. (2014) proposed a management framework that would include an integrated and an adaptive management of our water resources for potable use, which also includes issues such as flood control, fisheries, tourism and recreation, among others, and puts the ecosystem and delivery of ecosystem services at the forefront of decision making. While ecosystem services are not explicitly mentioned, this approach is reflected in the proposed methodology that was outlined by Irish Water for selecting and providing a secure water supply to the midlands and eastern region of Ireland (Irish Water, 2015c).

7.1.2 Commercial freshwater fisheries

Ireland's commercial eel fishery was closed in 2009, but some commercial fishing is still under way for salmon. Five fishery districts were open for draft net fishing in 2015 (Cork, Kerry, Limerick, Bangor and Letterkenny) and 54 districts were open for angling (29 of these were open for catch and release, while 64 rivers were closed).

Wild salmon is part of the Irish national identity and Ireland has been one of the largest producers of wild salmon in the North Atlantic. Ireland traditionally operated a commercial offshore fishery, an estuarine draft net fishery and in-river angling. For a number of years, fisheries managers and scientists were concerned about the declining numbers of salmon returning to the Irish coast. Since 1996, a progressive series of conservation initiatives have been introduced to address this decline in stocks. In 2002, Ireland introduced an annual quota for the recreational angling and commercial salmon fishery and reduced that quota progressively on an annual basis from 219,000 salmon in 2002 to 62,000 in 2007. In order to align fully with the International Council for the Exploration of the Sea (ICES) and the North Atlantic Salmon Conservation Organization (NASCO) advice, the Irish Government closed the mixed stock (commercial) fisheries in 2007. Harvest fisheries are now only allowed where stocks are shown to have a surplus of fish over the conservation limit (this includes commercial and angling). Commercial fisheries in estuaries are only permitted to have the stocks from individual rivers entering the estuaries when these are meeting conservation limits. The total salmon harvest ranged from 259,475 in 2001 to 108,661 in 2006. The drift net fishery was closed at the end of 2007 and since then the numbers of salmon harvested has ranged between 28,273 in 2007 to 32,303 in 2013. Since 2007, anglers have been harvesting the highest proportion of salmon (e.g. 68% in 2012). In 2012, 18% of the total salmon harvest was taken from the River Moy, 10% from the Munster Blackwater, 7% from the Laune and Feale, 6% from the Lee and 6% from the Nore. In 2015, 54 rivers were open for salmon angling, 29 for catch and release and 64 rivers were closed [SSCS (Standing Scientific Committee on Salmon), 2016].

Salmon are now managed on a river by river basis as opposed to on a national or district basis. A scheme of rehabilitation of rivers was introduced with priority given to rivers that were below the conservation limit in SACs that were funded through the introduction of a salmon conservation component on all angling and commercial licence sales (Salmon Conservation Fund). The current goal is to encourage the recovery of stocks in the rivers that are not yet meeting their conservation limits and to manage all rivers in compliance with the Habitats Directive. In the face of decreasing marine survival, the challenge is to show an improvement in stocks in those rivers over the next few years through investment in habitat improvements and other initiatives.

Commercial aquaculture

Aquaculture mainly takes place in coastal areas, but in Ireland it also occurs inland in freshwaters and in land-based recirculation systems. According to the Federation of European Aquaculture Producers [(FEAP), 2015], Ireland produced in the region of 3.5 million Atlantic salmon smolts in 2013. This industry is typically based in freshwater in a land-based hatchery and farming at sea. No statistics on freshwater Atlantic salmon aquaculture were available. Rainbow trout (*Oncorhynchus mykiss*), an imported species of salmonid originating from North America, are produced commercially in freshwaters in Kilkenny and Wicklow and account for 87% (or approximately 630 tonnes) of all Irish production (FEAP, 2015). Freshwater farms only grow rainbow trout to 300–350 g due to space limitation, but they sell them mainly to the Irish domestic market (FEAP, 2015). In 2013, approximately 55 tonnes of perch were produced in Ireland with an ex-farm value of approximately €400,000 (FEAP, 2015). Production increased to 70 tonnes in 2014 and was projected to reach 100 tonnes in 2015 (FEAP, 2015).

7.1.3 Other provisioning services

The provision and production of wild fruit and berries within wetlands (e.g. peatlands), hunting of waterfowl for subsistence and the use of fibres and other products and materials that originate in freshwater habitats can be considered provisioning services. An example of the last comes from an article in the *Irish Times* entitled “Turning fish skins into wallets” (see http://www.irishtimes.com/news/turning-fish-skins-into-wallets-1.1006912; 26 January 2006). Similarly, any freshwater plant, alga and animal material used in fodder, and fertiliser that may be used in agriculture and aquaculture is a provisioning service. Peat (as turf) for energy use can be considered a provisioning service, albeit a non-renewable service (in the short to mid-term), with many conservationists categorising peat as a 'use' by society rather than a 'service' to society.

7.2 Regulating and Maintenance Services

7.2.1 *Mediation of waste, toxins and other nuisances*

The bioremediation of waste, toxins and other substances is an important service in Irish rivers, lakes and wetlands (both natural and artificial). The ability of biota to uptake substances, for example, is one of the key steps in the provision of clean potable water and maintenance of biodiversity. Many substances, namely organic matter (plant, animal and microbial organic waste), sediment (mainly fine inorganic material from soil erosion through accretion), excess nutrients (phosphorus and nitrogen) and heavy metals, are assimilated by biota, especially by microbes. For example, Denison and Tilton (1998) reported removal rates of 75–93% for suspended solids, 30–50% for phosphates and 75–95% for nitrates in wetlands. The removal of nitrates and phosphates by constructed wetlands can be even higher, with the potential for a coliform removal rate of between 95% and 99.9% (Ottová *et al*., 1997), although phosphorus saturation may become an issue in the long term (i.e. as point sources of pollution), as is the case with some of these constructed systems in Ireland (Martin McGarrigle, Limnos Consultancy, 30 March 2016, personal communication). However, the capacity of aquatic ecosystems to assimilate waste is limited and can diminish if bacteria or algae deplete the level of dissolved oxygen. Similarly, excess nutrients, sediments and heavy metals can render water bodies toxic (e.g. loss of the freshwater pearl mussel), thus reducing the bioremediation capacity and changing the structure of the community (e.g. reduction in salmonids and increase in cyprinids), which could potentially reduce biodiversity and the "sense of place" often valued highly by users of water bodies.

7.2.2 *Mediation of flows (flood protection)*

The UK National Ecosystem Assessment [(UK NEA), 2011] highlighted how freshwaters, especially rivers, are both agents of flood risk but also dissipate floodwaters. The frequency and magnitude of flash floods are influenced by catchment land use and management, with activities such as urbanisation, increased drainage and other changes (e.g. hydromorphological change) altering the ability of catchments to retain and slow the movement of water. Additionally, the UK NEA (2011) highlights the number of solutions to flood risk management that involve expensive and often short-term maintenance and protection. However, the natural retention of floodwaters can occur through ecosystem mechanisms such as retention within catchment soils, drains and associated wetlands, thus reducing the need for expensive solutions and, in turn, protecting urban centres. For example, wetland vegetation inhibits and slows surface flow and, in the process, also provides for water storage, groundwater recharge and silt deposition (Bullock and O'Shea, 2016). If unaltered, particular wetlands, such as peatlands, act like a sponge, absorbing and retaining water.

7.2.3 *Maintaining nursery populations and habitats*

Freshwater habitats cover less than 1% of the Earth's surface, yet they support about 10% of all known species (Maltby and Ormerod, 2011). Consequently, freshwater ecosystems provide habitat and nurseries to a wide variety of organisms, including microbes, plants, invertebrates and vertebrates, which all depend on physical processes (e.g. sediment and water flows) and physicochemical conditions, which are provided by that habitat. In freshwaters, a variety of different types of habitats are created, which are due to the varying geomorphology and hydrology associated with streams, rivers, lakes, marshes, backwaters, peatlands and floodplains; all of these can vary spatially and temporally with climate and elevation, as well as by other factors such as sedimentation rates and instream vegetation (e.g. Acreman *et al*., 2011). In Ireland, the maintenance of suitable habitat and nurseries is vital for the provision of angling services (e.g. Kelly and Bracken, 1998; TDI, 2013), which, in accordance with Liquete *et al*.'s (2016) definition, links habitat and nursery maintenance to a concrete human benefit and can therefore be considered an ecosystem service.

A nursery is defined by Beck *et al*. (2001) as a habitat that contributes more than the average, compared with other habitats, to the production of individuals of a particular species that recruit to adult populations. In Ireland, and for salmonids and lamprey, this can be related to the provision of suitable spawning habitat (e.g. Curtis *et al*., 2009). It must be noted that the sustainability of maintaining habitat and nurseries relies on other services, e.g. clean water and regular water flows, but also on physical connectivity such as an absence of physical barriers (e.g. affecting fish recruitment) (e.g. Curtis *et al*., 2009). In addition, tangible uses in Ireland, such as the extensive recreational freshwater fisheries (game, pike and coarse angling), depend on less obvious aspects such as good habitat and good visual appearance (TDI, 2013), which are all dependent on the provision and maintenance of suitable habitats and a sense of place. Furthermore, several studies have highlighted how the ability of a nursery to function effectively (i.e. number of individuals recruited) is lessened with the loss of nursery habitat (Dobson *et al*., 2006; Cheminée *et al*., 2013). This highlights the importance of maintaining nursery habitats for the continuance and sustainability of associated services, goods and benefits.

