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Irish Natural Capital Accounting for Sustainable Environments (INCASE)

Authors: Jane C. Stout, Catherine A. Farrell, Mary Kelly-Quinn, Lisa Coleman,Stephen Kinsella, Cathal O'Donoghue, Daniel Norton, Carl Obst, Mark Eigenraam,Fiona Smith, Iseult Sheehy and Sarah Zimmermann.

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Rialtas na hÉireann
Government of Ireland

Environmental Protection Agency

The 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: Implementing regulation and environmental compliance systems to deliver good environmental outcomes and target those who don't comply.

Knowledge: Providing high quality, targeted and timely environmental data, information and assessment to inform decision making.

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> Urban waste water discharges;
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> Sources of ionising radiation;
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> Provide the Secretariat to the Climate Change Advisory Council and support to the National Dialogue on Climate Action;
> Support National, EU and UN Climate Science and Policy development activities.

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> Monitor air quality and implement the EU Clean Air for Europe Directive, the Convention on Long Range Transboundary Air Pollution, and the National Emissions Ceiling Directive;
> Oversee the implementation of the Environmental Noise Directive;
> Assess the impact of proposed plans and programmes on the Irish environment.

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> Assist in developing national plans for emergencies arising from nuclear accidents;
> Monitor developments abroad relating to nuclear installations and radiological safety;
> Provide, or oversee the provision of, specialist radiation protection services.

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> Provide independent evidence-based reporting, advice and guidance to Government, industry and the public on environmental and radiological protection topics;
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> Work with international and national agencies, regional and local authorities, non-governmental organisations, representative bodies and government departments to deliver environmental and radiological protection, research coordination and science-based decision making.

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The EPA is managed by a full time Board, consisting of a Director General and five Directors. The work is carried out across five Offices:

1. Office of Environmental Sustainability
2. Office of Environmental Enforcement
3. Office of Evidence and Assessment
4. Office of Radiation Protection and Environmental Monitoring
5. Office of Communications and Corporate Services

The EPA is assisted by advisory committees who meet regularly to discuss issues of concern and provide advice to the Board.

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Identifying pressures

Nature continues to be degraded globally. Despite our societies and economies depending on it, we often ignore or undervalue this degradation. To bring nature into everyday decision-making, the natural capital approach deliberately uses the language of business and economics. In this context, nature can be thought of as an array of stocks of natural assets, incorporating biodiversity, air, water and geology. The condition of these stocks influences the flow of goods and services, and the benefits that our societies and economies derive from these assets.

To identify and manage risk of environmental degradation to human economies, Natural Capital Accounting provides a framework to track changes in the extent and condition of stocks of assets, and in the flows of services over time. This enables prioritisation and appropriate management of natural assets and the multiple benefits they provide to people, and valuation of assets in holistic terms.

There are several potential approaches to Natural Capital Accounting, which can be implemented at various scales. What would work in an Irish context was not immediately clear. In addition, there was little knowledge and awareness of Natural Capital Accounting in Ireland, or how it could be applied to sustainable management of Irish natural assets. These were the challenges that the INCASE project addressed.

Informing policy

Developing Natural Capital Accounting approaches meets several policy objectives, linking natural and socio-economic systems. Integrating ecosystems and biodiversity into national and local planning, development processes and poverty reduction strategies, and accounts, is one of the Sustainable Development Goals. In addition, protecting ecosystems and biodiversity are key policy targets in the EU's Biodiversity Strategy for 2030 and the European Green Deal.

We tested the System of Environmental Economic Accounting – Ecosystem Accounting (SEEA-EA), a type of Natural Capital Accounting, at catchment scale in Ireland for the first time. Adopted by the United Nations in 2021 as the primary tool to integrate nature into national accounts, the SEEA-EA takes a spatial approach. It can be used by public bodies, businesses or landowners, at any scale, to map natural stocks such as forests, waterways and other habitats, and the flow of services from these stocks.

We built natural capital (ecosystem and geosystem) accounts for four Irish sub-catchments, focusing on extent, condition and services accounts. This involved accessing a wide variety of Irish data sources, over 200 datasets in all, from more than 30 agencies. This process highlighted the need for engagement with and collaboration across a range of data providers in Ireland, and the need for regular and reliable data collection. Outlining clear processes to build the accounts provided valuable insights into how to scale up to national level and apply the outputs for more informed decision-making by policymakers, land owners and managers, and other stakeholders. Natural Capital Accounting links natural and socio-economic data, and can provide evidence for investments in rural development, health and much more.

Developing solutions

Since the initiation of the INCASE project, there has been significant international progress in implementing the SEEA-EA accounting approach as a complementary metric to GDP, and there has been increased appreciation of the risks associated with biodiversity and ecosystem service loss. Thus, there is a need to benchmark natural capital stocks and flows over time, and our work has moved from the theoretical research sphere, and prototyping, to implementation by official statistics bodies.

We have the following recommendations:

- Developing and using ecosystem accounting is a national priority and requires investment in expertise and shared nature data infrastructure in Ireland.
- A detailed, high-resolution, regularly updated ecosystem map is required, and ecosystem condition assessment needs further development.
- The relationship between extent and condition of natural capital assets and flows of services and benefits requires more nuanced understanding.
- Ecosystem service assessment needs a standardised approach.
- A centralised data platform is required.
- Not all accounts can or should be monetised – but accounting for the diverse values of nature, including the inspiration it provides, is vital to the wellbeing of our society.

EPA RESEARCH PROGRAMME 2021–2030

Irish Natural Capital Accounting for Sustainable Environments (INCASE)

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EPA Research Evidence Synthesis Report

Prepared for the Environmental Protection Agency

by

Trinity College Dublin

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Executive Summary

There is increasing recognition in political, corporate and public spheres of the severe risks to society and the economy associated with environmental degradation, particularly climate change and biodiversity loss. Urgent action is required to mitigate and adapt to climate change, and to protect and restore biodiversity, across all sectors and at all scales. However, current economic paradigms do not take impacts and dependencies of society and the economy on the natural world into consideration, making it difficult to integrate the crises of nature into decision-making. Therefore, an approach that links the human and natural systems is needed.

The natural capital approach frames nature and ecological, geological, hydrological and atmospheric systems as assets, from which goods and services flow. It deliberately uses the language of business and economics to bring nature into decision-making. As part of this, natural capital accounting is a formalised framework for recording and tracking changes in stocks and flows of natural capital assets. These assets include biodiversity and ecosystems, as well as air, water and geology. Accounts can be used to track and assess changes in natural capital assets through space and time, to inform planning and management of assets, to demonstrate the importance of stocks and flows of natural capital assets in economic terms (including financial) and to monitor progress towards achieving environmental goals. The United Nations System of Environmental Economic Accounting – Ecosystem Accounting (SEEA-EA) aligns with the System of National Accounts and has become the primary tool for nations to integrate biodiversity and ecosystems into their national accounts, one of the Sustainable Development Goals (Goal 15.9).

The SEEA-EA takes a spatially explicit approach and, although typically used for national-scale accounts, can be implemented at various scales. In the Irish Natural Capital Accounting for Sustainable Environments (INCASE) project, we tested the application of SEEA-EA for the creation of accounts at catchment scale in Ireland. Extent, condition and service flow accounts were created for four contrasting catchments: the Dargle (east coast urban/uplands), Figile (midlands rural/peatlands), Bride (rural/farming) and Caragh (west coast rural/peatlands).

Through the creation of catchment-scale accounts, we gained valuable insights both in terms of the current status of the case study catchments and for developing accounts at the national and local scales. First, most of the land area in all four catchments was highly modified by human activity, and currently under some sort of management, often degrading the ability of natural capital stocks to deliver multiple ecosystem services. Notably, despite their importance as carbon stocks and their contribution to climate regulation services, most of the peatlands in our catchments were at risk from drainage, disturbance and land conversion pressures.

Second, accurate delimitation of ecosystem assets, which underpin extent, condition and ecosystem service flows, was hampered by a lack of high-resolution ecosystem maps for Ireland. Third, careful and consistent approaches to the selection of condition indicators and reference levels are required to ensure that they are compatible and comparable, and that their aggregation is ecologically meaningful, enabling comparison across ecosystem types. Fourth, the policy question being addressed will influence the selection of five or six appropriate and relevant services, but these may be limited by the data that are available. Although knowledge about the assessment of ecosystem service flows is growing, the relationship between ecosystem asset condition and the security of future flows requires further work. Finally, stakeholder engagement is critical in developing accounts.

Since the initiation of the INCASE project, there has been significant international progress in implementing ecosystem accounting as a complementary metric to gross domestic product, and increased appreciation of the risks associated with biodiversity and ecosystem service loss. Thus, there is a need to benchmark natural capital stocks and flows over time, and our work has moved from the theoretical research sphere and prototyping to implementation by official statistics bodies.

As a result of the INCASE project work, we make the following recommendations for developing ecosystem accounts in Ireland:

- Developing and using ecosystem accounting is a national priority.
- Increased expertise is required for operationalisation of ecosystem accounting in Ireland.
- A detailed, high-resolution ecosystem map is required.
- Ecosystem condition assessment needs further development.
- The relationship between extent and condition of natural capital assets and flows of services and benefits requires more nuanced understanding.
- Ecosystem service assessment needs a standardised approach.
- A centralised data platform is required.
- Not all accounts should be monetised.

1 Introduction

The Irish Natural Capital Accounting for Sustainable Environments (INCASE)[1] project piloted the development of natural capital accounts at the catchment scale to provide a comprehensive view of the stocks of natural capital assets and the flows of services, along with guidance on how to scale up the process to national level. A catchment-scale approach was initially adopted to link natural capital accounting (NCA) with the well-developed integrated catchment management approach used by the Water Framework Directive (WFD) river basin management plans. Four subcatchments were selected as models for the INCASE project, representing a range of conditions and characteristics (section 1.3).

The overarching aim of the INCASE project was to promote and enable better decisions and policy design for sustainable development by integrating nature and the environment into decision-making processes. INCASE took a transdisciplinary and multi-institutional approach to developing NCA in Ireland, involving natural scientists, economists, statisticians, social scientists, and public and private stakeholders. The main objectives were delivered via four integrated work packages (Table 1.1).

1.1 Overview of Natural Capital Accounting

In an economic context, "capital" refers to any store of value that an organisation can use in the production of goods and services, with the "six capitals" model used for integrated reporting purposes, namely financial, manufactured, intellectual, human, social and natural capital (IIRC, 2013). Natural capital refers to the stock of natural assets and the associated flow of ecosystem services that benefit and support humanity. These natural assets, such as rivers, soil and forests, provide *inter alia* the vital food, climate regulation and clean water necessary for human survival. Protecting these vital assets and ecosystem services for future generations is a fundamental aspect of sustainable development. Natural capital underpins all other capitals, as reflected by the nested Sustainable Development Goals[2] approach, which clearly defines the role of nature as underpinning all else (Farrell and Stout, 2020).

Current economic and business accounting systems do not include the value of natural capital or damages done to natural assets or ecosystem services. For example, the United Nations System of National

Table 1.1. INCASE work packages, main objectives and lead personnel

Work package	Main objectives	Project team members involved
1	Review NCA literature, identify data sources and methodological approaches, and identify datasets and a framework to test for NCA application in Ireland	Professor Jane Stout and Dr Catherine Farrell (TCD); Associate Professor Mary Kelly Quinn, Dr Siobhan Atkinson and Lisa Coleman (UCD)
2	Test NCA approaches in selected catchments and develop ecosystem accounts and environmental flow accounts	Professor Jane Stout and Dr Catherine Farrell (TCD); Associate Professor Mary Kelly Quinn, Dr Siobhan Atkinson and Lisa Coleman (UCD)
3	Develop tools for decision-makers, including visualisation, quality assessment and framework development	Professor Stephen Kinsella and Dr Daniel Norton (UL); Professor Cathal O'Donoghue (NUIG)
4	Project management, communications and stakeholder engagement	Professor Jane Stout and Dr Catherine Farrell (TCD); Iseult Sheehy, Fiona Smith, Orlaith Delargy, Hannah Hamilton and Sarah Zimmermann (NCI)

NCI, Natural Capital Ireland; NUIG, University of Galway; TCD, Trinity College Dublin; UCD, University College Dublin; UL, University of Limerick.

1 https://www.incaseproject.com (accessed 13 October 2023).

2 https://www.stockholmresilience.org/research/research-news/2016-06-14-how-food-connects-all-the-sdgs.html (accessed 13 October 2023).

Accounts (SNA)[3] provides a standard framework for the preparation of national economic accounts that allows for international comparison of economic activity, but excludes non-market phenomena, such as environmental damage (Hoekstra, 2020). Gross domestic product (GDP), a key SNA indicator, measures output growth; however, it is often misused in public discourse and is not balanced by measures of societal and environmental wellbeing. In 2009, the European Commission recommended complementing GDP with statistics covering other economic, social and environmental issues that are critical to people's wellbeing (EC, 2009).

NCA is a complementary statistical approach that captures the value of national natural assets and ecosystem services and aligns with the SNA. NCA is an umbrella term for accounting frameworks that systematically measure and report on stocks and flows of natural capital. Integrating NCA as a tool in broader decision-making facilitates multiple analyses, including identification of trade-offs, "disservices" and co-benefits. The accounts present a standardised filter and a common platform on which to inform integrated and inter-sectoral decision-making (Farrell and Stout, 2020).

International policy is a key driver of the development and broad adoption of NCA, with tools in development since the 1960s. The European Green Deal (EC, 2019a) sought to enable the transition of the EU economy to a sustainable economic model, with explicit aims to protect, conserve and enhance Europe's natural capital, and to protect health and wellbeing from environment-related risks and impacts. In addition, the development of standardised NCA practices was explicitly mentioned as part of a range of initiatives to pursue green finance and investment. The related EU Biodiversity Strategy for 2030 (EC, 2019b), the new Circular Economy Action Plan (EC, 2020) and the updated Bioeconomy Strategy (EC, 2018) all made clear commitments to the protection of natural capital. At national level, sustainable management of natural capital, valuing biodiversity and ecosystem services, and developing NCA are all included in government plans and strategies (Project Ireland 2040 – National Planning Framework, National Development Plan 2021–2030 and Ireland's third National Biodiversity Action Plan 'Actions for Biodiversity 2017–2021'). A more detailed review of NCA policy background can be found in Chapter 3 of the INCASE Stage 1 Feasibility Report (Farrell and Stout, 2020) (summarised in Appendix 1.1 of the INCASE Technical Research Report; see https://www.incaseproject.com/report).

In Ireland, the natural capital concept and development of NCA has been promoted by the not-for-profit organisation Natural Capital Ireland (NCI),[4] formerly the Irish Forum on Natural Capital, which brings together a diverse range of organisations and individuals from the academic, public, private and non-governmental organisation (NGO) sectors. NCI promotes the development and application of the natural capital agenda in Ireland, supporting the adoption of natural capital concepts in public policy and corporate strategy, promoting informed public and private sector decision-making and assisting in the establishment of a national NCA standard. At the same time, in 2020, the Central Statistics Office established the Ecosystem Accounts Division, with the view to developing Irish ecosystem accounts. Ecosystem accounts are developed using an NCA approach, and fulfil Ireland's reporting requirements to the European Commission (Eurostat).

Research projects in Ireland are also informing aspects of NCA and identifying ecosystem services with a view to developing more integrated policy and management approaches (see Chapter 5 of the INCASE Literature Review 2019,[5] and the summary in Appendix 1.2 of the INCASE Technical Research Report). In the private sector, the Capitals Coalition[6] is a dynamic global network encouraging businesses and financial organisations to assess their impacts and dependencies on natural, social and human capital. Two Irish semi-state bodies have already explored the development of natural capital accounts at various levels (Coillte in 2017 and Bord na Móna in 2018).

