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Irish Natural Capital Accounting for Sustainable Environments

(INCASE)

EPA Research Report

Prepared for the Environmental Protection Agency
by

Trinity College Dublin

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DISCLAIMER

This report is based on research carried out/data from 2018-2022. More recent data may have become available since the research was completed.

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

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Executive Summary

There is increasing recognition in political, corporate and public spheres of the severe risks to society and 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 economy on the natural world into consideration, making it difficult to integrate the crises of nature into decision-making. Therefore, an approach is needed that links the human and natural systems.

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, inform planning and management of assets, demonstrate the importance of stocks and flows of natural capital assets in economic terms (including financial), and monitor progress towards achieving environmental goals. The United Nations System of Environmental Economic Accounting - Ecosystem Accounts (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 Goal (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 INCASE project, we tested the application of UN 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 (rural midlands/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 national and local scale. Firstly, 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 regulating services, most of the peatlands in our catchments were at risk

from drainage, disturbance and land conversion pressures. Secondly, 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. Thirdly, careful and consistent approaches to the selection of condition indicators and reference levels are required to ensure they are compatible, comparable, and their aggregation is ecologically meaningful, enabling comparison across ecosystem types. Fourthly, the policy question being addressed will influence the selection of five to 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 GDP, 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:

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

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1. Introduction

1.1 Objectives

The INCASE 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 NCA with the well-developed Integrated Catchment Management approach used by the Water Framework Directive River Basin Management Plans. Four (sub) catchments were selected as models for the INCASE project, representing a range of conditions and characteristics (Chapter 2).

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 trans-disciplinary 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).

Table 1.1. INCASE Work Packages, main objectives and lead personnel

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

1.2 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 capital and natural capital (IRC, 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 (SDGs) 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 Accounts (SNA) 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 well-being (EC, 2009).

Natural Capital Accounting (NCA) is a complementary statistical approach that captures the value of national natural assets and ecosystem services, which 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 and tools have been in development since the 1960s. The European Green Deal (EC, 2019) 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 protect health and wellbeing from environment-related risks and impacts. In addition, the development of standardised NCA practices was explicitly mentioned as part of the range of initiatives to pursue green finance and investment. The related European Biodiversity Strategy for 2030 (EC, 2019) new Circular Economy Action Plan (EC, 2020)) and 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 3rd National Biodiversity Action Plan (NBAP) 2017-2021). A more detailed review of NCA policy background can be found in Chapter 3 of the INCASE Stage 1 Feasibility Report (summarised in Appendix 1.1).

In Ireland, the natural capital concept and development of NCA has been promoted by the not-for-profit organisation Natural Capital Ireland (NCI), formerly the Irish Forum on Natural Capital, which brings together a diverse range of organisations and individuals from academic, public, private and 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 natural capital accounting standard. At the same time, in 2020, the Central Statistics Office (CSO) established the Ecosystem Accounts Division (EAD) with the view to developing Irish ecosystem accounts and fulfil CSO reporting requirements to the European Commission (EUROSTAT).

Research projects in Ireland are also informing aspects of natural capital accounting and identifying ecosystem services with a view to developing more integrated policy and management approaches (see Chapter 5 of the INCASE Literature Review 2019, and summary in Appendix 1. 2).

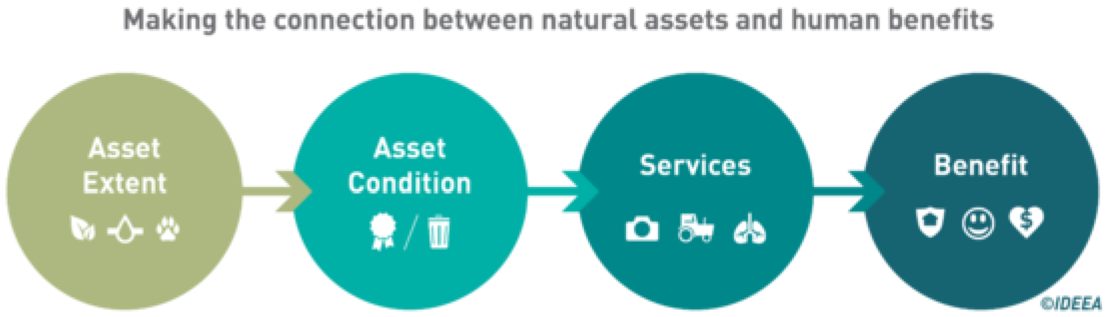
In the private sector, the Capitals Coalition is a dynamic global network driving business and finance and organisations to assess their impacts and dependencies on natural, social and human capital. Two Irish semi-state bodies have already explored the development of natural capital accounts at various levels (Coillte in 2017 and Bord na Móna in 2018).

1.3 System of Environmental Economic Accounting – Ecosystem Accounting

The System of Environmental Economic Accounting (SEEA) 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 EU and global level. The UN SEEA approach incorporates two aspects – the SEEA-Central Framework (SEEA-CF) and SEEA-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 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, as well as the challenge inherent in working with spatial data and novel measurement techniques, requires a collaborative approach which takes advantage of the strengths of National Statistical Offices in combination with the expertise of other agencies and research organisations. The implementation of ecosystem accounting is a cyclical process (Figure 1.3), with each phase involving an in-depth evaluation and reassessment at the end of each reporting cycle. In addition to the four phases outlined above, capacity building and communication are fundamental for successful implementation.



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

Asset condition – quality of the asset. For example, a peatland may be drained, which would be of lower condition than one with no drains, which impacts on not only its capacity to sequester carbon but also its biodiversity. Condition of assets influences the ability of an asset to deliver one or more services and as the 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 emission (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 either 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 UN SEEA-EA methodology is that it allows the contributions of ecosystems to society to be expressed in monetary terms so they can be compared to other goods and services we are more familiar with. Monetary estimates can provide information for decision-makers, for example for economic policy planning, cost-benefit analysis, and for raising awareness of the relative importance of nature to society.

Figure 1.1. The SEEA framework provides a filter for standardised information (Source: IDEEA Group)

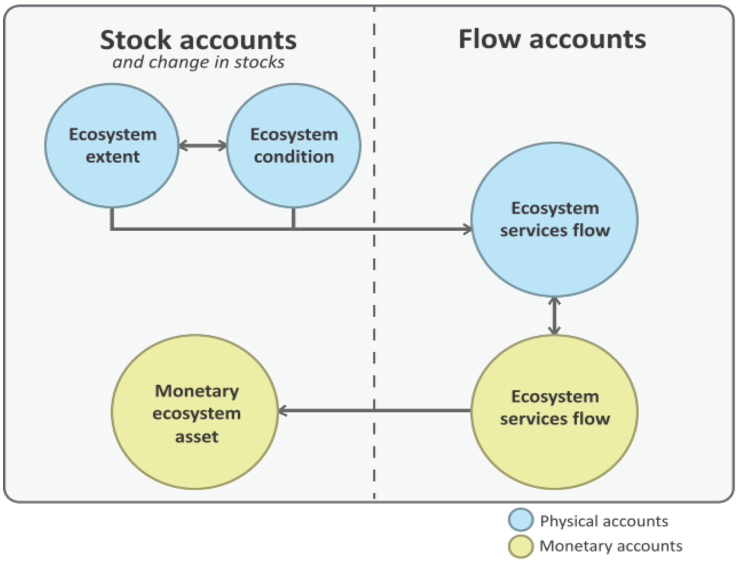


Figure 1.2. Connections between the SEEA-EA stock and flow accounts (Source: IDEEA Group)

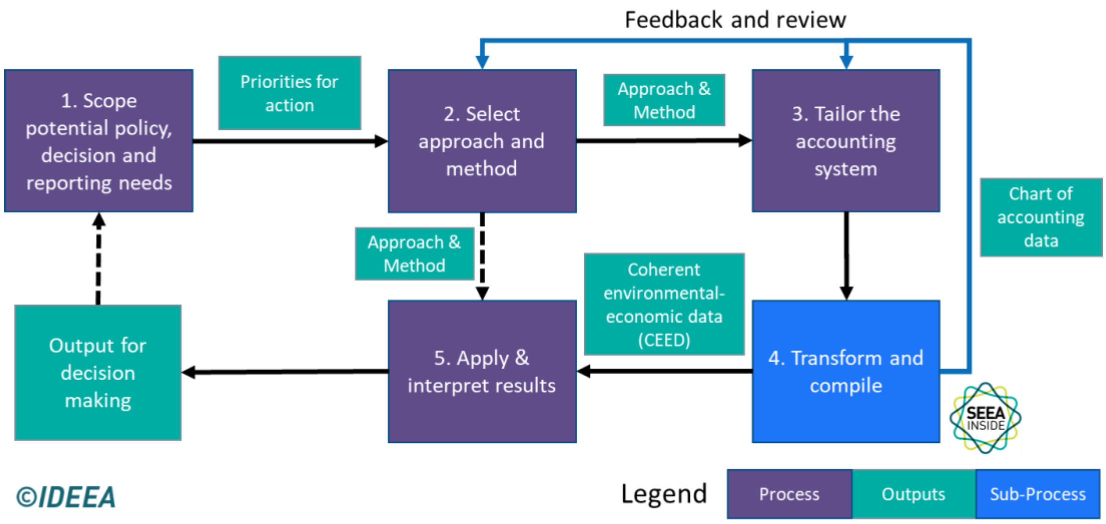


Figure 1.3. NCA design and implementation protocol (Source: IDEEA Group)

According to the latest UN recommendations regarding SEEA-EA (UNSD, 2021), there are several key points to consider:

- The SEEA-EA is designed to be flexible and modular. Depending on the specific environmental and economic context, a country may choose to implement only a selection of the accounts or to compile accounts for selected regions only. For example, countries may decide to only produce accounts in physical terms and not in monetary terms.

- For compilation of accounts in monetary terms, data requirements and methodological assumptions may be considered too significant to justify their compilation as part of official statistics. However, there may be demand for well-defined and comparable estimates in monetary terms for use in policy and analysis. Given these potentially competing considerations, it is appropriate to focus on compiling accounts that are both of high relevance for decision-making and for which data is sufficient.
- Since ecosystem accounting has a multidisciplinary scope, the use of multi-institutional approaches to implementation is advised. National Statistical Offices (NSOs) operate in different contexts with different ranges of responsibility. Depending on the national context, there may be opportunities to compile ecosystem accounts using collaborative approaches taking advantage of the strengths of NSOs in combination with the expertise of other agencies and research organisations.
- For monetary accounts, it is recommended that associated data in physical terms, i.e. changes in ecosystem extent and condition and flows of ecosystem services, are released to aid interpretation and application of the monetary data in policy and decision-making.
- Interpretation and analysis of ecosystem accounting data should be supported through the use of other data such as environmental protection expenditure, industry value added, employment and population.

1.4 Application of SEEA-EA in the INCASE Project

1.4.1 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 Water Framework Directive (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 the 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:

1. State agencies/Departments/bodies: EPA Catchments Unit, Central Statistics Office, National Parks and Wildlife Service (NPWS), National Biodiversity Data Centre (NBDC), Geological Survey Ireland (GSI), Forest Service, Teagasc, Irish Water, Department of Agriculture, Food and the Marine (DAFM), Department of the Environment, Climate and Communications (DECC), Department of Housing, Local Government & Heritage (DHLGH), Bord Iascaigh Mhara (BIM), Bord na Móna, Coillte and local authorities. (See Appendix 5.1 INCASE project communications summary for stakeholder list)
2. Related projects: Ordnance Survey Ireland (OSI)/EPA land cover mapping project, EPA Environmental Sensitivity Mapping (ESM) tool project, European Innovation Partnership (EIP) projects (Pearl Mussel Project and Bride Regenerative Farming Project), Kerry-Life project, ESDecide, Land2Sea, ESManage 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 as identified in the RBMP 2018–2021 (DHPLG, 2018) farming, forestry, energy, infrastructure, industry, human settlement, rural development, urbanisation, etc.). The main considerations for subcatchment selection are listed in Appendix 1 Technical Supporting Document for Stage 1 INCASE Feasibility Report, in line with specific criteria recommended during discussions with the EPA Catchments Unit during the INCASE project.

The four subcatchments selected (Figure 1.4 and Table 1.2) were the:

- **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.
- **Dargle**, County Wicklow: the catchment is a mix of expanding urban settlement, agriculture, forestry, moorland/heathland and peatland.
- **Figile**, County Offaly: considerably impacted by the peat extraction industry, there is large-scale transition towards renewable energy sources as well as peatland rehabilitation in this catchment.
- **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.

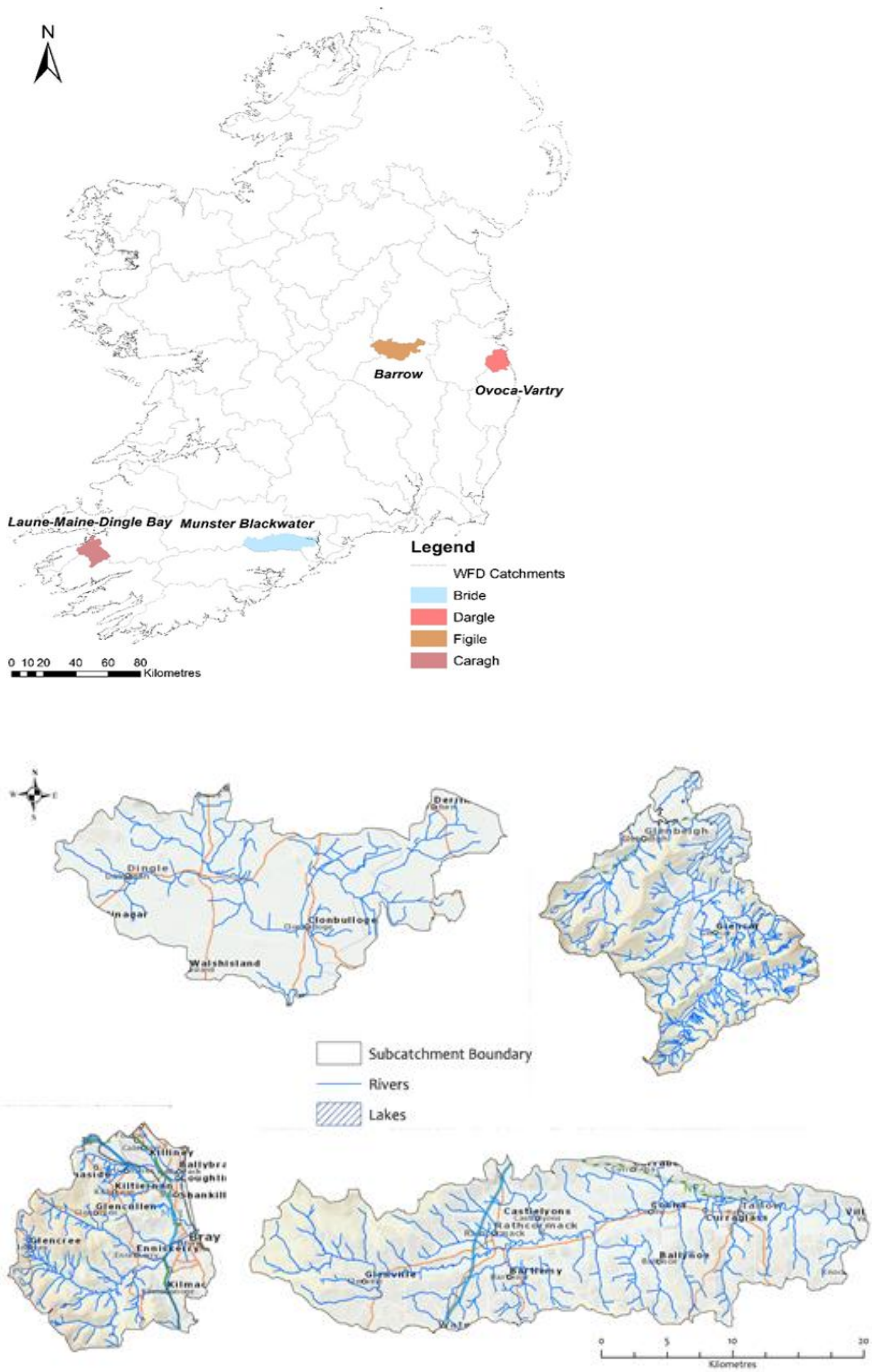


Figure 1.4. Locations of the INCASE subcatchments showing the outline of the accounting boundary and the main rivers and lakes against a backdrop of relief and road network (white lines). A) Figile (Barrow catchment), B) Caragh (Laune-Maine-Dingle Bay catchment), C) Dargle (Ovoca-Vartry catchment) and D) Bride (Munster Blackwater catchment)

Table 1.2. Main characteristics of each catchment, more detail available in Appendix 1 Technical Supporting Document for Stage 1 INCASE Feasibility Report

Catchment	Dargle	Caragh	Bride	Figile
County	Wicklow	Kerry	Cork	Offaly
Area (km^2)	177	230	427	301
Main ecosystem types	Peatlands and heathlands (upland) (64 %), Grassland and cropland (25 %). Woodlands and Forest (7%) Urban, freshwater channels & coastal margins	Peatlands & heathlands (upland) areas (64 %), Grassland & cropland (25 %). Woodlands & Forest (7%) Urban, freshwater channels & coastal margins	Grassland & cropland (agricultural) (86%), Woodland & forest (14%). Expanding towns (urban), freshwater channels & fragments of peatland & heathland on hills	Grassland & cropland (agricultural) areas (51%), Peatlands & heathland mosaics (32%), Woodland & forest (16%)
Main policy Issues	Urban and tourism expansion; upland bog flood mitigation & carbon storage; upland forestry & agriculture management; fisheries; biodiversity & nature conservation	Nature conservation with focus on range of species, including freshwater pearl mussels (Natura 2000 sites); carbon storage in peatlands; water quality in catchment; aquaculture in Dingle Bay; farming impacts	Agriculture (dairy with mixed farming); water quality issues linked to drainage to Youghal Bay; small-scale forestry management	Just transition under the Climate Action Plan; peat to renewable energy; domestic turf cutting; subsistence farming; poverty area; water quality; forestry and carbon; changing land use; peatland restoration
Stakeholders	Bray UDC; Wicklow CC; Coillte Nature; Dublin Mts Partnership; EPA; IFI; NPWS; farming community; Heritage/ Biodiversity Officers; Irish Water; Mountain biking trails (Trails Ireland); Marine Institute/BIM, OPW	BIM; Coillte; Dingle Hub project; EPA, IFI; KerryLife project; farming community; LAWPRO, OPW, PMP EIP; Marine Institute; NPWS; tourism operators	Farming communities; BRIDE project; EPA; NPWS, Teagasc	Bord na Móna; Coillte; CWF, Offaly CC; DAFM; IFI; EPA; Teagasc; SEAI; local communities
Assets	Urban, agriculture, forestry, freshwater, riparian; peatland; quarries; gravel aquifers	Agriculture; forestry; freshwater; riparian; blanket bog; heathland; coastal; quarries	Agriculture; forestry; freshwater; riparian; heathland; coastal; quarries	Agriculture; forestry; peatlands; freshwater; riparian; quarries
Services	Amenity & recreation; carbon storage; flood mitigation; timber	Agriculture biomass; carbon storage; fish; habitat/species conservation; flood regulation; sediment retention; timber; water filtration	Food; flood mitigation; minerals; timber	Carbon storage; renewable energy; food; sediment retention; timber; water filtration; flood mitigation
Benefits	Tourism; coastal protection; health & well bring; clean water	Aquaculture; Freshwater Pearl Mussel conservation; clean water	Agri-biomass; clean water; farming; nature conservation	Carbon; habitat; species; water quality; biomass (aquaculture)

1.4.2 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 as to the SEEA-EA accounting framework approach (Farrell and Stout, 2020). In addition, a **desktop review** of available national and catchment level datasets (with 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, both with data providers and potential 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 Technical Supporting Document for Stage 1 INCASE Feasibility Report), serving as a technical support document for applying the SEEA-EA in Ireland that can be added to over time. The inventory comprises an extensive array of datasets from national and EU agencies, state departments, local authorities, commercial enterprise, research, and ecological consultants. Ancillary datasets, reviewed for the catchments, include data relating to accessibility (roads and trackways), commercial use (forest plantation data), elevation, planning documents, food production (agricultural payments data), protection status (such as conservation designations) and soils.