7.2.4 Climate regulation

An important regulating service associated with freshwaters is climate regulation, which actively cycles carbon and oxygen and maintains air quality and influences the greenhouse effect, thereby regulating both local and global climate (de Groot *et al*., 2002). Wetlands, especially peatlands, are a good example of natural sinks for carbon sequestration and storage (Wilson *et al*., 2016). However, bog and peatland systems only remain carbon sinks when at good status (Wilson *et al*., 2016). Ward *et al*. (2007) set out a range of scenarios for Irish peatlands and carbon sequestration (and emissions), ranging from approximately 0.6 million tonnes carbon per annum sequestered as a “best case” scenario and 0.14 million tonnes carbon per annum emitted as a “worst case” scenario. These figures were based on 100% pristine conditions and 100% disturbance conditions, respectively (Ward *et al*., 2007). Interestingly, the restoration of peatlands has also been shown to be an effective management approach in Ireland. For example, Wilson *et al*. (2016) highlighted how the annual cumulative CO_2 balance was negative (i.e. carbon sink) in vegetated rewetted sites and always positive (i.e. carbon source) in the bare peat (both rewetted and drained) sites. Ward *et al*. (2007) estimated that peatlands in Ireland are sequestering approximately 0.04 million tonnes carbon per annum based on the derived Irish peat map (DIPM) disturbance scenario in summer 2004.

7.3 Cultural Services

7.3.1 Cultural services provided by fish

Tourism and recreation, in particular recreational fisheries (game, pike, coarse and sea angling), are very important in Ireland (Figure 7.2). These depend on good habitat, good water quality, good visual appearance, etc. In recent years, the emphasis has moved away from fish for culinary purposes (i.e. provisioning service) to fish for sport. The population now includes anglers who see benefits in having more coarse fish and greater species diversity (Fahy, 1995), albeit that this sometimes reflects a deterioration in water quality.

A socio-economic study was commissioned by IFI in 2012 to assess the volume, value and economic impact of recreational angling in Ireland (TDI, 2013). The main findings of the study were as follows:

- Up to 406,000 individuals participated in recreational angling in Ireland in 2012.
- The total direct expenditure on recreational angling in 2012 was estimated to be of the order of €555 million, but this is estimated to have risen to over €600 million in 2015 (NSAD, 2015). Approximately 20% of this figure was generated by out-of-state anglers.
- The overall economic impact of recreational angling is estimated to be approximately €755 million (direct and indirect). Subsequent survey work and analysis in 2015 has seen this figure rising to €836 million (NSAD, 2015).
- Total tourist angling expenditure can be estimated at approximately €280 million.
- Recreational angling was estimated to support approximately 10,000 jobs in 2012 and this increased to 11,000 jobs in 2015 (NSAD, 2015).

Figure 7.2. Examples of angling in Ireland [photographs: ©Inland Fisheries Ireland (http://www.fishinginireland.info/; accessed 1 September 2016), except top right: Fiona Kelly, Inland Fisheries Ireland].

- Sea angling and salmon and brown trout angling are the most popular categories where domestic anglers are concerned.

There is evidence of a decline in recreational angling participation levels over the decade up to 2012. Respondents in the "Survey of Recreational Anglers" identified outstanding scenery and friendliness/hospitality of the Irish people as the most appealing aspects of Ireland as a destination for recreational angling (TDI, 2013). Significant proportions of anglers also rated the Irish angling product highly in terms of its restful/relaxed ambience, the quality of the accommodation and the reputation of the angling product. The improvement in water quality is cited as the most positive development in angling in Ireland in recent years (TDI, 2013); however, there is evidence of a decline in recreational angling participation levels in recent years. Quality of fishing, economic recession, poor weather, lack of fish, overfishing, illegal fishing, netting, commercial fishing, pollution and invasive species were each identified as factors that have contributed to dissatisfaction with current fish stocks.

Angling in Ireland is a very significant economic activity, but it also plays a central role in rural and peripheral communities, providing recreational opportunities for young and old, and encourages participation in healthy outdoor activity. In many cases, the rural areas may be lacking in alternative tourist attractions and, in their absence, angling provides an important and sustainable source of income for the catering and accommodation service providers in these communities.

Recreational angling also attracts anglers outside the main traditional tourist seasons (shoulder periods are March to May and mid-August to October); this extends the traditional tourist season for accommodation and service providers and has the potential to provide increased employment and entrepreneurial opportunities within these communities.

The popularity and value of angling in Ireland relies significantly on non-catch-related factors identified by TDI (2013). The specific relative influence of factors that affected perceptions of reduced quality of fishing need to be identified, including the effect of water quality on fish stocks relative to other factors.

7.3.2 Examples of other recreation associated with Irish freshwaters

At present, Waterways Ireland estimates a value of at €53.5 to €62.5 million in relation to recreation opportunities at lakes and rivers in Ireland, with upward trends in usage between 2010 and 2014 (Waterways Ireland, 2016). The follow section outlines examples of recreation associated with Irish freshwaters.

Triathlon Ireland

Triathlon Ireland is the national governing body for the sports of triathlon, duathlon and aquathon, and currently has over 10,000 members in Ireland. Every year, lakes and rivers throughout the country are used by members for training purposes and organised races. Triathlon and aquathon participation (Figure 7.3) is a great indicator of the demand for safe water quality.

Canoeing, kayaking and rowing

Canoeing and kayaking are popular activities on many rivers and lakes throughout Ireland. Canoeing Ireland was formed in 1960 and is the governing body of paddle-based sport and recreation of canoeing in Ireland and of over 50 affiliated clubs nationwide. Activity on Irish freshwaters is very common and

Figure 7.3. Triathletes on the swimming leg of a triathlon in Lough Key, Co. Roscommon (photographs: Hugh Feeley, UCD).

Irish White Water (http://www.iww.ie/) lists 138 rivers nationwide where kayaking and canoeing guides are available to hire. Rowing in Irish lakes and rivers is also very popular. Established in 1899, the Irish Amateur Rowing Union, now Rowing Ireland, boasts over 80 affiliated clubs nationwide. Rowing is one of Ireland's most successful sports, with individuals and teams having won multiple world championships over the last two decades.

Waterskiing and wakeboarding

The Irish Waterski and Wakeboard Federation (IWWF), with a history dating back to the 1950s, is the national governing body in Ireland for all forms of waterskiing, wakeboarding, disabled skiing and barefooting (http://irishwwf.ie/clubs/). It has 17 affiliated clubs nationwide, of which many are located on rivers and lakes.

Hiking and hill walking

The National Trails Office was established in 2007 by the Irish Sports Council to co-ordinate and promote the use of recreational trails in Ireland. Currently it lists 818 trails and many of these are centred around lakes or rivers; for example, Glendalough, Co. Wicklow [nearly 1 million visitors every year (Wicklow County Council 2015)] and the 114 km Barrow Way, starting in Co. Kildare and finishing in Co. Carlow, which saw 1003 cyclists and 2416 walkers using the trail in August 2014 (Waterways Ireland, 2016). However, in general, the current provision of riverside recreation facilities in Ireland is modest (Bullock and O'Shea, 2016) and so this benefit is rated as medium-significant. However, investment has commenced on an extension to these facilities, including the expansion of a "blueway" network of walking and kayaking routes that could allow latent demand for recreation opportunities to be realised.

Conflicts between recreational cultural services

Ecosystems provide multiple services and multiple goods and benefits to society. Nevertheless, the management of ecosystems can change the type, magnitude and relative mix of services provided by an ecosystem and, in some instances, there may be an explicit choice in the management of an ecosystem. For example, *The Anglo-Celt* (http://www.anglocelt.ie/news/roundup/articles/2008/08/20/30100-byelaws-to-control-jet-skis-on-cavan-waters) reported that jet-skiing, speed boating and water skiing are partially or completely banned on Loughs Ramor, Sheelin, Oughter, Gowna, Annagh and Brackley because of their popularity for angling and swimming. The management of these lakes by the local County Council limits the type of recreational cultural service that can legally occur. Other conflicts may occur; for example, the introduction and spread of non-native coarse fish may improve coarse fish angling in the affected areas, but this will impact upon the native trout and salmon populations and the associated angling service.

7.3.3 Cultural services – examples in Irish folklore and history

In Ireland, many beliefs and traditions were associated with water. It was believed that the "Otherworld" could be accessed via water and as a result there are many sacred springs and wells throughout the country. These have since been adopted by Christianity despite their ancient, pagan origins. Our rivers and lakes have also featured extensively in Irish culture and folklore. For example, Ireland's longest river, the Shannon, is associated with the legend which saw Manannán's (the Irish Sea-God) granddaughter Sionann (or Sínann) arrive at the river seeking wisdom. Other tales surround war and power struggles in ancient Ireland; one story tells of how in the third century AD, High King Cormac mac Airt went to war with Fiacha, King of Munster. In the story, Cormac's druids made the River Blackwater and its springs run dry, thus depriving the people of Munster of access to water. Fiacha called upon Mogh Ruith, a powerful blind magician, for help and he restored the water. Throughout history, rivers and lakes were used for military conquest and as commercial highways, and the armies of many kings and queens were ferried along and across them. One of the most notable groups to use our waterways for their success were the vikings who arrived in Ireland prior to the turn of the ninth century.