3 https://ec.europa.eu/eurostat/statistics-explained/index.php?title=System_of_national_accounts_-_new_directions#Enhancing_the_quality_of_national_accounts (accessed 13 October 2023).

4 https://www.naturalcapitalireland.com (accessed 13 October 2023).

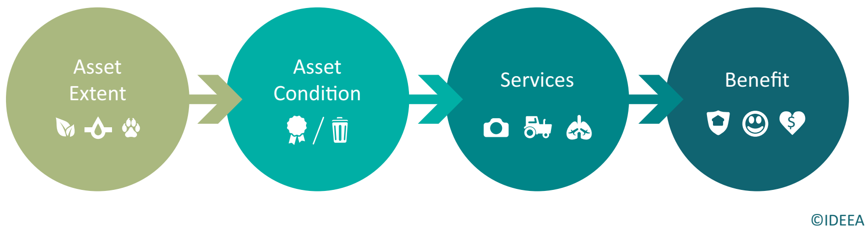
5 https://www.incaseproject.com/_files/ugd/94066f_6be27ef818374b718a3b5346c1202d14.pdf (accessed 13 October 2023).

6 https://capitalscoalition.org (accessed 13 October 2023).

1.2 System of Environmental Economic Accounting

The System of Environmental Economic Accounting (SEEA)[7] framework is a key NCA tool that integrates geospatial economic and environmental data in a standardised, structured way to analyse the relationships between environment and economy. This framework is the most widely used NCA approach at the EU and global levels. The United Nations SEEA approach incorporates two aspects – the System of Environmental Economic Accounting – Central Framework (SEEA-CF) and the System of Environmental Economic Accounting – Ecosystem Accounting (SEEA-EA) – which work together to build knowledge and information about environmental and ecosystem assets:

- The SEEA-CF is a conceptual framework for describing economic and environmental interactions in addition to changes in stocks of environmental assets. SEEA-CF covers physical accounts and flows of environmental assets (such as water), and environmental expenditure. A number of environmental accounts are collated by the Central Statistics Office in Ireland (since 2011) and reported to Eurostat.
- The SEEA-EA complements the SEEA-CF by adopting a geospatial approach to assessing the stocks and flows of ecosystems and ecosystem services. The approach measures *stocks* of natural capital (assets) and is employable at a range of scales. Knowledge of the extent and condition of the natural capital assets in ecosystems allows for integration of the supply and use of services (*flows*) from nature, which are then translated into *benefits* to people, in an accounting framework (Figure 1.1). This information can then be used consistently and



Asset extent – the type, range and scale of natural capital assets. The output of this stage is a georeferenced map, with the scale depending on the spatial unit (country, catchment or farm), and an asset register or account (in the form of a table/balance sheet).

Asset condition – the quality of the asset. For example, a peatland may be drained or undrained. A drained peatland will be of poorer condition than one with no drains, and its capacity to sequester carbon will be reduced, as will its biodiversity. The condition of an asset influences its ability to deliver one or more services, and asset condition will vary over space and time. Condition mapping is a key spatial component. At this stage, maps showing asset condition and pressures, and a risk register highlighting areas of degradation, can be developed.

Services – identification of the services, whether within the system or as a product of the system. In the case of a peatland, this may be carbon sequestration (a service) or emissions (a disservice) and/or water attenuation. Similarly, services may rely on a combination and the interaction of multiple assets. Service flows are described in the form of supply and use tables.

Benefits – the benefits to humans and identified beneficiaries. For example, the benefit may be climate regulation and/or flood control and the beneficiaries are local, downstream (flood mitigation) or global (reduced carbon emissions to atmosphere). For many services, there is a spatial correlation between potential beneficiaries and service availability. One of the aspects of the SEEA-EA methodology is that it allows the contributions of ecosystems to society to be expressed in monetary terms so they can be compared with other goods and services that we are more familiar with. Monetary estimates can provide information for decision-makers, for example for economic policy planning, cost–benefit analysis and raising awareness of the relative importance of nature to society.

Figure 1.1. The SEEA framework provides a filter for standardised information. Source: text adapted and image reproduced from IDEEA Group.

7 https://seea.un.org (accessed 13 October 2023).

repeatedly in reporting, alongside the SNA, enabling the tracking of changes in stocks and flows over time. The SEEA-EA framework comprises five integrated ecosystem (stock and flow) accounts (Figure 1.2).

The multidisciplinary nature of the accounts, and the challenges inherent in working with spatial data and novel measurement techniques, requires a collaborative approach that takes advantage of the strengths of national statistical offices and the expertise of other agencies and research organisations.

1.3 Application of System of Environmental Economic Accounting – Ecosystem Accounting in the INCASE Project

1.3.1 The catchment approach

A catchment is defined as an area where water is collected by the natural landscape and flows from source through river, lakes and groundwater to the sea. The catchment represents a distinct biophysical landscape unit with well-defined boundaries, forming the basis for reporting under the EU WFD. Furthermore, the integrated catchment management approach to preparing river basin management plans throughout the EU, as part of the implementation of the WFD, has many parallels in approach and philosophy with the systems approach of the SEEA-EA (DHPLG, 2018).

In this study, we combine datasets, such as those gathered for reporting under the EU WFD and the EU Habitats Directive (EC, 1992), to develop SEEA-EA accounts. This demonstrates how to make effective use of existing comprehensive datasets by aligning them to develop their further use towards more integrated environmental management.

The catchment approach provides a framework for identifying stakeholders and related projects. Key stakeholders and projects identified by the INCASE project included the following:

- State agencies/departments/bodies: EPA Catchments Unit, Central Statistics Office, National Parks & Wildlife Service (NPWS), National Biodiversity Data Centre (NBDC),[8] Geological Survey Ireland, Forest Service, Teagasc, Uisce Éireann, Department of Agriculture, Food and the Marine, Department of the Environment, Climate and Communications,

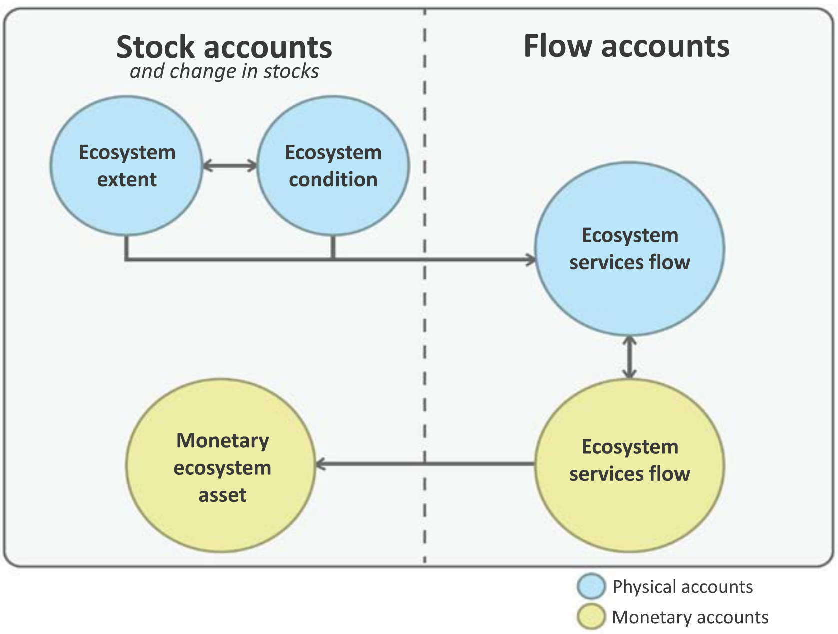


Figure 1.2. Connections between the SEEA-EA stock and flow accounts. Source: UN (2021, p. 32).

8 https://maps.biodiversityireland.ie/Dataset (accessed 13 October 2023).

Department of Housing, Local Government and Heritage, Bord Iascaigh Mhara, Bord na Móna, Coillte and local authorities. (See Appendix 5.1 of the INCASE Research Technical Report for a communications summary of the stakeholder list.)

- Related projects: Ordnance Survey Ireland (OSI)/EPA Land Cover mapping project,[9] EPA Environmental Sensitivity Mapping tool project,[10] European Innovation Partnership (EIP) projects[11] (the Pearl Mussel Project[12] and the Biodiversity Regeneration in a Dairying Environment (BRIDE) project[13]), KerryLIFE project,[14] ESDecide,[15] Land2Sea,[16] ESManage[17] and other related research projects.

Four subcatchments were selected to reflect the range of characteristics of land and water (biological, physical, chemical), such as soils, climate, bedrock, aspect and altitude, as well as habitats, land uses and pressures in Ireland (farming, forestry, energy, infrastructure, industry, human settlement, rural development, urbanisation, etc.), as identified in the River Basin Management Plan 2018–2021 (DHPLG, 2018). The main considerations for subcatchment selection are listed in Appendix 1 of the Technical Supporting Document for the INCASE Stage 1 Feasibility Report (Farrell and Stout, 2020), in line with specific criteria recommended during discussions with the EPA Catchments Unit during the INCASE project.

The four subcatchments selected (Figure 1.3) were:

1. **Bride**, County Cork: largely an agricultural catchment. Agriculture, urban diffuse pollution, forestry, hydro-morphological changes and wastewater treatment facilities are significant pressures in this catchment.
2. **Dargle**, County Wicklow: a catchment that is a mix of expanding urban settlement, agriculture, forestry, moorland/heathland and peatland.
3. **Figile**, County Offaly: a catchment that is considerably impacted by the peat extraction industry. There is large-scale transition towards renewable energy sources and peatland rehabilitation in this catchment.
4. **Caragh**, County Kerry: largely a peatland catchment and an important nature conservation area, with a focus on a range of species, including freshwater pearl mussel.

Further catchment characteristics are presented in Appendix 1 of the Technical Supporting Document for the INCASE Stage 1 Feasibility Report (Farrell and Stout, 2020).

1.3.2 Data inventory and assessment

Throughout the accounting process, we followed the steps outlined in the SEEA-EA framework as a guide to gather and assess relevant data (UNSD, 2021). An initial NCA-focused **workshop** was held in November 2019, with agencies and organisations coordinating, gathering and analysing environmental data in Ireland, highlighting relevant data sources, while also serving to raise awareness of the SEEA-EA accounting framework approach (Farrell and Stout, 2020). In addition, a **desktop review** of available national- and catchment-level datasets (with a particular focus on the INCASE catchments) was combined with **one-to-one engagement** through further focus groups and catchment workshops throughout the course of the project. Direct engagement across a wide array of agencies, with both data providers and potential

9 https://www.epa.ie/our-services/monitoring--assessment/assessment/irelands-environment/land--soil/current-trends-land-and-soil/ (accessed 13 October 2023).

10 https://enviromap.ie (accessed 13 October 2023).

11 https://research-and-innovation.ec.europa.eu/strategy/past-research-and-innovation-policy-goals/open-innovation-resources/european-innovation-partnerships-eips_en (accessed 13 October 2023).

12 https://www.pearlmusselproject.ie (accessed 13 October 2023).

13 https://www.thebrideproject.ie (accessed 13 October 2023).

14 https://www.npws.ie/research-projects/kerrylife (accessed 13 October 2023).

15 https://www.ucd.ie/esdecide/ (accessed 13 October 2023).

16 https://land2sea.ucd.ie (accessed 13 October 2023).

17 https://www.ucd.ie/esmanage/ (accessed 13 October 2023).

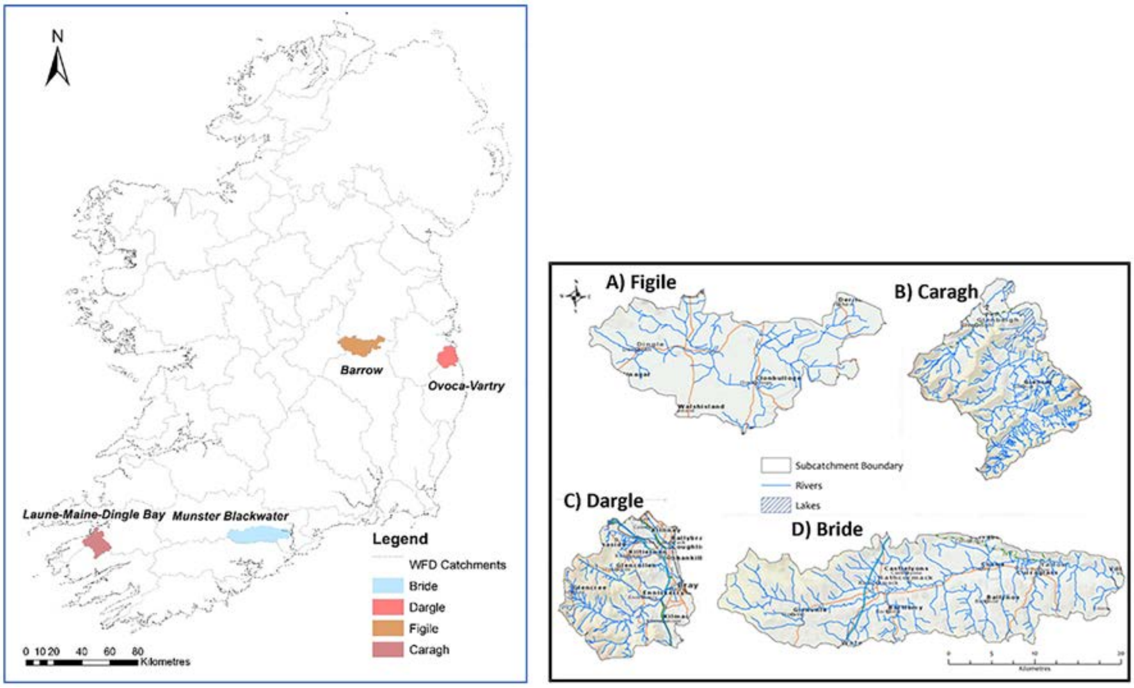


Figure 1.3. Locations of the INCASE subcatchments showing the outline of the accounting boundary and the main rivers and lakes against a backdrop of relief and road networks (orange lines). (A) Figile (Barrow catchment), (B) Caragh (Laune–Maine–Dingle Bay catchment), (C) Dargle (Ovoca–Vartry catchment) and (D) Bride (Munster Blackwater catchment).

end-users of the accounts, identified available relevant inputs.

Following this iterative process of collating and reviewing data, a data inventory detailing relevant national- and catchment-related datasets was developed (see Appendix 1 of the Technical Supporting Document for the INCASE Stage 1 Feasibility Report (Farrell and Stout, 2020)), serving as a technical support document for applying the SEEA-EA in Ireland, which can be added to over time. The inventory comprises an extensive array of datasets from national and EU agencies, state departments, local authorities, commercial enterprises and research and ecological consultants. Ancillary datasets, reviewed for the catchments, include data relating to accessibility (roads and trackways), commercial use (forest plantation), elevation, planning documents, food production (agricultural payments), protection status (conservation designations) and soils.

1.3.3 Scope of natural capital assets

The SEEA-EA considers ecosystem assets as the primary spatial units for accounting. Ecosystem assets are described as contiguous spaces of ecosystem type characterised by a distinct set of biotic and abiotic components and their interaction (UNSD, 2021). NCA approaches can include soils, mineral assets, groundwater aquifers, etc., as in the UK natural capital accounts. Within the SEEA-EA, both geosystem and atmospheric assets are considered either ecosystems themselves (aquifers) or abiotic components of the environment that supports ecosystems (e.g. as bedrock), from which abiotic flows are accounted for where relevant, for example peat extraction and wind energy generation. While some consideration was given to geosystem and atmospheric accounting, this synthesis report focuses on the ecosystem accounting aspect of the INCASE project.