1.4.3 Scope of Natural Capital assets

The SEEA-EA considers ecosystem assets (EAs) 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). Other natural capital accounting approaches have included soils, mineral assets, groundwater aquifers, etc. as in the UK natural capital accounts. INCASE extended the accounting to include geosystem and atmospheric assets, as distinct from ecosystem assets. Within the SEEA-EA, both geosystem and atmospheric assets are considered as either ecosystems themselves (aquifers), or abiotic components of the environment that supports ecosystems (such as bedrock), from which abiotic flows are accounted for where relevant, for example, peat extraction, wind energy generation, etc.

Ecosystem boundary*:* While many ecosystems in the ecological realms – e.g., terrestrial, freshwater, and marine ecosystems - are all 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).

Geosystem boundary: The geosystem is defined as the underground environment that consists of subsoil, bedrock, minerals, oil, natural gas, and groundwater, but not the soil or the ecosystem associated with soil, or groundwater that provides the abiotic support to ecosystems such as fens. Geosystems function in different ways and over different time-scales to ecosystems. The geo-assets (stock of minerals for example) that provide for the flow of natural resources (extracted materials) have built up over geological time. When they are used or combined with human and manufactured capital, the outputs can be recorded as benefits which may have a monetary value (for example quarry stone, lead/zinc).

The SEEA-EA outlines a number of aspects relating to geosystems as follows:

- Subsoil that is directly involved with ecosystem processes is considered part of the ecosystem asset with the precise subsoil boundary layer of an ecosystem being dependent on the structure of the soil, sediment, and bedrock.
- All aquifers are treated as ecosystems, as are subterranean caves and streams.
- Resources located in deeper layers of the lithosphere are included in the broader definition of environmental assets in the SEEA-EA.

Geosystem services are considered as the outputs from geosystems that contribute to human wellbeing specifically resulting from the subsurface, including the flow of natural resources from stocks that have built up over geological time (van Ree and van Beukering 2016; van Ree *et al.,* 2017). Examples include aggregates, minerals, energy from fossil fuels, pollutant attenuation provided by subsoils, geological heritage sites, landscape geomorphology including associated cultural values, groundwater used for drinking/industry or agriculture, geothermal energy, and carbon storage.

For INCASE, natural capital such as aquifers, subsoils, and bedrock were included as geosystem assets. We note that in reality the boundary is not always well defined, for example where groundwater interacts with ecosystems in wetlands, and we highlight potential ways of treating geosystems throughout this report.

Atmospheric boundary: Several important ecological processes are based on the interaction with the atmosphere, including respiration, nitrogen fixation, and those associated with the impact of air pollution on vegetation and fauna such as air filtration. To establish a clear boundary for accounting, the atmosphere directly above and within an ecosystem is considered part of the ecosystem asset as one of the abiotic components within the spatial unit. The interaction between the Earth's surface and its ecology, and the atmosphere is limited to the atmospheric boundary layer. For accounting purposes, this forms the natural upper boundary of ecosystem assets (UNSD, 2021). It is noted that further discussion on a more complete accounting treatment for the atmosphere is part of the SEEA-EA research agenda including the consideration of the atmosphere as a separate environmental asset (UNSD, 2021). This aspect was the least developed through the INCASE project given the lack of previous work in the area. For INCASE, we integrated atmospheric systems and services where data were available, e.g. for consideration of wind energy services in the Figile catchment.

2. Developing Ecosystem Extent Accounts

2.1 Extent accounts: the basics

Understanding the extent and type of natural capital assets in an accounting area is the fundamental basis and the initial step for all gathering of information in subsequent accounts. Defining ecosystem extent provides a common basis for stakeholder discussion regarding the composition of, and changes in, ecosystem types within an accounting area; a common framework is essential for accessibility and interpretation of accounts; and the spatial data most commonly used to compile an ecosystem extent account provides an underlying infrastructure for the measurement of ecosystem condition and for the measurement and modelling of many ecosystem services (UNSD, 2021).

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 (such as woodlands, aquifers, etc.); the spatial range and configuration of assets (where they are found); and an account of changes in natural capital assets over time.

In order to develop extent accounts, spatial datasets are required that are reliable (and for change accounts, they are required over time, i.e. contiguous time series datasets), that quantify the natural capital assets included in the accounts, and that cover the full accounting area. Depending on the scale of the accounting, the resolution of the spatial data should match the required outputs (to address the policy question). For example, developing natural capital accounts for a farm may require high resolution data to distinguish relatively localised and linear features. For this scale, a detailed ecosystem map with MMU <0.1 ha would probably be appropriate (depending on farm size). For national level accounts, CORINE data (MMU 25 ha) may be sufficient to show aggregate trends.

Under the accounting framework, opening and closing extent balances of each ecosystem type (area) are given at the beginning and end of an accounting period. Additions to extent of one ecosystem type will involve the reduction of another. Using spatially detailed data, additional detail on the nature of ecosystem conversions may be obtained by comparing datasets from two periods to compile an ecosystem type change matrix. This record of change is useful as it may result in a change in supply of ecosystem services due to the change. Conversions are considered managed (such as afforestation of a grassland ecosystem type) or unmanaged (usually associated with natural processes, for example natural regeneration of scrub on formerly managed grassland due to abandonment of land by people).

The CORINE time series data are complemented by change layers, which highlight changes in land cover with an MMU of 5 ha. Different MMUs mean that the change layer has higher resolution than the status layer. It is noted that due to differences in MMUs the difference between two status layers will not equal to the corresponding CLC-Change layer (Farrell *et al*., 2021a).

The extent account can be represented in

- A tabular form with natural capital assets grouped according to their type: this represents an asset register(s) or account(s) (in the form of a table/balance sheet).
- The change account represents time series data and highlights the conversion of one natural capital asset to another over a period of time.
- Extent account information can also be illustrated in the form of geo-referenced map(s) (the scale depending on the spatial unit selected, such as national or catchment level) which aid in understanding the spatial configuration and relationships between different assets.

2.2 Developing Ecosystem extent accounts in Ireland

There is currently no national ecosystem map of Ireland. While there are several survey datasets 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 INCASE, the following national datasets were reviewed, and their application potential for developing ecosystem extent accounts assessed (Table 2.1)**.**

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	In development during the INCASE time frame	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.

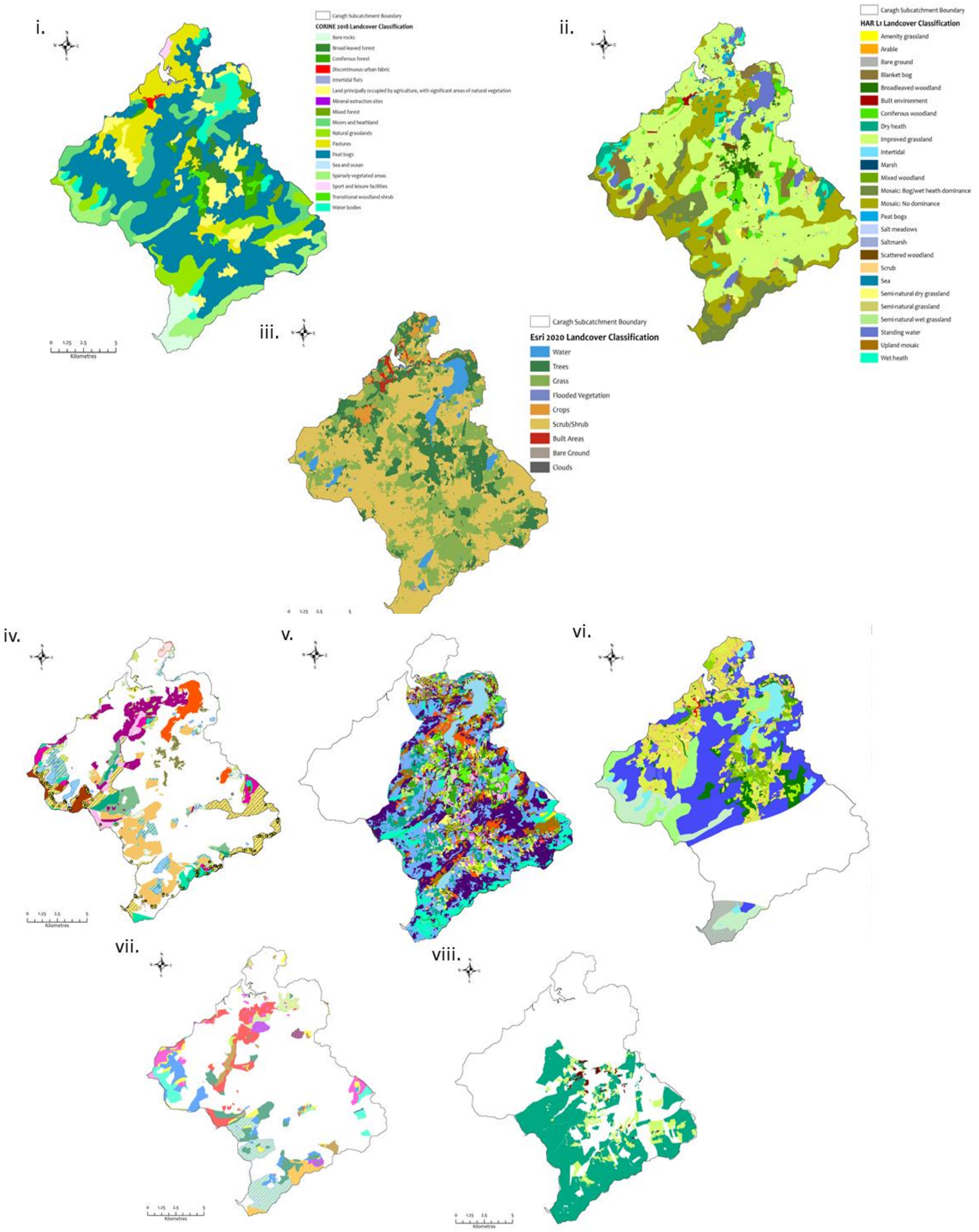


Figure 2.1. Ecosystem extent data available for the Caragh catchment: i. CORINE data 2018; ii. NPWS Habitat Asset Register 2016; iii. ESRI Landcover 2020; iv. Annex I Habitats Data coverage 2019; v. KerryLife landcover (2015-2017 data); vi. Coastal Zones 2018; vii. Commonage Habitats 2012; viii. Pearl Mussel Project Habitats 2020

At the time of the INCASE project data analysis and technical work (2019-2021), reliable time series data available was limited to CORINE data, so this formed the basis for our ecosystem extent accounts and we used available CORINE data as a coarse indicator of ecosystem type. For each INCASE catchment, CORINE datasets were analysed using GIS 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 detail 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 (UN et al. 2021). The SEEA-EA recommends the use of national ecosystem typologies, such as the Heritage Council Classification system in Ireland (Fossitt, 2000), that can be aligned with the 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 level, and comparisons between catchments to be made. A typology such as the MAES classification developed for the EU region allows for comparison of ecosystem types across Europe, while alignment with the IUCN Global Typology allows for comparison with areas outside of 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 given the resolution (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*. 2020,a).

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
	2.1. 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. Agricultural areas	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
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		T:2 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	322	Moors and heathland	H: Heath and dense bracken	HH: Heath	Heathlands		T3: Shrublands and shrubby woodlands	T3.3: Cool temperate heathlands

	vegetation associations								
	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
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

2.3 Ecosystem extent accounts for INCASE catchments

The main ecosystem types in each of the INCASE catchments were identified as follows (Table 2.3, Figure 2.2.):

- *Freshwater*: this included surface water bodies such as rivers, lakes, as well as canals and swamps. As outlined, CORINE data does not detect freshwater rivers and lakes below the MMU. However, given high cover of lake waterbodies in the Caragh these are detected.
- *Grasslands*: this included all improved, semi-improved and semi-natural grassland types, as well as marsh. Grasslands have highest cover in the Bride, followed by the Figile, Dargle and least cover in the Caragh (though 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 grassland in CORINE land cover tables.
- *Heathlands*: wet and dry heathland types (including bracken dominated areas), which often occur in a mosaic with peatlands on peat soils; this category also includes alpine heathlands which occur at high altitudes and often forming directly on subsoil (no peat layer present). Heathlands are extensive and are detected more clearly in later CORINE datasets. Generally associated with peatlands and upland areas in the INCASE catchments.
- *Peatlands*: collectively comprising raised bog, mountain and lowland blanket bog, cutover, fen, and all degraded peatland types. These were extensive in the Figile, Caragh and the Dargle with relatively low cover in the Bride.
- *Woodlands*: this category related to 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 is mostly detected as Transitional woodland, and requires supplementary datasets to distinguish this ecosystem type from non-commercial areas.
- *Forest*: wooded areas planted and managed for the primary purpose of commercial production. These are the dominant ecosystem type shown by CORINE data with highest percentage cover in the Dargle but highest overall cover in the Figile and the Bride.
- *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.

- *Coastal*: dune complexes, machair, saltmarshes, tidal areas, sea cliffs and beaches were included here; often occurring as linear features in the accounting areas. These linear features were largely undetected with low cover in the Dargle (Bray beach and a dune system near Killiney) and highest cover in the Caragh (salt marsh and dune areas).

Aligning with and taking into account the structure and resolution of the CORINE datasets, we combined the following ecosystem types (these areas often overlap in CORINE), within our INCASE ecosystem accounts and discussions: Woodlands and Forest, Peatlands and Heathlands and Grasslands and Croplands. As marine areas were excluded from our accounting areas we did not develop this aspect. We note that a similar process should be carried out to align the OSI Landcover mapping with the national and IUCN typologies to enable comparisons across areas and temporal reporting.

Accounts were initially developed for the Dargle subcatchment (published as Farrell *et al*,. 2021a) and informed subsequent work on the remaining subcatchments.

Table 2.3. Extent accounts for all four catchments based on CORINE Land Cover data

		Dargle					Figile					Bride					Caragh		
	Total catchment area (ha)	**17,684**					**30,143**					**42,715**					**22,966**		
CLC Code	**CORINE dataset**	***2000***	***2006***	***2012***	***2018***	*Overall CLC Change*	***2000***	***2006***	***2012***	***2018***	*Overall CLC Change*	***2000***	***2006***	***2012***	***2018***	*Overall CLC Change*	***2000***	***2006***	***2012***
	Freshwater																		
512	Waterbodies	45	*45*	*26*	*26*	*-20*	0	0	0	0	*0*	0	0	0	0	*0*	941	898	900
	Coastal																		
423	Intertidal flats	0	*0*	*0*	*0*	*0*	0	0	0	0	*0*	0	0	0	0	*0*	33	34	34
523	Sea and ocean	9	*9*	*10*	*10*	*0*	0	0	0	0	*0*	0	0	0	0	*0*	1	0	0
	Total	***9***	***9***	***10***	***10***	***1***	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***34***	***34***	***34***
	Woodlands & Forest																		
311	Broad-leaved forest	166	*296*	*580*	*580*	*414*	0	27	671	671	*671*	247	198	293	259	*12*	193	212	485
312	Coniferous forest	1,421	*1,886*	*1,788*	*1,830*	*409*	454	560	463	493	*39*	3,176	2,695	2,642	2,324	*-852*	367	805	645
313	Mixed forest	550	*477*	*372*	*372*	*-178*	0	496	1,504	1,504	*1,504*	224	329	313	363	*139*	326	107	194
324	Transitional woodland-shrub	1,444	*850*	*625*	*486*	*-958*	3,373	2,658	2,006	2,153	*-1,220*	2,565	2,723	2,527	2,864	*299*	784	393	161
	Total	***3,581***	***3,509***	***3,365***	***3,268***	***-313***	***3,827***	***3,741***	***4,644***	***4,821***	***-994***	***6,211***	***5,945***	***5,774***	***5,809***	***-402***	***1,670***	***1,517***	***1,485***
	Peatlands & Heathlands																		
322	Moors and Heathlands	0	*2,214*	*3,125*	*3,157*	*3,157*	0	0	0	0	*0*	0	0	0	0	*0*	0	1,416	1,757
411	Inland marshes	0	*0*	*0*	*0*	*0*	0	0	0	0	*0*	88	45	41	41	*-47*	0	0	0
412	Peat Bogs	4,062	*1,897*	*1,201*	*1,201*	*-2,861*	10,979	10,024	9,659	9,512	*-1,467*	67	97	10	10	*-57*	12,865	11,678	10,589
332	Bare rocks	0	*0*	*0*	*0*	*0*	0	0	0	0	*0*	0	0	0	0	*0*		272	667
333	Sparsely vegetated areas	0	*73*	*28*	*28*	*28*	0	0	0	0	*0*	0	0	0	0	*0*	1,207	1,968	1,590
334	Burnt areas	0	*0*	*0*	*65*	*65*	0	0	0	0	*0*	0	0	0	0	*0*			
	Total	***4,062***	***4,184***	***4,354***	***4,451***	***389***	***10,979***	***10,024***	***9,659***	***9,512***	*-1,467*	***155***	***142***	***51***	***51***	***-104***	***14,072***	***15,334***	***14,603***

	Grasslands & Croplands																		
211	Non-irrigated arable land	706	*442*	*444*	*476*	*-230*	1,587	1,066	889	985	*-602*	7,955	3,448	3,436	2,473	*-5,482*	0	0	0
231	Pastures	3,575	*3,095*	*3,132*	*3,056*	*-519*	12,925	13,267	13,730	13,574	*648*	26,172	30,340	30,666	31,603	*5,432*	2,360	2,105	2,180
242	Complex cultivation patterns	934	*587*	*527*	*487*	*-447*	427	457	454	467	*40*	998	1,353	1,285	1,254	*256*	0	0	0
243	Land principally occupied by agriculture, with significant areas of natural vegetation	1,259	*1,607*	*1,732*	*1,756*	*497*	108	1,257	450	450	*342*	1,128	1,211	1,212	1,233	*105*	2,139	2,035	2,081
321	Natural grasslands	140	*0*	*0*	*0*	*-140*	0	0	0	0	*0*	0	0	0	0	*0*	1,623	919	1,555
	Total	***6,614***	***5,731***	***5,835***	***5,775***	***-839***	***15,047***	***16,047***	***15,523***	***15,475***	*428*	***36,253***	***36,352***	***36,599***	***36,564***	*311*	***6,122***	***5,058***	***5,816***
111	Continuous urban fabric	0	*37*	*46*	*46*	*-46*	0	0	0	0	*0*	0	0	0	0	*0*	0	0	0
112	Discontinuous urban fabric	2,441	*2,645*	*2,629*	*2,636*	*-195*	177	206	156	156	*-21*	39	135	159	159	*120*	51	49	53
121	Industrial or commercial units	78	*119*	*257*	*276*	*-198*	0	0	31	31	*31*	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
131	Mineral extraction sites	0	*0*	*26*	*0*	*0*	61	74	79	97	*36*	0	45	42	42	*42*	2	3	2
132	Dump sites	30	*81*	*0*	*0*	*30*	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
141	**Green urban areas**	191	*151*	*93*	*93*	*98*	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
	Total	***3,376***	***4,208***	***4,097***	***4,158***	***782***	***291***	***332***	***317***	***335***	***45***	***96***	***276***	***291***	***291***	***195***	***126***	***125***	***128***