Throughout Ireland's rich history of myths, folklore and legends, freshwater animals are referenced regularly. The following sections list some examples of freshwater animals and their place in Irish tradition, history and culture.

Aquatic invertebrates

Aquatic invertebrates have little or no reference in Irish folklore. One mention relates to the old saga "Tochmarc Étaíne" in which the character Fúamnach's vengeance sees the main character Étaíne make several transformations before she is reborn, one of which is a dragonfly (or possibly a butterfly – translation unclear). Nevertheless, although references to aquatic invertebrates in Ireland are extremely rare, it is interesting that, internationally, folklore can be found as far back as circa 2100 BC in the *Epic of Gilgamesh* from ancient Mesopotamia, which likens the briefness of Gilgamesh's life to that of an adult mayfly (Macadam and Stockan, 2015).

Moorkens (1999) reviewed the cultural history of the freshwater pearl mussel in Ireland and across Europe. Interestingly, man has had a close relationship with pearl mussels since at least the Bronze Age, with shell valves used as utensils for scooping up food and for ornamental purposes (Moorkens, 1999). Caesar is said to have returned to Rome with a breastplate covered in British pearls (Jackson, 1925; cited in Moorkens, 1999) and ever since, mussels across their range have been exploited for pearls, which has led to the destruction of many famous populations, with thousands of mussels often being killed in the pursuit of a single pearl (Moorkens, 1999). There is evidence that pearl fishing has continued in Ireland in recent years, in spite of being illegal (Moorkens, 1999).

Fish

Fish have played an important role in Irish folklore, with famous stories such as Fionn mac Cumhaill and the "Salmon of Knowledge". Salmon were regarded as the pinnacle of good physical and mental health, with Cú Chulainn, another famous Irish legend, using the "salmon leap" movement to best his enemies (Mac Coitir, 2010). Other associations with salmon range widely from death (e.g. drowned people were often said to appear in the form of a large black salmon) to place names (e.g. the Irish name for Leixlip, Co. Kildare, is "Léim an Bhradáin", which means salmon's leap). Salmon also had high prestige as food in early Ireland, with each king employing an "iascaire", or professional fisherman, who caught salmon for their household (Mac Coitir, 2010). Similarly, trout have their place in Irish folklore, with the story of the "White Trout". Other less charismatic and introduced fish species are not referenced as much in Ireland. However, the famous "Book of Kells", an illustrated Gospel book in Latin from circa 800 AD, has several depictions of fish, many of which, it could be argued, are not salmonids (Pedreschi, 2013). Pedreschi (2013) also produced an interesting summary of other fish-related folklore (or freshwater monsters!) in which references exist for various forms of "péist" (beast), many of which reside in water (e.g. the "Book of Feenagh" tells of "Loc na pesti" where a water beast killed 900 youths as they bathed), and lake names, such as Loch na hOnchon in County Wicklow, meaning "Lake of the Water Monster".

Birds

Ireland's traditional folklore has many myths and legends featuring birds; these are often used as symbols of the abstract human condition such as immortality, purity and strength (Wilson and Carmody, 2011). One example is the famous Irish myth "The Children of Lir", which sees King Lir's children turned into swans by their stepmother for 900 years, only to be saved by Christianity. Swans are also referred to in many other sagas, ranging from their singing and transporting the souls of the dead, to feats of athleticism, such as the aforementioned Cú Chulainn's achievement of stunning 20 swans with a slingshot (Wilson and Carmody, 2011). Interestingly, sowing a swan's feather into a husband's pillow was thought to ensure his fidelity (Anderson, 2008). Many experts believe that the notoriety of swans in legend aided their protection and enhanced the "taboo" surrounding their killing. Other freshwater birds, e.g. kingfishers, have also been associated with myth, beliefs and folklore. It was believed that the dead bodies of kingfishers would not rot and, if kept between clothes, would keep away moths and provide a nice smell; furthermore, their plumage was thought to be an antidote to certain diseases, and most interestingly, it was believed that if a kingfisher was stuffed and suspended by a thread, its bill would point in the direction of the prevailing wind (Anderson, 2008). Similarly, it was believed that dipping bait into water in which a heron had been cooked would give an angler the heron's power to catch fish, while a large number of dippers at an unfrequented location was not only a sign of plentiful fish but also a warning of the approach of malignant disease (Anderson, 2008). Archaeological evidence provides an insight into how our ancestors not only used birds for food, but also for lighting and waterproofing (grease), and for weaponry, decoration and bedding (feathers) (Wilson and Carmody, 2011). Several place names also have their origins with birds; for example, Bealach an Chruidín, Co. Cavan, can be directly translated as "the kingfishers way" (Anderson, 2008).

Otter

Known as the "Madra Uisce" (water dog or hound) in the modern Irish language, the otter has a rich tradition in Irish history and culture. One creature from legend that inhabited the depths of lakes and rivers is the "Dobhar Chú" (hound of the deep), a 7-foot long blood-thirsty, human-eating monster that was said to be a cross between a giant otter and a hound. The Dobhar Chú is also known as the king otter and it supposedly never slept. This mythical creature could only be killed using silver, which resulted in the slayers dying themselves within 24 hours (Mac Coitir, 2010). The pelt of an otter, on the other hand, was a prized possession, as it bestowed power and safety on the beholder (Mac Coitir, 2010). In several legends, the otter often appears acting as the helper to various saints. For example, in the "Life of St Kevin" an otter helps St Kevin save his psalter before it fell into the lake. The same otter used to bring salmon to the monks each day (Mac Coitir, 2010). Another account of otters in folklore sees a psalter saved yet again by an otter in the story of "Suibhne Geilt" (or Mad Sweeney). The old tale "Táin Bó Fraích" describes a great hunt using hounds, which successfully pursued several animals, one being an otter (Mac Coitir, 2010). Interesting, in early medieval Ireland, the otter, if kept as a pet, was classified at the same level of a dog in terms of legal penalties by the Irish Brehon Laws. In more recent times, otters were hunted down and trapped both because of their fur and because they were considered vermin that prey on fish stocks (Mac Coitir, 2010). The otter is responsible for many place names in Ireland, for example Otter Island (Oileán an Mhadra Uisce), Burriscarra, Ballintubber, Co. Mayo, Otterstown (Baile an Oitéaraigh), Athboy, Co. Meath and Otterbrook (Glaise an Dobharchú), Rathfarnham, Co. Dublin.

7.3.4 Other cultural services

Research and education and the importance of history and cultural heritage, as well as *in situ* viewing/experience and sense of place all are important and valued cultural services associated with freshwaters. The use of wildlife and freshwater landscapes in art, poetry and literature is very common in Ireland. For example, James Joyce referred to both the River Liffey and the Vartry River in his world famous novel *Ulysses*, Jack B. Yeats painted "Liffey swim" in 1923, which is now on view in the National Gallery of Ireland, and his brother William Butler Yeats used freshwater to inspire his renowned 1888 poem "The Lake Isle of Innisfree".

Existence and bequest are important aspects of cultural services. Existence is the satisfaction felt by an individual who knows that nature, wildlife and ecosystems exist regardless of whether the individual has visited the ecosystem in the past or has future intentions to visit (e.g. Cordell *et al*., 2003). Bequest is the willingness to preserve wildlife and ecosystems for the experience and use of future generations (e.g. Mountford and Kepler, 1999; Oleson *et al*., 2015).

In 2007, the Heritage Council published a report on valuing heritage in Ireland. Surveys indicated that over 90% of individuals thought it was (very or fairly) important to protect our heritage, including our natural environment (Lazenby Simpson *et al*., 2007). Similarly, 90% of respondents were proud of their Irish heritage. Interestingly, the most significant benefits associated with the preservation of heritage (with particular reference to the natural environment) were highlighted as follows within the report:

- keeping in touch with the past for future generations;
- pride in our own country/nationality;
- preserving an attractive natural environment;
- health benefits; and
- educating people.

7.4 Current Importance of Ecosystem Services in Ireland

A qualitative estimation of the relative importance of freshwater ecosystem services, the goods and benefits to beneficiaries at a national level, in Ireland was undertaken using available information (as previously outlined) and expert opinion. The categorisation of relative importance is outlined in Table 7.1. Using CICES (see CICES, 2013) results are outlined in Table 7.2 for provisioning services, in Table 7.3 for regulating and maintenance services, and in Table 7.4

for cultural services. This evaluation will be tested and refined through stakeholder engagement in the test-study case catchments selected within the ESManage Project. Groundwaters and hyporheic zones have been included, as previously mentioned papers, such as Boulton *et al*. (2008), highlight that subterranean invertebrate biodiversity probably sustains high levels of valuable ecosystem services, such as water purification, bioremediation, and water infiltration and transport, and provide a cultural service, albeit of low interest, with respect to holy wells.