While many ecosystems in the ecological realms – e.g. terrestrial, freshwater and marine ecosystems – are located close to the Earth’s surface, they all have three-dimensional characteristics. In the case of terrestrial systems, the biotic components usually incorporate below-ground (soil life and plant roots below the surface) and above-ground (vegetation growing above the surface) aspects (UNSD, 2021).

2 Overview of the Research

2.1 Developing Ecosystem Extent Accounts

Understanding the extent and type of natural capital/ecosystem assets in an accounting area is the initial step in developing ecosystem extent accounts, and forms the basis for stakeholder engagement and collating information for subsequent ecosystem condition assessments. The extent account quantifies, within the defined accounting area, the extent of natural capital assets (size, shape, area and distribution), the type of natural capital assets (woodlands, aquifers, etc.) and the spatial range and configuration of assets (where they are found), and serves as an account of changes in natural capital assets over time. To develop extent accounts, spatial datasets are required that are reliable, quantify the natural capital assets included in the accounts and cover the full accounting area (for change accounts, contiguous time series datasets are required to provide data over time).

Currently, there is no national ecosystem map of Ireland to support the development of NCA. While there are several surveys that are carried out at varying scales, for example as part of national reporting under the EU Habitats Directive and/or commissioned surveys for local area plans, these are not standardised, contiguous datasets. As part of the INCASE project, several national datasets were reviewed, and their application potential for developing ecosystem extent accounts assessed (Table 2.1).

At the time of the INCASE project data analysis and technical work (2019–2021), available and reliable time series data were limited to the Coordination of Information on the Environment (CORINE) inventory,[18]

Table 2.1. Ecosystem extent datasets (national cover) reviewed for the INCASE project

Dataset	Publication and resolution	Description	Purpose	Relevance to INCASE
CLC	Available time series: 1990, 2000, 2006, 2012 and 2018. Coverage: national, European. Resolution: MMU 25 ha; minimum width 100 m for linear features	Pan-European, with data for Ireland produced by the EPA	A wide variety of applications, underpinning various EU policies (environment, agriculture, transport, spatial planning, etc.)	National coverage: MMU 25 ha leads to missing local habitat and linear features, such as freshwater rivers and hedgerows
NPWS Habitat Asset Register	Parker *et al.*, 2016. Publication date: 2016. Coverage: national. Resolution: 50 m	Combination of > 20 datasets to create a terrestrial habitat dataset	Key input to model ecosystem service indicators as part of the MAES pilot project	High resolution with national coverage; typology reflects source information, grouped into a register of habitat assets; all inputs, processes and outputs well documented, but data from variable time periods prior to 2016 publication
OSI Land Cover	Published 2023 (after INCASE data analysis had been completed)	National dataset relying on semi-automated methods for interpretation of aerial imagery	Developed by OSI/EPA to inform land use and land use change reporting	Potentially useful for national and local NCA (using landcover as proxy for ecosystem type)
Esri Land Cover	Temporal scale: 2020. Publication date: 2021. Resolution: 10 m	Global coverage, created using Sentinel-2 imagery and a deep-learning model	Can be used in any analyses that require landcover as a spatial input at any point on Earth	High resolution with national coverage; limited to 10 broad landcover classifications; no long-term time series data available at the time of INCASE project data analysis

CLC, CORINE Land Cover; CORINE, Coordination of Information on the Environment; MAES, Mapping and Assessment of Ecosystems and their Services; MMU, minimum mapping unit.

18 https://land.copernicus.eu/en/products/corine-land-cover (accessed 13 October 2023).

and so this formed the basis for our ecosystem extent accounts, and we used available CORINE data as coarse indicators of ecosystem type. For each INCASE catchment, CORINE datasets were analysed using geographical information system tools (ArcGIS) to develop core extent accounts (maps and tables) for four time series (2000, 2006, 2012 and 2018). While CORINE served as the base layer for the core extent accounts, supplementary datasets (where available and relevant) provided more information to support and refine detail on the extent of specific ecosystem types (Farrell *et al.*, 2021a).

Prior to analysis, we aligned the CORINE Land Cover (CLC) classes with the national typology, as recommended by the SEEA-EA (UNSD, 2021). The SEEA-EA recommends the use of national ecosystem typologies, such as the Heritage Council Classification system[19] in Ireland (Fossitt, 2000), which can be aligned with International Union for Conservation of Nature (IUCN) Global Ecosystem Typology (Keith *et al.*, 2020a) as a common system to allow for comparative analysis across study areas (UNSD, 2021).

For example, alignment of ecosystem types with the Heritage Council Classification system facilitates discussions at national and catchment levels, and allows comparisons between catchments to be made. A typology such as the Mapping and Assessment of Ecosystems and their Services (MAES) classification developed for the EU region allows for comparison of ecosystem types across Europe, while alignment with the IUCN Global Ecosystem Typology allows for comparison with areas outside the EU. We aligned the Level 1 and Level 2 categories of the national typology (Fossitt, 2000) to the relevant CLC Level 3 classes, based on expert opinion. Alignment to Level 3 of the national typology was not possible because of the resolution (minimum mapping unit (MMU) 25 ha) of the CORINE data. Following this, we aggregated the aligned Level 1 and 2 categories to high-level ecosystem types for the INCASE catchments (Table 2.2). We also aligned the ecosystem types with the IUCN Global Ecosystem Typology (Keith *et al.*, 2020a).

2.2 Developing Ecosystem Condition Accounts

A three-stage approach is used in the SEEA-EA for the compilation of ecosystem condition accounts. Outputs at each stage are relevant for policymaking and decision-making:

- In **stage 1**, key (ecosystem condition) characteristics are selected and data on relevant variables are collated.
- In **stage 2**, a general ecosystem reference condition is determined and for each variable a corresponding reference level is established that allows a condition indicator to be derived.
- In **stage 3**, condition indicators are normalised to support aggregation and the derivation of ecosystem condition indexes (note that stage 3 cannot be executed until stage 2 has been completed).

These three stages in the compilation of ecosystem condition accounts are used in an integrated way, with the move from one stage to another requiring a progressive building of data and the use of clear assumptions. The accounting structure provides the basis for organising data, aggregating across both areas of the same ecosystem type and also across the complete area of an ecosystem type within the defined accounting area, such as delineated catchment areas under the WFD river basin management plans. Outputs and learnings from each stage can be of relevance to policymaking and decision-making (UNSD, 2021).

Nationally available datasets relevant for condition accounts were aligned with the SEEA-EA Ecosystem Condition Typology (Table 3.1), with comprehensive datasets outlined in Appendix 3.1 of the INCASE Technical Research Report. We also identified ancillary datasets that are useful to inform condition. These datasets are available nationally and at subcatchment level, and generally relate to environmental characteristics (soil type, soil organic carbon (SOC), soil texture, elevation, climate). They are useful to inform the underlying condition, and in some cases historical coverage, of ecosystems (e.g. peat soil texture can be used to indicate the

19 https://www.heritagecouncil.ie/content/files/best_practice_guidance_habitat_survey_mapping_onscreen_version_2011_8mb.pdf (accessed 13 October 2023).

Table 2.2. The crosswalk between the national typology (Fossitt, 2000) and CLC classes and alignment with the INCASE grouping and the IUCN Global Ecosystem Typology

CLC classification (including CLC classes recorded in the Dargle)				Irish national typology		INCASE grouping	IUCN Global Ecosystem Typology		
Class	**Subclass**	**Code**	**Landcover description**	**Level 1**	**Level 2**	**Ecosystem type**	**Realm**	**Biome**	**Ecosystem functional group**
1. Artificial surfaces	1.1. Urban fabric	111	Continuous urban fabric	B: Cultivated and built land	BL: Built land	Urban	Terrestrial	T7: Intensive land use	T7.4: Urban and industrial ecosystems
		112	Discontinuous urban fabric	B: Cultivated and built land	BL: Built land			T7: Intensive land use	T7.4: Urban and industrial ecosystems
	1.2. Industrial, commercial and transport units	121	Industrial or commercial units	B: Cultivated and built land	BL: Built land			T7: Intensive land use	T7.4 Urban and industrial ecosystems
		122	Road and rail network and associated land	B: Cultivated and built land	BL: Built land			T7: Intensive land use	T7.4: Urban and industrial ecosystems
	1.3. Mine, dump and construction sites	131	Mineral extraction sites	B: Cultivated and built land	BL: Built land			T7: Intensive land use	T7.4: Urban and industrial ecosystems
		132	Dump sites	B: Cultivated and built land	BL: Built land			T7: Intensive land use	T7.4: Urban and industrial ecosystems
		133	Construction sites	B: Cultivated and built land	BL: Built land			T7: Intensive land use	T7.4: Urban and industrial ecosystems
	1.4. Artificial, non-agricultural vegetated areas	141	Green urban areas	G: Grassland and marsh	GA: Improved grassland			T7: Intensive land use	T7.4: Urban and industrial ecosystems
		142	Sports and leisure facilities	B: Cultivated and built land	BC: Cultivated land			T7: Intensive land use	T7.4: Urban and industrial ecosystems
2. Agricultural areas	2.1. Arable land	211	Non-irrigated arable land	B: Cultivated and built land	BC: Cultivated land	Cropland		T7: Intensive land use	T7.1: Annual croplands
	2.3. Pastures	231	Pastures	G: Grassland and Marsh		Grasslands		T7: Intensive land use	T7.2: Sown pastures and fields
	2.4. Heterogeneous agricultural areas	241	Complex cultivation patterns	G: Grassland and marsh				T7: Intensive land use	T7.2: Sown pastures and fields
		243	Land principally occupied by agriculture, with significant areas of natural vegetation	G: Grassland and marsh				T7: Intensive land use	T7.5: Derived semi-natural pastures and old fields
		321	Natural grassland	G: Grassland and marsh				T7: Intensive land use	T7.5: Derived semi-natural pastures and old fields

Table 2.2. Continued

CLC classification (including CLC classes recorded in the Dargle)				Irish national typology		INCASE grouping	IUCN Global Ecosystem Typology		
Class	**Subclass**	**Code**	**Landcover description**	**Level 1**	**Level 2**	**Ecosystem type**	**Realm**	**Biome**	**Ecosystem functional group**
3. Forest and semi-natural areas	3.1. Forests	311	Broad-leaved forest	W: Woodland and scrub	WD: Highly modified/ non-native woodland	Forest		T7: Intensive land use	T7.3: Plantations
		312	Coniferous forest	W: Woodland and scrub				T7: Intensive land use	T7.3: Plantations
		313	Mixed forest	W: Woodland and scrub				T7: Intensive land use	T7.3: Plantations
		324	Transitional woodland shrub	W: Woodland and scrub	WS Scrub/transitional woodland			T7: Intensive land use	T7.3: Plantations
			n/a	W: Woodland and scrub	WN: Semi-natural woodland	Woodlands		T2: Temperate–boreal forests and woodlands	T2.2: Deciduous temperate forests
			n/a	W: Woodland and scrub	WL: Linear woodland/ scrub			T7: Intensive land use	T7.5: Derived semi-natural pastures and old fields
	3.2. Shrub and/ or herbaceous vegetation associations	322	Moors and heathland	H: Heath and dense bracken	HH: Heath	Heathlands		T3: Shrublands and shrubby woodlands	T3.3: Cool temperate heathlands
	3.3. Open spaces with little or no vegetation	334	Burnt areas	H: Heath and dense bracken	HH: Heath			T3: Shrublands and shrubby woodlands	T3.3: Cool temperate heathlands
		332	Bare rocks	E: Exposed rock and disturbed ground	ER: Exposed rock			T3: Shrublands and shrubby woodlands	T3.4 Rocky pavements, lava flows and screes
		333	Sparsely vegetated areas	E: Exposed rock and disturbed ground	ER: Exposed rock			T3: Shrublands and shrubby woodlands	T3.4: Rocky pavements, lava flows and screes

Table 2.2. Continued

CLC classification (including CLC classes recorded in the Dargle)				Irish national typology		INCASE grouping	IUCN Global Ecosystem Typology		
Class	**Subclass**	**Code**	**Landcover description**	**Level 1**	**Level 2**	**Ecosystem type**	**Realm**	**Biome**	**Ecosystem functional group**
4. Wetlands	4.1. Inland wetlands	412	Peat bogs	P: Peatlands	PB: Bogs	Peatlands	Freshwater-terrestrial	TF1: Palustrine wetlands	TF1.6: Boreal, temperate and montane peat bogs; TF1.7: Boreal and temperate fens
		411	Inland marshes	F: Freshwater	FS: Swamps	Freshwater	Freshwater-terrestrial	TF1: Palustrine wetlands	TF1.3: Permanent marshes; TF1.4: Seasonal floodplain marshes
5. Waterbodies	5.1. Inland waters	512	Waterbodies	F: Freshwater	FL: Lakes and ponds		Freshwater	F1: Rivers and streams; F2: Lakes	F1.1: Permanent upland streams; F1.2: Permanent lowland rivers; F2.2: Small permanent freshwater lakes
4. Wetlands	4.1. Inland wetlands	423	Intertidal flats	C: Coastland		Coastal	Freshwater-marine	FM1: Transitional waters	
5. Waterbodies	5.2. Marine waters	523	Sea and ocean	C: Coastland	CD: Sand dune systems		Marine-terrestrial	MT1: Shoreline systems; MT2: Supralittoral coastal systems	MT 1.2: Muddy shorelines; MT 2.1: Coastal shrublands and grasslands

n/a, not available.

former extent of peat-forming ecosystems). Local catchment datasets were also identified and reviewed to inform local conditions at catchment level. In general, these datasets were commissioned for specific area/habitat surveys and had partial coverage within a catchment. Nonetheless, they provided useful information in relation to biodiversity hotspots to build up a richer picture of the INCASE catchments.

Most data that provide information as to the condition of ecosystems in Ireland are gathered for the purposes of reporting under EU directives. Nationally, there are datasets for the water quality of waterbodies under the WFD, habitats and species reported under the Habitats Directive and the Birds Directive, and forests under the National Forest Inventory (Table 2.3).

Developing natural capital accounts at national level is supported by these national datasets. Depending on accounting area and scale (e.g. a 2-ha woodland or a 150-ha farm), a complete and detailed habitat survey with species information may or may not be available, as these data are gathered at varying resolutions.

Data on condition characteristics and measures of condition variables (e.g. species presence/abundance) are generally presented in aggregate form (e.g. the structure and function of habitats) and for the most part are collected in accordance with a sampling strategy that enables them to be reported in an aggregated indicator at national level (e.g. the conservation status of habitats), and so catchment reporting is limited (other than for water resources). Note that, for INCASE catchments, these data were more relevant as ancillary data supporting both extent accounts and condition accounts, and for directly accounting for soils as a geosystem asset.

The INCASE project did not progress reference condition definitions, and nationally a reference condition needs establishing for all ecosystem types. Currently, there are relatively clear indicators for water quality (through the WFD) and there are indicators that could be used for Annex 1 habitats, but these need to be expanded to cover all habitat types.

2.3 Developing Ecosystem Services and Benefits Accounts

Building information about natural capital *stocks* (their extent and condition) is fundamental to the development of natural capital accounts. Indeed, both *stocks* and *flows* are important in terms of accounting for nature. However, many people have a greater awareness of the *flows* of services and benefits from natural capital and, concurrently, the potential risks relating to changes and/or declines in service flows, than of *stocks*. For example, many people are aware of the climate regulation service provided by forests ("planting trees is good"). However, many are not aware that the extent and condition of those forests (e.g. where the trees are planted and how forests are structured in terms of species, tree condition and age) affects not only the current standing stock of carbon in the forest, but also the flow of carbon sequestered by the forest.