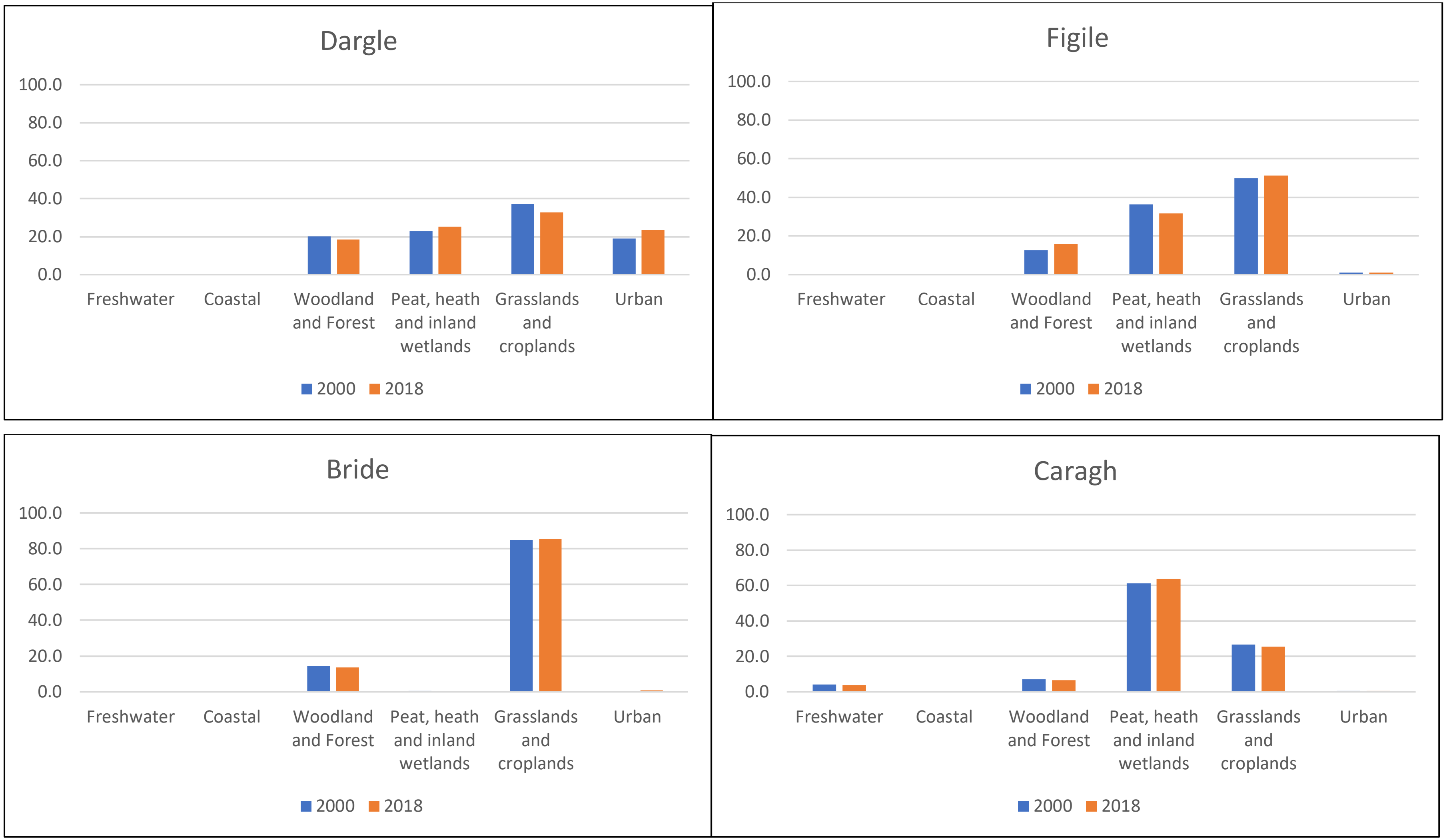


Figure 2.2. Extent accounts for the INCASE catchments based on data from 2000 (blue bars) and 2018 (orange bars)

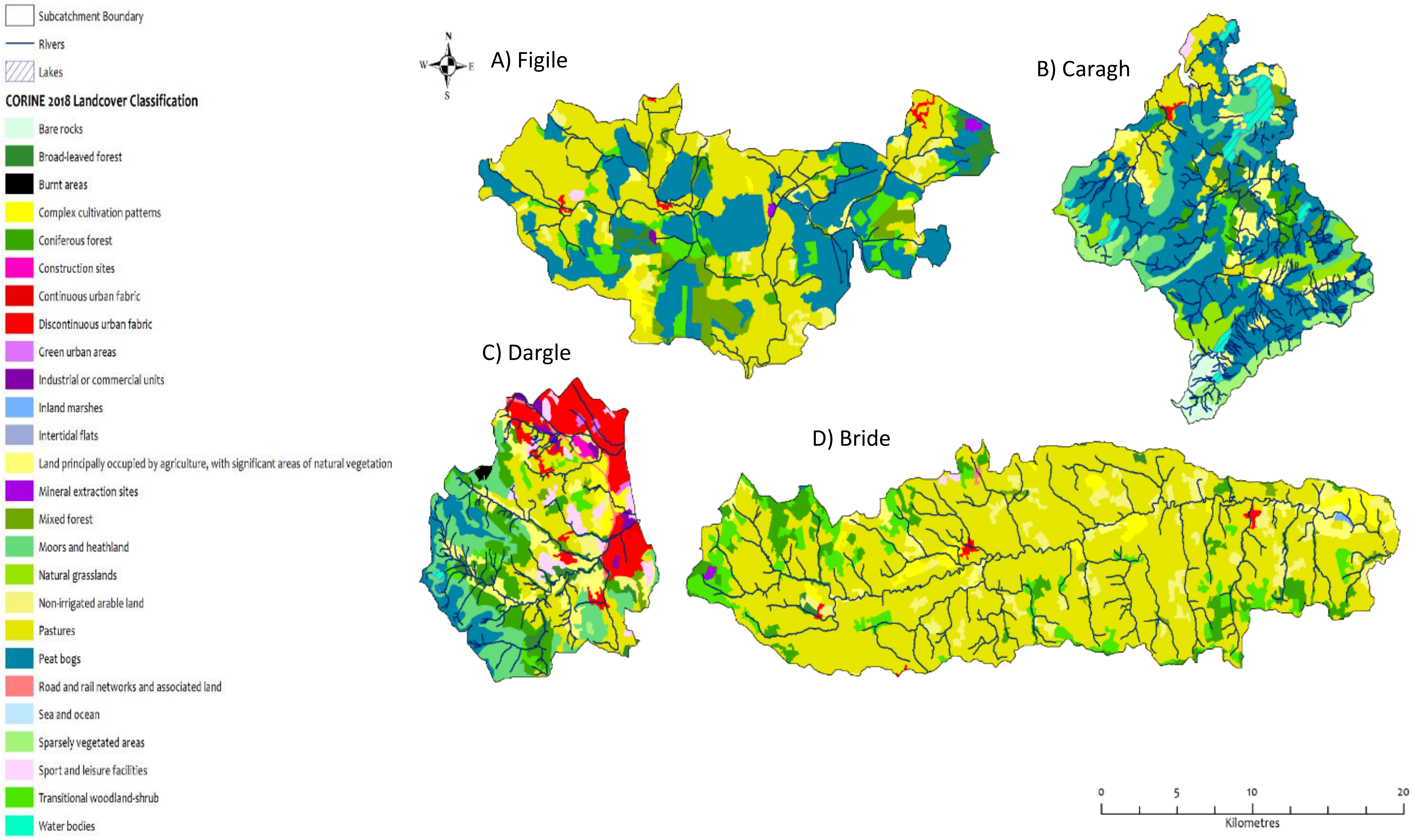


Figure 2.3. INCASE catchments, A) Figile, B) Caragh, C) Dargle and D) Bride, showing extent of CORINE land cover classes (level 3)

2.4 The role of supplementary datasets

Combining CORINE data with relevant supplementary datasets can help to build a more informed narrative about ecosystem composition and relative changes (see Dargle case study - Farrell *et al*. 2021a).

- *Waterbodies*: There is a water courses classification in CORINE, but linear features need a minimum width of 100 metres to be picked up. Given that several rivers, lakes and/or freshwater wetlands can be much smaller, these features were supplemented to the CORINE layer using the EPA rivers datasets
- *Woodlands and woody features*: There are limited woodlands (hedgerows or patches of semi-natural native woodland types) detected by CORINE, despite an extensive network of hedgerows, parkland, and riparian woodland areas obvious from aerial imagery throughout Ireland. For the INCASE catchments, overlaying the CORINE dataset with commercial forest datasets alongside the Small Woody Features (SWF) HRL and the Urban Atlas and supporting Urban Atlas Street Trees Layer (STL) HRL supplemented data on woodlands and urban green space, respectively. The national survey of native woodlands (data provided from 2003-2008) and a survey of ancient and long-established woodlands (ALEW) from 2010 also supplemented data on woodlands.
- *Commercial forests*: these areas were verified using Coillte commercial datasets and National Forest Inventory data.
- *Habitats of conservation significance*: Annex I habitats listed on the EU Habitats Directive are mapped as part of reporting under Article 17. Overlaying these data on CORINE highlighted specific habitats, otherwise indistinguishable using CORINE.
- *National habitats surveys*: national wetland and hedgerow surveys, and, where available, commissioned project and local authority surveys were aligned with CORINE to provide supplementary datasets to build a more detailed picture of ecosystem types within each accounting area.

We note that in terms of accounting, these supplementary datasets should be treated separately from the CORINE data and if integrated, would have to be subtracted from the relevant ecosystem type as indicated by CORINE. For example, areas of [CLC 324] Transitional scrub overlapping with the Woody features HRL would have to be adjusted for overlaps if the higher resolution data is to be included in the extent accounts and change accounts.

2.5 Geosystem extent accounts

A number of workshops were coordinated with members of Geological Survey Ireland (GSI) and an array of data layers (open access data available from GSI) were used to test the potential to map the extent and types of geo-assets. The main geological layers are:

- *Bedrock*: This underpins everything and as such is considered as the base layer which influences overlying geo-assets including groundwater, minerals (metallic and non-metallic), and geothermal potential. For example, the properties of the bedrock influence the properties of the aquifer and groundwater natural quality; and the quality (condition) and quantity of minerals present. Bedrock is therefore the foundation for the various 'assets' as viewed from the human perspective.
- *Geo-forms:* When bedrock is subjected to geological forces, it results in geo-forms (geomorphological features – mountains, valleys, caves etc.). This aspect is of particular relevance for example when considering flows of services such as cultural services.
- *Quaternary deposits or subsoils*[3] are overlain on bedrock. Subsoils can also influence the properties of the aquifer and groundwater natural quality (by means of groundwater vulnerability related to depth of overlying subsoils). Quaternary deposits also result in a set of 'geo-forms' such as crags and tails, drumlins, and dry valleys), formed as a result of glacial or post-glacial processes. Quaternary deposits also have their own intrinsic properties e.g., permeability, and uses, e.g., sand and gravel is used for aggregate and is an aquifer in places.

Extent accounts can be developed using ArcGIS in a similar way to the development of ecosystem accounts. We note that given the lack of time series data, change accounts are not feasible for geo-assets. Based on an understanding of the geo-layers and data availability, the following geological assets were included in geosystem accounts (see Farrell and Daly, 2020):

- *Bedrock:* the base layer (foundational layer) of all geo-assets.
- *Metallic minerals*: extracted for commercial use. Data not available 2020; work in progress between GSI and Tellus.
- *Non-metallic minerals:* extracted for commercial use.
- *Hydrocarbons*: probably not relevant in the INCASE catchments but will be relevant when offshore accounts are built (national accounts)

[3] Note that the term 'subsoil' is equivalent to 'Quaternary deposits'. It is used by applied geologists as an intuitive term for the uncemented material above the bedrock and below the topsoil. 'Quaternary' refers to a geological age and is not readily understandable to non-geologists or the general public and hence 'subsoil'.

- *Subsoils***:** this includes the Quaternary deposits; varying types and thickness across the bedrock which influences a range of services (groundwater provision (quality and quantity); aggregates and protection of underlying groundwater).
- *Groundwater*: groundwater aquifer type and extent. Note that the availability and quality is influenced by: (i) in the case of bedrock, properties such transmissivity/permeability and storativity, and (ii) in the case of sand/gravel, permeability, and saturated thickness, as well as (iii) human activities (discussed under *Chapter 4: Condition*).
- *Geothermal energy*: geothermal is split into two types – core (upwelling of heat from deeper layers) and shallow (solar heat stored in shallow subsurface).
- *Geo-forms:* landscape, caves, etc; essentially these are 'the results' of geological assets and processes combining to create forms which make up the landscape as perceived by humans.

Geosystem extent accounts were developed for subsoils and geo-forms (landscape) in the Dargle subcatchment to demonstrate the development of extent accounts for geosystems.

i. SUBSOILS:

These are quaternary deposits; and occur in varying types and thickness across the bedrock, which influences a range of services (groundwater provision (quality and quantity); aggregates). Subsoils cover approximately 74% of the Dargle catchment (Table 2.4, Figure 2.4A). Glacial tills, predominantly derived from granites, are the main subsoil type (40% of catchment). 'Made ground' is a relatively small proportion (3%). Blanket peat and gravels, predominantly derived from limestones, have similar extents – 13% and 12%, respectively. The remaining area, which is a relatively high proportion (26%) consists of outcrop and sub-crop.

Table 2.4. Extent Subsoil types recorded in the Dargle (ArcGIS measurements) based on DGeo2. (Quaternary deposits)

Description	Area (Ha)	%
A, Alluvium	**457**	3
Ag, Alluvium (gravelly)	**4**	<1
As, Alluvium (sandy)	**16**	<1
Rck, Bedrock outcrop or subcrop	**4,551**	26
BktPt, Blanket Peat	**2,333**	13
Cut, Cut over raised peat	**1**	<1
FenPt, Fen Peat	**7**	<1
GGr, Gravels derived from granite	**385**	2
GLs, Gravels derived from Limestones	**1,598**	9
GLPSsS, Gravels derived from Lower Palaeozoic sandstones and shales	**32**	<1

IrSTCSsS, Irish Sea Till derived from Cambrian sandstones and shales	**183**	1
IrSTLs, Irish Sea Till derived from Limestones	**464**	3
L, Lacustrine sediments	**9**	<1
Mbs, Marine beach sands	**8**	<1
Scree, Scree	**43**	<1
TCSsS, Till derived from Cambrian sandstones and shales	**647**	4
TGr, Till derived from granites	**4,065**	23
TLs, Till derived from limestones	**1,205**	7
TLPSsS, Till derived from Lower Palaeozoic sandstones and shales	**531**	3
TMp, Till derived from Metamorphic rocks	**263**	1
TQz, Till derived from quartzites	**338**	2
Urban	**506**	3
Water	**39**	<1
Total	***17,684***	***100***

ii. GEO-FORMS:

These are the landscape features, such as the corries at Lough Bray, which essentially are 'the results' of geological assets and processes combining to create landforms which make up the landscape as perceived by humans. The geo-forms are both a product of the bedrock and the Quaternary deposits. A range of datasets and maps of Quaternary geomorphology, Physiography, Elevation and Geological heritage are of relevance here. The main features of note in the Dargle (according to size) are Lough Bray, the Great Sugar Loaf, and Enniskerry Delta (Table 2.5, Figure 2.4B).

Table 2.5. Extent Geo-heritage site recorded in the Dargle (ArcGIS measurements)

Site-name	Area ha	Description	Geological features
Carrickgollogan	23	Carrickgollogan is a small but prominent hill.	This is a geological anomaly as the Cambrian quartzites are much older than the Ordovician slates.
Killiney Hill	6	A coastal hill site, laid out as a public park with a mixture of heath and outcrop around the summit.	This is probably the best example of a number of composite *roche moutonnée* ridges in Dublin.
Enniskerry Delta	170	A large accumulation of sands and gravels which has been quarried extensively historically.	An excellent example of a deglacial, ice marginal, meltwater-deposited feature.
Murphystone Quarry	1	A large working quarry extracting granite from the northernmost pluton of the Leinster granite.	As a well-managed active quarry, it is a good example of the long tradition of quarrying in the area.
The Scalp	25	The scalp comprises a deep channel that was formed by meltwater erosion.	A site with good teaching potential as the feature is accessible, spectacular, and easily viewed.
Glencullen River	80	A narrow, steep-sided wooded valley in the northeast Wicklow mountains.	The valley formed along a geological fault and is a meltwater channel.
Three Rock Mountain	61	A landmark mountain to the southwest of Dublin city, on which craggy stumps of granite stand proud.	The granite outcrops (tors) are natural, formed by differential weathering of granite bedrock.
River Dargle Valley	17	A stretch of the river meandering from a wide and flat valley into cascades.	This is an important County Geological site partly because of its dramatic gorge landform.
Rocky Valley	20	This site comprises a very small, disused quarry on the side of the rocky valley.	Palynological data provide the most reliable age so far obtained for the Bray Group rocks.
The Scalp	20	The scalp comprises a deep channel that was formed by meltwater erosion.	The Scalp channel is up to 70m deep and has a U-shaped profile, typical of meltwater channels.
Glen of The Downs	1	A deep channel that was formed by meltwater erosion on the north-eastern flank of the mountains.	The Glen of the Downs is considered to have formed completely in the late-glacial Period.
Great Sugar Loaf	179	A prominent, scree covered, quartzite conical mountain peak.	The steep upper slopes are blanketed with extensive patches of loose angular quartzite boulders.
Killiney Bay	20	A 5 kilometres long coastal section exposes a succession of several units of glacial till.	A particularly impressive exposure into deep till with many sedimentological characteristics exposed.
Ballybetagh Bog	5	This site comprises three sections of bog within the same narrow valley.	Ballybetagh Bog is internationally renowned as a classical site of Irish Quaternary studies.
Ballycorus	8	This is a historic mine site, with opencast workings and smelter chimney and flue.	The site is of great value as geological heritage and local industrial heritage site in the county.
Powerscourt Deerpark Cave	0	A small cave, which may have been enlarged by excavation, within a stream bed.	This cave is the only known natural cave in Wicklow.
Powerscourt Waterfall	118	A large corrie with a notable waterfall in the corrie backwall.	Important for both the glacial feature and for the rocks' influence in forming the waterfall.
Bray Head	54	Coastal headland with extensive natural exposure and sea cliffs, plus railway cuttings.	The Cambrian trace fossils found on Bray Head are a type locality for some species, and important.
Lough Bray	264	The Lough Bray site consists of two lakes that occupy two of the most accessible corries in Ireland.	This is a fine example of two corries and an arête, with bounding moraine features.

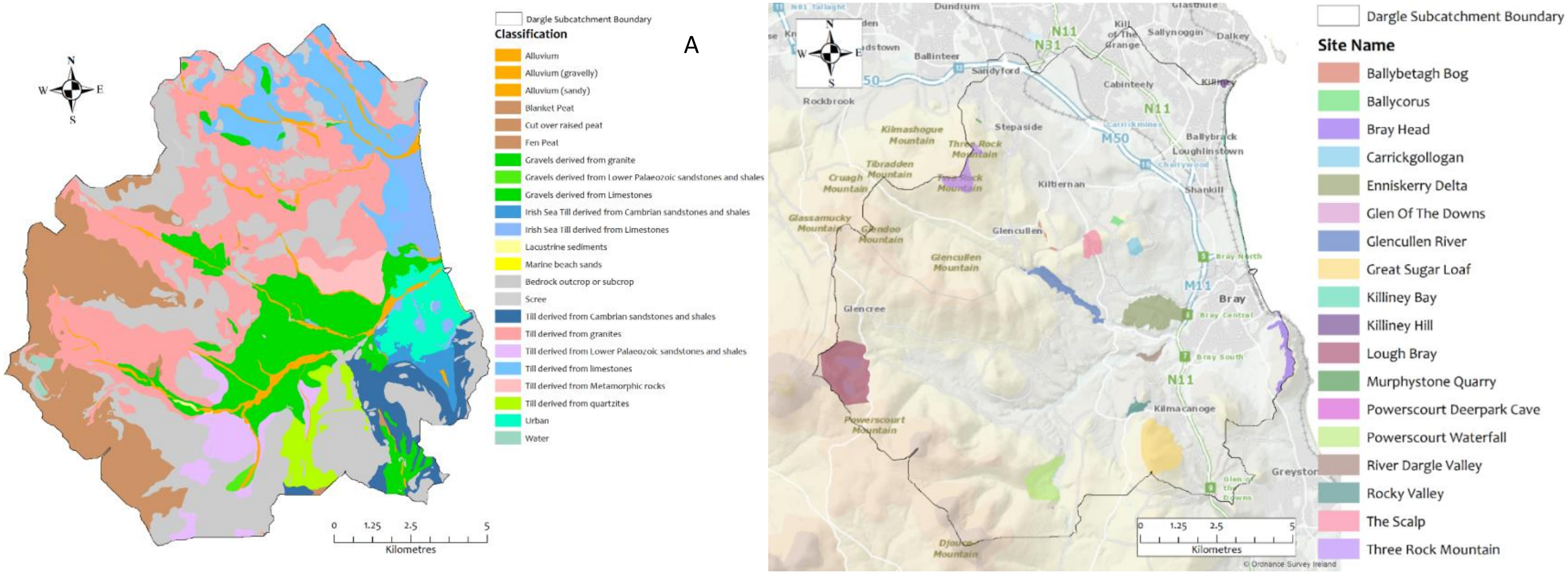


Figure 2.4. A) Subsoils and B) Geo-heritage sites in the Dargle subcatchment

3. Developing Ecosystem Condition accounts

3.1 Condition accounts: the basics

For each natural capital asset included in the scope of the accounting, organising available biophysical information in relation to its condition provides a structured approach to showing how the characteristics and quality of natural capital assets have changed over time (UNSD, 2021). Condition is assessed with respect to an ecosystem's composition, structure, and function which, in turn, underpin the ecological integrity of the ecosystem, and support its capacity to supply ecosystem services on an ongoing basis. Condition accounts can be linked to service and benefit accounts to show if and/or how flows are also changing as a result of a change in condition. Given that condition accounts use data from different monitoring systems, they build on and synthesise existing monitoring systems (UNSD, 2021).