7.4.1 Provisioning services

In Table 7.2 the provisioning services relating to “biomass” (Nutrition) have been categorised as “low” (with the exception of groundwater; similarly, *in situ* farming of freshwater fish does not occur in Irish wetlands) in terms of importance in Ireland. The rationale for this categorisation is highlighted in section 7.1.2. In contrast, “water” (Nutrition) has been categorised as “high” in terms of importance given the levels and spatial scale of abstracted water for drinking water purposes (see section 7.1.1). The only exception is wetlands, where little or no abstraction occurs and which are thus rated as of “low” importance as they may contribute indirectly to sources of water abstraction. “Fibres and other materials from plants, algae and animals for direct use or processing” (Materials; Biomass) was included, as such materials may be used to create goods. As highlighted in 7.1.3, a good example of this comes from an article in the *Irish Times* entitled “Turning fish skins into wallets” (see http://www.irishtimes.com/news/turning-fish-skins-into-wallets-1.1006912, 26 January 2006). While the use of such material is not well documented and, therefore, it is perhaps not widely used, we assigned a “low” importance rating. “Materials from plants, algae and animals for agricultural use” (Material; Biomass) mostly comprises the production of silage (1,076,400 ha) and hay (less than 200,000 ha) in wetland areas (e.g. Shannon Callows, turloughs) (CSO, 2010) during summer and autumn months and is likely to be important in localised areas. The use of “genetic materials from all biota” (Material; Biomass) is unknown and, at present, is not considered applicable in Ireland, although this may change in the future. “Water (both surface water or groundwater) for non-drinking purposes” (Materials) is considered important for all water resources (excluding wetlands – considered not applicable) in Ireland given its widespread use for agricultural and industrial purposes (see section 7.1.1).

7.4.2 Regulating and maintenance services

The regulating and maintenance services and their importance in Ireland are listed in Table 7.3. Geochemical and biological processes within catchments provide a regulating service by mitigating or attenuating pollutants arising from anthropogenic sources (e.g. Feeley *et al*., 2013; Archbold *et al*., 2016). Similarly, chemical and biological processes within freshwaters can assimilate various pollutants (e.g. Balvanera *et al*., 2014) by providing improved final services and resultant goods and benefits, such as water quality and healthy fish populations. As a result, all goods and benefits within the division “Mediation of waste, toxics and other nuisances” are considered to be of “high” importance in Ireland (Table 7.3). Freshwater habitats also have a role to play in flood protection and, in many cases, flood provision. For example, aquatic habitats, such as wetlands and marshes, slow water flow and, as a result, reduce flood risk (Zedler and Kercher, 2005). In turn, the floodwaters deposit supplies of sediment and organic matter, which enhance the fertility of the surrounding landscape and which also

Table 7.1. Definitions of the categories of relative importance of ecosystem services and associated goods and benefits to beneficiaries provided by Irish freshwater ecosystems

		Spatial scale			
		National	Regional	Local	Unknown
Scale of benefits	Abundant or common	High	High	Medium	Unknown
	Less than common	High	Medium	Low	Unknown
	Uncommon	Medium	Low	Low	Unknown
	Unknown	Unknown	Unknown	Unknown	Unknown

Table 7.2. The relative importance[a] of freshwater provisioning ecosystem services and associated goods and benefits to beneficiaries in Ireland

Division	Group	Class	Relevance to Ireland	River	Lake	Groundwater and hyporheic zones	Wetlands	Artificial and HMWB
Nutrition	Biomass	Wild plants and animals and their outputs	Wild fruit/berries, fish (eel, trout) from wild fisheries and wildfowl (e.g. ducks) for consumption	Low	Low	N/A	Low	Low
		Plants and animals from *in situ* aquaculture	*In situ* farming of freshwater fish (e.g. trout) for consumption and other products; e.g. cranberry growing	Low	Low	N/A	N/A	Low
	Water	Surface water for drinking	Abstracted surface water from rivers, lakes and other open water bodies for drinking	High	High	N/A	Low	High
		Groundwater for drinking	Abstracted groundwater for drinking	N/A	N/A	High	N/A	N/A
Material	Biomass	Fibres and other materials from plants, algae and animals for direct use or processing	Algae, reeds, animal skins, peat/turf for fuel	Low	Low	N/A	Medium	Low
		Materials from plants, algae and animals for agricultural use	Hay and silage	N/A	N/A	N/A	Medium	N/A
		Genetic materials from all biota	Genetic material (DNA) from wild plants, algae and animals for biochemical, industrial and pharmaceutical processes (e.g. medicines, fermentation, detoxification; bio-prospecting activities). *Potential not yet exploited*	Unknown	Unknown	Unknown	Unknown	Unknown
	Water	Surface water for non-drinking purposes	Abstracted surface water from rivers, lakes and other open water bodies for domestic use (washing, cleaning and other non-drinking use), irrigation, livestock consumption, industrial use (consumption and cooling) etc.	High	High	N/A	N/A	High
		Groundwater for non-drinking purposes	Abstracted groundwater for domestic use (washing, cleaning and other non-drinking use), irrigation, livestock consumption, industrial use (consumption and cooling) etc.	N/A	N/A	High	N/A	N/A

Adapted from CICES (2013).

Energy has been omitted from this table.

[a]See Table 7.1.

N/A, not applicable in Ireland.

Table 7.3. The relative importance[a] of freshwater regulating and maintenance ecosystem services and associated goods and benefits to beneficiaries in Ireland

Division	Group	Class	Relevance to Ireland	River	Lake	Groundwater and hyporheic zones	Wetlands	Artificial and HMWB
Mediation of waste, toxics and other nuisances	Mediation by biota	Bio-remediation by microorganisms, algae, plants and animals	Biochemical detoxification/decomposition/mineralisation of waste and toxic materials (i.e. water cleaning)	High	High	High	High	High
		Filtration/sequestration/ storage/accumulation by microorganisms, algae, plants and animals	Biological filtration/sequestration/storage/accumulation of pollutants in freshwater biota, adsorption and binding of heavy metals and organic compounds in biota	High	High	High	High	High
	Mediation by ecosystems (biota in association with the physical components)	Filtration/sequestration/ storage/accumulation by ecosystems	Bio-physicochemical filtration/sequestration/storage/ accumulation of pollutants in freshwater ecosystems, including sediments; adsorption and binding of heavy metals and organic compounds in ecosystems	High	High	High	High	High
		Dilution by freshwater ecosystems	Bio-physicochemical dilution of gases, fluids and solid waste, wastewater in lakes, rivers and sediments	High	High	High	High	High
Mediation of flows	Liquid flows	Hydrological cycle and water flow maintenance	Flood regulation	High	High	High	High	High
		Flood protection	Habitats for aquatic plants and animals	High	High	N/A	High	High
	Mass flows (materials carried by water)	Mass stabilisation and control of erosion rates	Reduced rates of bank and bed erosion/landslides	High	High	N/A	High	High
		Buffering and attenuation of mass flows	Regulation of transport and storage of sediment by rivers and lakes	High	High	N/A	N/A	High
Maintenance of physical, chemical and biological conditions	Life-cycle maintenance, habitat and gene pool protection	Maintaining nursery populations and habitats	Habitats for aquatic plants and animals	High	High	Medium	High	High
	Pest and disease control	Pest and disease control	Reduction in some pests and disease-causing organisms	Low	Low	N/A	Low	Low
	Water conditions	Chemical condition of freshwaters	Maintenance/buffering of chemical composition of freshwater column and sediment to ensure favourable living conditions for biota	High	High	High	High	High
	Atmospheric composition and climate regulation	Global climate regulation by reduction in greenhouse gas concentrations	Sequestration of greenhouse gas/carbon sequestration by water columns and sediments and their biota	High	High	High	High	High
		Micro and regional climate regulation	Temperature, humidity and wind speed modification; maintenance of regional precipitation/temperature patterns.	Low	Low	N/A	Low	Low

Adapted from CICES (2013).

[a]See Table 7.1.

N/A, not applicable in Ireland.

Table 7.4. The relative importance[a] of freshwater cultural ecosystem services and associated goods and benefits to beneficiaries in Ireland

Division	Group	Class	Relevance to Ireland	River	Lake	Groundwater and hyporheic zones	Wetlands	Artificial and HMWB
Physical and intellectual interaction with biota, ecosystems and landscapes	Physical	Experiential use of plants, animals and landscapes in different environmental settings	*In situ* wildlife watching (including aquatic biodiversity)	High	High	N/A	High	High
			Landscape appreciation	High	High	N/A	High	High
		Physical and experiential interactions	Contact (e.g. swimming, boating and leisure fishing [angling])	High	High	N/A	High	High
			Non-contact (e.g. walking, hiking)	Medium	Medium	N/A	Low	Low
	Intellectual and representative interactions	Scientific, educational, heritage, cultural, entertainment, aesthetic	Subject matter for research and education, both on location and via other media, historic records, cultural heritage (e.g. preserved in water bodies), *ex situ* viewing/experience of natural world through different media, sense of place, artistic representations of nature	High	High	Low	High	Medium
Spiritual, symbolic and other interactions with biota, ecosystems, and land-/seascapes (environmental settings)	Spiritual and/or emblematic	Symbolic	Emblematic plants and animals	Low	Low	N/A	Low	Low
		Sacred and/or religious	Spiritual, ritual identity (e.g. holy places), sacred plants and animals and their parts	Medium	Medium	Low	Low	Low
	Other cultural outputs	Existence	Enjoyment provided by wild species, wilderness and ecosystems	High	High	N/A	High	High
		Bequest	Willingness to preserve plants, animals, ecosystems for the experience and use of future generations, moral/ethical perspective or belief	High	High	High	High	High

Adapted from CICES (2013).