Measurement of ecosystem services is therefore central to describing an integrated set of ecosystem accounts, particularly in highlighting and explaining the variety of contributions that ecosystems make to people and the economy (UNSD, 2021) while underpinning understanding of the changing capacity of ecosystem assets to supply services. The ecosystem accounting framework is therefore designed to present a clear understanding of the following:

- the range of ecosystem services;
- the spatial heterogeneity of ecosystem service delivery, relating to one or a number of ecosystem types;
- the role that different ecosystems play in supply of services and, central to that, the effects of changes in stocks (extent and condition) of ecosystem and natural capital assets in the supply of services (we note that this is a fundamental cornerstone of NCA and presents an integrated tool for recording both *stocks* and *flows* essential for analysis of the relationship between both, which is very poorly understood at present in terms of the non-linearities of the extent/condition and service relationship);
- the local to global beneficiaries of ecosystem services, and associated benefits.

Within the INCASE project, we adhered to the guidance set out in the SEEA-EA (UNSD, 2021) while also recognising and referencing ongoing work at EU level to implement the SEEA-EA by the EU MAES project, the Mapping and Assessment for Integrated

Table 2.3. Ecosystem condition datasets (national cover) reviewed for the INCASE project

Data source	Description	Data	Scale	Other information
WFD – EPA	Time series data relating to WFD cycles	Range of biotic and abiotic characteristics (physico-chemical and hydromorphological quality elements) combined with the aggregated indicator *ecological status*. Supported by further datasets, including MQI[a] data for rivers, hydrometrics and river flow. The MQI looks at several key indicators, such as longitudinal/latitudinal connectivity, hydromorphology and riparian condition	National – all waterbodies (rivers, lakes, groundwater, coastal and transitional). The development of the MQI has involved an assessment of the current river network, mapped for larger channels for the whole country (60,000 km)	Datasets are also available for protected waterbodies, such as rivers protected for salmonids and/or drinking water. In 2021, the EPA launched a series of PIP maps[b] for nitrogen and phosphorus to show the highest risk areas in the landscape for losses of nitrogen and phosphorus to waters
Habitats and birds (nature) directives – NPWS	Article 17 (habitats and species) reporting, with time series data available (2007, 2013, 2019)	Article 17 conservation status assessments of Habitats Directive's habitats and species based on distribution and range, structures and functions, and future prospects for habitats; distribution and range, population size, suitable habitat and future prospects for species; combined with aggregated indicator *conservation status*	National – distribution, type and conservation status of habitats and species at grid level, indicating known presence or absence in each 10-km grid, as well as full-resolution survey data	Detailed information at higher resolution is derived from NPWS stratified sampling surveys or from other available spatial data sources[c]
National Forest Inventory[d]	Designed using permanent sample plots for repeated measurements	Range of information to assess changes in the state of Ireland's forests over time	Gathered at national level, the data include condition variables, including forest area change, volume increment and latest felling volume estimates	The data are unsuitable for use at catchment level, given the limited number of sample points
Irish Soil Information System[e]	A digital soil information system (national soils database) provides spatial quantitative information	Attributes include soil type, soil depth, soil texture (indicative), drainage and SOC	National association soil map for Ireland at a scale of 1:250,000	Data are national, but as they are given to a resolution of 250 m they are not reliable for areas with a scale resolution below 250 m
HRL developed by the ESA using satellite imagery	HRL are designed to be used in conjunction with other landcover and/or land use layers (e.g. CORINE) to provide more information on specific landcover types	HRL include imperviousness, forest, grassland, water and wetness, and small woody features layers. Can inform on condition, e.g. imperviousness indicates the presence of sealed surfaces/built habitats	Depending on the layer, time series data are available for 2012, 2015 and 2018 and at resolutions ranging from 5 m to 20 m	
NBDC datasets	Biodiversity data accessible for decision-making, to assist public and private engagement and to support conservation	Data on Irish habitats and species in Ireland, including invasive species and selected focus species groups (e.g. pollinators)	Data are available in point data format, generally displayed in a 10-km grid, but with various ranges depending on the dataset	The National Biodiversity Indicators have been updated using data to the end of 2020. The latest status and trends report has been published recently (NBDC, 2021)

Table 2.3. Continued

Data source	Description	Data	Scale	Other information
Pollutant data – EPA	Air pollutants recorded for dense urban areas (e.g. Dublin). Water pollutants modelled (phosphorus and nitrogen PIP maps[b]) as estimates of the annual nutrient losses from agricultural land at specific locations	PIP maps use spatial data on farm management, soils and hydrogeology	National coverage data. PIP models estimate loads at an annual temporal resolution and provide information to compare relative potential nutrient sources	Local knowledge and evidence will be needed to have confidence in temporal changes in water quality throughout the year
Focused ecological survey datasets	Site-level data (usually gathered for commissioned species and habitat surveys) can include ecosystem condition assessment for focused ecosystem/habitat types	Can include measures of species presence or absence, species diversity, vegetation density and/or population trends (for specialist species). Forest data include stand age, dominant tree type, yield class and biomass yield (Coillte BioClass assessment tool designates biodiversity condition). Data on Irish wetlands comprise location/point data, with some site descriptions and qualitative comments on condition	Generally, most species and/or habitat surveys rarely include condition assessments except if carried out for EU Habitats Directive (Article 17) reporting and/or gathered for results-based payments schemes, such as the condition scoring developed for EIP projects	In the INCASE catchments, relevant EIP projects include data gathered at farm level and habitat level for the Pearl Mussel EIP project (Caragh), the Sustainable Uplands Agri-environment Scheme EIP (Dargle), the BRIDE EIP project (Bride) and FarmPEAT EIP (Figile)
Landscape characteristics	In the absence of condition data relating to agricultural/enclosed farm areas, this dataset provides a high-level aggregate to identify potential HNVf areas	The HNVf layer is a dataset developed using five indicators (semi-natural habitat cover, stocking density, hedgerow density, river and stream density and soil diversity). As a composite indicator, it should not be used in conjunction with condition indicators already used in the calculation of HNVf, to avoid double counting	It has national cover, but has not been updated since 2016	Other landscape characterisation datasets have been developed, but are commissioned surveys for specific areas

[a]https://reformrivers.eu/guidebook-evaluation-stream-morphological-conditions-morphological-quality-index-mqi.html (accessed 13 October 2023).

[b]https://www.catchments.ie/next-generation-pollution-impact-potential-maps-launched/ (accessed 13 October 2023).

[c]The lack of data for a given location may be a function of lack of sampling or other data sources, rather than absence of the habitat or species. Consequently, data may or may not be suitable for use at subcatchment level. All NPWS full-resolution survey data, which underlie the coarser grid-level data (the latter being in the format required by EU for official reporting), are published by NPWS as open data. There are exceptions where full-resolution survey data are restricted (for ecological sensitivity reasons, or non-NPWS intellectual property rights).

ESA, European Space Agency; HNVf, High Nature Value farmland; HRL, high-resolution layers; MQI, Morphological Quality Index; PIP, pollutant impact potential.

[d]https://www.gov.ie/en/publication/823b8-irelands-national-forest-inventory/ (accessed 13 October 2023).

[e]http://gis.teagasc.ie/soils/ (accessed 13 October 2023).

Ecosystem Accounting project,[20] and the Knowledge Innovation Project on an Integrated System of Natural Capital and Ecosystem Services Accounting. In developing services accounts for the INCASE catchments, the first step was to identify the range of services, non-use values, abiotic flows and spatial functions supplied by ecosystems in each catchment. Initially, we developed a longlist of recognisable services and other flows for the INCASE catchments, as outlined here:

- *Provisioning*: grazing biomass, crop biomass, wood biomass, medicinal products, seaweed

20 https://maiaportal.eu (accessed 13 October 2023).

cropping, fish (local harvesting), wild fish (commercial), drinking water and other domestic uses.
- *Regulating*: air filtration, carbon storage, carbon sequestration, local climate regulation, coastal protection, habitat provision (nursery), fire protection, sediment retention, water storage, fluvial flow, baseflow to streams and rivers, flood regulation, water filtration.
- *Intermediate*: nutrient cycling, primary production, pollination, pest control, soil formation, water cycling.
- *Cultural*: recreation, aesthetic, education.
- *Non-use flows*: ecosystem and species appreciation.
- *Abiotic flows*: mineral (metallic) aggregates, mineral (non-metallic) aggregates, peat (domestic), geothermal, hydropower, wind power, solar power.
- *Spatial functions*: navigation.

From this longlist we developed a shortlist, and applied selection criteria as a means to identify services that were both relevant and feasible to develop accounts for within the catchments and time frame of the INCASE project. We adapted the approach outlined by Oudenhoven *et al.* (2018), which describes key criteria for developing ecosystem service indicators to inform decision-making, using the main categories of credibility, salience, legitimacy and feasibility.

We show the ranking applied to the Dargle as an example of how to select services in an open and transparent way that could be used in any NCA exercise (Table 2.4). We applied the following criteria: policy relevance, natural capital involved/percentage of catchment involved in supply of the service, likely supply/demand/use, issues relating to sustainable use (pressures and threats) and, based on our data inventory and assessment, likely availability of data. Based on our criteria and assessment, climate regulation scored highest (73/75) compared with other ecosystem services in the Dargle, given the extent of peat soils, forestry and policy relevance. Ecosystem appreciation, recreation and habitat (nursery) provision were next (68/75) in the Dargle, with water quality and regulation of flooding also highly ranked (63/75 and 59/75, respectively); however, we did not have capacity and data were limited, and so these are not included in this report. Food, timber and water provisioning also scored highly (54/75, 53/75 and 51/75, respectively), while activities such as mineral and peat extraction scored relatively low (note that peat extraction and wind energy were included for the Figile as being of high ranking). Note that this was the process to refine the selection of services. In terms of developing the accounts, this was further guided by data availability and data relevance, assessed through the process of developing the accounts and assessing the service supply and use.

Having refined a shortlist of services, the next step was to consider what service(s) is(are) directly attributable to an ecosystem asset or ecosystem type, usually informed through existing literature and/or by assessing spatial data/models. In some instances, a service may be attributable to a number of ecosystem types (e.g. regulation of water flows across woodlands and peatlands) or a single ecosystem may deliver a range of services (e.g. peatlands deliver climate, water regulation and grazing services) in various orders of magnitude, depending on supply and use in the catchment. At the same time, following from the development of the shortlist of services for inclusion, other aspects should continue to be considered through the process. Such aspects include those relevant to the related policy issue being addressed by the accounts, who owns the ecosystem, what is it used for, etc. All of this information can be gathered in a logic chain tailored to the service in the particular accounting area, such as catchment area. Development of the logic chain in turn assists in gathering data relevant to assess the ecosystem service flow and, where data are not available, the identification of alternatives to direct measures in terms of potential proxies.

Logic chains are outlined in the SEEA-EA, and Natural England (Lusardi *et al.,* 2018) has developed a comprehensive list of logic chains that are relevant as reference material to develop logic chains in the Irish context. Within the INCASE project, we developed logic chains for each service, following the SEEA-EA, and these are outlined in relation to the assessment of the relevant services (see INCASE Final Technical Report). Note that these logic chains were intended to demonstrate the approach rather than to be definitive/standard. There is no reason why they could not be developed using participatory approaches in the future.

Table 2.4. Workshopping ecosystem services for the INCASE project: a selection of ecosystem services provided by the Dargle ecosystem were scored based on a number of different criteria and using a weighted scoring system

Service	Policy relevance (weighting[a]: 20)	Natural capital involved/% catchment (weighting[a]: 10)	Level of supply/ demand/use (weighting[a]: 20)	Sustainable use (pressures and threats) (weighting[a]: 20)	Data availability (weighting[a]: 5)	Total (maximum score: 75)	National ranking: high/ medium/low
Food	CAP, Origin Green, bioeconomy, climate, WFD, nature directives; sustainable farming, Commonage Framework Plan, animal welfare – score: 18/20	Grasslands 5000 ha; croplands 500 ha; peatland and heathland 4000 ha (>50% catchment) – score: 8/10	Low/low/low – score:10/20	Related to other services, such as climate, water quality, flood, biodiversity; drives a lot of pressures on other natural capital stocks; land abandonment – score:15/20	Some data available – score: 3/5	54/75	High; affects all other issues
Water	WFD/Uisce Éireann; planning – score: 13/20	Surface and groundwater waterbodies (extent and condition) – score: 5/10	High/increasing/ increasing – score: 15/20	Urban wastewater and onside wastewater treatment systems – score: 15/20	Engage EPA/ Uisce Éireann/WCC/ LAWPRO – score: 3/5	51/75	Medium
Timber/NTPs	Forest policy; timber industry – score: 15/20	Forests; heathlands; 30% catchment – score: 8/10	Medium/high/ increasing; linked to aesthetics – score: 15/20	All planted on peat soils; forestry a pressure in Glencullen; related to other services, such as climate, water quality, flood and biodiversity – score: 12/20	No data on yield class; could use timber per ha as a proxy – score: 3/5	53/75	Medium
Mineral aggregates; peat	Not active in the catchment – score: 0/20	Mineral aggregates – score: 10/10	High/low/low – score: 0/20	Not an issue – score: 0/20	Not all quarries listed; peat cutting inactive – score: 0/5	10/75	Low
Water (quality)	WFD: PAAs in Carrickmines and the Dargle – score: 20/20	Catchment scale; cross-cutting issues – score: 5/10	Medium/high/high – score: 15/20	Loss of good eco status – score: 18/20	EPA data – score: 5/5	63/75	Medium
Water (flooding)	Planning; climate – score: 15/20	Catchment scale; floodplains – score: 5/10	High demand – score: 20/20	Effectiveness of hard engineering? Loss of floodplains; increasing flooding – score: 18/20	Modelling data? – Score: 1/5	59/75	Medium
Habitat/nursery (biodiversity)	Nature directives (habitats and species); Farming with Nature (RBAPs) – score: 20/20	Catchment scale – score: 8/10	Intermediate services – score: 18/20	Loss of biodiversity; national biodiversity crisis – score: 18/20	NPWS HD data; NBDC; HNVf maps; NPWS network maps – score: 4/5	68/75	High; affects all

Table 2.4. Continued

Service	Policy relevance (weighting[a]: 20)	Natural capital involved/% catchment (weighting[a]: 10)	Level of supply/ demand/use (weighting[a]: 20)	Sustainable use (pressures and threats) (weighting[a]: 20)	Data availability (weighting[a]: 5)	Total (maximum score: 75)	National ranking: high/ medium/low
Climate (global)	Climate; CAP; planning – score: 20/20	Woodlands (4000 ha); forests (3000 ha); peatlands and heathlands (4000 ha); wetlands – score: 10/10	Increasing – score: 20/20	Climate change; national climate crisis – score: 20/20	Stocks of carbon (SOC); vegetation carbon? Emission factors (IPCC reporting?) – score: 3/5	73/75	High; affects all
Climate (local cooling)	Climate; health and wellbeing; planning – score: 12/20	Urban areas and street trees; 30% – score: 3/10	Low/high/increasing – score: 15/20	Increased temperature and population – score: 15/20	Data? – score: 3/5	48/75	Medium
Air quality	Climate; health and wellbeing; planning – score: 12/20	Urban areas and street trees; 30% – score: 3/10	Low/high/increasing – score: 15/20	Increased pollutants? – score: 15/20	Data? – score: 3/5	48/75	Medium
Ecosystem and species appreciation services	Nature directives (habitats and species); Farming with Nature (RBAPs) – score: 20/20	Catchment scale – score: 8/10	Intermediate services – score: 18/20	Loss of biodiversity; national biodiversity crisis – score: 18/20	NPWS HD Data; NBDC; HNVf maps; NPWS network maps – score: 4/5	68/75	High; affects all
Recreation local	Planning framework; health and wellbeing (EPA) – score: 19/20	Urban green space; amenity areas/grasslands and parklands; coastal; DMP; trails – score: 8/10	Increasing; more people need more green space? Better access and walking/ cycle paths? – score: 18/20	Loss of habitats to “greenways”; loss of coastal habitats and coastal squeeze? DMM conversion? If planned incorrectly could have negative impacts – score: 20/20	Local use of parks from DLR/WCC? Health statistics? Coillte data? – score: 3/5	68/75	Medium
Recreation tourism (linked to landscape aesthetics)	Tourism Ireland; nature directives – score: 20/20	Catchment scale – score: 10/10	High/increasing?/ high – score: 18/20	Healthy landscapes for sustainable use – score: 18/20	WMNP data on visitors; Powerscourt data; TI data; DMP/ Coillte data? – score: 2/5	68/75	Medium

This stylised table is used to demonstrate an initial approach to mapping catchment ecosystem services as part of applying the SEEA-EA.