In making explicit the connections between ecosystem condition and economic systems, condition accounts provide a means to mainstream a wide range of ecological concepts and data into economic and development planning processes. In turn, the regular production of ecosystem condition accounts may help to systematise and strengthen existing monitoring systems to support relevant and aligned condition data gathering (UNSD, 2021), particularly given the integral role of condition accounts in tracking change and thereby supporting prioritisation of investment in ecosystem conservation and/or restoration for return on selected benefits. We note that ecosystem condition and ecosystem services are linked, but the relationship varies between different services, and often is not linear (UNSD, 2021).

Ecosystem condition is the quality of an ecosystem measured in terms of its abiotic and biotic characteristics. *Quality* is assessed with respect to ecosystem structure, function, and composition which, in turn, underpin the ecological integrity of the ecosystem, and support its capacity to supply ecosystem services (UNSD, 2021).

Ecosystem characteristics are the system properties of the ecosystem and its major abiotic and biotic components (water, soil, topography, vegetation, biomass, habitat, and species) with examples of characteristics including vegetation type, water quality and soil type. Ecosystem characteristics may be stable in nature, such as soil type or topography, or dynamic and changing as a result of both natural processes and human activity, such as water quality and species abundance.

Ecosystem condition characteristics are those ecosystem characteristics that are relevant for the assessment of ecosystem condition; these are generally dynamic and changing characteristics (Table 3.1). One of the main functions of the Ecosystem Condition Typology is to provide a standardised aggregation scheme that can be meaningfully used across countries, continents, and ecosystem types. The typology outlines the type of condition variables that can be used to track condition of ecosystems over time.

Table 3.1. Potential condition characteristics based on SEEA-EA (UNSD, 2021) (ECT = Ecosystem Condition Typology)

The SEEA Ecosystem Condition Typology (SEEA ECT)			**INCASE relevant condition data available**	
Ecosystem condition	**ECT groups**	**ECT classes**	**Condition Variable Descriptor**	**Qualitative / Quantitative metric gathered**
	Abiotic ecosystem characteristics	1. *Physical state characteristics* (including soil structure, water availability).	Soil texture Soil drainage Soil Organic Carbon Soil depth Hydrometrics MQI (WFD) ESA Impervious surfaces HRL	Qualitative Qualitative Qualitative Quantitative Quantitative Qualitative Qualitative
		2. *Chemical state characteristics* (including soil nutrient levels, water quality, air pollutant concentrations).	Chemical (Q-value) WFD P/N PIP maps Air pollutants	Quantitative Quantitative Quantitative
	Biotic ecosystem characteristics	3. *Compositional state characteristics* (including species-based indicators).	ESA Dominant leaf type HRL Biological indicators (WFD) *Stand age (forest) *Dominant species *Species diversity *Species p/a *EIP species level scores	Qualitative Qualitative Quantitative Qualitative Quan / Qual Quan / Qual Quan / Qual
		4. *Structural state characteristics* (including vegetation, biomass, food chains).	ESA Tree density HRL *Yield class (forest) *Vegetation density / cover *Biomass (crops) *Coillte BioClass (Coillte only) *EIP habitat level scores	Qualitative Quan / Qual Quan / Qual Quan / Qual Quan / Qual Quan / Qual
		5. *Functional state characteristics* (including ecosystem processes, disturbance regimes).	*Specialist species groups *EIP habitat level scores	Quan / Qual Quan / Qual
	Landscape level characteristics	6. *Landscape and seascape characteristics* (including landscape diversity, connectivity, fragmentation, embedded semi-natural elements in farmland).	HNV farming *Map of Irish Wetlands *Landscape characterisation *EIP farm level scores	Qualitative Quan / Qual Qualitative Quan / Qual

Notes: MQI (Morphological Quality Index) for rivers; *Most of these datasets are held by various agencies, with limited coverage depending on the data purpose / use for reporting under EU Habitats and Birds Directives and / or focus of the dataset, for example farm condition scoring under EIPs.

Ecosystem condition variables are quantitative metrics describing individual condition characteristics of an ecosystem asset. Variables differ from characteristics (even if the same descriptor is applied to them) as they have a clear and unambiguous definition (measurement instructions, formulae, etc.) and well-defined measurement units that indicate the quantity or quality they measure, for example number of bird species. Generally, selection of condition variables should prioritise those that reflect a role in ecosystem processes, and hence contribute to whole-ecosystem functioning, and their risk of change (Mace, 2019).

3.2 Building 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 policy and decision making.

i. In ***stage 1***, key (ecosystem condition) characteristics are selected and data on relevant variables are collated.
ii. 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.
iii. In ***stage 3***, condition indicators are normalised to support aggregation and the derivation of ecosystem condition indexes (*note*: stage 3 cannot be executed without having completed Stage 2).

These three stages in the compilation of ecosystem condition accounts are used in an integrated way, 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 the 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 RBMPs. Outputs and learnings from each stage can be of relevance to policy and decision making (UNSD, 2021).

The UN SEEA-EA provides a number of guidelines in relation to required data inputs and we summarise these here by means of information, and as a backdrop to the INCASE catchments studies where we demonstrate the capacity to develop condition accounts using available datasets:

- The *SEEA ecosystem condition typology* (ECT) is a hierarchical typology for organising data on ecosystem condition characteristics. By describing a meaningful ordering and coverage of characteristics, it can be used as a template for variable and indicator selection and provide a structure for aggregation (Table 3.1).
- Ecosystem condition accounts are compiled in biophysical terms and data should be of a resolution appropriate to the accounting area / policy focus.
- Altogether, condition accounts should cover as much relevant ecological information as possible, using as few variables as possible.
- Where there are time series data available, the accounting structure can show changes over time between the opening and closing points of accounting periods.
- Knowledge of local ecosystems should be incorporated, and the selection of variables and metrics should be based on existing ecological knowledge and monitoring systems, with ecologists involved in the selection process.

Depending on the data availability, condition accounts may be illustrated using a combination of maps and tables outlining asset condition. Given limited data availability, condition accounts are often rudimentary, with few examples where the three stages of condition accounting have been achieved. Those published examples generally combine and integrate disparate ancillary datasets (Table 3.2) and data relating to policy-relevant pressures. It should be noted that these data can also infer the associated ecosystem service supply and use (such as locations of and/or intensity of use) for the next stages of accounting (services and benefits).

Similar to the extent accounts, the condition information can be represented by a combination of:

- Geo-referenced map(s): the scale depending on the spatial unit selected, such as national or catchment level).
- Tabular condition accounts developed using condition variables, relating the variables to a reference condition, condition indicators.

3.3 Ecosystem condition data available in Ireland

Following the iterative process of stakeholder engagement and data inventory, we identified available datasets to develop condition accounts both at national level and datasets relating to the INCASE catchments. We summarise the key points relating to condition datasets reviewed, noting that some of these points relate also to extent data and data required for services and benefits accounts.

There is an array of data spread amongst agencies with data specialisms from varying perspectives generally relating to the activities of the user. For example, DAFM and Teagasc, from the perspective of agriculture; Forest Service and Coillte from the perspective of forestry; EPA from the perspective of environmental quality and reporting (water, climate, waste, etc.), NPWS from the perspective of conservation and reporting under EU Nature Directives; research Institutes (wide-ranging interests); IFI (fisheries); Irish Water (water supply), BIM (fish biomass), GSI (sub-surface assets). In fact, all data on natural systems in Ireland are collected for a specific purpose (consider WFD and Nature Directives (Habitats and Birds), Air quality) and for the purpose of national reporting (for example forest statistics to FAO, GHG emissions under National Inventory Reporting) and/or payments (Land Parcel Identification System).

Nationally available datasets relevant for condition accounts were aligned with the SEEA-EA ecosystem condition typology (ECT) (Table 3.1), with comprehensive datasets outlined in **Appendix 3.1**. We also identified ancillary datasets that are useful to inform condition (Table 3.2). These datasets are available nationally and at sub-catchment level, and generally relate to environmental characteristics (soil type, soil organic carbon, soil texture, elevation, climate). They are useful to inform the underlying condition, and in some cases historical coverage of ecosystems (for example peat soil texture can be used to indicate former extent of peat-forming ecosystems).

Local catchment datasets were also identified and reviewed to inform local condition 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 for ecosystems in Ireland are gathered for the purposes of reporting under EU Directives. Nationally there are datasets for Water Quality of waterbodies under the Water Framework Directive, Habitats and Species reported under the Habitats and Birds Directives, and Forests under the National Forest Inventory (Table 3.2). Developing natural capital accounts at national level is supported by these national datasets. Depending on accounting area and scale (for example, a 2ha woodland, or a 150ha 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 (such as species presence / abundance) are generally presented in aggregate form (such as structure and function of habitats), and for the most part collected in a sampling strategy to report in an aggregated indicator at national level (such as 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.

Table 3.2. 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 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 PIP maps 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[4]
National Forest Inventory	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	A digital soil information system (national soils database) provides spatial	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

[4] 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).

	quantitative information			
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 (www.biodiversityireland.ie)
Pollutant data – EPA	Air pollutants recorded for dense urban areas (e.g. Dublin). Water pollutants modelled (P/N PIP maps) as estimates of the annual nutrient losses from agricultural	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

	land at specific locations			
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

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

3.4 Ancillary data

Ancillary (supporting) data include variables relating to stable environmental characteristics that are unlikely to change due to human activities, like elevation or slope, but which remain relevant in the measurement of condition. Data on these characteristics may be of particular interest from scientific or policy perspectives (e.g., as input data for ecosystem service assessment), and in some situations may be considered appropriate proxies for condition. Ancillary data identified by INCASE includes a range of data types (Table 3.3).

Table 3.3. Ancillary data for condition accounts

Data type	Description	Dataset examples
Accessibility	Can inform ecosystem service supply / demand as an indicator of use / pressure.	For example, a road network (OSI data), population density adjoining a coastal ecosystem, and/or access trails through a woodland or peatland site (recreational – link to ecosystem service supply / demand).
Certs / Audits	Ideal practice is to encode all relevant characteristics individually in the condition account and create appropriate aggregated indices there (as a substitute of the audit process).	Blue Flag beach status - encompasses accessibility and available services.
Management (Land-use intensity)	Data can serve as proxy information for landcover (extent accounts), particularly in relation to grassland, cropland and forest plantations. Intensity of landuse (derived from type of production and lands receiving payments under agri-environmental schemes) can be used as a proxy for condition. Natural resource management: If there is an underlying stock that is being extracted (timber, fish) this stock can be considered under the SEEA ECT class where it best fits (as a compositional, structural, or functional characteristic).	Land Parcel Identification System (LPIS) is used by the Department of Agriculture, Forestry and the Marine (DAFM) to inform the use in any given year for lands eligible for the Basic Payment Scheme under the EU CAP - payments linked to ES supply. The LPIS could be developed further to record habitats in more detail and therefore catalogue the range of assets (extent and condition) within land parcels and identify flows of services as proposed under Payment for Ecosystem Services (PES) Schemes. Commercial forest datasets (linked to timber provision).
Protected areas	Areas designated for nature conservation present information about the regulatory instruments relating to the habitats. Designation is not a direct indicator of condition but can inform targets set around condition against a reference.	EU HD/BD: Natura 2000 (SAC, SPA); National Parks; NHA; nature reserve EU WFD: Protected waters (drinking, salmonid)
Pre-aggregated indexes	Data collected and processed to meet policy obligations are often in a highly aggregated format. Best practice is to add all relevant condition characteristics and condition variable datasets individually and perform appropriate aggregations within the condition account.	Ecological Condition (WFD) Conservation status (HD, Article 17) Landslide Susceptibility (GSI) Coastal Vulnerability Index (GSI)
Pressures (relating to	'Raw' pressure indicators (e.g.pollutant loads, habitat loss) should be avoided and	Extraction (quarrying minerals, peat, sand)

degradable stocks)	the underlying 'degradable stocks' (e.g.pollutant concentrations, abundance of invasive species) should be used instead as a condition indicator. If this is not possible, and pressures are still used as a proxy, then they should be assigned to the same ECT class that the underlying degradable stock, such as soil depth, would belong to as outlined in Table 3.1. For INCASE, we include pressures as ancillary data.	Intensity of agricultural production (livestock numbers / fertiliser volumes applied) Invasive species (occurrence) Pollutants (air, soil. water) Population (levels and density) Significant pressures (WFD) Threats and pressures (EU HD)
Stable Environmental characteristics	Environmental variables that are virtually constant (e.g., climate, local topography (slope, aspect), or geology).	Soil type (soil series datasets) Elevation

3.5 Reference condition, reference levels and developing ecosystem condition indicators

Once condition variable data are gathered and tabularised (*stage 1*) for ecosystem assets (Table 3.4), the SEEA-EA recommends variables are re-scaled against a reference level (Table 3.5) to develop standardised condition indicators (*stage 2*), which can then be aggregated across ecosystem assets, and ecosystem types to develop condition indices (*stage 3*) (Table 3.6). These steps were not carried out for the INCASE catchments, but we summarise the approach recommended by the SEEA-EA to inform discussion around the knowledge gaps pertaining to condition accounting.

3.5.1 Selection of reference condition

For ecosystem accounting, a reference condition represents a state of an ecosystem that is used for setting reference levels and pertains to the assessment of ecological integrity (following Stoddard *et al.*, 2006). Ecosystem condition indicators can be derived when condition variables are set against reference levels. This highlights that an agreed and established reference ecosystem condition is required to fulfil all stages of the condition accounting outlined in the SEEA-EA, with known reference level values for each ecosystem condition variable used in rescaling the variable to develop condition indicators.

Selection of reference conditions must follow a consistent approach to ensure that reference levels for condition variables are measured against the same reference condition. The SEEA-EA recommends the use of two reference levels (a 'favourable' and an 'unfavourable' one) for rescaling (UNSD, 2021). The SEEA-EA also highlights that while other concepts are superficially like the concept of reference levels including target levels (usually defined for planning or policy) and threshold levels (science-based estimations for values at which a significant change in ecosystem functioning occurs), these should not be used as condition reference levels.

Using the natural state as the reference condition is preferred, such as an Annex I reference condition outlined in the EU Habitats guidance. However, where systems are highly anthropogenic, such as an agricultural ecosystem, reference conditions should be characterised by integrity, stability, and resilience (UNSD, 2021).

Furthermore, it is noted that the term reference condition is also often used to assess the impact of human activities on ecosystems, often implying varying levels of human disturbance, for example, minimally disturbed condition, historic condition, least-disturbed condition, best-attainable condition (Stoddard *et al*., 2006). These specific meanings of condition should not be confused with the terms reserved for reference condition as applied in the SEEA-EA which pertain, as highlighted already, to the assessment of ecological integrity (UNSD, 2021).

3.5.2 Condition indicators

Once reference levels have been established, condition indicators can be developed (*stage 2)* (Table 3.5). *Ecosystem condition indicators* are re-scaled versions of ecosystem condition variables, which are transformed to a common dimensionless normative scale, with the two endpoints of the scale representing favourable ("good": 1 or 100%) and unfavourable ("bad": 0 or 0%) values.

The SEEA-EA recommends that ecosystem condition indicators should be constructed from a single variable of an ecosystem condition account, while composite indicators of condition that are aggregated over multiple variables should be considered as sub-indexes. Condition indicators usually have the same descriptor as the associated variable, while indicators for different condition variables used for the same ecosystem type will have different measurement units and may be measured at different scales. For example, bird indicators and vegetation biomass indicators for a forest ecosystem will be monitored and measured at different scales.

It is possible to aggregate ecosystem condition indicators to form sub-indices according to the ECT classes both within ecosystem types and across different ecosystem types. Aggregation of condition indicators requires scaling/normalisation of indicator values against a single reference condition for the ecosystem type, so that different variables and classes of characteristics can be compared. An aggregated sub-index is derived for each class in the SEEA ECT which can provide a composite measure from the combination of indicators that describe the same class in the typology for a given ecosystem type (UNSD, 2021).

3.5.3 Condition indices and sub-indices

Following from this condition indicators can support aggregation and the derivation of ecosystem condition indices. This is described as an optional stage in condition accounting, and where it is undertaken, a clear link should be made to information on movements in individual indicators as described in *stage 2*. The aggregation of ecosystem condition indicators aims to generate summarised information from a large number of data points and may be carried out at spatial or at temporal scales. This can be useful in order to communicate general trends.

An ecosystem condition index is derived from a second aggregation step using the sub-indices for each ecosystem type (using the 'mean values' approach). Aggregation is possible across indicators within the same ECT class, across classes of characteristics in the ecosystem condition typology (as shown in Table 3.6), or across ecosystem types. Sub-indices derived through aggregation can relate to specific typology classes (e.g., structural state of forests) or ecosystem types (e.g., an ecosystem condition index for forests). Care and caution are advised however, in interpreting indices as an increase in one and a decrease in another may be counter-intuitive, such as bird numbers in a forest declining as dead wood increases. Interpretation requires expert view and understanding.

Another example of aggregation is creation of an overall ecosystem condition index where the aggregation can take the form of a condition index applied to each ecosystem type, weighted by area of the ecosystem type within the ecosystem accounting area, then summed for all ecosystem types in the area to derive an overall ecosystem condition index (Czúcz *et al*., 2021. This makes it possible to express the average condition of the ecosystem assets (UNSD, 2021).

Table 3.4. Stylised ecosystem condition variable account (based on UNSD, 2021). The table organises a number of condition variables (opening and closing values for the accounting period) according to the SEEA ECT for one ecosystem type shown here (for simplicity) but can be extended to include a number of ecosystem types. In this example, variable 7 (which measures a functional state characteristic) has opening and closing values of 15 and 0 t/ha/y, respectively

SEEA ECT Class	**Variables**		**Ecosystem type**		
	Descriptor	Measurement unit	Opening value	Closing value	Change
Physical state	Variable 1	ml/g	0.4	0.25	0.15
	Variable 2	% area	10	30	20
Chemical state	Variable 3	g/g	0.05	0.04	0.01
Compositional state	Variable 4	no. of species	85	80	5

	Variable 5	% of ecosystem assets with presence	75	50	25
Structural state	Variable 6	t/ha	110	65	45
Functional state	Variable 7	t/ha/yr	15	10	5
Landscape/water-scape characteristics	Variable 8	% area	50	20	30

Table 3.5. Stylised ecosystem condition indicator account (based on UNSD, 2021). Variables are re-scaled against the reference levels of a known reference condition (upper and lower levels). For example, for variable 7, the re-scaled opening value is 1, and the closing value re-scaled to 0.66

SEEA ECT Class	Indicators	Ecosystem type					
		Variable values		Reference level values		Indicator values (rescaled)	
	Descriptor	Opening value	Closing value	Upper level	Lower level	Opening value	Closing value
Physical state	Indicator 1	0.4	0.25	0.7	0.1	0.5	0.25
	Indicator 2	10	30	0	100	0.9	0.7
Chemical state	Indicator 3	0.05	0.04	0.08	0	0.625	0.5
Compositional state	Indicator 4	85	80	90	0	0.94	0.89
	Indicator 5	75	50	100	0	0.75	0.50
Structural state	Indicator 6	110	65	200	20	0.5	0.25
Functional state	Indicator 7	15	10	15	0	1	0.66
Landscape/water-scape characteristics	Indicator 8	50	20	100	0	0.5	0.2

Table 3.6. Stylised ecosystem condition indices reported using rescaled indicator values (based on UN et al. 2021). In this step, variable 7, now re-scaled to develop indicator 7, is given a weighting (0.08) relative to other indicators and against an overall ecosystem index of 1.0 to reflect its overall 'role' in determining ecosystem condition. All indicators are weighted and assigned an index value. These are then summed to show the overall ecosystem condition index and how it has changed over time

SEEA ECT Class	Indicators	Ecosystem type			Ecosystem type	
		Indicator value			Index value	
	Descriptor	Opening value	Closing value	Indicator weight	Opening value	Closing value
Physical state	Indicator 1	0.5	0.25	0.05	0.025	0.013

	Indicator 2	0.9	0.7	0.05	0.045	0.035
	Sub-index				*0.07*	*0.048*
Chemical state	Indicator 3	0.625	0.5	0.1	0.063	0.05
Compositional state	Indicator 4	0.94	0.89	0.067	0.063	0.062
	Indicator 5	0.75	0.50	0.033	0.025	0.017
	Sub-index				*0.150*	*0.126*
Structural state	Indicator 6	0.5	0.25	0.12	0.06	0.03
Functional state	Indicator 7	1	0.66	0.08	0.08	0.053
Landscape and seascape characteristics	Indicator 8	0.5	0.2	0.5	0.25	0.1
Ecosystem condition index	Index			1.0	0.610	0.356

3.6 Ecosystem condition accounts for INCASE catchments

The key datasets used for developing condition accounts for the INCASE catchments, as well as most relevant ancillary datasets, are outlined above with a comprehensive overview in Farrell and Stout (2020) Appendix 1.. Given that there are limited datasets that can be used to develop ecosystem condition variables and *stage 1* condition accounts as described in the SEEA-EA, we describe our approach to developing rudimentary condition accounts as a means to identify what is feasible based on currently available data, and where further research and data gathering should focus to address data gaps.