[a]See Table 7.1.

N/A, not applicable in Ireland.

provides essential habitats for many invertebrate and vertebrate species; furthermore, it also increases the productivity of both the floodplain and the main river channel (Johnson *et al*., 1995; Daily, 1997). The physical movement and disturbance of materials and sediments by biological communities via bioturbation (mixing and redistribution of sediments) and bioerosion [the biological breakdown of carbonate rock into smaller fragments by mechanical abrasion and chemical dissolution of calcium carbonate ($CaCO_3$); Neumann, 1966] contributes to the provision and sustainability of ecosystem goods and services (Prather *et al*., 2013). This ecosystem engineering enables biological communities to physically change their environment through burrowing, feeding and locomotory behaviour, which directly affects sediment structures and composition in aquatic environments (Murray *et al*., 2002; Meysman *et al*., 2006; Prather *et al*., 2013). These dynamics facilitate the establishment and persistence of biological communities by creating habitat, hydraulic pathways, protection and refugia for large numbers of species. Finally, freshwaters, especially wetlands, are natural sinks for carbon sequestration and storage. Therefore, where applicable, all regulating and maintenance services are given a "high" importance rating. The only exceptions are "Reduction in some pests and disease-causing organisms" and "Temperature, humidity, and wind speed modification; maintenance of regional precipitation/temperature patterns", as the former probably will not reduce pest and disease and will probably act as a transportation pathway, and as the latter, on a national scale, is less influenced by freshwaters (and more by the Atlantic Ocean), although local effects cannot be ruled out (Table 7.3).

7.4.3 Cultural services

The CICES division "Physical and intellectual interaction with biota, ecosystems and landscapes" within cultural services has two main groupings (Table 7.4). The first group, "Physical", relates to the "Experiential use of plants, animals and landscapes in different environmental settings" and the "Physical and experiential interactions". This group covers the enjoyment and benefits of being in/seeing the natural environment and of using the natural environment (e.g. angling). With the exception of groundwater, all other water bodies were given a "high" importance rating. Examples of their importance in Ireland are given in sections 7.3.1 and 7.3.2. Similarly, the group "Intellectual and representative interactions" associated with scientific, educational, heritage, cultural, entertainment and aesthetics values has a "high" importance in Ireland, although artificial and HMWBs have been given a reduced importance of "medium" owing to the availability of natural alternatives and groundwaters have been given an importance of "low". An example of historical aspects of freshwaters in Ireland is the "Battle of the Boyne". The second division within cultural services is "Spiritual, symbolic and other interactions with biota, ecosystems and land-/seascapes". Groundwaters are considered not relevant within this division with the exception of "Sacred and or/ religious" (Goods and Benefits), which is ranked at "low" importance owing to the association with (and number of) holy wells throughout the country. Within the group "Spiritual and/ or emblematic", rivers and lakes have been given a "medium" rating, while all other water bodies are given a "low" importance rating. These water bodies and their biological element may hold some importance for sections of the population. The last group, "Other cultural outputs", is subdivided into "Existence" and "Bequest". The existence services have been given "high" importance in Table 7.4 for all water bodies, with the exception of the groundwater. The rationale for this comes from the literature; many authors (e.g. Swart *et al*., 2001; de Groot *et al*., 2002; Chan *et al*., 2012) suggested that nature plays an important role for many individuals and allows them to feel connected to the world around them. For bequest, all water bodies have been assigned as "high". Although there is a lack of evidence for Ireland, several studies (e.g. Garibaldi and Turner, 2004; Oleson *et al*., 2015) suggest that bequest and the preservation of wildlife and ecosystems is "high", owing to the unique relationship and history communities have with the ecosystem and the continuity of culture and practices.

7.5 Responses of Ecosystem Services to Management

The next exercise undertaken was to evaluate and identify the potential for change in ecosystem services in Irish freshwaters in response to selected management options (see Table 7.5). The management options were chosen following a meeting with the EPA in March 2016; these mainly related to reductions in nutrient and sediment inputs through onsite measures to reduce the potential for loss of nutrient and sediments and/or management of riparian zones to capture runoff of these contaminants (Table 7.5). We have included "intensification" (vis-à-vis Food Harvest 2020 and Food Wise 2025), which will probably increase the nutrient and sediment pressure on some Irish rivers with potentially negative effects on ecosystem services. Thus, the changes to management highlighted in Tables 7.7–7.9 may be either positive or negative in response to reduction in contaminant inputs (the latter in the case of further intensification without additional measures to address nutrient and sediment problems). Also included in the following discussion is "mediation of flows", although this will not be a focus of the ESManage project. We have included the river column from Tables 7.2–7.4, rating the relative importance of the services to beneficiaries. Three potential response categories (high, medium and low; see Table 7.6) have been used and these are based, where possible, on evidence from the Irish and international literature; however, in some cases expert opinion was used. Only selected management options for river catchments are dealt with in this section; these primarily relate to reductions in nutrients and sediment (Table 7.5). The only exception is in relation to the "mediation of flow" (Division) within the regulating and maintenance services (see Table 7.8), which is not affected by nutrient and sediment inputs.

7.5.1 *Provisioning services*

The potential response of all provisioning services from river ecosystems considered to have some importance in Ireland is "high" (Table 7.7). The rationale for this assignment relates to the probability that changes in nutrient and sediment inputs within a catchment or landscape will be mirrored by a high response in the delivery and sustainability of related goods and benefits. Examples include the reduced costs of treating drinking water in Ireland, which is associated with reductions in nutrient and other contaminants such as pesticides and heavy metals (FSAI, 2006; Bradley *et al*., 2015). Similarly, the supply of clean, unpolluted waters is required and preferred by many industries (e.g. Intel on the Rye Water, Co. Kildare; Kelly-Quinn and Baars, 2012), while reductions in nutrients and sediment also

Table 7.5. Description of potential management options indicated in Tables 7.7–7.9

Management goal	Management option
Reduced nutrient and sediment	Extensification
	Intensification[a]
	Improvements and upgrades to WWTPs
	Reductions in catchment nitrogen and phosphorus inputs and loss to watercourses
	Riparian management
	Other local measures
Flow maintenance	Land use change
	Riparian measures
	Hydraulic controls (where applicable)

[a]Response likely negative unless accompanied by mitigation measures.

Table 7.6. Definitions of the response of ecosystem services and associated goods and benefits to selected management in Irish freshwater ecosystems

Response	Definition
High	The response of the service will be significant in terms of meeting relevant policy (e.g. WFD) goals. Includes both positive and negative responses
Medium	The response of the service will be noticeable but not significant in terms of meeting relevant policy (e.g. WFD) goals. Includes both positive and negative responses
Low	The response of the service will not be noticeable or significant in terms of meeting relevant policy (e.g. WFD) goals. Includes both positive and negative responses

Table 7.7. Potential response of provisioning ecosystem services and associated goods and benefits provided by Irish river ecosystems to management[a]

Division	Group	Class	Goods and benefits	Importance in rivers[b]	Potential management[c]	Potential response to management[a,d]	Possible indicators
Nutrition	Biomass	Wild plants and animals and their outputs	Fish (eel, trout) from wild fisheries and wildfowl (e.g. ducks) for consumption	Low	Changes in nutrient and sediment inputs: (1) Active management for reductions in nutrients and sediment;[e] (2) Extensification; (3) Riparian management; and (4) Intensification	High	Supply, historical and current, sustainable catch/harvest
		Animals from *in situ* aquaculture	*In situ* farming of freshwater fish (e.g. trout) and other products (e.g. cranberry growing, for consumption)	Low			
	Water	Surface water for drinking	Abstracted surface water from rivers, lakes and reservoirs for drinking	High		High	Volumes available for abstraction, volumes abstracted, treatment costs, instances and nature of contamination and associated costs of treatment, instances of water-related illness, quality of the water in terms of colour, taste, and smell and level of contaminants
Material	Biomass	Fibres and other materials from plants, algae and animals for direct use or processing	Algae, reeds and animal skins	Low		High	Demand and use of algae, reeds and animal skins
	Water	Surface water for non-drinking purposes	Abstracted surface water from rivers, lakes and other open water bodies for domestic use (washing, cleaning and other non-drinking use), irrigation, livestock consumption, industrial use (consumption and cooling) etc.	High		High	Volumes available for abstraction, volumes abstracted, treatment costs, instances and nature of contamination and associated costs of treatment, instances of water-related illness, quality of the water in terms of colour, taste and smell, and level of contaminants (less relevant for non-drinking purposes)

See response categories in Table 7.6.