[a]Weightings were agreed by the research team based on review of papers on weighting relevance and discussion with wider stakeholders.

CAP, common agricultural policy; HD, Habitats Directive; HNVf, High Nature Value farmland; IPCC, Intergovernmental Panel on Climate Change; LAWPRO, Local Authority Waters Programme; RBAP, results-based payment approach; WCC, Wicklow County Council; WMNP, Wicklow Mountains National Park.

Our approach to services was as follows:

- *Provisioning*: crop biomass, grazed biomass, timber biomass.
- *Regulating*: climate regulation.
- *Cultural*: recreational (qualitative) and modelled data for forests.
- *Non-use flows*: eco/geosystem appreciation.
- *Abiotic flows*: water from groundwater (demand approach) and peat for domestic energy.

3 Examination of the Findings

3.1 Results and Key Learning Points for Ecosystem Extent Accounts

Aligning with and taking into account the structure and resolution of the CORINE datasets, we combined the following ecosystem types within our INCASE ecosystem accounts and discussions: woodlands and forest, peatlands and heathlands, and grasslands and croplands (Table 3.1). The change in extent (hectares; 2000 to 2018) of main ecosystem types based on CLC Level 3 classes in each of the four INCASE catchments is presented in Table 3.2 and Figure 3.1. The CLC status changes were analysed using the Environmental Systems Modelling Platform (EnSym) tool.

3.2 Results and Key Learning Points for Ecosystem Condition Accounts

Given that there are a limited number of datasets that can be used to develop ecosystem condition variables and *stage 1* condition accounts, as described in the SEEA-EA, we developed rudimentary condition accounts and identified what is feasible based on currently available data, and where further research and data gathering should focus to address data gaps. We used the condition data available for freshwater rivers and lakes, and developed an approach to assessing condition of peatlands with limited data, incorporating expert ecological views. The outline approach to developing ecosystem extent and condition accounts for the Dargle catchment was published in 2021 (Farrell *et al*., 2021a).

3.2.1 Ecosystem condition case study: freshwater rivers and lakes

Condition data are gathered under WFD reporting for rivers and lakes (and also coastal waters, transitional waters and groundwater). The main condition indicator is “ecological status”, based on biotic and abiotic qualitative and quantitative data (supporting physico-chemical and hydromorphological quality elements). The WFD classification scheme for water quality comprises five status classes: high, good, moderate, poor and bad. “High status” is defined as the biological, chemical and hydromorphological conditions associated with no or very low human impact. Note that the term “impact” is used rather than “pressure”, as low pressure can result in high impact and vice versa, depending on the sensitivities of the receptor.

For all waterbodies[21] in Ireland, ecological status data were available for four time periods that relate broadly to the WFD cycle,[22] as follows:

- baseline data gathered for initial WFD assessment: 2007–2009;
- follow-on reporting phase from initial baseline/mid-term review: 2010–2012;
- WFD first full cycle period: 2010–2015;
- assessment to 2018: 2013–2018 (best available data at time of INCASE data analysis).

Using the Dargle subcatchment as a model for the other catchments, again we noted that the time series data for the WFD reporting periods (2007–2018 available) do not align with those of the CORINE extent accounts. However, we used the time series data available to compare general trends in the condition of rivers and lakes with the ecosystem extent accounts (Farrell *et al*., 2021a). For the Dargle, ecological status ranged from poor in urban-dominated areas to high in some largely rural, forest-dominated areas. Despite differences in ecological status, many watercourses were considered at risk (2010–2015 assessment period; the 2018 pressure data were not released at time of analysis)

21 Note that under the WFD terminology, a waterbody can be a river or tributary, a lake, a body of groundwater, an estuary or a coastal area.

22 Ecological status should be considered the most representative and homogeneous indicator across Europe, but missing data reported under the first and second cycles of implementation of the WFD might hamper the use of this information for trend analysis. In addition, the ecological status is reported only every 6 years. See https://ec.europa.eu/environment/nature/knowledge/ecosystem_assessment/pdf/5th%20MAES%20report.pdf (accessed 13 October 2023).

Table 3.1. Main ecosystem types within the INCASE catchments

Ecosystem type	Description
Freshwater	This category comprises surface waterbodies, such as rivers, lakes, canals and swamps. As mentioned, CORINE data are unable to detect freshwater rivers and lakes below the MMU. However, lake waterbodies in the Caragh, given their high cover, were detected in this subcatchment
Coastal	This ecosystem consists of dune complexes, machair, saltmarshes, tidal areas, sea cliffs and beaches, which often occurred as linear features in the accounting areas. These linear features were largely undetected, with lowest cover in the Dargle (Bray beach and a dune system near Killiney) and highest cover in the Caragh (salt marsh and dune areas)
Woodland and forest	**Woodlands.** This category includes all semi-natural woodland types, including native woodlands, hedgerows, treelines and scattered parklands. We distinguished woodlands from commercial plantations (forest) on the basis of structure (plantation) and use. Using CORINE, this ecosystem type was mostly detected as transitional woodland, and supplementary datasets are required to distinguish this ecosystem type from non-commercial areas **Forest.** Wooded areas planted and managed for the primary purpose of commercial production. CORINE data show forest to be the dominant ecosystem type, with the highest percentage cover being in the Dargle but highest overall cover in the Figile and the Bride
Peat and heathland	**Peatlands.** This category comprises raised bog, mountain and lowland blanket bog, cutover, fen and all degraded peatland types. These ecosystem types were found to be extensive in the Figile, the Caragh and the Dargle, with relatively low cover in the Bride **Heathlands.** Wet and dry heathland types (including bracken dominated areas) often occur in a mosaic with peatlands on peat soils. This category also includes alpine heathlands that occur at high altitudes and often form directly on subsoil (no peat layer present). Heathlands are extensive and are detected more clearly in later CORINE datasets, and are generally associated with peatlands and upland areas in the INCASE catchments
Grasslands and croplands	**Grasslands.** This includes all improved, semi-improved and semi-natural grassland types, and marsh. Grasslands cover is highest in the Bride, followed by the Figile and the Dargle, and lowest in the Caragh (although natural grasslands associated with the uplands in the Caragh are detected) **Croplands.** Areas developed for the purpose of crop production, including cereals, biomass crops, fruit and vegetables, were included here. Croplands are relatively low in cover and amalgamated with grasslands in CLC tables
Urban	This grouping was largely aligned with the national Level 1 ecosystem type cultivated and built land (Fossitt, 2000), the main focus of interest being urban green and blue spaces from an ecosystem accounting perspective. The Dargle showed the highest cover, with low levels in the Caragh and the Figile, given their rural character

of not maintaining or achieving high ecological status owing to significant pressures from urban wastewater and diffuse urban water run-off, and from forestry and hydromorphological changes (Farrell *et al.*, 2021a). This illustrates how condition accounts can be supplemented with ancillary data on pressures to inform risk management and identification of natural capital assets that require attention.

Further data can inform freshwater condition, including the Morphological Quality Index (MQI), hydrometric data to estimate nutrient loadings, hydrometric data on river flows, macroinvertebrate data, Small Streams Risk Score, and data on the status of freshwater habitats and species reported under the EU nature directives, along with other ancillary data (for full details see Appendix 3.1 of the INCASE Technical Research Report).

In summary, there are suitable time series data to develop condition accounts for freshwater rivers and lakes in Ireland under WFD reporting gathered by the EPA, from sub-basin to the broader catchment scale. Condition status is assessed as ecological status, which combines biotic and abiotic scores (supporting physico-chemical quality elements and hydromorphological quality elements). This pre-aggregated index may be used as a sub-index as part of the SEEA-EA condition accounts. The characterisation carried out as part of WFD reporting

Table 3.2. Change in extent (hectares; 2000 to 2018) for the Dargle, Figile, Bride and Caragh catchments based on CLC Level 3 classes, developed using the EnSym tool (CLC status changes)

CLC code		Dargle (total ecosystem area 17,684 ha)					Figile (total ecosystem area 30,143 ha)					Bride (total ecosystem area 42,715 ha)					Caragh (total ecosystem area 22,966 ha)				
		CORINE dataset				Overall CLC change	CORINE dataset				Overall CLC change	CORINE dataset				Overall CLC change	CORINE dataset				Overall CLC change
		2000	2006	2012	2018		2000	2006	2012	2018		2000	2006	2012	2018		2000	2006	2012	2018	
Freshwater																					
512	Waterbodies	45	45	26	26	–20	0	0	0	0	0	0	0	0	0	0	941	898	900	900	–41
	Coastal																				
423	Intertidal flats	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	33	34	34	34	1
523	Sea and ocean	9	9	10	10	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	–1
	Total	9	9	10	10	1	0	0	0	0	0	0	0	0	0	0	34	34	34	34	0
Woodlands and forest																					
311	Broad-leaved forest	166	296	580	580	414	0	27	671	671	671	247	198	293	259	12	193	212	485	458	265
312	Coniferous forest	1421	1886	1788	1830	409	454	560	463	493	39	3176	2695	2642	2324	–852	367	805	645	627	259
313	Mixed forest	550	477	372	372	–178	0	496	1504	1504	1504	224	329	313	363	139	326	107	194	163	–163
324	Transitional woodland-shrub	1444	850	625	486	–958	3373	2658	2006	2153	–1220	2565	2723	2527	2864	299	784	393	161	237	–547
	Total	3581	3509	3365	3268	–313	3827	3741	4644	4821	–994	6211	5945	5774	5809	–402	1670	1517	1485	1485	–185
Peatlands and heathlands																					
322	Moors and heathlands	0	2214	3125	3157	3157	0	0	0	0	0	0	0	0	0	0	0	1416	1757	1757	1757
411	Inland marshes	0	0	0	0	0	0	0	0	0	0	88	45	41	41	–47	0	0	0	0	0
412	Peat bogs	4062	1897	1201	1201	–2861	10,979	10,024	9659	9512	–1467	67	97	10	10	–57	12,865	11,678	10,589	10,582	–2283
332	Bare rocks	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		272	667	667	667
333	Sparsely vegetated areas	0	73	28	28	28	0	0	0	0	0	0	0	0	0	0	1207	1968	1590	1590	383
334	Burnt areas	0	0	0	65	65	0	0	0	0	0	0	0	0	0	0					0
	Total	4062	4184	4354	4451	389	10,979	10,024	9659	9512	–1467	155	142	51	51	–104	14,072	15,334	14,603	14,596	524

Table 3.2. Continued

CLC code		Dargle (total ecosystem area 17,684 ha)					Figile (total ecosystem area 30,143 ha)					Bride (total ecosystem area 42,715 ha)					Caragh (total ecosystem area 22,966 ha)				
		CORINE dataset				Overall CLC change	CORINE dataset				Overall CLC change	CORINE dataset				Overall CLC change	CORINE dataset				Overall CLC change
		2000	2006	2012	2018		2000	2006	2012	2018		2000	2006	2012	2018		2000	2006	2012	2018	
Grasslands and croplands																					
211	Non-irrigated arable land	706	442	444	476	–230	1587	1066	889	985	–602	7955	3448	3436	2473	–5482	0	0	0	0	0
231	Pastures	3575	3095	3132	3056	–519	12,925	13,267	13,730	13,574	648	26,172	30,340	30,666	31,603	5432	2360	2105	2180	2180	–180
242	Complex cultivation patterns	934	587	527	487	–447	427	457	454	467	40	998	1353	1285	1254	256	0	0	0	0	0
243	Land principally occupied by agriculture, with significant areas of natural vegetation	1259	1607	1732	1756	497	108	1257	450	450	342	1128	1211	1212	1233	105	2139	2035	2081	2088	–51
321	Natural grasslands	140	0	0	0	–140	0	0	0	0	0	0	0	0	0	0	1623	919	1555	1555	–68
	Total	6614	5731	5835	5775	–839	15,047	16,047	15,523	15,475	428	36,253	36,352	36,599	36,564	311	6122	5058	5816	5823	–299
111	Continuous urban fabric	0	37	46	46	–46	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
112	Discontinuous urban fabric	2441	2645	2629	2636	–195	177	206	156	156	–21	39	135	159	159	120	51	49	53	53	2
121	Industrial or commercial units	78	119	257	276	–198	0	0	31	31	31	0	0	0	0	0	0	0	0	0	0
122	Road and rail networks and associated land	85	199	198	198	–113	0	0	0	0	0	0	40	36	36	36	0	0	0	0	0
131	Mineral extraction sites	0	0	26	0	0	61	74	79	97	36	0	45	42	42	42	2	3	2	2	0
132	Dump sites	30	81	0	0	30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
133	Construction sites	66	158	31	90	–24	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
141	Green urban areas	191	151	93	93	98	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
142	Sport and leisure facilities	485	818	817	819	–334	52	52	52	52	0	57	57	54	54	–3	73	73	73	73	0
	Total	3376	4208	4097	4158	782	291	332	317	335	45	96	276	291	291	195	126	125	128	128	2

Spatial resolution: MMU 25 ha/100 m.

Source: Author's compilation based on European Environment Agency Copernicus Programme; see https://www.eea.europa.eu/en/about/key-partners/copernicus#:~:text=The%20Copernicus%20programme%20collects%20and,emergency%20management%2C%20and%20safeguard%20civil.

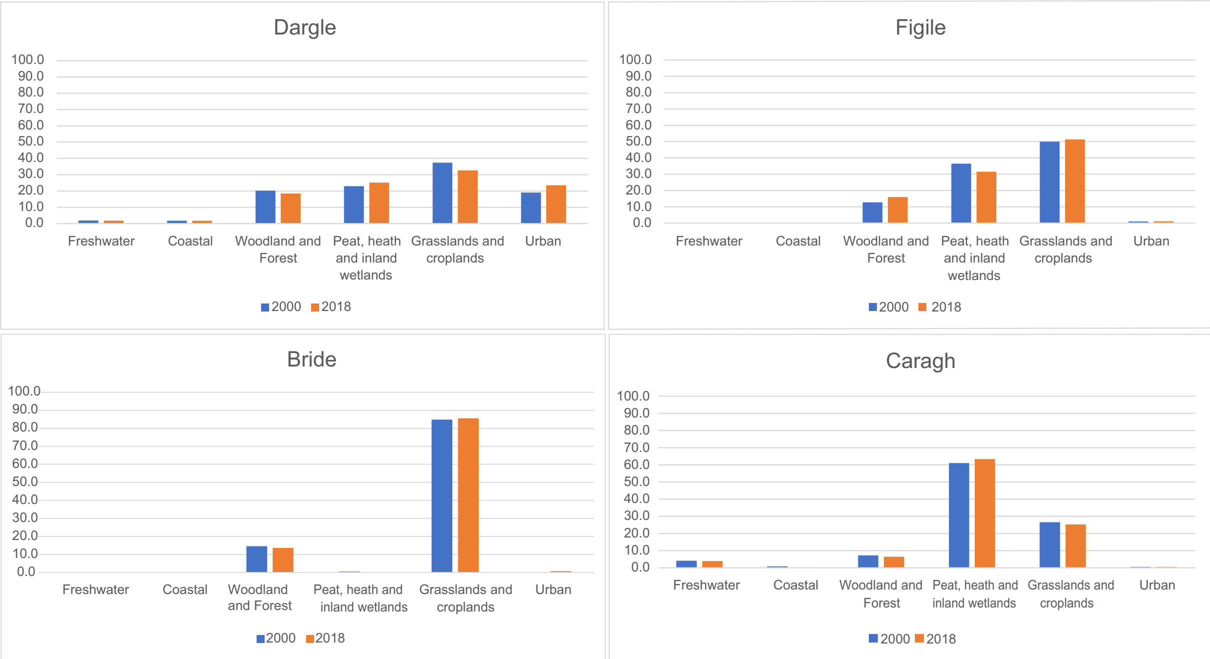


Figure 3.1. Extent accounts for the INCASE catchments based on data from 2000 (blue bars) and 2018 (orange bars).

indicates trends relative to thresholds (characterising risk by relating pressures and ecological status). This presents a risk register of sorts (see Farrell *et al.* (2022) for more information on risk registers). In addition, a number of ancillary metrics recorded by the EPA (MQI, hydrometrics) can inform the hydromorphological quality of rivers and streams. Hydrometrics also include records of river flow, and models of recorded flow can be developed to inform how land use activities can affect river flow.