We outline condition data available for freshwater rivers and lakes and an approach to assessing condition of peatlands with limited data, incorporating expert ecological views. An outline approach to developing ecosystem extent and condition accounts for the Dargle catchment has been published (Farrell *et al*. 2021a).

3.6.1 Ecosystem condition case study: freshwater rivers and lakes

Condition data are gathered under WFD reporting for rivers and lakes (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 includes 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 water bodies[5] in Ireland, ecological status data are available for 4 time periods which relate broadly to the WFD cycles[6] as outlined as follows:

- Baseline 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 the time series data for the WFD reporting periods (2007 to 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 condition of rivers and lakes with the ecosystem extent accounts (Farrell *et al*. 2021a,a). Ecological Status ranged from poor, for the urban dominated areas in parts of the Dargle, to high for 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) of maintaining or achieving high ecological status due 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 include the Morphological Quality Index (MQI), hydrometric data to estimate nutrient loadings, hydrometric data on river flows, macroinvertebrate

[5] Note: under the WFD terminology, a water body can be a river or tributary, a lake, a body of groundwater, an estuary, or a coastal area.

[6] Ecological Status should be considered the most representative and homogeneous indicator across Europe, but missing information in the data reported under the first and second cycle 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. https://ec.europa.eu/environment/nature/knowledge/ecosystem_assessment/pdf/5th%20MAES%20report.pdf

data, Small Streams Risk Score, freshwater habitats and species reported under the EU Nature Directives, along with other Ancillary data (for full details see Appendix 3.1).

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 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-EEA Condition accounts. The characterisation carried out as part of WFD reporting indicates trends relative to thresholds (characterising risk by relating pressures and ecological status). This presents a risk register of sorts (*s*ee Farrell *et al.,*2022 for more information on risk registers). There are also a number of ancillary metrics recorded by the EPA (MQI, Hydrometrics) which inform the hydromorphological quality of rivers and streams, and also the latter records flow and models the recorded flow to inform how changes can affect the river flow.

In addition, nationally reported trends for habitats and species under Article 17 of the Habitats Directive and Article 12 of the Birds Directive are available for freshwater habitats and species. This data is representative of national trends and comprises a pre-aggregated index Conservation Status, which integrates an assessment of condition (structure and function), range, pressure, and threats. This also presents a risk register of sorts (see Farrell *et al.*, 2022 for more information on risk registers). Reporting is based largely on stratified sampling, and surveys contain detailed non aggregated data which may be available for sites in natural capital accounting areas.

3.6.2 Ecosystem condition case study: peatlands

Building on ecosystem accounts developed to date for wetlands and peatlands in the UK and 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 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 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 that peatland habitats comprised ca. 50% degraded peatland habitats (cutover and eroding bog) and ca. 50% Annex I peatland types, occurring within a mosaic with dry heathland alongside patches of wet grassland, scrub, and plantation. There were no indicators of condition or trends for the 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 erosion is ongoing and condition is deteriorating. Burn scars are clearly visible with uncontrolled burning occurring regularly, according to local knowledge. Former peat cuttings are clearly visible along with an extensive drainage network. While there is no active peat cutting visible or 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 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 demonstrated that developing ecosystem extent and type accounts, and highlighting changes in both aspects over time, served 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 infers that remaining peatlands are *other* peatland types derived from former Annex I type and include eroding bog, industrial cutaway peatland or cutover bog. By inference, these peatlands are considered to be in a degraded (or bad) condition (Farrell *et al*. 2021c).

Peatland type is therefore a means to inform condition. 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, due to limited time-series data detailing extent and type, we could only highlight 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).

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 two 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), as well as providing 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 two of SEEA-EA condition accounts) is fundamental for each peatland type (and 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*. 2020,b).

For Annex I habitats, reference conditions can be established with relative ease, while those habitats beyond legal reporting frameworks will require more detailed analysis, as shown here. While 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 readymade EU reporting frameworks.

3.6.3 Geosystem condition case study: groundwater

For all groundwater bodies in Ireland, ***chemical status data*** are available for 4 time periods which relate broadly to the WFD cycles.

- Baseline 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.

Groundwater data were available for four groundwater bodies in the Dargle catchment for 2013-2018 (Table 3.7., Figure 3.1.)

Table 3.7. Groundwater status in the Dargle (ArcGIS measurements)*

Name	Type	WFD Risk Status 2010-2015	SP
Kilcullen	Groundwater	Not at risk	
Enniskerry Gravels	Groundwater	Review	Y (anthropogenic)
Wicklow	Groundwater	Review	Y (anthropogenic)
Industrial Facility (P0019-02)	Groundwater	At risk	Y (industrial IPCL)

Source: WFD Cycle 2 Sub-catchment Dargle_SC_010;
SP: Significant pressures include urban wastewater; urban diffuse run-off; forestry and anthropogenic pressures.
*** Note: these data are in the process of revision by *P. Maher, GSI.*

Pressures: diffuse and point source pressures are mapped relative to individual water bodies. Significant Pressures are only assigned to At Risk water bodies where action is required. The most recent pressure data relate to 2015 (2018 data not released yet). The main pressures in the Dargle catchment relate to anthropogenic pressures (which can't be fully defined at this time) (Figure 3.1).
Risk characterisation: is based on assessment after the 2010-2015 WFD cycle. Water bodies are assigned an automated risk (At Risk, Not at Risk, Review) (Figure 3.1). This is the risk of not meeting WFD objectives for that water body. The groundwater body characterisation is undertaken by the EPA Hydrometric & Groundwater Section.
Groundwater vulnerability map: Groundwater is most at risk where the subsoils are absent or thin and in areas of karstic limestone, where surface streams sink underground at swallow holes. Groundwater vulnerability maps are based on the type and thicknesses of subsoils (sands, gravels, glacial tills (or boulder clays), peat, lake and alluvial silts and clays) and the presence of karst features. Groundwater that readily and quickly receives water (and contaminants) from the land surface is

considered to be more vulnerable than groundwater that receives water (and contaminants) more slowly and consequently in lower quantities. Most of the groundwater is extremely or highly vulnerable in the Dargle catchment (Figure 3.1).

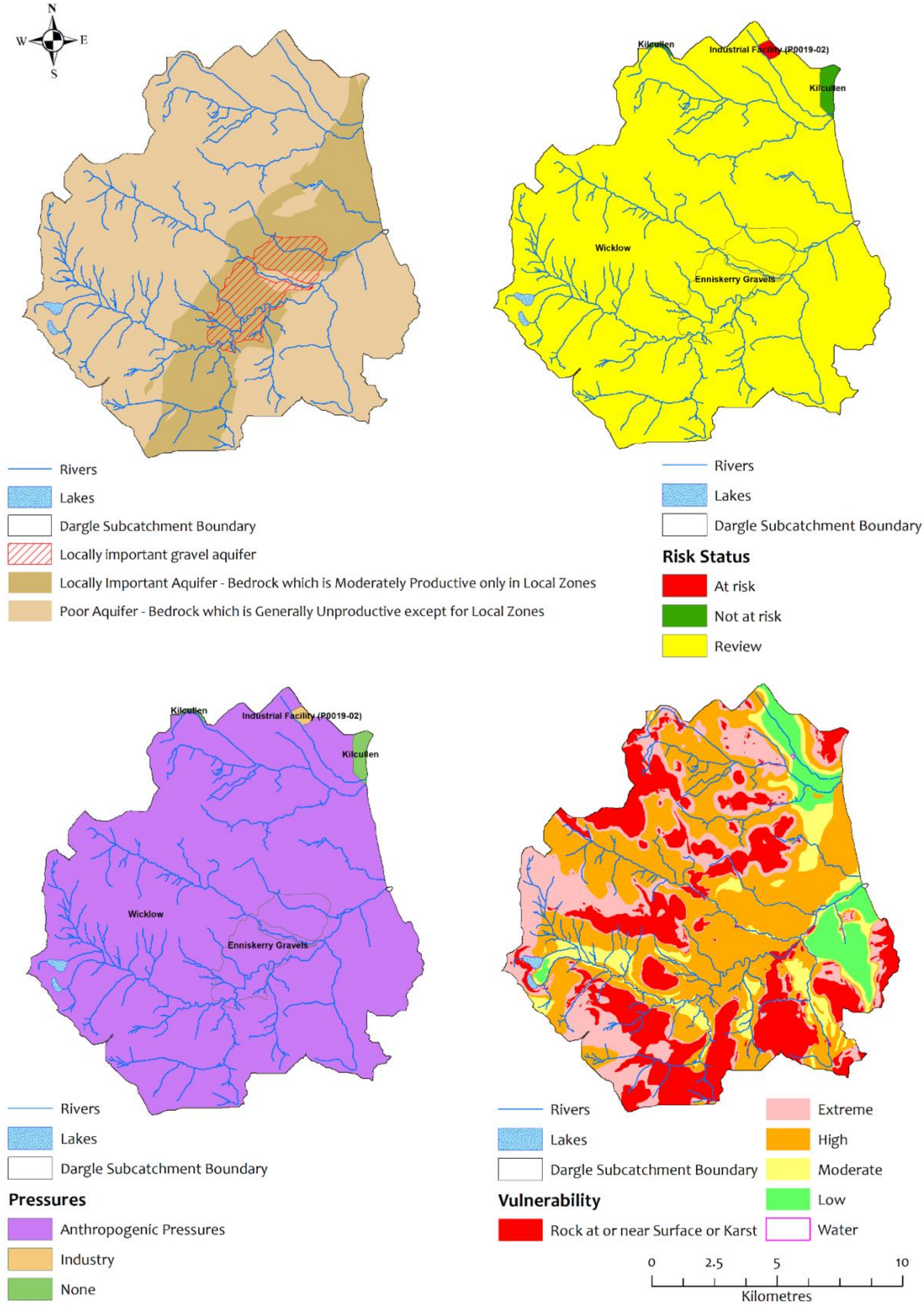


Figure 3.1. Top left, extent of aquifers in the Dargle; top right: risk characterisation; bottom left: main pressures; bottom right: groundwater vulnerability map

3.7 Conclusions and next steps for condition accounts

Condition accounts are the least developed within the European Region and at national levels, though efforts are becoming more focused (Czúcz *et al*., 202); Keith *et al 2020.*b; 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 INCASE reflect those identified in other studies and include

- The lack of data to build condition accounts, though 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 of 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*.,2020; Rendon *et al.*,2019; Maes *et al*., 2020).

In relation to INCASE catchments, WFD data provides 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, as well as for sites within the Natura 2000 network, are available, though site-specific data relating to catchment level are very limited (Farrell *et al*., 2021a). Use of these and other datasets (such as National Forest Inventory data gathered at national scale) data are 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 used to effect, serving as placeholders to highlight data gaps until more appropriate data are gathered (Burkhard *et al*.,2018; Geijzendorffer *et al*.,2015; Maes *et al*.,2020; Vačkářů and Grammatikopoulou, 2019; Grunewald *et al*.,2020).

In relation to peatlands, data relating to drainage and vegetation cover, is 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, therefore inferring poor condition) within the SAC area. Linking these data with remote sensing approaches detecting peatland drainage (Connolly and Holden, 2013), would provide information about potential peatland ecosystem condition indicators (Farrell *et al.* 2021c).

A similar approach, working with ecosystem experts, would make information available for selection of relevant ecosystem condition variables and condition indicators for other ecosystem types(woodlands, grasslands, freshwater etc.), particularly in the local and regional context. Efforts to combine advances in remote sensing at the EU level to develop Essential Biodiversity Variables as well as national efforts, 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).

While challenges remain, following the examples of other studies (Maes *et al.*,2020, Rendon *et al.,*2019) and proposed condition variables set out in the SEEA-EA guidance (UNSD, 2021), more focused work at the individual ecosystem type level to incorporate and provide information for other datasets, such as survey data commissioned for development and planning projects and/or species data collated by NGOs and citizen science programmes, will facilitate gathering of relevant condition data and, thereby, development of more robust condition accounts (Farrell et al. 2021a, b).

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 will require an assessment of what upper and lower reference levels should be selected for each habitat / ecosystem type. For ecosystems in which humans have been influencing the environment for long periods of time, a ‘natural’ state will no longer represent a meaningful reference for condition accounts or may be impractical to use because it results in low values of indicators that measure the 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 in order to identify ideal condition variables across all ecosystem types (Vallecillo *et al.,* 2022).

4. Developing Services and Benefits Accounts

4.1 Background

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, for many there is a greater awareness of the *flows* of services and benefits from natural capital and concurrently, the potential risks relating to changes in and/or declines in service flows. For example, there is a greater awareness of the climate regulation service provided by forests ("*planting trees is good*") rather than the extent and condition of those forests (e.g., where the trees are planted and how are the forests structured in terms of species, tree condition or age) that not only determines the current standing stock of carbon in the forest but also the flow of carbon sequestered by the forest. The awareness of nature's services has developed over a number of decades (Gomez-Baggethun et al. 2010), as described in Box 4.1.

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, MAIA, and KIP INCA projects. We provide our main discussion as before in the context of the SEEA-EA and the approach to ecosystem accounting, incorporating discussion in relation to abiotic flows (geosystem and atmospheric services) where appropriate.

Box 4.1. Growing awareness of nature's services.

In 1997, two seminal works relating specifically to ecosystem services were published. The first was *Nature's services: societal dependence on natural ecosystems* (Daily, 1997), which described in the order of thirteen services that nature provides for human existence. This was followed by a synthesis of studies assembled through the work of those in the field of *Ecological Economics* and other available case studies, into a quantitative global assessment of the value of seventeen ecosystem services across sixteen biomes (from marine to urban) (Costanza *et al.,* 1997). The study drew considerable attention and highlighted the potentially high economic values underpinned by ecosystem services.

Both publications created widespread debate and discussion, feeding into design and scope of the Millennium Ecosystem Assessment (MA) launched in 2000 (MA, 2005), which comprised the first attempt at describing and evaluating the full range of services that humans derive from nature, at a global scale (twenty-four services / benefits considered). While the MA focussed on the benefits, research and practice since has teased out these separate aspects, with the service component relating to the 'transaction' between the user and the ecosystem / natural system (such as water filtration), and the benefit component defined as the gain received by the beneficiary (clean water). Since then, there have been a number of approaches to classification of ecosystem services, such as the Common International Classification of Ecosystem Services (CICES) in the EU region (Haines-Young and Potschin, 2018), the Final Ecosystem Goods and Services (FEGS) approach used by the US EPA (Landers and Nahlik, 2013) and nature's contributions to people proposed by the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Service (IPBES) (Diaz *et al.,* 2018). Each of these and subsequent publications through the journals of *Ecosystem Services* and *Ecological Economics*, led to the widespread use of the term ecosystem services and furthered the discussions as to how they should be valued and integrated into economic decision making (Braat and de Groot, 2012; Gómez-Baggethun *et al.,* 2010).

In Ireland, while there has been limited work in developing natural capital accounts to date, the assessment of ecosystem services has been carried out through a number of projects. An initial overview assessment was carried out by Bullock *et al.* (2008) with subsequent studies since then carried out from an ecosystem perspective such as that of freshwater systems (Feeley *et al*., 2016), forests (Bullock *et al*., 2016), coastal (Ryfield *et al*., 2019), marine (Norton et al. 2018) and/or from a service perspective such as that of pollination (Murphy and Stout,2019), with some work carried out at agricultural / catchment scale (Norton *et al*., 2020). Assessing flows includes measuring and modelling services and has tended to involve monetary valuation approaches (such as the example from Woodlands of Ireland, Bullock and Hawe, 2013).

In tandem with progress in scientific and economic literature through Irish related studies, the establishment of the Irish Forum on Natural Capital – now Natural Capital Ireland (NCI) – in 2014 has helped to grow awareness as to natural capital approaches in Ireland. NCI was one of the driving partners to develop the INCASE project, which in itself has contributed significantly to awareness of both natural capital approaches and natural capital accounting (Farrell *et al*. 2021*,*a,b.c).

Within the UN SEEA-EA framework, ecosystem services is the connecting concept between ecosystem assets and the production and consumption activity of economic sectors or end-users, including businesses, households, and governments (the beneficiaries), reflecting the work of CICES, FEGS and IPBES approaches (which are relatively well aligned, despite being developed from different motivations and perspectives).

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 range of ecosystem services.
- The spatial heterogeneity of ecosystem service delivery, relating to one or a number of ecosystem types.
- The role 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 natural capital accounting which 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.

While much economic production relies on inputs from ecosystems (and *inter alia* natural ecosystems), these dependencies and/or associated impacts (either positive or negative) are generally not explicitly recorded in traditional reporting mechanisms. Addressing information deficits by making explicit the role of ecosystems, essentially serves to extend the supply chains of production to incorporate the role of ecosystem assets as suppliers or producing units. Thus, internalising ecosystem impacts (i.e., externalities) in the production process (UNSD, 2021). This inclusion, together with information on ecosystem extent and condition, can support decision making in relation to maintaining healthy stocks and flows to ensure continued sustainable production of these ecosystem services (UNSD, 2021).

These complex relationships and dependencies are made explicit by identifying and explaining the role of the ecosystem(s) through service provision. We note that this is a logical approach, but it is important to recognise that natural systems are complex and there remains an underlying degree of uncertainty inherent to this approach (Mace *et al*., 2012, Mace, 2019). Nonetheless, the accounting framework raises awareness as to this complexity, highlighting knowledge gaps and uncertainties for further research.

4.2 Ecosystem services and benefits definitions

Ecosystem services are the contributions of ecosystems to the benefits that are used in economic and other human activity, where use incorporates direct physical consumption, passive enjoyment, and indirect receipt of services (UNSD, 2021).

Benefits are the goods and services that are ultimately used and enjoyed by people and society. While derived from the SNA definition of economic benefit [7], in ecosystem accounting, a benefit reflects a gain or positive contribution to well-being arising from the use of ecosystem services (UNSD,2021).

For example, a riparian woodland assists in flood alleviation for householders further down the catchment. In this scenario, the woodland (the ecosystem asset of a particular type, extent, and condition) acts to slow down and mitigate the flooding potential / risk (an indirect ecosystem service) for the economic unit (the household). Thus, the ecosystem service of flood mitigation (what the ecosystem “does”) generates the benefit (the house not flooding) that is enjoyed by the householder and may be valued in a number of ways.

[7] An economic benefit is defined as denoting a gain or positive utility arising from an action (2008 SNA, 3.19).

The supply of an ecosystem service is associated with an ecosystem structure or process, or a combination of ecosystem structures and processes following on work outlined by the cascade model (Potschin *et al*. 2017) (Figure 4.1).