[a]Instream and catchment management.

[b]Taken from Table 7.2.

[c]See Table 7.5 for descriptions of management options.

[d]See Table 7.6.

[e]Improvements and upgrades to WWTPs and/or reductions in catchment nitrogen and phosphorus inputs and loss to watercourses.

N/A, not applicable.

Table 7.8. Potential response of regulating and maintenance ecosystem services and associated goods and benefits provided by Irish river ecosystems in response to management[a]

Division	Group	Class	Goods and benefits	Importance in rivers[b]	Potential response management[c]	Response to management[a,d]	Possible indicator
Mediation of waste, toxics and other nuisances	Mediation by biota	Bio-remediation by microorganisms, algae, plants, and animals	Biochemical detoxification/ decomposition/mineralisation/ decomposition/detoxification of waste and toxic materials (i.e. water cleaning)	High	Changes in nutrient and sediment inputs:	Medium	
		Filtration/ sequestration/storage/ accumulation by microorganisms, algae, plants and animals	Biological filtration/sequestration/ storage/accumulation of pollutants in freshwater biota, adsorption and binding of heavy metals and organic compounds in biota	High	(1) Active management for reductions in nutrients and sediment; (2) Extensification;		
	Mediation by ecosystems (biota in association with the physical components)	Filtration/ sequestration/storage/ accumulation by ecosystems	Bio-physicochemical filtration/ sequestration/storage/accumulation of pollutants in freshwater ecosystems, including sediments; adsorption and binding of heavy metals and organic compounds in ecosystems	High	(3) Riparian management; and (4) Intensification	Medium	Resilience/ assimilative capacity/ thresholds/water treatment costs
		Dilution by freshwater ecosystems	Bio-physicochemical dilution of gases, fluids and solid waste, wastewater in atmosphere, lakes, rivers and sediments	High			
Mediation of flows	Liquid flows	Hydrological cycle and water flow maintenance	Flood regulation	High	(1) Land use change; (2) Riparian measures; and	High	Flood defence costs, insurance costs, need for warning systems
		Flood protection	Habitats for aquatic plants and animals	High	(3) Hydraulic controls (where applicable)		
	Mass flows (materials carried by water)	Mass stabilisation and control of erosion rates	Reduced rates of bank and bed erosion/ landslide	High		High	Sediment loads in rivers, changes in thalweg position, loss of land surface area
		Buffering and attenuation of mass flows	Regulation of transport and storage of sediment by rivers and lakes	High			

Table 7.8. Continued

Division	Group	Class	Goods and benefits	Importance in rivers[b]	Potential response management[c]	Response to management[a,d]	Possible indicator
Maintenance of physical, chemical, biological conditions	Life-cycle maintenance, habitat and gene pool protection	Maintaining nursery populations and habitats	Habitats for aquatic plants and animals	High	Changes in nutrient and sediment inputs: (1) Active management for reductions in nutrients and sediment;[e] (2) Extensification; (3) Riparian management; and (4) Intensification	High	Salmonid spawning habitat and recruitment, aquatic biodiversity (surrogate species)
	Pest and disease control	Pest and disease control	Reduction in some pests and disease-causing organisms	High		Medium	*Cryptosporidium*, Weil's disease occurrence, etc.
	Water conditions	Chemical condition of freshwaters	Maintenance/buffering of chemical composition of freshwater column and sediment to ensure favourable living conditions for biota	High		High	Chemical composition, exceedances of thresholds
	Atmospheric composition and climate regulation	Global climate regulation by reduction in greenhouse gas concentrations	Sequestration of greenhouse gas/carbon sequestration by water columns and sediments and their biota	High		High	DOC concentrations in water, carbon and greenhouse gas fluxes
		Micro and regional climate regulation	Temperature, humidity and wind speed modification; maintenance of regional precipitation/temperature patterns	Low			

See response categories in Table 7.6

[a]Instream and catchment management.

[b]Taken from Table 7.3.

[c]See Table 7.5 for descriptions of management options.

[d]See Table 7.6.

[e]Improvements and upgrades to WWTPs and/or reductions in catchment nitrogen and phosphorus inputs and loss to watercourses.

Table 7.9. Potential response of cultural ecosystem services and associated goods and benefits provided by Irish river ecosystems in response to management[a]

Division	Group	Class	Examples	Importance in rivers[b]	Potential management[c]	Potential response to management[a,d]	Possible indicator
Physical and intellectual interaction with biota, ecosystems and landscapes	Physical	Experiential use of plants, animals and landscapes in different environmental settings	*In situ* wildlife watching (including biodiversity)	High	Changes in nutrient and sediment inputs: (1) Active management for reductions in nutrients and sediment;[e] (2) Extensification; (3) Riparian management; and (4) Intensification	High	Numbers belonging to e.g. Birdwatch Ireland, An Taisce
			Landscape appreciation	High			Property value near water bodies
		Physical and experiential interactions	Contact [e.g. swimming, boating and leisure fishing (angling)]	High			Numbers engaged in various recreational activities (e.g. boat hire, membership, angling license/permit purchases and willingness to pay)
			Non-contact (e.g. walking, hiking)	Low			
	Intellectual and representative interactions	Scientific, educational, heritage, cultural, entertainment, aesthetic	Subject matter for research and education both on location and via other media; historic records, cultural heritage (e.g. preserved in water bodies); *ex situ* viewing/experience of natural world through different media; sense of place, artistic representations of nature	High		High	Research and art (written visual and performing) output based on freshwater, architectural/cultural heritage designations and willingness to pay
Spiritual, symbolic and other interactions with biota, ecosystems, and land-/seascapes (environmental settings)	Spiritual and/or emblematic	Symbolic	Emblematic plants and animals	Low		High	
		Sacred and/or religious	Spiritual, ritual identity (e.g. holy places), sacred plants and animals and their parts	Low			
	Other cultural outputs	Existence	Enjoyment provided by wild species, wilderness and ecosystems	High		High	Changes to biodiversity (e.g. birds, fish, invertebrates, mammal), willingness to pay and non-monetary demand indicators
		Bequest	Willingness to preserve plants, animals, ecosystems for the experience and use of future generations, moral/ethical perspective or belief	High			

See response categories in Table 7.6

[a]Instream and catchment management.

[b]Taken from Table 7.4.

[c]See Table 7.5 for descriptions of management options.

[d]See Table 7.6.

[e]Improvements and upgrades to WWTPs and/or reductions in catchment nitrogen and phosphorus inputs and loss to watercourses.

improve the environmental conditions for wildlife and fish, both directly and indirectly (e.g. McCarthy and Moriarty, 1989; Townsend *et al*., 1992; Suttle *et al*., 2004; Greig *et al*., 2005; O'Grady and Delanty, 2008).

Regulating and maintenance services

The potential responses of regulating and maintenance services (Table 7.8) in river ecosystems is rated between "medium" and "high". The response of "Mediation of waste, toxics and other nuisances" goods and benefits to the management of nutrients and sediments is probably "medium". The reductions in pressures improve the capacity of the ecosystem service providers (ESPs) (e.g. biofilms) to regulate and reduce terrestrial inputs, but this capacity is finite, unless ESPs have been previously impaired by pollution or underpopulation. However, the reduced toxic/detrimental effects of nutrients and sediment can actually improve the ESP diversity and uptake ability (e.g. Balvanera *et al*., 2014). In Ireland, the relationship between phosphorus and ecological water quality is well established (Donohue *et al*., 2006); therefore management to reduce nutrients and sediment and potential changes in diversity will, by extension, probably also affect ecosystem services (Woodward, 2009; Cardinale *et al*., 2012; Mace *et al*., 2012; Durance *et al*., 2016). Changes in "Maintenance of physical, chemical, biological conditions" will probably be "high" owing to improvements in habitat from reduced toxicity and physical stress to biota (e.g. Donohue *et al*., 2006; Larsen and Ormerod, 2010; Jones *et al*., 2012). The only exception within this section is "Pest and disease control" (Table 7.8), which is given a "medium" response rating to nutrient and sediment management. The rationale for this assignment relates to the fact that these management options may reduce the input of pest/disease sources (e.g. *Cryptosporidium* oocytes) from hosts (i.e. livestock) through improved management (e.g. drainage), but, once within the freshwater system, there are few biological or biogeochemical processes that remove or reduce them (e.g. Chalmers *et al*., 1997; Reinoso *et al*., 2008).

The potential management relating to "Mediation of flows" requires a different suite of measures (see Table 7.8). Nevertheless, the response of these services is potentially "high". For example, research in the UK has demonstrated that redesigned landscapes and careful management can reduce the magnitude of flood peaks by 40% (Jackson *et al*., 2008), although the effectiveness of various management approaches may vary hugely on a catchment to catchment basis (Pattison and Lane, 2011). Similarly, the water needs of humans and natural ecosystems are a delicate balance with limitations on the amount of water that can be withdrawn from freshwater systems before their natural functioning and productivity, native species, and the services, goods and benefits they provide, become severely degraded (Richter *et al*., 2003; Kelly-Quinn *et al*., 2014). Therefore, any management in relation to maintenance of flows will probably results in a "high" response.