In addition, nationally reported data showing trends in habitats and species covered under Article 17 of the Habitats Directive and Article 12 of the Birds Directive are available for freshwater habitats and species. These data are representative of national trends (note that this renders the data generally not suitable at the local/catchment/regional scale) and form a pre-aggregated index conservation status, which integrates an assessment of condition (structure and function), range, pressure and threats. The index also constitutes a risk register of sorts (see Farrell *et al.* (2022) for more information on risk registers). Reporting under the EU nature directives is based largely on stratified sampling, and surveys contain detailed non-aggregated data that may be available for sites in NCA areas.

3.2.2 *Ecosystem condition case study: peatlands*

Building on ecosystem accounts developed to date for wetlands and peatlands in the UK[23] and the Netherlands (Hein *et al*., 2020a), we tested how to make effective use of existing datasets relating to peatland stocks (extent, type and condition) to assess and develop condition accounts for peatlands in two INCASE catchments, the Dargle and the Figile. These data were published in 2021 (Farrell *et al*., 2021c).

Peatland extent and condition

Peatland extent was established using national-scale open-access data: CORINE, EU Habitats Directive Article 17 and national soil data (peat texture as an indicator of previous extent). Peatland condition for the Dargle included commonage survey data

23 https://www.ons.gov.uk/economy/environmentalaccounts/bulletins/uknaturalcapitalforpeatlands/naturalcapitalaccounts (accessed 13 October 2023).

from 2001 and a desktop survey of the Wicklow Mountains SAC (which partially overlaps with the Dargle catchment) based on 2006 data. Data relating to the condition of commonage areas in Ireland were gathered nationally in the early 2000s in response to overgrazing pressures in upland areas. Ground truthing (site inspection and vantage point survey by a trained peatland ecologist), use of aerial imagery (Google Earth Pro) and stakeholder engagement (local knowledge) was incorporated to assess peatland condition (structure and function) in each catchment (Farrell *et al*., 2021c).

The datasets showed that commonage areas were damaged in 2001, and peatland habitats accounted for *c*.50% degraded peatland habitats (cutover and eroding bog) and *c*.50% of Annex I peatland types, occurring within a mosaic, with dry heathland alongside patches of wet grassland, scrub and plantation. No indicators of condition, or trends in condition over time, were available for Annex I habitats (Farrell *et al*., 2021c).

Comparing 2009 and 2020 aerial imagery datasets highlighted localised areas of gullying and active erosion at the upper reaches of the catchment, increasing the exposure of areas of underlying gravels. Comparison of the area of exposed gravel between 2009 and 2020 indicates that erosion is ongoing and condition is deteriorating. Burn scars are clearly visible, with uncontrolled burning occurring regularly, according to local sources. Former peat cuttings are clearly visible, along with an extensive drainage network. Although no active peat cutting is visible or has been reported by locals, drainage networks remain active. Recreational paths show signs of trampling and bare peat exposure (Farrell *et al*., 2021c).

The levels of degradation vary within the catchment and are related to the peatland type (Annex I blanket bog and wet heathland, and cutover and eroding bog), but, overall, the structure and function are impacted negatively with ongoing erosion and degradation of the peatland habitats, and the condition of the Dargle peatlands is considered “bad” (Farrell *et al*., 2021c).

While data relating to peatland condition in the study catchments were limited, we have demonstrated that developing ecosystem extent and type accounts, and highlighting changes in both aspects over time, can serve as a proxy for peatland ecosystem condition. In the case of peatlands, intact peatland types, as defined under the Irish national typology, are, in the main, considered Annex I habitats (blanket bog, raised bog, wet heathland, alkaline fen) and included under Article 17 reporting. This suggests that remaining peatlands are *other* peatland types derived from former Annex I type and include eroding bog, industrial cutaway peatland and cutover bog. By inference, these peatlands are considered to be in a degraded (or bad) condition (Farrell *et al*., 2021c).

Peatland type can therefore be used as a rudimentary means/proxy to inform ecosystem condition, for the purposes of ecosystem accounting. It is noted that a change in condition also affects extent and type accounts, for example where intensified drainage and/or extraction of peat converts an Annex I bog to a cutover bog (from good to bad condition), or where restoration restores a drained, degraded raised bog to an *active* raised or blanket bog (from bad to good/better condition). These changes would be typically recorded in the SEEA-EA extent and type and change accounts (UNSD, 2021). However, as time series data detailing extent and type are limited, we could highlight only overall changes in peatland extent using soil texture data (Farrell *et al.,* 2021c). Understanding how and why peatland types cross threshold levels and are converted to other peatland or ecosystem types (related to pressures and use) will be integral to developing peatland ecosystem stock accounts (and, equally, ecosystem flow accounts) (Farrell *et al*., 2021b), as there are knock-on consequences for ecosystem service provision (Kimmel and Mander, 2010).

Key findings for testing with other ecosystem types

Datasets relating to ecosystem condition variables were limited, and we relied on extent and type data, ancillary information gathered at varying intervals and expert ecological opinion to develop rudimentary condition accounts (Farrell *et al*., 2021c). Drainage, disturbance (erosion) and land conversion were shown to be relevant indicators of peatland condition and pressures, reflecting work carried out at EU scale (Maes *et al*., 2020).

More widespread data gathering (at standardised time intervals) relating to relevant peatland condition variables, such as extent of bare peat, peat depth (required to assess carbon stocks), water level (drainage intensity) and presence of indicator species/plant communities, would facilitate building *stage 1* condition accounts, as outlined in the SEEA-EA (Farrell *et al*., 2021b), and provide indicators of ecosystem services, such as carbon sequestration and regulation of water flows (Connolly and Holden, 2011).

The selection of realistic reference levels (a requirement of stage 2 of SEEA-EA condition accounts) is fundamental for each peatland and other habitat types (and is essential to establish restoration targets). While the SEEA-EA provides guidance on reference conditions (UNSD, 2021), the selection of reference condition levels should reflect local and regional contexts to address the geographical variation of peatland ecosystems (and wetland ecosystems in general) at both national and EU scales (Keith *et al*., 2020b).

For Annex I habitats, reference conditions can be established with relative ease, while habitats beyond legal reporting frameworks will require more detailed analysis, as shown here. Although detailed conservation status assessments are carried out for a relatively small area of the national peatland inventory, and only for Annex I habitats (NPWS, 2019), the approach used here could be extended with relative ease to develop assessments for a wider range of peatland-dominated catchments and/or landscape units (Farrell *et al*., 2021c). Combining these with EU WFD data collected at sub-basin level would serve to link peatland status and trends with trends in the ecological status of waterbodies (Farrell *et al*., 2021a,b), making use of ready-made EU reporting frameworks.

Summary conclusions

Condition accounts are the least developed within the European region and at national levels, although efforts are becoming more focused (Czúcz *et al*., 2021; Keith *et al.,* 2020b; Maes *et al*., 2020). At this time only bespoke condition accounts can be developed at catchment and/or national scale in Ireland (Farrell *et al.,* 2021a). The challenges identified by the INCASE project reflect those identified in other studies and include:

- the lack of data to build condition accounts, although we note national-level accounts could be developed for some ecosystem types, such as those reported under EU directives;
- the absence of targeted and reliable time series data on structure and function for areas outside EU reporting areas;
- the need for agreed reference levels (Maes *et al*., 2020).

Despite clear guidance provided in the SEEA-EA, a number of questions remain to be addressed and require multidisciplinary efforts, particularly from ecologists with specialist knowledge from across the range of ecosystem types of relevance, to guide and develop the links between condition, capacity to deliver services and sustainable use (Czúcz *et al*., 2021; Keith *et al*., 2020b; Maes *et al*., 2020; Rendon *et al*., 2019).

In relation to INCASE catchments, WFD data provide a comprehensive resource to develop ecosystem condition accounts for waterbodies in general and could be used as indicators of sub-basin condition in the absence of condition data for other ecosystem types (Farrell *et al.,* 2021a). Other condition datasets available for habitats listed under Annex I of the EU Habitats Directive, and for sites within the Natura 2000 network, are available, although site-specific data relating to catchment level are very limited (Farrell *et al*., 2021a). The use of these and other datasets (e.g. National Forest Inventory data gathered at national scale) is appropriate for condition accounts developed at national scale rather than catchment scale (Farrell *et al*., 2021a), as used in other studies (Maes *et al*., 2020; Rendon *et al*., 2019).

Aligning ancillary datasets with the core extent accounts data in the INCASE catchments illustrated the effective use of soils data to infer the historical extent of peatlands and heathlands – an important consideration for the contribution of drained peatlands to carbon emission (Farrell *et al*., 2021b). In this way, ancillary data and proxies can be placeholders to highlight data gaps until more appropriate data are gathered (Burkhard *et al*., 2018; Geijzendorffer *et al*., 2015; Grunewald *et al*., 2020; Maes *et al*., 2020; Vačkářů and Grammatikopoulou, 2019).

In relation to peatlands, data relating to drainage and vegetation cover are often reflected in the name of the peatland ecosystem type (Level 3 of the national ecosystem typology). Within the Dargle, a desktop survey of the Wicklow Mountains SAC highlights areas of active blanket bog (considered to be in good condition), as well as cutover bog and eroding bog (considered to be drained and eroding, and thus inferred to be in poor condition). Linking these data with remote-sensing approaches detecting peatland drainage (Connolly and Holden, 2011) would provide information about potential peatland ecosystem condition indicators (Farrell *et al.,* 2021c).

A similar approach, i.e. working with ecosystem experts, would make information available for a selection of relevant ecosystem condition variables and condition indicators for other ecosystem types (woodlands, grasslands, freshwater, etc.), particularly in the local and regional contexts.

Efforts to combine advances in remote sensing at the EU level to develop Essential Biodiversity Variables[24] and national efforts[25] will facilitate alignment with local ecosystem types and contribute to filling data gaps, ultimately facilitating effective ways of tracking and accounting for changes in a standardised comparable way (Farrell *et al.,* 2021a,b).

Next steps

Although challenges remain in gathering relevant condition data and developing robust condition accounts (Farrell *et al*., 2021a,b), inspiration can be drawn from other studies (Maes *et al*., 2020; Rendon *et al*., 2019) and the condition variables set out in the SEEA-EA guidance (UNSD, 2021). More focused work at the individual ecosystem level could incorporate other datasets, including survey data commissioned for development and planning projects, and species data collected by NGOs and citizen science programmes (taking into account the biases that may be associated with such data). However, SEEA-EA benefits from full spatial coverage, not discrete sample data, as well as temporal sampling to track changes in condition over time, and so repeated, spatially extensive datasets are required.

For SEEA purposes, it is expected that countries or regions will measure ecosystem condition using a national or regionally agreed set of reference conditions. This will require an agreement based on understanding of each ecosystem type, and links with selection of condition variables. While reference condition can be set for Annex I habitats, most habitats in Ireland lie outside these definitions, and the upper and lower reference levels that should be selected for each habitat/ecosystem type remain to be determined.

In the case of ecosystems that have been exposed to human influence for long periods of time, the "natural" state is no longer a meaningful reference for condition accounts, or its use may be impracticable because it results in low values of indicators of current condition (Farrell *et al.,* 2021a). For these, the SEEA-EA recommends defining an anthropogenic reference condition. Such a reference condition should be determined in relation to stable ecological conditions (UNSD, 2021). The EU is currently in the process of collating condition data to identify ideal condition variables across all ecosystem types (Vallecillo *et al.,* 2022).

3.3 Results and Key Learning Points for Ecosystem Services and Benefits Accounts

A range of data sources were used to develop ecosystem services accounts (each listed or referred to in the relevant section of the INCASE Final Technical Report). The available data provide a snapshot and rudimentary assessment of selected services in the INCASE catchments. We note that ecosystem services accounts are based on available data for the services assessed and are therefore limited in terms of accuracy, reliability and robustness. However, the assessment approach can be used as a basis for further work to develop flow accounts. A summary of our supply accounts is given in Table 3.3 (extended supply and use tables are available online: https://www.incaseproject.com/report).

The main economic sectors identified were agricultural (crop and grazing biomass), forestry (timber biomass), mining (peat in the Figile and water use), industrial (water use), household (water, peat fuel, recreational use) and governmental sectors (carbon stocks and flows, designated ecosystems). In summary, with regard to services in each catchment:

- **Dargle.** Provisioning services are relatively low in this catchment, with a high supply/use of recreation services (related to high cover of forests and high population), and high carbon

24 https://geobon.org/ebvs/what-are-ebvs/ (accessed 13 October 2023).

25 https://jcresearch.wixsite.com/ihabimap (accessed 13 October 2023).

Table 3.3. Summary services assessments collated for supply/use accounts for the INCASE catchments

		Dargle			Figile			Bride			Caragh		
INCASE service	Metric	Catchment	Import	Total ES	Catchment	Import	Total ES	Catchment	Import	Total ES	Catchment	Import	Total ES
Provisioning													
Crops	t DM	3485		3485	13,513		13,513	28,891		28,891	0		0
Grazed biomass	t DM	21,727		21,727	75,272		75,272	196,302		196,302	79,619		79,619
Timber	m3	46,693		46,693	52,658		52,658	125,806		125,806	21,112		21,112
Climate regulation													
SOC to 1 m	t C	4,208,746		4,208,746	16,903,915		16,903,915	6,121,786		6,121,786	9,872,358		9,872,358
Carbon flows (peat soils)	t C	25,568		25,568	75,743		75,743	744		744	17,940		17,940
Cultural													
Recreation related	Number of people	1,122,764		1,122,764	101,885		101,885	120,320		120,320	39,269		39,269
Non-use flows													
Eco/geosystem and species appreciation	Area (ha) (% catchment)	7214 (24%)		7214 (24%)	398 (1.4%)		398 (1.4%)	1069 (2.5%)		1069 (2.5%)	19,197 (84%)		19,197 (84%)
Abiotic flows													
Water supply	m^3	175,393		175,393	907,262		907,262	2,379,659		2,379,659	116,157		116,157
Peat (wet tonnes)	t	0	3120	3120	87,060		87,060	0	660	660	12,900		12,900

Data were retrieved from multiple sources and cover varying years in the period 2016–2019 (see INCASE Final Technical Report).

stocks and emissions. Water demand is high in this catchment, but largely imported for human consumption.

- **Figile.** Grazing biomass supply/use and water supply/use is high in this catchment. The Figile has the highest SOC stocks and carbon emissions of all the catchments studies (related to the high cover of peatlands – >60% peat soils). The area of ecosystem appreciation is the lowest in this catchment.
- **Bride.** This catchment has the highest levels of provisioning services supply/use, and the highest abstraction levels of water from groundwater (predominantly demanded by the agricultural sector).
- **Caragh.** This catchment has the highest flow relating to supply/use of eco/geosystem appreciation, with relatively high levels of grazing and carbon stocks supply/use. The main sector benefiting, based on supply/use tables, is the government (global society).