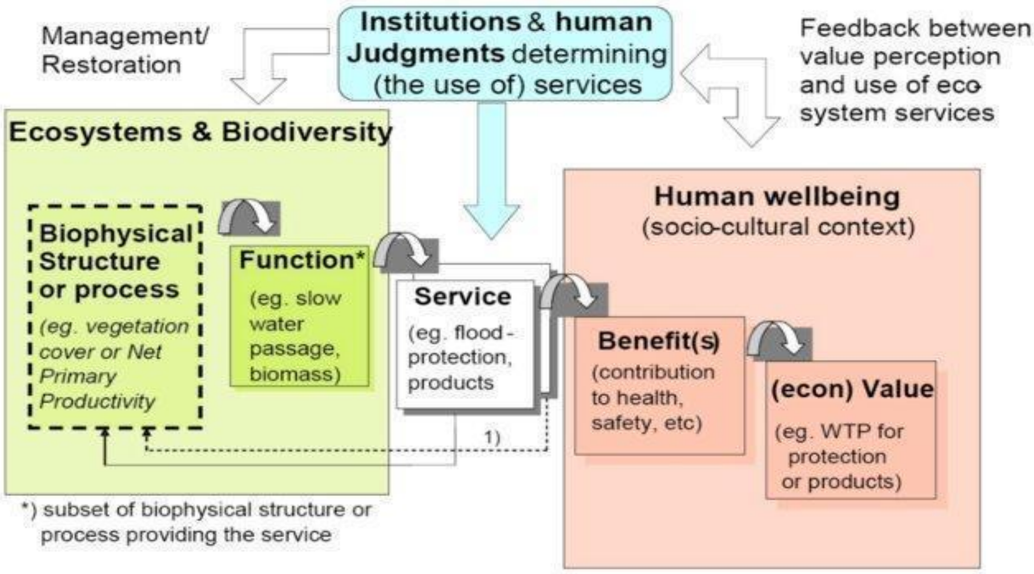


Figure 4.1. Cascade diagram outlining the relationship between ecosystem (extent and condition), services and benefits (*Source*: Noges *et al*., 2015, MARS project)

Services may rely on one, or a combination of, and/or the interaction of multiple ecosystem assets. The UN SEEA-EA outlines a number of ecosystem services, reflecting a number of existing classifications such as CICES, FEGS, and IPBES and the areas which have been the focus of ecosystem service measurement in the literature to date (UNSD, 2021). Types of services listed in the UN SEEA-EA are described later in this chapter.

Benefits within the SEEA-EA are classified as either SNA benefits or non-SNA benefits. SNA benefits are goods or services that are included within the production boundary of the SNA such as food, water, and timber which are valued by existing markets. Examples of non-SNA benefits include clean air and flood protection provided by ecosystems, relating to gains or contributions to people and society that, while recognised as being of great value, are not currently valued by the market (UNSD, 2021).

Different benefits are provided to different economic sectors, described as users or beneficiaries. For example, water is supplied across a range of sectors including household, agriculture, commercial, and industrial units within the catchment (local), while climate regulation is a contribution to the benefit of global climate, and therefore society in general (global).

4.3 Compilation of services accounts

In ecosystem accounting, following standard accounting treatments, the measure of supply and use are equivalent and considered equal to the actual flow between the ecosystem asset and people. We note that while this feature is consistent with the use of these terms in measuring economic activity (e.g. the supply and use of vehicles, or entertainment services), it is important to remember when collating ecosystem accounts as it differs from the use of these terms in much of the literature relating to ecosystem services where the term *supply* refers to the ecosystem's potential to supply services irrespective of use (i.e. capacity) (UNSD, 2021) such as in the NPWS MAES pilot project (Parker *et al.,* 2016). The main elements of the ecosystem accounting framework relating to services and benefits are:

- The supply of ecosystem services to users is presented in *Supply* tables, outlining the services supplied by each ecosystem type.
- The contribution of ecosystem services to *benefits* (i.e., the goods and services ultimately used and enjoyed by people and society) is presented in *Use* tables, showing the linkages between service(s) and the main beneficiaries such as the benefiting economic sector.

In the SEEA-EA, *ecosystem capacity* is the ability of an ecosystem to generate an ecosystem service under current ecosystem condition, management and uses, at the highest yield or use level that does not negatively affect the future supply of the same or other ecosystem services from that ecosystem (UNSD, 2021). Therefore, capacity is an integral aspect of the ecosystem, reflecting the ecosystem type, extent and condition and should be considered in discussions relating to how service flows change over time (past, present, and likely future trends).

One of the main aims of ecosystem accounting is to isolate and record the ecosystem's contribution to the benefits received. This is challenging as it requires teasing out of the *actual* contribution of the ecosystem, rather than *combined contributions* that often include human input (see later examples relating to grazing biomass).

Within the SEEA-EA framing, the primary focus of ecosystem accounting is on the measurement of final ecosystem services (UNSD, 2021).

- *Final ecosystem services* are those ecosystem services in which the user of the service is a clearly identifiable economic unit (e.g., a household or business). In this way, final ecosystem services represent the flow between an ecosystem asset and an economic unit.

- *Intermediate services* are those ecosystem services in which the user of the ecosystem services is an ecosystem asset and where there is a connection to the supply of final ecosystem services (e.g. plant transpiration or photosynthesis). While intermediate services may be measured within the reporting framework separating them from final ecosystem services ensures that there is no doubling accounting.

We note that it is often difficult to delineate boundaries and as such measurement of intermediate services should generally focus on cases where there are observable connections between ecosystem assets that are of high analytical or policy interest. For example, the role of sea-grass meadows in providing nursery services for juvenile fish caught elsewhere when they reach maturity (UNSD, 2021). Furthermore, while we recognise that in the literature it is recommended to avoid the use of the term intermediate services (Potschin-Young *et al*., 2017), use of the term in the SEEA-EA is specifically to delineate those services that support ecosystems (and thereby intermediate), in delivery of a final service to humans (UNSD, 2021).

4.4 Required data inputs

Ecosystems are complex (Mace *et al.,* 2012), and services relevant to the policy issue being addressed by the accounting framework should be selected for inclusion in the supply and use tables, requiring identification of the flows of ecosystem services, whether within the system or as a product of the system. Equally there must be a clear understanding of the boundary between ecosystem services and benefits. This can be supported through use of a logic chain (Box. 4.2., Table 4.1.). Understanding the boundary is important to ensure ecosystem contributions are fully appreciated and to avoid potential double counting, as highlighted already.

Required data inputs for ecosystem services are similar to ecosystem extent and condition accounts in that reliable time series data are required for each service, at a resolution appropriate to the scale of the accounting. In general, biophysical information is required such as tonnes of dry matter (biomass), volumes of water, tonnes of carbon, etc. Where relevant, and available, economic data can be used to develop monetary flow accounts for selected services.

We note that in the absence of specific data relating to services, data relating to pressures can also infer the use of services (for example grazing intensity or livestock numbers) or demand (for example a high-density population adjoining an urban park). Another example is in the absence of counters to measure recreational use, the presence or absence of access points, car parks and/or waymarked trails can infer use (from a qualitative perspective). Where there are obvious signs of degradation relating to pressures, these can also infer use. For example, geospatial datasets showing bare peat areas due to overgrazing are indicators of condition but also use for grazing and can infer intensity of use (demand) (*see later*).

4.5 Presentation / outputs

Supply and use tables are accounting tables structured to record the flow of goods and services among economic units, between economic units and the environment and among ecosystem assets. Entries can be made in either or both physical and monetary terms (UNSD, 2021). The supply table comprises a list of the services down the left column and is linked to a specific ecosystem type(s) (Table 4.2**.)**. The use table shows the use of final ecosystem services by selected, relevant economic units (remember in the SEEA-EA, supply equals use, allowing for allocation of relative proportions to particular use by identified economic sectors) as in Table 4.3. Intermediate services are shown as being used by ecosystem types.

The units[8] used to measure the supply of the service correspond to those used to measure the use of the service, for example tonnes of dry matter. While a number of ecosystem services may be identified, often data are the limiting factor in compilation of accounts and data will be presented through a combination of:

- Logic chains for selected services.
- *Supply* accounts linking services to the relevant natural capital assets and *Use* accounts linking services to the relevant economic sector / ecosystem type for intermediate services. Biophysical and monetary accounts for supply and use tables where data are available / relevant.
- Geo-referenced map(s), the scale depending on the spatial unit selected, such as national or catchment level.

[8] Within the SEEA-EA, economic units are classified following the general structure of the SNA. In Ireland there is a structure outlined by the CSO based on the EU European System of National and Regional Accounts 2010 (ESA2010) - EU (2013), Regulation (EU) No. 549/2013. Depending on the scale, this can be adapted based on what works best for the accounting area. For example, accounting at a farm scale would require a tailored list based on the accounting perspective.

Box 4.2. Logic chains

The challenge for ecosystem and *inter alia* natural capital accounting lies in establishing, for accounting and statistical purposes, consistent descriptions, and boundaries for all services that, in turn, can support consistent choices in measurement and valuation. **Most challenging in this task is defining the boundary between services and benefits.** This is problematic since, for the most part, the recognition of services and their importance starts from the perspective of how the environment is being used by, or is useful to, people (including businesses). That is, the starting point for description, and especially for monetary valuation, is commonly the use or demand side (UN et al. 2021). To work through the issues in a consistent way, a tool referred to as a "logic chain" has been applied. The intent is to provide a standard framing for recording information **relevant to the description and measurement of individual services.**

A logic chain reflects a sequence in which an ecosystem asset supplies an ecosystem service to an economic unit who uses that ecosystem service as an input to a production or consumption activity which derives an SNA or non-SNA benefit (UNSD, 2021). The logic chain therefore can be effectively used to identify likely data needs to compile accounts and a number of indicative logic chains are included in the SEEA-EA (Annex 6.1 of UNSD, 2021). We outline the treatment of each of the selected INCASE services with a logic chain later in the chapter with an example outlined in Table 4.1. Each logic chain for a given ecosystem service has the following components:

Ecosystem assets*:* All ecosystem services are treated as being supplied by ecosystem assets and hence it is relevant to describe the source of the ecosystem service. Importantly, the description should be of an ecosystem type, e.g., a forest, or combination of ecosystem types, as distinct from an individual component or resource within an ecosystem, e.g., timber/tree. Where relevant for descriptive and measurement purposes, it may be useful to highlight particular ecological characteristics of the ecosystem assets that are relevant to the supply of ecosystem services, for example the presence of particular species or other indicators of ecosystem condition.

Factors determining supply and use: In most cases, but particularly for regulating services, there are certain factors that invoke the recognition of an ecosystem service. For many provisioning and cultural services the supply of benefits can be considered to reflect a joint production process involving contribution from the ecosystem but also from human inputs such as labour and produced assets. As appropriate, and to ensure a common understanding of the ecosystem service context, logic chains should include a listing of these relevant factors and human inputs. Information on land-use and land-cover is also relevant here (e.g. changes in land use and land use intensity; degradation of ecosystems due to anthropogenic pressures).

Potential physical metric(s) for the ecosystem service: This is the suggested 'physical; measure of the ecosystem service and may rely on the use of proxies where recommended metrics aren't available.

Benefits**:** Benefits are usually relatively straightforward to describe if they are known goods and services within the production boundary of the SNA (SNA benefits) such as food and fibre. Benefits are harder to describe for regulating and many cultural services, i.e., non-SNA benefits. The description of the benefit should provide a basis for understanding the importance placed on the ecosystem service.

Benefits are attributed to the ***Main users and beneficiaries*** aligned with recognisable economic sectors (as outlined in the SNA).

Table 4.1. Logic chain (with example of grazed biomass, a provisioning service). Grazed biomass is the service supplied by a number of ecosystem types including pastures. These vary in terms of soil fertility, geo-climatic context and/or whether the farm is managed intensively or extensively (the human inputs). Other factors included are demand and farming practices. The ecosystem service is measured by the grazing biomass produced. The benefit is the produce, which is either sold by the producer or consumed at farm (local) level

Common ecosystem type/s	**Factors determining supply**		**Factors determining use**	**Potential physical metric(s)**	**Benefits**	**Main users and beneficiaries**
	Ecological	**Societal**				
Pastures	Soil fertility; climate; water supply; genetics.	Farm management (human inputs).	Demand for biomass; farming practices.	Gross tonnes of grazed biomass.	Livestock and livestock products (SNA benefits).	Agricultural producers, households.

Table 4.2. Example of a stylised *Supply* account: economic sectors and ecosystem types are listed across the top. Services are listed on the left and can be added to (examples listed here are grazing and wood biomass as). The flow of services is indicated by assessing the bio-physical flow (such as tonnes of dry latter) and attributing to the ecosystem type. In this example there was an import of grazing biomass as well as that produced by the grassland ecosystem in the accounting area

		Economic sector										
	Metric	Agriculture sector	Forestry sector	**Other Sectors**	Households	Government	**Total use**	Grassland	Forest	**Total supply (resident)**	Imports	**Total supply**
Grazing biomass	tonnes							5			3	**8**
Wood biomass	tonnes								10			**10**
Other services												

Table 4.3. Example of a stylised *Use* account: economic sectors and ecosystem types are listed across the top (such as agricultural and forestry sectors). Services are listed on the left. The flow of services is assigned to the economic sector(s) (beneficiary). For example, households are using wood biomass as fuel in the example below as well as the forestry sector. The biophysical metric is usually shown in the physical use account

		Economic sector										
	Metric	Agriculture sector	Forestry sector	**Other Sectors**	Households	Government	**Total use**	Grassland	Forest	**Total supply (resident)**	Imports	**Total supply**
Grazing biomass	tonnes	8									3	**8**
Wood biomass	tonnes		8		2							**10**
Other services												

4.6 Type and selection of services

The reference list outlined in the SEEA-EA outlines three broad categories of ecosystem services: provisioning, regulating and maintenance services and cultural services reflecting the approaches and classification schemes developed by IPBES, CICES etc. We outline the main SEEA-EA services in Table 4.4.**,** along with flows related to non-use values, abiotic flows, and spatial functions. We discuss their treatment in the INCASE study examples.

i) Provisioning services are those ecosystem services representing the contributions to tangible benefits that are extracted or harvested from ecosystems, e.g., grazed biomass (UNSD,2021).

ii) Regulating and maintenance services are those ecosystem services resulting from the ability of ecosystems to regulate biological processes and to influence climate, hydrological and biochemical cycles, and thereby maintain environmental conditions beneficial to individuals and society, e.g., climate regulation (UNSD, 2021).

iii) Cultural services are the experiential and intangible services related to the perceived or actual qualities of ecosystems whose existence and functioning contributes to a range of cultural benefits (UNSD, 2021). We note that cultural is a 'catch all' phrase for a group of services that includes recreation and amenity, and artistic interpretation. These are probably the least understood of the services while often being a strong entry point for those inspired by nature or who benefit from experiential aspects of natural systems.

iv) Flows related to non-use values: Non-use values include the values assigned to ecosystems and their associated biodiversity irrespective of whether they are used or there is any intention to use the ecosystems (UNSD, 2021). This integrates flows from non-use or existence values (described as *bequest* and *option* values in traditional economic frameworks) and may be indicated by nature conservation designations and / or protected status. Given that these flows related to non-use values are significant policy drivers underpinned by legislative frameworks such as the EU Habitats, Birds and Water Framework directives, they are included as being of significant relevance from a policy perspective.

v) Abiotic flows: Given the array of benefits derived from the environment that do not fall within the category of ecosystem services, another aspect is included relating to abiotic flows or those flows which do not rely on functional characteristics of the ecosystem. For example, a peatland is a carbon store and may actively perform as a carbon sink, providing an ecosystem service due to peatland ecosystem processes and characteristics. Peat soil can also be extracted from drained, degraded peatlands and burned as a fuel. Extraction does not rely on the functioning of the ecosystem, rather it relies on how the peatland functioned in the past. In this framing, *abiotic flows* are contributions to benefits from the environment that are not underpinned by or reliant on functional ecological characteristics and processes (UNSD, 2021) in this example a functioning peatland ecosystem. We note that there is some crossover at this point with geosystems as depending on the location of the resources and the point of abstraction/extraction, geological resources may be attributed as flows from ecosystem assets (e.g., sand and gravel) or from deeper geological resources. In this way, the SEEA-EA integrates flows from geosystem assets as abiotic flows, and in particular where they are considered relevant to the overall accounting purpose / focus. Flows related to geophysical processes include abstraction of water (including groundwater), and the capture of wind, solar, tidal, geothermal, and similar sources of energy (UNSD, 2021, Table 4.4**.**) thereby integrating atmospheric flows as outlined in **Chapter 1.**

vi) *Spatial function:* we note that these are not treated as either ecosystem services or abiotic flows but included to ensure coverage of all aspects of ecosystems (UNSD, 2021). Examples include use of rivers and canals for navigation (location).

Table 4.4. Reference list of SEEA-EA services (UNSD, 2021); services assessed by INCASE are highlighted

Provisioning services		**Description**
Biomass provisioning service	Crop provisioning services	Crop provisioning services are the ecosystem contributions to the growth of cultivated plants that are harvested by economic units for various uses including food and fibre production, fodder and energy. This is a **final** ecosystem service.
	Grazed biomass provisioning services	Grazed biomass provisioning services are the ecosystem contributions to the growth of grazed biomass that is an input to the growth of cultivated livestock. This service excludes the ecosystem contributions to the growth of crops used to produce fodder for livestock (e.g., hay, soya-meal). These contributions are included under crop provisioning services. This is a **final** ecosystem service but **may be intermediate** to livestock provisioning services.
	Livestock provisioning services	Livestock provisioning services are the ecosystem contributions to the growth of cultivated livestock and livestock products (e.g., meat, milk, eggs, wool, leather), that are used by economic units for various uses, primarily food production. This is a final ecosystem service. No distinct livestock provisioning services to be recorded if grazed biomass provisioning services are recorded as a **final** ecosystem service.
	Aquaculture provisioning services	Aquaculture provisioning services are the ecosystem contributions to the growth of animals and plants (e.g. fish, shellfish, seaweed) in aquaculture facilities that are harvested by economic units for various uses. This is a **final** ecosystem service.
	Wood provisioning services	Wood provisioning services are the ecosystem contributions to the growth of trees and other woody biomass in both cultivated (plantation) and uncultivated production contexts that are harvested by economic units for various uses including timber production and energy. This service excludes contributions to non-wood forest products. This is a **final** ecosystem service.

	Wild fish and other natural aquatic biomass provisioning services	Wild fish and other natural aquatic biomass provisioning services are the ecosystem contributions to the growth of fish and other aquatic biomass that are captured in uncultivated production contexts by economic units for various uses, primarily food production. This is a **final** ecosystem service.
	Wild animals, plants and other biomass provisioning services	Wild animals, plants and other biomass provisioning services are the ecosystem contributions to the growth of wild animals, plants and other biomass that are captured and harvested in uncultivated production contexts by economic units for various uses. The scope includes non-wood forest products (NWFP) and services related to hunting, trapping and bio-prospecting activities; but excludes wild fish and other natural aquatic biomass (included in previous class). This is a **final** ecosystem service.
Genetic material services		Genetic material services are the ecosystem contributions from all biota (including seed, spore or gamete production) that are used by economic units, for example (i) to develop new animal and plant breeds; (ii) in gene synthesis; or (iii) in product development directly using genetic material. This is most commonly recorded as an **intermediate** service to biomass provisioning.
Water supply		Water supply services reflect the combined ecosystem contributions of water flow regulation, water purification, and other ecosystem services to the supply of water of appropriate quality to users for various uses including household consumption. This is a final ecosystem service.
Other provisioning services		
Regulating / maintenance services		
Global climate regulation services		Global climate regulation services are the **ecosystem contributions** to the regulation of the chemical composition of the atmosphere and oceans that affect global climate through the accumulation and retention of carbon and other GHG (e.g., methane) in ecosystems and the ability of ecosystems to remove carbon from the atmosphere. This is a **final** ecosystem service.
Rainfall pattern regulation services (at sub-continental scale)		Rainfall pattern regulation services are the ecosystem contributions of vegetation, in particular forests, in maintaining rainfall patterns through evapotranspiration at the sub-continental scale. Forests and other vegetation recycle moisture back to the atmosphere where it is available for the generation of rainfall. Rainfall in interior parts of continents fully depends upon this recycling. This may be a **final or intermediate** service.
Local (micro and meso) climate regulation services		Local climate regulation services are the ecosystem contributions to the regulation of ambient atmospheric conditions (including micro and mesoscale climates) through the presence of vegetation that improves the living conditions for people and supports economic production. Examples include the evaporative cooling provided by urban trees ('green space'), the role of urban water bodies ('blue space') and the contribution of trees in providing shade for humans and livestock. This may be a **final or intermediate** service.
Air filtration service		Air filtration services are the ecosystem contributions to the filtering of air-borne pollutants through the deposition, uptake, fixing and storage of pollutants by ecosystem components, particularly plants, that mitigates the harmful effects of the pollutants. This is most commonly a **final** ecosystem service.
Soil quality regulation services		Soil quality regulation services are the ecosystem contributions to the decomposition of organic and inorganic materials and to the fertility and characteristics of soils, e.g., for input to biomass production. This is most commonly recorded as an **intermediate** service.
Soil and sediment retention services	Soil erosion control services	Soil erosion control services are the ecosystem contributions, particularly the stabilising effects of vegetation, that reduce the loss of soil (and sediment) and support use of the environment (e.g., agricultural activity, water supply). This may be recorded as a **final** or intermediate service.
	Landslide mitigation services	Landslide mitigation services are the ecosystem contributions, particularly the stabilising effects of vegetation, that mitigates or prevents potential damage to human health and safety and damaging effects to buildings and infrastructure that arise from the mass movement (wasting) of soil and rock. This is a **final** ecosystem service.