7.5.3 Cultural services

The response of cultural services (Table 7.9) to reductions in sediment and nutrients within river catchments is probably "high". This is related to the visual and experiential interaction associated with these services. Brown (2013) found water, and proximity to it, to be one of the most valued "landscapes" within the cultural ecosystem services framework. Certain improvements, such as reductions in colour (i.e. turbidity), smell and less visible algal "scum" (caused by excess nutrients), will improve this experience and value assigned by the user. Similarly, improvements in water quality through nutrient and sediment management will improve angling and other uses (e.g. swimming) through increased fish numbers, recruitment and cleaner water, for example, thus improving the individual's experience. Regarding spiritual, symbolic, existence and bequest benefits, evidence suggests that the preservation of wildlife and ecosystems (in this case through improved nutrient and sediment management) is highly valued by society (e.g. Garibaldi and Turner, 2004; Oleson *et al*., 2015) owing to the unique relationship and history that communities have with the ecosystem, as well as their desire to preserve it for the future.

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Abbreviations

CICES	Common International Classification of Ecosystem Services
CO_2	Carbon dioxide
DAHRRGA	Department of Arts, Heritage, Regional, Rural and Gaeltacht Affairs
DBP	Disinfection by-products
DECLG	Department of Environment, Community and Local Government (now Department of Housing, Planning, Community and Local Government)
DOC	Dissolved organic carbon
EPA	Environmental Protection Agency (Ireland)
ESP	Ecosystem service provider
EU	European Union
GIS	Geographical information system
GSI	Geological Survey of Ireland
ha	Hectares
HMWB	Heavily modified water bodies
ICCG	Irish Char Conservation Group
IFI	Inland Fisheries Ireland
IPPC	International Plant Protection Convention
IWRM	Integrated water resource management
MEA	Millennium Ecosystem Assessment
NOM	Natural organic matter
NPWS	National Parks and Wildlife Service
PE	Population equivalent
RBD	River basin district
SAC	Special Area of Conservation
THM	Trihalomethane
TCD	Trinity College Dublin
WFD	Water Framework Directive
WWTP	Waste water treatment plant
UCD	University College Dublin
UK NEA	United Kingdom National Ecosystem Assessment
UN	United Nations

Appendix 1

Names and description of three main final ecosystem services categories and intermediate services. See Feeley *et al*. (2016a) for more details.

	Service	Description
Final services	Provisioning	Readily understandable as the material or energy outputs from ecosystems and include the supply of fish, food, fibre or other renewable materials (TEEB, 2010; Bullock and O'Shea, 2016). For example, the supply of water for consumption, agriculture and industry are among the key provisioning services of freshwater ecosystems (Haines-Young and Potschin, 2013).
	Regulating and maintenance	Sometimes referred to as maintenance services; these incorporate the various ways in which living organisms can mediate or moderate the ambient environment that affects mankind (Haines-Young and Potschin, 2013). For example, they ensure water quality by removing excess nutrients and degrading waste and toxic substances by exploiting living processes. Other examples include regulation of local climate and human health, and water flow moderation (Haines-Young and Potschin, 2013).
	Cultural[a]	These are perhaps the most variably defined of all. They have been proposed to include the non-material benefits that people obtain from contact with ecosystems, such as direct or indirect benefits in the form of amenity and recreation, and also certain non-use goods that are valued for their pure existence or are perceived to contribute to quality of life (TEEB, 2010; Bullock and O'Shea, 2016). CICES (Haines-Young and Potschin, 2013) categorises cultural services as being the physical setting for recreational activity and for cultural values.
Intermediate services	Supporting processes[b]	These underpin almost all other services. In freshwaters they relate to all levels of aquatic biodiversity from genetic to communities diversity, primary production and other ecosystem processes and functions that underpin well-functioning ecosystems and their resilience to internal and external pressures (Mace *et al*., 2012).

[a]Fisher and Turner (2008) considered aesthetic and spiritual values and recreation as benefits and not as ecosystem services. This, again, highlights the need for an agreed language to improve communication with stakeholders. Kenter *et al*. (2014) further expanded the concept of cultural services to include "shared" and "plural" values that go beyond individual's "self-regarding" values [see Kenter *et al.* (2015) for further discussion].

[b]Also known as "supporting" and "habitat" services.

Appendix 2

Summary of freshwater ecosystem services listed by the Irish stakeholders at a meeting at University College Dublin, August 2015, and additional ecosystem services highlighted by Bullock and O'Shea (2016) for Irish freshwaters.

Provisioning	Regulating and maintenance	Cultural
Water for consumption	Nutrient attenuation	Sense of place
Water for other uses	Water purification	Inspiration
Algal biomass	Flood regulation	Biodiversity (birds etc.)
Fish (as food)	Erosion prevention	Connectivity to nature/spirituality
Genetic resources	Local climate regulation	Archaeological heritage
	Carbon regulation	Angling
	Biological control	Other recreation
	Sediment capture and deposition	Education
	Flow moderation	

Appendix 3

Irish freshwater stakeholders as compiled by ESManage Project[a]

Central government
Department of Agriculture, Food and the Marine (DAFM)
Department of Transport, Tourism and Sport
Department of Housing, Planning, Community and Local Government (DHPCLG)
Department of Communications, Climate Action and the Environment (DCCAE)
Department of Arts, Heritage, Regional, Rural and Gaeltacht Affairs (DAHRRGA)
National Parks and Wildlife Service (NPWS)
State agencies/statutory bodies and regulators
Environmental Protection Agency (EPA)
Office of Public Works (OPW)
Bord Iascaigh Mhara (BIM)
Inland Fisheries Ireland (IFI)
Health Service Executive (HSE)
Health and Safety Authority (HSA)
An Bord Pleanála
Marine Institute
Met Éireann
Fáilte Ireland/Tourism Ireland
Ordnance Survey Ireland (OSI)
Heritage Council
Geological Survey of Ireland (GSI)
Transport Infrastructure Ireland
Commission for Energy Regulation (CER)
Dublin Docklands Development Authority
Local government
City and County Councils
River Basin District co-ordination
Local Authorities Water and Communities Office (LAWCO)
Local Government Management Agency (LGMA)
Semi-state organisations
Bord na Móna
Coillte
Utilities
Irish Water
Electricity Supply Board (ESB)
Ervia

National organisations
Irish Farmers Association (IFA)
Irish Creamery Milk Suppliers Associations
Woodlands of Ireland
Irish Onsite Wastewater Association
Irish Ramsar Wetlands Committee
Irish Forum on Natural Capital
Community groups
Federation of Group Water Schemes
Local groups (e.g. Dodder Action)
Recreation groups
Inland Waterways Association of Ireland
Canoeing Ireland
National Course Fishing Federation of Ireland (NCFFI)
Federation of Irish Salmon and Sea Trout Anglers (FISSTA)
National Anglers Representative Association (NARA)
Salmon and Sea Trout Recreational Anglers of Ireland (SSTRAI)
Trout Anglers Federation of Ireland (TAFI)
The Irish Federation of Pike Angling Clubs (IFPAC)
Irish Trails
Triathlon Ireland
Irish Waterski and Wakeboard Federation
Rowing Ireland
Academia/education/research/data provision
Environmental Science Association of Ireland (ESAI)
Teagasc
National Biodiversity Data Centre
Universities (various)
Institutes of Technology (various)
National and international scientific community (various)
NGOs
An Taisce
Coastwatch
Irish Wildlife Trust
Irish Peatland Conservation Council
BirdWatch Ireland
Friends of the Earth
Sustainable Water Network (SWAN) Ireland
Bat Conservation Ireland
Others
Industry (various)
Farmers
Households

Northern Ireland
Rivers Agency (Department of Agriculture and Rural Development, Northern Ireland)
Loughs Agency (Department of Agriculture and Rural Development, Northern Ireland)
Department of Environment (Northern Ireland)
Agri-Food and Biosciences Institute (AFBI)
Northern Ireland Water
The Canoe Association of Northern Ireland

[a]As of 1 August 2016 – note while the authors have attempted to be as inclusive as possible they cannot guarantee all relevant stakeholders are included in this table.

AN GHNÍOMHAIREACHT UM CHAOMHNÚ COMHSHAOIL

Tá an Ghníomhaireacht um Chaomhnú Comhshaoil (GCC) freagrach as an gcomhshaol a chaomhnú agus a fheabhsú mar shócmhainn luachmhar do mhuintir na hÉireann. Táimid tiomanta do dhaoine agus don chomhshaol a chosaint ó éifeachtaí díobhálacha na radaíochta agus an truaillithe.