3.3.1 General comments on the INCASE services account

- **Crops.** This service varies across all catchments, with the highest estimates for the Bride, followed by the Figile.
- **Grazing.** The highest levels were estimated for the Bride, followed by the Caragh (high cover of rough grazing areas).
- **Timber.** The highest estimated wood growth was for the Bride (related to the area of commercial forest).
- **Water supply from groundwater.** The highest abstraction levels were estimated for the Bride and the Figile, attributable to high livestock numbers. Most of the water for domestic use is imported into the Dargle.
- **Climate regulation.** The Figile has the highest SOC, followed by the Caragh. There was no carbon removal estimated, with most peat soils acting as net emitters of carbon based on drainage/use.
- **Recreational use of forests.** The INCASE-modelled estimates show highest potential supply/use for forests in the Dargle, followed by the Bride (related to high population levels).
- **Eco/geosystem appreciation.** The highest cover of nature designations was recorded in the Caragh, with high cover also in the Dargle (mostly peatlands and heathlands), along with a more detailed description of geoheritage features.
- **Peat (an abiotic flow as opposed to an ecosystem service flow – domestic use).** The highest levels were estimated for the Figile and the Caragh; peat is likely to be imported in the Dargle and the Bride.

Service supply and use accounts can be considered in terms of the extent and condition accounts, linking service flow to the ecosystems and geosystems in each catchment, and similarly establishing how (patterns of) the service supply/use is linked to extent and/or condition. We reiterate a number of summary points here to reflect the underpinning SEEA-EA approach to services:

- Recorded supply does not equal ecosystem capacity (i.e. the overall ability of an ecosystem to sustainably supply goods and services; Vargas *et al*., 2019) in relation to the SEEA-EA.
- Ecosystem services are transactions and/or exchanges between the ecosystem and the user (the economic sector or another ecosystem type).
- Ecosystem services do not necessarily involve movement or transformation in physical terms. This may be particularly true for some cultural services (e.g. visual amenity) or certain regulating services (e.g. water purification, which is more of a biochemical process). Nonetheless, the transactions/exchanges are in concept observable and quantifiable.
- Ecosystem services are contributions to benefits. This is an important concept and can be considered in the framing of a supply chain in which the input–output has been extended to include the ecosystem service as an input. Intermediate services as framed in the SEEA-EA can be viewed as inputs to final ecosystem services.
- Exports and imports are common features and can be recorded to show flows between catchments/accounting areas, and between countries.
- The ecosystem or geosystem provides the input, and the output is related to the benefit.
- This interplay between natural capital assets and benefits can also be thought of in terms of flows from various types of capital: services are the flows from natural capital, which, combined

with flows from other traditional economic capital concepts, such as financial, physical, human or social capital, leads to various benefits.

Key message. The flow of the service depends on the extent and condition of the natural capital asset. This point is critical and highlights the need to establish how flows have changed over time in response to changes in extent and condition accounts over time. This information will support scenario analyses to inform how flows will change into the future based on changes in extent and condition accounts.

3.3.2 Valuation methods and approaches

Building on the extent, condition and services (physical) accounts, the SEEA-EA methodology enables the contributions of ecosystems, and broader natural capital assets, to society to be expressed in monetary terms, thus facilitating comparison with other goods and services that we are more familiar with. Recognising (i) that monetary values cannot be comprehensive and are unable to reflect the full range of values of nature and (ii) that monetary values are not appropriate for use in all decision-making contexts, we note that monetary estimates can provide information for decision-makers, for example for economic policy planning, input–output analysis and for raising awareness of the dependence of society on nature.

Following from the traditional monetary valuation approaches, NCA instead focuses on integrating natural capital and the associated service flows into the SNA approach, thus highlighting how natural capital is supporting the current measured economy (previously not integrated in a structured way). Valuation methods are developing over time, and new metrics that can be aligned with those of the SNA (e.g. GDP), using natural capital approaches, are emerging. This enables heretofore limited approaches focused solely on the economy to be extended and incorporates the significant role that natural capital plays in underpinning society and economy. A recent example of a new metric is gross ecosystem product (Ouyang *et al*., 2020).

From an economic perspective, the relationship between people and the environment is commonly characterised as comprising both use and non-use values, as described in the Total Economic Value (TEV) framework developed by Pearce and Turner (1990). The word "total" refers to the sum of use and non-use values, and the TEV framework brings together a number of value perspectives, including intrinsic values. The TEV framework is one of the most widely used and commonly accepted frameworks for classifying environmental economic benefits and for attempting to integrate them into decision-making, and is succinctly described in a summary paper available from the UK Valuing Nature network (Ozdemiroglu and Hails, 2016).

Most of the ecosystem services outlined in the SEEA-EA are treated as use values, given the benefits revealed through direct or indirect interactions, although non-use values are also included as complementary valuations. Following from this, within the TEV framework, provisioning services can largely be categorised as direct use and regulating services as indirect use, while both can also be considered to have non-use values in terms of option and/or bequest (value for future generations) value. Supporting services are considered in a broader frame, as they (or intermediate services in the SEEA-EA) underpin ecosystem function and therefore all values. It follows from this that cultural services can be considered from both use value and non-use value perspectives. For example, recreation can have direct use and indirect use values, while ecosystem appreciation or nature conservation is ascribed existence values, carrying option and bequest values for future generations.

In practice, the valuation methods used to estimate market prices in the national accounts can be applied to ecosystem services and assets, especially where there are links to the SNA. The valuation methods are outlined in the SEEA-EA, and we summarise the approaches here in the Irish context. The general approach is to take each ecosystem service in turn and assess the potential valuation approach in terms of the following.

Availability of direct (observable) price. This includes stumpage values charged to timber logging businesses or land rental prices (market price). We note that, generally, the SEEA-EA recommends that use data derived from payments for ecosystem services schemes are not used in the estimation of prices for ecosystem services, unless there is clear evidence that the scheme targets a specific service. We also note that, although market prices for carbon are available, it may be considered appropriate to use other measures, such as the social cost of carbon (an estimate of the economic costs or damages of emitting 1 additional tonne of carbon dioxide into the atmosphere, and thus an estimate of the benefits of reducing emissions), instead of or as well as market prices, for comparison.

Related market prices for similar goods or services. For example, it may be the case that market prices are available for fish and/or non-timber forest products from one waterbody/forest, but not from a similar waterbody/forest. The prices of the former can be used as a proxy for the latter.

Methods that embody the price for the ecosystem service in a market transaction. For example, grazing biomass can be estimated as a residual value (resource rent). Note that the resource rent method is often most readily applied using broad industry-level data, and the resulting price estimates may lack the granularity required for developing location-specific monetary values. Other methods include hedonic pricing, which relates to property/rental values.

Actual costs. These include, for example, travel costs to recreation sites (travel cost method).

Hypothetical costs. These are based on expected expenditures or markets, for example replacement costs and/or avoided damage costs. One method emerging in this area is the simulated exchange value method.

Key message on valuation of ecosystem assets. The more relevant issue is ecological and relates to the need to establish a clearer picture of the relationship between current ecosystem (or broader natural capital) condition and future flows of services. This requires reasonable assumptions to be made, based on current ecological knowledge and available data. Again, this highlights the need for reliable, relevant and robust data to build extent and condition accounts.

Given that the INCASE project was intended to explore the use of NCA in Irish catchments, one of the outcomes of this approach is highlighting the lack of open-source available data for assessment of services. In an effort to develop the accounts, various estimates were used, including modelling approaches. However, as with any estimates, these include a level of error. Applying a valuation approach that further depends on estimates or the use of proxies undoubtedly leads to monetary amounts that do not reflect the actual natural capital value in these catchments. In addition, the use of proxies means that the value of the ecosystem service per se is not estimated in most cases, and this limitation needs to be effectively communicated to users of the accounts (e.g. decision-makers). For the INCASE catchments, given that the biophysical information and service accounts developed for each catchment did not comprise reliable data, and the likely high level of error, we did not apply monetary valuation techniques to the services and/or flows, nor the natural capital assets.

Instead, we have highlighted appropriate valuation methods (Table 3.4) that could be applied in the Irish context once the approaches to services assessment and overall accounting have matured in terms of inclusion and assessment of more services, more detailed landcover mapping (e.g. the forthcoming OSI-EPA Land Cover map for Ireland), more robust data, and modelling approaches to physical flows and supporting data for valuation.

Table 3.4. Suggested valuation approach for some ecosystem services in the Irish context, as per the SEEA-EA

Service	Final benefit valuation, as outlined in the SEEA-EA	Proposed valuation approach
Crop biomass	The final benefit measure of the harvested biomass can be used as a proxy measure of the crop provisioning service	Rental price (cropland conacre)
Grazing biomass	The final benefit measure of the biomass can be used as a proxy measure of the grazed biomass provisioning service	Rental price (grassland conacre)
Wood	Valuation of the gross biomass harvested to constitute the benefit derived from wood provisioning services for that year	Stumpage price and/or resource rents
Water purification	The value of abiotic flows may be measured using observed market prices, and the net present value of these flows can be recorded alongside the value of ecosystem assets. Alternatively, the replacement cost approach and the productivity change method may be applied	Treatment cost difference between surface water and groundwater
Carbon	There are ways of valuing of carbon: (i) using carbon prices from emission trading systems, such as the EU Emissions Trading System; (ii) using the marginal costs of abatement; and (iii) using the social cost of carbon	DPER[a] shadow carbon price or social cost of carbon
Recreation	The final benefit is health and wellbeing, with additional benefits to businesses involved in recreational activities	Travel costs[b] (excluding consumer surplus)
Eco/geosystem appreciation	The SEEA-EA suggests that these values may be presented in complementary valuations to the main SEEA-EA accounts	Non-use stated preference methods[c]
Peat (domestic energy)	The value of abiotic flows may be measured using observed market prices and the net present value of these flows can be recorded alongside the value of ecosystem assets	Market price[d]

[a]The Irish DPER has revised the approach for valuing carbon price and now recommends the use of carbon shadow pricing based on estimated marginal abatement cost rather than the market value of allowances in the EU Emissions Trading System. The abatement cost approach was also suggested by Horlings *et al.* (2020) as more practicable than the use of the social cost of carbon, at least in the Netherlands.

[b]The travel cost method is a well-developed non-market valuation approach (Hanley *et al.*, 2016), although SEEA-EA (UNSD, 2021) notes that consumer surplus should not be included, as is common in the literature, to keep in line with the exchange value approach used in the SEEA-EA.

[c]In terms of non-use valuation, there are a number of published resources on non-use valuation using stated preference methods (Guijarro and Tsinaslanidis, 2020). The most commonly used methods are the contingent valuation method and the choice modelling method. In both cases, the change in consumer surplus is used to measure economic welfare of a population in response to a change in an environmental good or service.

[d]Abiotic flows are suggested to be measured in terms of resource rent (i.e. market price less production costs); however, they may also be measured using observed market prices, and the net present value of these flows can be recorded alongside the value of ecosystem assets.

DPER, Department of Public Expenditure and Reform.

4 Conclusions and Policy Recommendations

The INCASE project has advanced understanding and application of NCA approaches for Ireland. Given that our objective was to develop catchment-scale accounts, we used the spatially explicit United Nations SEEA-EA for four case study subcatchments – the Dargle, the Caragh, the Figile and the Bride. We developed initial accounts, a preliminary data visualisation tool (R-shiny app[26]) and a framework for monetisation. Extensive stakeholder consultation and a wide range of communication methods (summarised in Appendix 5.1 of the INCASE Final Technical Report) has resulted in a high level of engagement with the project and its outputs.

4.1 Key Learnings

Much of the land area in all four catchments is **highly managed**. For example, in the Dargle, ecosystem types are largely grouped in the intensive land use category (Farrell *et al.,* 2021a), T7 of the IUCN Global Ecosystem Typology (Keith *et al*., 2020a), including sown pastures, urban areas and plantations. Only scattered fragments of semi-natural ecosystem types are present, reflecting the steady and increasing conversion of natural lands, such as temperate woodlands, heathlands and wetlands (peatlands and fens), to intensive agricultural use in former centuries, as well as the more recent expansion of urban areas in the late 19th and early 20th centuries.

Other areas (e.g. the Dargle) now show an opposing trend, towards extensification (Farrell *et al*., 2021a). The widespread lack of natural lands is of concern, particularly given the upcoming EU Nature Restoration Law, and the Global Biodiversity Framework post-2020 biodiversity targets, both of which will require extensive restoration and conservation of habitats in Ireland. Accounts also revealed the importance of peatlands for carbon stocks and their contribution to climate-regulating services, and that most of the peatlands in our catchments are at risk from drainage, disturbance and land conversion pressures.

Ecosystem extent accounts are highly dependent on the scale and policy question for which the accounts are being developed. Since the extent account underpins all other accounts, due care should be given to selecting what is included and why, to ensure that the aspects relevant to the policy question are included. Accounts are more accurate with high spatial resolution, and time series data are essential to show change over time. Landcover or land use data provide much relevant information for the measurement of ecosystem extent and may also be of use in ecosystem service flows accounts, but are not sufficient to delineate ecosystem assets; a dedicated ecosystem map is required for accurate representation of ecosystem type.

Ecosystem condition characteristics are functional and dynamic characteristics of the ecosystem that can be tracked over time, and the precise structure of condition accounts depends on the characteristics that are selected and the availability of data. As ecosystems operate at multiple scales, and several ecosystem assets may contribute to a single service, and a single ecosystem asset can produce a flow of several services, more detailed extent and condition data (e.g. vegetation coverage, species and species composition data) are required. In the absence of data to inform conditions directly, ancillary data and proxies can be used, or commissioned surveys should be considered. As with extent accounts, condition accounts have policy applications, but these also need to be clearly defined, and the purpose of accounting should influence what sort of data are gathered and the scale at which they are gathered. Finally, a careful and consistent approach to the selection of reference levels is required to derive ecosystem condition indicators, to ensure that they are compatible and comparable, and their aggregation is ecologically meaningful, enabling comparison across ecosystem types.

Ecosystem services flows are often estimated via proxies and/or national averages. In advance of

26 https://www.incaseproject.com/tools (accessed 13 October 2023).

developing natural capital accounts, a key step is identifying what services are relevant and why, and what data are available. It is advised that a list of five or six services is feasible for initial accounts, to develop an understanding of the accounting approach and methods, but the policy question being addressed will influence the selection of appropriate and relevant services. Data on ecosystem contributions to benefits are often not available (many are currently under development), and so proxies are regularly used as a guide or placeholder until more specific data on service flows are available. However, it is important that the limitations of these proxies are recognised by account users.

Although knowledge about the assessment of ecosystem service flows is growing, the relationship between ecosystem asset condition and the security of future flows requires further work. In addition, the spatial and temporal variation in service delivery is often not known, and cannot be incorporated into accounts. For example, to estimate crop provisioning services and grazed biomass, national averages of yield per hectare of crops/grass were used, but these vary across Ireland and between years.

Stakeholder engagement is critical in developing accounts (see the blog[27] on Changes & Challenges in Land Use within our Dargle Catchment on the INCASE website). Stakeholder engagement should include participatory mapping to define the "natural capital–ecosystem service–economic benefit" logic chain early in the iterative SEEA-EA process.

Since the initiation of the INCASE project, there has been significant international progress in implementing ecosystem accounting as a complementary metric to GDP (e.g. in the USA and EU). In addition, biodiversity and ecosystems services are recognised as on a par with climate in terms of planetary boundaries.