Solid waste remediation services		Solid waste remediation services are the ecosystem contributions to the transformation of organic or inorganic substances, through the action of micro-organisms, algae, plants and animals that mitigates their harmful effects. This may be recorded as a **final** or intermediate service.
Water purification services (water quality amelioration)	Retention and breakdown of nutrients	Water purification services are the ecosystem contributions to the restoration and maintenance of the chemical condition of surface water and groundwater bodies through the breakdown or removal of nutrients and other pollutants by ecosystem components that mitigate the harmful effects of the pollutants on human use or health. This may be recorded as a **final or intermediate** ecosystem service.
	Retention and breakdown of other pollutants	
Water flow regulation services	Baseline flow maintenance services	Water regulation services are the ecosystem contributions to the regulation of river flows and groundwater and lake water tables. They are derived from the ability of ecosystems to absorb and store water, and gradually release water during dry seasons or periods through evapotranspiration and hence secure a regular flow of water. This may be recorded as a **final or intermediate** ecosystem service.
	Peak flow mitigation services	Water regulation services are the ecosystem contributions to the regulation of river flows and groundwater and lake water tables. They are derived from the ability of ecosystems to absorb and store water, and hence mitigate the effects of flood and other extreme water-related events. Peak flow mitigation services will be supplied together with river flood mitigation services in providing the benefit of flood protection. This is a **final** ecosystem service.
Flood control services	Coastal protection services	Coastal protection services are the ecosystem contributions of linear elements in the seascape, for instance coral reefs, sand banks, dunes or mangrove ecosystems along the shore, in protecting the shore and thus mitigating the impacts of tidal surges or storms on local communities. This is a **final** ecosystem service.
	River flood mitigation services	River flood mitigation services are the ecosystem contributions of riparian vegetation which provides structure and a physical barrier to high water levels and thus mitigates the impacts of floods on local communities. River flood mitigation services will be supplied together with peak flow mitigation services in providing the benefit of flood protection. This is a **final** ecosystem service.
Storm mitigation services		Storm mitigation services are the ecosystem contributions of vegetation including linear elements, in mitigating the impacts of wind, sand and other storms (other than water related events) on local communities. This is a **final** ecosystem service.
Noise attenuation services		Noise attenuation services are the ecosystem contributions to the reduction in the impact of noise on people that mitigates its harmful or stressful effects. This is most commonly a **final** ecosystem service.
Pollination service		Pollination services are the ecosystem contributions by wild pollinators to the fertilization of crops that maintains or increases the abundance and/or diversity of other species that economic units use or enjoy. This may be recorded as a **final or intermediate** service.
Biological control services	Pest control services	Biological control services are the ecosystem contributions to the reduction in the incidence of species that may prevent or reduce the effects of pests on biomass production processes or other economic and human activity. This may be recorded as a **final or intermediate** service.
	Disease control services	Disease control services are the ecosystem contributions to the reduction in the incidence of species that may prevent or reduce the effects of species on human health. This is most commonly a **final** ecosystem service.
Nursery population and habitat maintenance services		Nursery population and habitat maintenance services are the ecosystem contributions necessary for sustaining populations of species that economic units ultimately use or enjoy either through the maintenance of habitats (e.g., for nurseries or migration) or the protection of natural gene pools. This service is an **intermediate** service and may input to a number of different **final** ecosystem services including biomass provision and recreation-related services.

Other regulating and maintenance services		
Cultural services		
Recreation-related services		Recreation-related services are the ecosystem contributions, in particular through the biophysical characteristics and qualities of ecosystems, that enable people to use and enjoy the environment through direct, in-situ, physical and experiential interactions with the environment. This includes services to **both locals and non-locals** (i.e., visitors, including tourists). Recreation-related services may also be supplied to those undertaking recreational fishing and hunting. This is a **final** ecosystem service.
Visual amenity services		Visual amenity services are the ecosystem contributions to local living conditions, in particular through the biophysical characteristics and qualities of ecosystems that provide sensory benefits, especially visual. This service combines with other ecosystem services, including recreation-related services and noise attenuation services **to underpin amenity values**. This is a **final** ecosystem service.
Education, scientific and research services		Education, scientific and research services are the ecosystem contributions, in particular through the biophysical characteristics and qualities of ecosystems, that enable people to use the environment through intellectual interactions with the environment. This is a **final** ecosystem service.
Spiritual, symbolic, and artistic services		Spiritual artistic and symbolic services are the ecosystem contributions, in particular through the biophysical characteristics and qualities of ecosystems, that are recognised by people for their cultural, historical, aesthetic, sacred or religious significance. These services may underpin people's cultural identity and may inspire people to express themselves through various artistic media. This is a **final** ecosystem service.
Other cultural services		
Flows related to non-use values		
Ecosystem and species appreciation services		Ecosystem and species appreciation concerns the wellbeing that people derive from the existence and preservation of the environment for current and future generations, irrespective of any direct or indirect use.
Other environmental flows		
Abiotic flows	Geophysical sources	Flows related to geophysical processes including abstraction of water (including groundwater), and capture of **wind**, solar, tidal, **geothermal**, and similar sources of energy.
	Geological resources	Flows related to geological resources including extraction of **fossil fuel**, mineral ores, sand & gravel.
Spatial functions		Flows related to the use of the environment as the *location* for transportation and movement, and for buildings and structures.
		Flows related to the use of the environment as a *sink* for pollutants and waste (excluding the mediation of pollutants and wastes recorded as ecosystem services).

4.7 INCASE flows selection and assessment

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 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 short list, and applied selection criteria as a means to identify those services which were both relevant to and feasible to develop accounts for within the catchments and timeframe 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 (Table 4.5**.**).

We show the ranking applied to the Dargle as an example of how to select services in an open and transparent way which could be used in any natural capital accounting exercise (Table 4.6.). We applied the criteria *Policy Relevance*, *Natural capital involved* / % 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) in the Dargle given the extent of peat soils, forestry, and the policy relevance. Ecosystem appreciation, recreation, habitat (nursery) provision were next (68/75) with water quality and regulation of flooding also highly ranked (63 and 59/75 respectively), but 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, 53 and 51/75, respectively) while activities such as mineral and peat extraction scored relatively low (note, 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.

Table 4.5. Key criteria for developing ecosystem service indicators to inform decision making (*from* Table 2 in Oudenhoven *et al*., 2018)

	Criteria	**Short description, and overview of included criteria**
Credibility: indicators and information that they provide are perceived as scientifically adequate.	Valid representation of subject.	The indicator represents the subject to be indicated.
	Agreed by scientific community or experts.	The indicator has been backed by expert judgment and agreed on by the scientific community. It has been objectively verified by experts.
	Backed by scientific literature.	The indicator is backed up by scientific literature
	Embedded in conceptual framework.	The indicator is embedded in / or meets criteria of a conceptual framework.
	Quantifiable.	The indicator is evidence based, can be quantified and is backed up by high-quality data.
Salience: indicators to convey useful, relevant information for decision makers on a specific policy objective as perceived by potential users.	Relevant to information needs.	The indicator is relevant to the information needs of decision makers, policy actors and, ideally, affected stakeholders.
	Scalable and transferable.	The indicator is applicable at different spatial scales and can be compared and aggregated across different geographical areas.
	Monitor change over time.	The indicator is temporally explicit and allows for monitoring over time. It measures progress and provides early warning when needed.
	Understandable.	The indicator is readily understood by decision makers and, preferably, the broad audience. Indicators combined convey a simplified, broad message.
	Raise awareness.	The indicator contributes to raising awareness and motivates to take action.
Legitimacy: indicators, information and the process are perceived as legitimate and politically fair by the audience of an ES indicator study.	Selected through an inclusive process.	The indicators have been selected through an inclusive process.
	Widely accepted.	The indicator is widely accepted and agreed upon by the multiple stakeholders involved.
Feasibility: criteria ensuring that indicators can be assessed and monitored continuously.	Data availability.	There is sufficiently detailed data available for the indicator.

	Time availability.	There is sufficient time available for developing and quantifying the indicator.
	Affordable.	The process of selecting, generating, and using the indicator is affordable and cost-efficient
	Flexible.	The indicator can be revisited and updated, if required

Table 4.6. Workshopping ecosystem services for the INCASE project: selection of relevant ecosystem services for the Dargle, applying relevant selection criteria and weighted scoring system

	Policy relevance	Natural capital involved/% catchment	Level of supply/demand/use	Sustainable use (pressures and threats)	Data availability	Dargle ranking	National ranking: high/medium/low
Weighting[a]	20	10	20	20	5	75	
Service							
Food	CAP, Origin Green, bioeconomy, climate, WFD, nature directives; sustainable farming, Commonage Framework Plan, animal welfare	Grasslands 5000 ha; croplands 500 ha; peatland and heathland 4000 ha (>50% catchment)	Low/low/low	Related to other services, such as climate, water quality, flood, biodiversity; drives a lot of pressures on other natural capital stocks; land abandonment	Some data available		High; affects all other issues
Scoring	18	8	10	15	3	54	
Water	WFD/Irish Water; planning	Surface and groundwater waterbodies (extent and condition)	High/increasing/increasing	Urban wastewater and one-off (Onsite wastewater treatment system (OWTS)) significant pressure	Engage EPA/Irish Water/WCC/LAW PRO		Medium
Scoring	13	5	15	15	*3*	51	
Timber/NTPs	Forest policy; timber industry	Forests; heathlands; 30% catchment	Medium/high/increasing; linked to aesthetics	All planted on peat soils; forestry a pressure in Glencullen; related to other services, such as climate, water quality, flood and biodiversity	No data on yield class; could use timber per ha as a proxy		Medium
Scoring	15	8	*15*	12	3	53	
Mineral aggregates; peat	Not active in the catchment	Mineral aggregates	High/low/low	Not an issue	Not all quarries listed; peat cutting inactive		Low
Scoring	0	10	0	0	0	10	
Water (quality)	WFD: PAAs in Carrickmines and the Dargle	Catchment scale; cross-cutting issues	Medium/high/high	Loss of good eco status	EPA data		Medium
Scoring	20	5	15	18	5	63	

Water (flooding)	Planning; climate	Catchment scale; floodplains	High demand	Effectiveness of hard engineering? Loss of floodplains; increasing flooding	Modelling data?		Medium
Scoring	15	5	20	18	1	59	
Habitat/nursery (biodiversity)	Nature directives (habitats and species); Farming with Nature (RBAPs)	Catchment scale	Intermediate services	Loss of biodiversity; national biodiversity crisis	NPWS HD data; NBDC; HNVf maps; NPWS network maps		High; affects all
Scoring	**20**	**8**	**18**	**18**	**4**	**68**	
Climate (global)	Climate; CAP; planning.	Woodlands (4000 ha); forests (3000 ha); peatlands and heathlands (4000 ha); wetlands	Increasing	Climate change; national climate crisis	Stocks of carbon (SOC); vegetation carbon? Emission factors (IPCC reporting?)		High; affects all
Scoring	20	10	20	20	3	73	
Climate (local cooling)	Climate; health and wellbeing; planning.	Urban areas and street trees; 30%	Low/high/increasing	Increased temperature and population	Data?		Medium
Scoring	12	3	15	15	3	48	
Air quality	Climate; health and wellbeing; planning	Urban areas and street trees; 30%	Low/high/increasing	Increased pollutants?	Data?		Medium
Scoring	12	3	15	15	3	48	
Ecosystem and species appreciation services	Nature directives (habitats and species); Farming with Nature (RBAPs)	Catchment scale	Intermediate services	Loss of biodiversity; national biodiversity crisis	NPWS HD Data; NBDC; HNVf maps; NPWS network maps		High; affects all
Scoring	20	8	18	18	4	68	
Recreation local	Planning framework; health and wellbeing (EPA)	Urban green space; amenity areas/grasslands and parklands; coastal; DMP; trails	Increasing; more people need more green space? Better access and walking/cycle paths?	Loss of habitats to “greenways”; loss of coastal habitats and coastal squeeze? DMM conversion? If planned incorrectly could have negative impacts	Local use of parks from DLR/WCC? Health statistics? Coillte data?		Medium

Scoring	19	8	18	20	3	68	
Recreation tourism (linked to landscape aesthetics)	Tourism Ireland; nature directives	Catchment scale	High/increasing?/high	Healthy landscapes for sustainable use	WMNP data on visitors; Powerscourt data; TI data; DMP/Coillte data?		Medium
Scoring	20	10	18	18	2	68	

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.

Having refined a short list 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 / spatial models. In some instances, a service may be attributable to a number of ecosystem types (such as regulation of water flows across woodlands, peatlands, etc.) or a single ecosystem may deliver a range of services (for example, 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 the 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 (Lussardi *et al.,* 2018) have developed a comprehensive list of logic chains that are relevant as reference material to develop logic chains in the Irish context. Within INCASE, we developed logic chains for each service, following the SEEA-EA and these are outlined in relation to the assessment of the relevant services. Note that these logic chains were intended to demonstrate the approach rather than being definitive/standards. There is no reason that they could not be developed using participatory approaches in the future.

We outline our approach to services as follows:

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

4.7.1 Provisioning services

4.7.1.1 Crop provisioning services (Table 4.7.) are the ecosystem contributions to the growth of cultivated plants that are harvested by economic units for various uses including food and fibre production, fodder, and energy, which are considered the “final ecosystem services” (UNSD, 2021). As with other agriculture-dominated ecosystem services, crop provision is a joint production between nature and humans with the latter supplying many external inputs (e.g., labour, machinery, fertiliser, pesticides). Unravelling the individual contributions from this joint production for the purposes of ecosystem services accounts is complex, and at this time proxy measures are recommended (UNSD, 2021).

Table 4.7. Crop provision logic chain

Ecosystem type/s	**Factors determining supply**		**Factors determining use**	**Physical metric/s**	**Benefit**	**Main users and beneficiaries**
	Ecological	**Societal**				
Crop-lands	Type and condition of vegetation; soil type; weather	Ecosystem management (fertiliser application; seed sowing; cultivation).	Landowners' occupation / preferences; market price /subsidies; CAP Policy.	Volumes of crops produced per hectare per crop type	**SNA benefits:** Food from **crops** e.g., cereals, vegetables, fruit.	Food processors, transport, retail; Households as final consumers
Data required				*Area and yields of cropland / crop type.*	*Volume of harvested biomass.*	

Context / relationship to other accounts

- **Ecosystem extent / type(s)**: The main ecosystem type associated with this service is croplands. While CORINE Landcover distinguishes [CLC 211] Non-Irrigated Arable Land, other classes including [CLC 241] Complex cultivation patterns and [CLC 243] Land principally occupied by agriculture, with significant areas of natural vegetation, may also infer use for cropland. To verify cropland area in each catchment, we used data gathered under the Land Parcel Identification System (LPIS)[9] which outlined areas that are claimed as croplands under the Basic Payment Scheme administered by DAFM, to inform more robust estimates of crop areas (**Fig. 4.2**).
- **Ecosystem condition**: We had no condition indicators available for croplands other than identification of the main crop grown in a given land parcel reported under LPIS.
- **Ecosystem service assessment**: To provide an estimate of the harvested biomass, the average yield for each crop per hectare (using national average values) was multiplied by the total area in hectares of that crop thereby linking the crop service to the extent accounts.
- **Benefits**: The SEEA-EA (UN et al. 2021) (Annex 6.1) recommends that the final benefit measure of the harvested biomass can be used as a proxy measure of the crop provisioning service, and this was the approach followed for the INCASE catchments.

[9] Land Parcel Identification System (LPIS) is a spatial database of all agricultural parcels in the EU Member States that is used for Common Agricultural Policy (CAP) purposes including area-based payments (Zimmermann et al., 2016).

Figure 4.2. The extent of croplands (top) and grassland areas (bottom) as shown by CORINE landcover and LPIS in the Bride. The areas overlap in general, with greater area of crops and detail on grassland use reported under LPIS.
Full details of how crop provisioning services were calculated and their results are given in Appendix 4.1.

In terms of overall production, barley (spring and winter) is the most important crop in the INCASE catchments, followed by winter wheat. Maize is also a significant crop in the Bride catchment, likely used as supplementary forage for livestock in the catchment. The Bride is the largest catchment with the highest estimates for crop provisioning service, while the Caragh has only 1 ha of crops reported in 2019. In terms of area, preliminary results from the Census of Agriculture 2020 suggest that 5.1% of the land area of Ireland is covered in arable and horticultural crops reflecting the coverage of the Figile and the Bride. The Dargle and Caragh have relatively lower crop cover compared to national figures.

Yield estimates by the CSO are based on national levels; however, yields vary temporally and spatially across catchments, and therefore there are limitations to this approach. For example, there was a 3% - 25% increase in yields in 2019 compared to 2018 (CSO, 2020) due to an extended drought period in Ireland during the summer of 2018 (Met Éireann, 2020). Annual growth estimates / reporting would capture changes in the crop provisioning services, with a suitable spatial measurement to allow for variation across catchments. We note that estimates from Collins and Phelan (2019) are based on status estimates used for forage planting.

4.7.1.2 Grazed biomass (Table 4.8.) provisioning services are the ecosystem contributions to the growth of grazed biomass that is an input to the growth of cultivated livestock. This service excludes the ecosystem contributions to the growth of crops used to produce fodder for livestock (e.g., hay, soya-meal). These contributions are included under crop provisioning services and are final ecosystem services in their own right, but may be intermediate to livestock provisioning services (UNSD, 2021).

As with crop provisioning, this is a joint production between nature and humans, and again, proxy measures are recommended (UNSD, 2021).

Table 4.8. Grazed biomass provision logic chain

Ecosystem type/s	Factors determining supply		Factors determining use	Physical metric/s	Benefit	Main users and beneficiaries
	Ecological	Societal				
Grasslands	Type and condition of vegetation; soil type; weather	Ecosystem management (fertiliser application; seed sowing; cropping / silage).	Landowners' occupation / preferences; market price /subsidies; CAP Policy.	Biomass produced or consumed; Number and type of reared animals; Livestock health & productivity	SNA benefits: Products from animals e.g., meat, dairy products, honey	Food processors, transport, retail; Households as final consumers
Permanent pasture and commonage (peatland, heathland, coastal).	Type and condition of vegetation; soil type; weather	Ecosystem management (stocking density; burning).	As above and Commonage Framework Plans.			
Data required				*Area and yields of biomass / livestock.*	*Volume of grazed biomass.*	

Context / relationship to other accounts

- **Ecosystem extent / type(s)**: The main ecosystem type associated with this service were areas where livestock can be grazed. CORINE Landcover distinguishes a number of pastures and agricultural lands including Level 3 landcover classes [231] Pastures, [241] Complex Cultivation Patterns, [243] Land Principally Occupied by Agriculture, with significant areas of Natural Vegetation, and [321 Natural Grassland [CLC 211]. In Ireland, other areas used for grazing include peatlands, heathlands, uplands and coastal commonages, which include Level 3 landcover classes [322] Moors and Heathland and [412] Peat Bogs and others. To refine our assessment, we used spatial data gathered under the LPIS which outlined areas that are claimed as permanent pastures, commonages, and rough grazing under the Basic Payment Scheme administered by DAFM to inform more realistic estimates (as shown in **Fig. 4.2**).

- **Ecosystem condition**: We had no condition indicators available for agricultural areas, with limited condition (commonage assessment data) assessments for peatland and heathland areas. Those available included assessments developed for EIP projects such as the Pearl Mussel Project, BRIDE EIP and SUAS EIPs, which employ ecologists to assess habitat condition on participating farms and develop an overall farm score. This approach to condition assessment provides updated and relevant data and carried out at a national scale across all farms would provide an annual condition scoring both at habitat and farm level.