Is féidir obair na Gníomhaireachta a roinnt ina trí phríomhréimse:

Rialú: *Déanaimid córais éifeachtacha rialaithe agus comhlíonta comhshaoil a chur i bhfeidhm chun torthaí maithe comhshaoil a sholáthar agus chun díriú orthu siúd nach gcloíonn leis na córais sin.*

Eolas: *Soláthraímid sonraí, faisnéis agus measúnú comhshaoil atá ar ardchaighdeán, spriocdhírithe agus tráthúil chun bonn eolais a chur faoin gcinnteoireacht ar gach leibhéal.*

Tacaíocht: *Bímid ag saothrú i gcomhar le grúpaí eile chun tacú le comhshaol atá glan, táirgiúil agus cosanta go maith, agus le hiompar a chuirfidh le comhshaol inbhuanaithe.*

Ár bhFreagrachtaí

Ceadúnú

Déanaimid na gníomhaíochtaí seo a leanas a rialú ionas nach ndéanann siad dochar do shláinte an phobail ná don chomhshaol:

- saoráidí dramhaíola *(m.sh. láithreáin líonta talún, loisceoirí, stáisiúin aistrithe dramhaíola)*;
- gníomhaíochtaí tionsclaíocha ar scála mór *(m.sh. déantúsaíocht cógaisíochta, déantúsaíocht stroighne, stáisiúin chumhachta)*;
- an diantalmhaíocht *(m.sh. muca, éanlaith)*;
- úsáid shrianta agus scaoileadh rialaithe Orgánach Géinmhodhnaithe *(OGM)*;
- foinsí radaíochta ianúcháin *(m.sh. trealamh x-gha agus radaiteiripe, foinsí tionsclaíocha);*
- áiseanna móra stórála peitril;
- scardadh dramhuisce;
- gníomhaíochtaí dumpála ar farraige.

Forfheidhmiú Náisiúnta i leith Cúrsaí Comhshaoil

- Clár náisiúnta iniúchtaí agus cigireachtaí a dhéanamh gach bliain ar shaoráidí a bhfuil ceadúnas ón nGníomhaireacht acu.
- Maoirseacht a dhéanamh ar fhreagrachtaí cosanta comhshaoil na n-údarás áitiúil.
- Caighdeán an uisce óil, arna sholáthar ag soláthraithe uisce phoiblí, a mhaoirsiú.
- Obair le húdaráis áitiúla agus le gníomhaireachtaí eile chun dul i ngleic le coireanna comhshaoil trí chomhordú a dhéanamh ar líonra forfheidhmiúcháin náisiúnta, trí dhíriú ar chiontóirí, agus trí mhaoirsiú a dhéanamh ar leasúchán.
- Cur i bhfeidhm rialachán ar nós na Rialachán um Dhramhthrealamh Leictreach agus Leictreonach (DTLL), um Shrian ar Shubstaintí Guaiseacha agus na Rialachán um rialú ar shubstaintí a ídíonn an ciseal ózóin.
- An dlí a chur orthu siúd a bhriseann dlí an chomhshaoil agus a dhéanann dochar don chomhshaol.

Bainistíocht Uisce

- Monatóireacht agus tuairisciú a dhéanamh ar cháilíocht aibhneacha, lochanna, uiscí idirchriosacha agus cósta na hÉireann, agus screamhuiscí; leibhéil uisce agus sruthanna aibhneacha a thomhas.
- Comhordú náisiúnta agus maoirsiú a dhéanamh ar an gCreat-Treoir Uisce.
- Monatóireacht agus tuairisciú a dhéanamh ar Cháilíocht an Uisce Snámha.

Monatóireacht, Anailís agus Tuairisciú ar an gComhshaol

- Monatóireacht a dhéanamh ar cháilíocht an aeir agus Treoir an AE maidir le hAer Glan don Eoraip (CAFÉ) a chur chun feidhme.
- Tuairisciú neamhspleách le cabhrú le cinnteoireacht an rialtais náisiúnta agus na n-údarás áitiúil *(m.sh. tuairisciú tréimhsiúil ar staid Chomhshaol na hÉireann agus Tuarascálacha ar Tháscairí)*.

Rialú Astaíochtaí na nGás Ceaptha Teasa in Éirinn

- Fardail agus réamh-mheastacháin na hÉireann maidir le gáis cheaptha teasa a ullmhú.
- An Treoir maidir le Trádáil Astaíochtaí a chur chun feidhme i gcomhair breis agus 100 de na táirgeoirí dé-ocsaíde carbóin is mó in Éirinn.

Taighde agus Forbairt Comhshaoil

- Taighde comhshaoil a chistiú chun brúnna a shainaithint, bonn eolais a chur faoi bheartais, agus réitigh a sholáthar i réimsí na haeráide, an uisce agus na hinbhuanaitheachta.

Measúnacht Straitéiseach Timpeallachta

- Measúnacht a dhéanamh ar thionchar pleananna agus clár beartaithe ar an gcomhshaol in Éirinn *(m.sh. mórphleananna forbartha)*.

Cosaint Raideolaíoch

- Monatóireacht a dhéanamh ar leibhéil radaíochta, measúnacht a dhéanamh ar nochtadh mhuintir na hÉireann don radaíocht ianúcháin.
- Cabhrú le pleananna náisiúnta a fhorbairt le haghaidh éigeandálaí ag eascairt as taismí núicléacha.
- Monatóireacht a dhéanamh ar fhorbairtí thar lear a bhaineann le saoráidí núicléacha agus leis an tsábháilteacht raideolaíochta.
- Sainseirbhísí cosanta ar an radaíocht a sholáthar, nó maoirsiú a dhéanamh ar sholáthar na seirbhísí sin.

Treoir, Faisnéis Inrochtana agus Oideachas

- Comhairle agus treoir a chur ar fáil d'earnáil na tionsclaíochta agus don phobal maidir le hábhair a bhaineann le caomhnú an chomhshaoil agus leis an gcosaint raideolaíoch.
- Faisnéis thráthúil ar an gcomhshaol ar a bhfuil fáil éasca a chur ar fáil chun rannpháirtíocht an phobail a spreagadh sa chinnteoireacht i ndáil leis an gcomhshaol (*m.sh. Timpeall an Tí, léarscáileanna radóin).*
- Comhairle a chur ar fáil don Rialtas maidir le hábhair a bhaineann leis an tsábháilteacht raideolaíoch agus le cúrsaí práinnfhreagartha.
- Plean Náisiúnta Bainistíochta Dramhaíola Guaisí a fhorbairt chun dramhaíl ghuaiseach a chosc agus a bhainistiú.

Múscailt Feasachta agus Athrú Iompraíochta

- Feasacht chomhshaoil níos fearr a ghiniúint agus dul i bhfeidhm ar athrú iompraíochta dearfach trí thacú le gnóthais, le pobail agus le teaghlaigh a bheith níos éifeachtúla ar acmhainní.
- Tástáil le haghaidh radóin a chur chun cinn i dtithe agus in ionaid oibre, agus gníomhartha leasúcháin a spreagadh nuair is gá.

Bainistíocht agus struchtúr na Gníomhaireachta um Chaomhnú Comhshaoil

Tá an ghníomhaíocht á bainistiú ag Bord lánaimseartha, ar a bhfuil Ard-Stiúrthóir agus cúigear Stiúrthóirí. Déantar an obair ar fud cúig cinn d'Oifigí:

- An Oifig um Inmharthanacht Comhshaoil
- An Oifig Forfheidhmithe i leith cúrsaí Comhshaoil
- An Oifig um Fianaise is Measúnú
- An Oifig um Cosaint Raideolaíoch
- An Oifig Cumarsáide agus Seirbhísí Corparáideacha

Tá Coiste Comhairleach ag an nGníomhaireacht le cabhrú léi. Tá dáréag comhaltaí air agus tagann siad le chéile go rialta le plé a dhéanamh ar ábhair imní agus le comhairle a chur ar an mBord.

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ESManage Project: Assessment of Ecosystem Services Provision

Authors: Hugh B. Feeley, Michael Bruen, Craig Bullock, Mike Christie, Fiona Kelly and Mary Kelly-Quinn

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Climate - Water - Sustainability
Identifying pressures • Informing policy • Developing solutions

Identify Pressures

Ireland's freshwaters are among the best in Europe. However, they are under increasing pressure from a range of land-use and other anthropogenic pressures, especially from elevated nutrients (nitrogen and phosphorus) and sediment inputs, but also increasingly from pesticides, water abstractions, and invasive species. The continuing loss of high status waters is a major concern. Ireland's planned future land-use intensification for food production, together with climate change will further stress aquatic resources both in terms of quality and quantity. This report highlights the range of pressures currently facing freshwaters in Ireland and how these pressures have implications for a range of ecosystem services, and in turn, the goods and benefits society derives from them.

Inform policy

This report describes succinctly the ecosystem services framework as a tool to identify and value the goods and benefits provided by ecosystems and enable improved environmental management across the Irish landscape. Importantly it emphasises how the use of the ecosystem services framework can support the objectives of the Water Framework Directive (WFD), Floods Directive (FD), integrated river basin/catchment planning, and management of freshwater resources.

Develop solutions

In order to incorporate the ecosystem services framework into policy related to the management of freshwater resources the full range of Ireland's freshwater ecosystems and their underlying biological resources must be identified. This report consolidates this knowledge and outlines current pressures and management structures relating to freshwaters in Ireland. It then identifies the diversity of ecosystem services Irish society derives from the full range of its freshwater resources and rates their relative importance. The report projects how the delivery and sustainability of ecosystem services provided by Irish freshwaters may change in relation to selected management strategies into the future and describes the resulting implications for the achievement of WFD and FD goals.

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