Thus, there is a need to benchmark natural capital stocks and flows over time, and our work has moved from the theoretical research sphere and prototyping to implementation by official statistics bodies. Indeed, the Central Statistics Office in Ireland now has an Ecosystem Accounts Division, and the work of the INCASE project will inform development of accounts at a national level.

4.2 Recommendations

Developing and using ecosystem accounting is a national priority. There is no time to lose in addressing urgent environmental issues, developing integrated land use planning and making informed decisions. Despite gaps in biophysical datasets, ecosystem accounting needs to be not just developed, but actively used to address policy gaps and conflicts. For example, an economic impact assessment, focusing on the impacts of food production, showed that environmental targets are unlikely to be met under current policy. Ecosystem accounts have the potential to provide the comparable data necessary to inform integrated policy formation, and should be prioritised for such a use, while presenting a ready-made tool to track changes required by targets set under the EU Nature Restoration Law.

Increased expertise is required for operationalisation of ecosystem accounting in Ireland. As can be seen from the detail in this report, the full INCASE Final Technical Report and its appendices, ecosystem accounting is a technical undertaking, requiring integration of skills from a range of disciplinary experts. Thus, large multidisciplinary teams are required. In addition, as ecosystem extent accounts underpin other accounts, and ecosystem condition accounts are the least developed, ecological expertise is fundamental. Integrating ecological understanding with economic modelling also needs further attention.

A regularly updated, detailed and high-resolution ecosystem map is required. CORINE datasets provide contiguous time series data and are used for high-level ecosystem and landcover reporting across the EU Region at the Tier I (EU Region, using CLC Level 2 classes) and Tier II levels (national regions, using CLC Level 3 classes) (Burkhard *et al.*, 2018; EEA, 2016; La Notte *et al.*, 2017).

While the accuracy of CORINE has improved between 2000 and 2018, reflected particularly in the distinction

27 https://www.incaseproject.com/post/changes-and-challenges-in-land-use-within-our-dargle-catchment-a-farmer-s-view (accessed 13 October 2023).

of peatland and heathland areas, there are limitations of CORINE for catchment scale (Tier III level), including the following:

- Lack of insight and detail on ecosystem subtypes and variants. We broadly aligned CLC Level 3 classes to Level 1 of the national ecosystem typology (Fossitt, 2000). However, being able to use Level 3 of the national typology, for example distinguishing improved grassland from semi-natural grassland types, could improve both accurate extent mapping and quantifying flows of services, which vary considerably. For example, biomass provision from improved grassland is likely to be higher than that from wet, semi-natural grassland types, which are likely to provide a greater level of water and sediment retention services than improved grassland types (Farrell *et al.,* 2021a).
- Lack of ability to detect linear features: rivers, hedgerows, and landscape features less than the MMU or minimum mapping width of CORINE (e.g. locally important wetlands and woodlands) are not included. Supplementary datasets are effective in refining and providing detail but, in general, these are gathered at varying intervals and scales and are generally not consistent either with each other or with the available CORINE time series (Farrell *et al*., 2021a).
- Requirement for ancillary data: bringing in datasets (e.g. soil texture), other indicator maps (e.g. the High Nature Value farmland datasets) and areas designated highlights the usefulness of combining unrelated data that provide information on soil characteristics, management or intensity of use and/or designation for nature conservation (Farrell *et al*., 2021a).

These limitations extend across all scales of reporting, presenting recurring challenges in building ecosystem accounts at any level, as shown across the EU Region (EEA, 2016; Grêt-Regamey *et al.*, 2017; Grunewald *et al.*, 2020; Hein *et al.*, 2020a; La Notte *et al.*, 2017). The OSI national landcover map (recently released for Ireland) (Wall *et al*., 2020), with a resolution of 10 m, provides finer detail on ecosystem extent and will be aligned with the national ecosystem typology. However, it needs to be regularly updated to be useful for accounting purposes. Aligning approaches with the IUCN Global Ecosystem Typology will facilitate effective comparison across the EU Region and globally (UNSD, 2021) in terms of the extent of intensively used ecosystems and natural lands, providing information to plan targeted restoration to rebuild natural networks and re-connect isolated areas protected for nature, a key action identified in the EU Biodiversity Strategy for 2030 (EC, 2019b).

Ecosystem condition assessment needs further development. The selection of condition indicators and their reference levels need a careful and consistent approach. Aspects of condition accounting should be explored in terms of their potential relevance in terms of scale and policy issue being addressed. Condition scoring of on-farm habitats developed by various EIP projects has the potential to be very useful, providing updated, reliable data, but this approach needs to be implemented nationally.

The relationship between extent and condition of natural capital assets and flows of services and benefits requires more nuanced understanding. In particular, ecological condition is a product of environmental context (geographically and geologically) and management (human influence), and both can affect service flows. This means that condition varies spatially and temporally, and using national averages is inadequate. Teasing out the ecosystem contribution and the human contribution is difficult, as highlighted in the biomass services assessment, but over time this issue can be resolved by standardising the approach (see, for example, White *et al*., 2022). Further research on the interrelationships between environmental quality, catchment characteristics and land use activities (e.g. Curtis and Morgenroth, 2013) is also vital.

Ecosystem service assessment needs a standardised approach. Ideally, flows of each service should be recorded more than once, giving reliable, standardised time series data, enabling the link to be made between changes in extent and condition and changes in supply and use of services over time. This information would allow accounts to be built and would provide information on how activities (linked to policies) affect ecosystem stocks and flows, and how they are likely to do so in the future. The SEEA-EA outlines a number of options to assess service flows and these should be clearly outlined from the outset of the accounting, along with the assumptions and data sources (time period, scale, limitations, etc.).

We assessed a wide range of (open-source) data sources for use data, and, in general, data enabling service assessment were limited. The regulatory services require further dedicated modelling, particularly services relating to climate, water and biodiversity. Service-mapping tools (SWAT, Aries, EnSym, InVEST, etc.) are available, and their use should be explored in further research at varying scales.

A centralised data platform is required. For INCASE, considerable time and effort was spent sourcing and assessing data for use in developing all accounts. Having a centralised data platform to facilitate streamlined access to data, with appropriate documentation of processing, tools and any other core metadata, and establishing data agreements, will facilitate further research and applications in this area. In addition, data need to be gathered at the appropriate scale for the accounting area; for the INCASE project this was at catchment level rather than at electoral division level. As part of the work by the INCASE team, a Data4Nature workshop convened by NCI presented an opportunity to outline shortcomings in data.

The key messages are outlined in a report by NCI (2021). The report presents a good overview of relevant data issues and ties in with an overview of data gaps and next steps in terms of research and data gathering.

Not all accounts should be monetised. The SEEA-EA approach to monetary valuation must be placed in the context of the broader range of value perspectives. During the INCASE catchment workshops, the issue of monetary valuation arose, despite minimal reference to monetisation and no monetary accounts being presented.

Advancing the understanding of value transfer techniques, i.e. transferring primary data from selected sites to other locations, will be essential to inform valuation aspects. The approach to establishing aggregate values across services or between accounting areas also requires further understanding. However, the focus should remain on biophysical accounts, as developing monetary accounts will take too much time and will vary according to market demand, supply and valuation techniques.

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Abbreviations

BRIDE	Biodiversity Regeneration in a Dairying Environment
CLC	CORINE Land Cover
CORINE	Coordination of Information on the Environment
EIP	European Innovation Partnership
EnSym	Environmental Systems Modelling Platform
EPA	Environmental Protection Agency
EU	European Union
GDP	Gross domestic product
INCASE	Irish Natural Capital Accounting for Sustainable Environments
IUCN	International Union for Conservation of Nature
MAES	Mapping and Assessment of Ecosystems and their Services
MMU	Minimum mapping unit
MQI	Morphological Quality Index
NBDC	National Biodiversity Data Centre
NCA	Natural capital accounting
NCI	Natural Capital Ireland
NPWS	National Parks & Wildlife Service
OSI	Ordnance Survey Ireland
SEEA	System of Environmental Economic Accounting
SEEA-CF	System of Environmental Economic Accounting – Central Framework
SEEA-EA	System of Environmental Economic Accounting – Ecosystem Accounting
SNA	System of National Accounts
SOC	Soil organic carbon
TEV	Total Economic Value
WFD	Water Framework Directive

An Ghníomhaireacht Um Chaomhnú Comhshaoil

Tá an GCC freagrach as an gcomhshaol a chosaint agus a fheabhsú, mar shócmhainn luachmhar do mhuintir na hÉireann. Táimid tiomanta do dhaoine agus don chomhshaol a chosaint ar thionchar díobhálach na radaíochta agus an truaillithe.

Is féidir obair na Gníomhaireachta a roinnt ina trí phríomhréimse:

Rialáil: Rialáil agus córais chomhlíonta comhshaoil éifeachtacha a chur i bhfeidhm, chun dea-thorthaí comhshaoil a bhaint amach agus díriú orthu siúd nach mbíonn ag cloí leo.

Eolas: Sonraí, eolas agus measúnú ardchaighdeáin, spriocdhírithe agus tráthúil a chur ar fáil i leith an chomhshaoil chun bonn eolais a chur faoin gcinnteoireacht.

Abhcóideacht: Ag obair le daoine eile ar son timpeallachta glaine, táirgiúla agus dea-chosanta agus ar son cleachtas inbhuanaithe i dtaobh an chomhshaoil.

I measc ár gcuid freagrachtaí tá:

Ceadúnú

> Gníomhaíochtaí tionscail, dramhaíola agus stórála peitril ar scála mór;
> Sceitheadh fuíolluisce uirbigh;
> Úsáid shrianta agus scaoileadh rialaithe Orgánach Géinmhodhnaithe;
> Foinsí radaíochta ianúcháin;
> Astaíochtaí gás ceaptha teasa ó thionscal agus ón eitlíocht trí Scéim an AE um Thrádáil Astaíochtaí.

Forfheidhmiú Náisiúnta i leith Cúrsaí Comhshaoil

> Iniúchadh agus cigireacht ar shaoráidí a bhfuil ceadúnas acu ón GCC;
> Cur i bhfeidhm an dea-chleachtais a stiúradh i ngníomhaíochtaí agus i saoráidí rialáilte;
> Maoirseacht a dhéanamh ar fhreagrachtaí an údaráis áitiúil as cosaint an chomhshaoil;
> Caighdeán an uisce óil phoiblí a rialáil agus údaruithe um sceitheadh fuíolluisce uirbigh a fhorfheidhmiú
> Caighdeán an uisce óil phoiblí agus phríobháidigh a mheasúnú agus tuairisciú air;
> Comhordú a dhéanamh ar líonra d'eagraíochtaí seirbhíse poiblí chun tacú le gníomhú i gcoinne coireachta comhshaoil;
> An dlí a chur orthu siúd a bhriseann dlí an chomhshaoil agus a dhéanann dochar don chomhshaol.

Bainistíocht Dramhaíola agus Ceimiceáin sa Chomhshaol

> Rialacháin dramhaíola a chur i bhfeidhm agus a fhorfheidhmiú lena n-áirítear saincheisteanna forfheidhmithe náisiúnta;
> Staitisticí dramhaíola náisiúnta a ullmhú agus a fhoilsiú chomh maith leis an bPlean Náisiúnta um Bainistíocht Dramhaíola Guaisí;
> An Clár Náisiúnta um Chosc Dramhaíola a fhorbairt agus a chur i bhfeidhm;
> Reachtaíocht ar rialú ceimiceán sa timpeallacht a chur i bhfeidhm agus tuairisciú ar an reachtaíocht sin.

Bainistíocht Uisce

> Plé le struchtúir náisiúnta agus réigiúnacha rialachais agus oibriúcháin chun an Chreat-treoir Uisce a chur i bhfeidhm;
> Monatóireacht, measúnú agus tuairisciú a dhéanamh ar chaighdeán aibhneacha, lochanna, uiscí idirchreasa agus cósta, uiscí snámha agus screamhuisce chomh maith le tomhas ar leibhéil uisce agus sreabhadh abhann.

Eolaíocht Aeráide & Athrú Aeráide

> Fardail agus réamh-mheastacháin a fhoilsiú um astaíochtaí gás ceaptha teasa na hÉireann;
> Rúnaíocht a chur ar fáil don Chomhairle Chomhairleach ar Athrú Aeráide agus tacaíocht a thabhairt don Idirphlé Náisiúnta ar Ghníomhú ar son na hAeráide;
> Tacú le gníomhaíochtaí forbartha Náisiúnta, AE agus NA um Eolaíocht agus Beartas Aeráide.

Monatóireacht & Measúnú ar an gComhshaol

> Córais náisiúnta um monatóireacht an chomhshaoil a cheapadh agus a chur i bhfeidhm: teicneolaíocht, bainistíocht sonraí, anailís agus réamhaisnéisiú;
> Tuairiscí ar Staid Thimpeallacht na hÉireann agus ar Tháscairí a chur ar fáil;
> Monatóireacht a dhéanamh ar chaighdeán an aeir agus Treoir an AE i leith Aeir Ghlain don Eoraip a chur i bhfeidhm chomh maith leis an gCoinbhinsiún ar Aerthruailliú Fadraoin Trasteorann, agus an Treoir i leith na Teorann Náisiúnta Astaíochtaí;
> Maoirseacht a dhéanamh ar chur i bhfeidhm na Treorach i leith Torainn Timpeallachta;
> Measúnú a dhéanamh ar thionchar pleananna agus clár beartaithe ar chomhshaol na hÉireann.

Taighde agus Forbairt Comhshaoil

> Comhordú a dhéanamh ar ghníomhaíochtaí taighde comhshaoil agus iad a mhaoiniú chun brú a aithint, bonn eolais a chur faoin mbeartas agus réitigh a chur ar fáil;
> Comhoibriú le gníomhaíocht náisiúnta agus AE um thaighde comhshaoil.

Cosaint Raideolaíoch

> Monatóireacht a dhéanamh ar leibhéil radaíochta agus nochtadh an phobail do radaíocht ianúcháin agus do réimsí leictreamaighnéadacha a mheas;
> 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 um chosaint ar an radaíocht a sholáthar, nó maoirsiú a dhéanamh ar sholáthar na seirbhísí sin.

Treoir, Ardú Feasachta agus Faisnéis Inrochtana

> Tuairisciú, comhairle agus treoir neamhspleách, fianaise-bhunaithe a chur ar fáil don Rialtas, don tionscal agus don phobal ar ábhair maidir le cosaint comhshaoil agus raideolaíoch;
> An nasc idir sláinte agus folláine, an geilleagar agus timpeallacht ghlan a chur chun cinn;
> Feasacht comhshaoil a chur chun cinn lena n-áirítear tacú le hiompraíocht um éifeachtúlacht acmhainní agus aistriú aeráide;
> Tástáil radóin a chur chun cinn i dtithe agus in ionaid oibre agus feabhsúchán a mholadh áit is gá.

Comhpháirtíocht agus Líonrú

> Oibriú le gníomhaireachtaí idirnáisiúnta agus náisiúnta, údaráis réigiúnacha agus áitiúla, eagraíochtaí neamhrialtais, comhlachtaí ionadaíocha agus ranna rialtais chun cosaint chomhshaoil agus raideolaíoch a chur ar fáil, chomh maith le taighde, comhordú agus cinnteoireacht bunaithe ar an eolaíocht.

Bainistíocht agus struchtúr na Gníomhaireachta um Chaomhnú Comhshaoil

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

1. An Oifig um Inbhunaitheacht i leith Cúrsaí Comhshaoil
2. An Oifig Forfheidhmithe i leith Cúrsaí Comhshaoil
3. An Oifig um Fhianaise agus Measúnú
4. An Oifig um Chosaint ar Radaíocht agus Monatóireacht Comhshaoil
5. An Oifig Cumarsáide agus Seirbhísí Corparáideacha

Tugann coistí comhairleacha cabhair don Ghníomhaireacht 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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