- **Ecosystem service assessment**: Within the SEEA-EA (UNSD, 2021), there are two different approaches used to measure the services directly associated with grazed land: the first (used by INCASE) estimates biomass based on the area of the ecosystem associated with the grazing services, and considers grazed biomass as a final service; the second relates to demand by livestock, and thereby considers the service as intermediate to livestock production.
- **Benefits**: The SEEA-EA (UNSD, 2021) (Annex 6.1) recommends that the final benefit measure of the biomass be used as a proxy measure of the grazed biomass provisioning service, and this was the approach followed for the INCASE catchments.

Full details of how grazed biomass provisioning services were calculated and their results are given in Appendix 4.1.

Based on our assessments, the Caragh and the Dargle had the highest cover of rough grazing (predominantly peatlands and upland commonages). All catchments have similar areas of extensive pasture, except the Dargle. The Bride had the highest estimated levels of improved pasture and subsequently highest yields overall (lowest overall yield reported in the Dargle). In terms of area, preliminary results from the Census of Agriculture 2020 suggest that 60% of the land area of Ireland is grassland and rough grazing (this estimate does not include commonage), reflecting the coverage of the Bride catchment. The Dargle and Figile have relatively lower cover relating to the high land use relating to urban and industrial peat extraction respectively. The Caragh has the highest grazing area, with relatively equal parts grassland and rough grazing / commonage available.

Given that the yield is taken as the same across all catchments, more refined growth estimates for spatial and temporal changes would provide more accurate estimates (as for crop biomass). A new product called High Resolution Vegetation Phenology and Productivity may be useful in examining the level of grazing productivity at catchment level (updated annually).

We note that an alternative approach is to measure the livestock production and treat grazing as an intermediate service. Livestock numbers for each catchment were estimated but there is a mismatch between estimated numbers of livestock within the catchment due to the boundaries of electoral divisions (Ag census data are gathered at ED units) not aligning with catchment boundaries, as well as data available for 2010 Census of Agriculture only (CSO, 2012). However, an overview of livestock units can be useful to highlight what livestock types are using the grazing areas which can serve to link with other aspects such as potential pressures (see Chapter 4.10). The aggregated numbers of livestock in each catchment and their estimated grazing demand do not match with the estimated INCASE grazing provision (See Appendix 4.1, Tables A4.5 and A4.6). More accurate data relating to livestock type and number, grazing type, and growth estimates are required to align these assessments. Similarly, data on import and export of grazing biomass between catchments would tell a more detailed story relating to grazing biomass supply and use in each catchment.

4.7.1.3 Wood provisioning services (Table 4.9.) are the ecosystem contributions to the growth of trees and other woody biomass in both cultivated (plantation) and uncultivated production contexts that are harvested by economic units for various uses, including timber production and energy. This is considered a final ecosystem service, and excludes contributions to non-wood forest products. Wood biomass assessment should be considered in the context of other ecosystem services, e.g., carbon, where the carbon in harvested wood is subtracted from the carbon stock, but growth adds to the carbon stock. This would rely on robust estimates of carbon pools in vegetation in each catchment (not developed for INCASE but should be addressed by further research, such as the DAFM funded For-ES project).

Table 4.9. Wood biomass provision logic chain

Ecosystem type/s	**Factors determining supply**		**Factors determining use**	**Physical metric/s**	**Benefit**	**Main users and beneficiaries**
	Ecological	**Societal**				
Forests	Extent and type of forest; soil type / nutrient status; yield class; climate.	Ecosystem management (tree type, stocking density; thinning); infra-structure.	Forest policy; timber quality, demand; age; felling programme.	Volume of wood, paper / other wood products	Timber, paper / other products from wood	Sawmills; forest owners / managers; end users
Data required	*Area, tree type*			*Area & yield class.*		

Context / relationship to other accounts

- **Ecosystem extent / type(s)**: The main ecosystem type associated with this service was Forests. CORINE Landcover distinguishes a number of Forest and Woodlands classes including Level 3 landcover classes [311] Broad-Leaved Forest, [312] Coniferous Forest, [313] Mixed Forest and [324] Transitional Woodland Shrub. The latter generally relates to clear-fell or recently planted area, though may also record semi-natural (non-commercial) woodland. We verified the extent of commercial plantations using spatial data gathered by Coillte, and the Private Forest dataset 2019, which outlined commercial forested areas with information on the dominant tree type and age class (**Fig. 4.3**).

- **Ecosystem condition**: We had no condition indicators available for Forests; tree type and year planted only were provided by commercial datasets. We note that the National Forestry Inventory (DAFM 2018) gathers data for national reporting, but this is not suitable for catchment level assessments (though it should be considered for national level accounts).
- **Ecosystem service assessment**: In section 6.55 of SEEA (UNSD,2021), the most common method suggested to measure this ecosystem service is to measure the gross biomass harvested. However, growth (net increment) in cultivated forestry stands (a flow) is adding to the stock each year until harvest and should be recorded as an ecosystem service flow in each year. This is recorded as used by the forest manager as an input to their work in progress (i.e. the standing stock of timber). This is the equivalent of the work in progress approach used in the SNA (UN et al., 2010).
- **Benefits**: At this time, the SEEA-EA recommends the benefit is represented as the net increment of timber per annum, recognising that this will be a function of ecosystem contribution and management.

No yield class data were available for commercial forests in the INCASE catchments. To provide an estimate of the potential wood biomass flows, two approaches were taken as follows:

Estimate of the harvested wood products (wood provisioning service): To estimate the harvested areas within catchments, removals identified in each of the catchments by the Tree Cover Density HRL Change Map 2015-2018 were measured and then verified using Google Earth imagery. Fifty-two sites where forestry removals had taken place during the period 2016-2018 were identified. These data were then combined with the Coillte and DAFM private forests data to estimate areas, age, species, and year of harvest for each area. Note, where age information was not available, age was estimated based on surrounding stands and historical imagery (Table 4.10.).

Table 4. 10 Estimated harvested wood in INCASE catchments (2016, 2017 & 2018)

Year	Dargle		Figile		Bride		Caragh		
	Area harvested ha	Volume m3	Area harvested ha	Volume m3	Area harvested ha	Volume m3	Area harvested ha	Volume m3	Total volume m3
2016	10.6	7,669	12.3	3,299	86.2	62,256	0	0	***73,224***
2017	41.6	18,824	12.7	5,739	45	34,201	9	6,052	***64,816***
2018	37.3	22,818	42.4	21,834	38.6	36,474	4	3,075	***84,201***
Total area	***89.5***	***49,311***	***67.4***	***30,872***	***169.8***	***132,931***	***13***	***9,127***	***222,241***

/ volume									

Tree growth or addition to standing stock (wood growth ecosystem service): This was assessed by combining the area of forest with annual growth estimates (based on tree species and soil type) (Table 4.11.). In the INCASE catchments, Sitka spruce (*Picea sitchensis*) was the dominant species, and soil type varied but was verified by SIS dataset to be largely peat in the Caragh, Figile and Dargle. We note from Table 4.10. and 4.11. that the estimated harvested wood and the estimated wood growth in both tables show discrepancies. For example, the sum of the harvested wood in the Bride of 132,000 m^3 between 2016-2018 corresponds to the total growth over the age of the stand. The annual growth estimated in the Bride on the other hand is 125,000 m^3 and is based on a number of assumptions that would need to be tested to be used as a reliable basis for further analysis.

Table 4.11. Estimated wood growth in INCASE catchments

Catchment	Coillte (ha)	Private (ha)	Total area (ha)	Estimated annual growth (m^3 yr^{-1})
Dargle	1,630	1,314	2,944	46,693
Figile	1,620	2,292	3,912	52,658
Bride	4,042	2,339	6,381	**125,806**
Caragh	679	888	1,567	21,112
Total area of commercial forest	***7,971***	***6,833***	***14,804***	***246,269***

Full details of how wood biomass provisioning services were calculated and their results are given in Appendix 4.1.

In terms of the two approaches, the highest level of harvested wood and growth was estimated for the Bride, also reflecting the highest extent of commercial plantation. Lowest estimates were reported for the Caragh, which has the lowest commercial forest cover. The Dargle and Figile had relatively similar harvested areas and growth estimates (relating to cover). Growth estimate is probably the best approach to get a reflection of ecosystem contribution and we used this aspect in the INCASE S/U accounts.

Estimates for timber removals were over a 3-year period and despite using best available information, harvest years for certain sites may not be accurate. We had no data on yield class, and therefore yield class was estimated based on tree species, age, and a combined approach that used estimates of yield based on spatial modelling (yield class estimated at townland level by O'Donoghue *et al*., 2021; Farrelly *et al*., 2011) and expert opinion for each catchment. More robust and accurate data on yield per species and forest stand would make the estimates more accurate. Commercial forestry is a complex cultivation process and there have been a number of limitations due to planning appeals related to felling licences in Ireland, influencing harvested areas annually. This highlights the role of societal factors determining supply and use and the need to consider these aspects in making value judgements in relation to trends based solely on estimates of growth and removals.

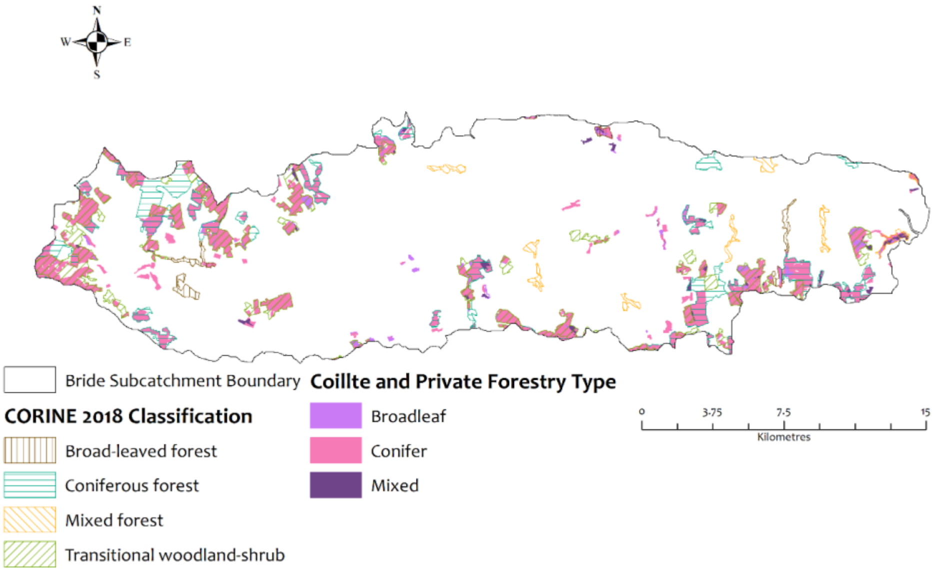


Figure 4.3. The CORINE woodland and forest classes in the Bride overlap with most of the commercial areas, with some areas not included

4.7.1.4 Water supply services (Table 4.12.) reflect the combined ecosystem contributions of water flow regulation, water purification, and other ecosystem services to the supply of water of appropriate quality to users for various uses, including household consumption (which is the final, provisioning ecosystem service). In other words, this is the supply of water that has been purified by movement through vegetation, soil and subsoil, and the service is a combination of both supply and purification, which are difficult to separate. For the INCASE project, only sources of groundwater were included in this service assessment as i) these were the only data available; and ii) this is the approach used by the NSO in the Netherlands, reflecting the only water abstraction whereby filtration by ecosystems was providing an ecosystem service (Horlings *et al*., 2020). We include reference to geosystems here, reflecting their contribution through aquifers and also the filtration service provided by subsoils (an intermediate service).

Table 4.12. Water supply (provision) logic chain

Ecosystem type/s	Factors determining supply		Factors determining use	Physical metric/s	Benefit	Main users and beneficiaries
	Ecological	Societal				
Fresh-water rivers & lakes; ground-water.	Extent of surface / groundwater; volume / flow of water; water quality.	Ecosystem management; pipe network; leakage.	Spatial configuration; human / other consumptive demand; price; planning and policies relating to water including WFD, DWD, source protection	Water abstracted per capita; availability for abstraction or volume water extracted / treated to drinking water standards per year.	Plentiful water for drinking, commercial & domestic use, irrigation of gardens, livestock, wildlife use.	Householders; Industrial; Agricultural; Irish Water; Local Authorities; Group water schemes (Co-ops).
Data required				*Actual supply or demand as a proxy.*	*Volume consumed by type or quality.*	

Context / relationship to other accounts

- **Eco/geo-system extent / type(s)**: The main ecosystem types associated with this service were freshwater rivers and lakes and groundwater bodies. CORINE Landcover distinguishes freshwater ecosystems but as these were generally below the MMU, data were supplemented by EPA WFD data and groundwater data from GSI. For the INCASE project, only sources of groundwater were included.

- **Eco/geo-system condition**: We had access to chemical status and risk characterisation data for groundwater waterbodies gathered under the WFD.
- **Eco/geo-system service assessment**: The treatment of water supply is described in section 6.4.2 of the SEEA (UNSD, 2021). The SEEA- EA recommends:
    - Distinguishing between different purposes for water abstraction, given that this helps identify the role of the ecosystem service. For example, water used for industrial purposes may not be dependent on water quality, while water for drinking will be influenced by water purification services.
    - Where water abstraction does not involve an ecosystem contribution it should be recorded as an abiotic flow.
    - Where the direct contributions to water supply cannot be separately recorded, it is appropriate to record the volume of water abstracted as a proxy for the ecosystem contributions. This flow should be recorded as a final ecosystem service.

Benefits: The SEEA-EA (UNSD, 2021) outlines the final benefit as being the volume of water consumed by the economy and the society as the final benefit.

Due to limited data on water abstraction and use, a demand approach was used as a proxy to estimate the volumes of water used in each catchment (summarised in **Table 4.12**). This approach is also used to allocate the water supply service to the various end-users in the service use account:

Permitted abstraction: Since 2018 water abstractions in Ireland in excess of 25 m^3 day^{-1} are required to be registered[10]. The abstractions register provided an overview of the significant water users within each catchment.

Domestic demand: This is measured by multiplying the average household usage by the number of households whose water source can be traced to groundwater source. GSI (2021) data show Groundwater Source Protection Areas and Source Protection Areas for public water schemes and group water schemes in Ireland. Data on water schemes with groundwater sources were only available for the Figile and the Bride; for the Dargle and the Caragh, houses with private sources were identified by small area census data (CSO, 2017). We note that this accounted for groundwater supply only, while the majority of domestic demand (95% of the c. 35,000 households) in the Dargle was supplied by Irish Water from a source outside of the catchment which would be recorded as an import to the Dargle in supply and use tables.

Agricultural demand: Demand for this sector was estimated by aggregating livestock numbers in each catchment based on CSO 2010 data (as outlined in the section on grazing biomass) and estimating daily demand of grazed livestock per unit, per catchment. The assumption was made that all grazing livestock demand is supplied by groundwater within each catchment since bored wells are the most common water sources on farms (Ryan, 2009). Note the same limitations apply to data on livestock numbers: data not gathered at catchment level but at ED level, and data available from 2010 only.

Industrial demand: This was estimated from data gathered by the EPA on active Integrated Pollution Control (IPC) sites. Each site is required to return an annual environmental report which details the usage of energy and water. This data includes the main users of water, and largely correlated with those sectors reported in the abstractions register.

Full details of how water supply provisioning services were calculated and their results are given in Appendix 4.1

[10] in accordance with the European Union (Water Policy) (Abstractions Registration) Regulations 2018 (S.I. No. 261 of 2018)

In terms of water supply the estimated demand reflects the potential contribution of groundwater in each catchment. Potential demand is highest in the Figile and the Bride, from domestic, agricultural, and industrial users (Table 4.13.). We note that despite high numbers of households in the Dargle, demand is not matched by groundwater potential, as most of this demand is met by sources outside the catchment (piped treated water from a number of catchments, see Kelly-Quinn *et al.,* 2014). Domestic demand is highest in the Bride, as is agricultural demand (reflecting high numbers of livestock – mainly bovine); sheep are the dominant livestock type in the Dargle and the Caragh. Industrial demand is high in the Bride and we note all water supplied to industrial (IPC) licensed facilities in the Dargle are supplied by public water supply. In terms of demand, the estimates reflect potential demand relating to groundwater based on data gathered for abstraction, the number of households in each catchment reliant on groundwater, livestock numbers and industrial (reported) use. Data on *actual* supply would support more accurate supply and use accounts.

Table 4.13. Summary of estimated annual groundwater demand (m^3) for INCASE catchments

Groundwater Demand	**Dargle (m^3 $year^{-1}$)**	**Figile (m^3 $year^{-1}$)**	**Bride (m^3 $year^{-1}$)**	**Caragh (m^3 $year^{-1}$)**
Domestic demand (based on 2018 data)[11]	106,786	424,372	633,314	26,730
Households dependant on groundwater	*831*	*2,908*	*4,582*	*184*
Agricultural demand (based on 2010 data)	68,607	414,042	1,605,590	89,427
Total livestock numbers based on 2010 data (cattle, dairy cows, ewes and other sheep, horses)	*16,407 (Sheep 13,693)*	*39,116 (Bovines 26,513; Sheep 12,399)*	*77,667 (Bovines 71,402)*	*25,847 (Sheep 22,000)*
Industrial demand (IPC Sites, based on 2020 data)	0	68,848	140,755	0
Type and number	*5x surface coating; 1x chemicals*	*2x intensive piggery; 2x energy*	*1x piggery; 1x slaughterhouse*	*0*
Estimated totals m^3	***175,393***	***907,262***	***2,379,659***	***116,157***

4.7.2 Regulating services

4.7.2.1 Global climate regulation

Global climate regulation services are the ecosystem contributions to the regulation of the chemical composition of the atmosphere and oceans that affect global climate through the accumulation and retention of carbon and other GHG (e.g., methane) in ecosystems and the ability of ecosystems to

[11] https://www.cso.ie/en/releasesandpublications/er/dmwc/domesticmeteredpublicwaterconsumption2018/

remove carbon from the atmosphere. This is a final ecosystem service (UNSD, 2021). This service is essentially broken into a stock component (maintenance of carbon stock) and a flow component (removal of carbon) through functional characteristics of the ecosystem type involved (Table 4.14.).

Table 4.14. Global climate regulation logic chain (SOC = Soil Organic Carbon)

Ecosystem type/s	**Factors determining supply**		**Factors determining use**	**Physical metric/s**	**Benefit**	**Main users and beneficiaries**
	Ecological	**Societal**				
Forests	Age; yield class; species; soil; tree density; carbon pools (above and below ground biomass, dead matter, soil).	Planting; silvicultural management (thinning, felling practices).	Forest policy; supply and demand of timber; climate policy.	**Stocks**: SOC; Biomass; extent and type of ecosystem. **Flows**: Emission factors based on ecosystem type and condition.	Reduced concentrations of GHG in the atmosphere leading to less climate change and fewer adverse effect (non-SNA benefits).	Global society
Woodlands	SOC; vegetation cover (type and extent; above and below ground biomass, dead matter, soil).	Management (drainage, cultivation; aeration of peat soils; thinning).	Woodland policy (none at this time); CAP; climate policy			
Linear and scattered woodlands / parklands	SOC; vegetation cover (type and extent; above and below ground biomass, dead matter, soil).	Management (cutting, planting; maintenance).	Hedgerow policy (none at this time); planting policy; CAP; climate policy			
Peatlands and Heathlands	Peat depth; water table; drainage; vegetation cover (type and extent); carbon pools.	Management (grazing, planting, burning, drainage, land-use).	National Peatlands strategy; CAP; climate policy.			
Semi-natural grasslands	SOC; vegetation cover (type and extent); carbon pools (above and below ground biomass, dead matter, soil).	Management (grazing, planting, burning, drainage, land-use).	CAP; climate policy.			
Data required				*Extent of ecosystem and SOC; emission factors for GHG.*	*Volume of carbon stored, and volume removed from atmosphere*	

Context / relationship to other accounts

- **Ecosystem extent / types**: A number of ecosystem types are associated with this service including forest and woodlands, peatlands and heathlands and grasslands. CORINE Landcover distinguishes a number of relevant landcover classes including Agricultural Areas (excluding croplands), all Forest types, [322] Moors and Heathland and [412] Peat Bogs. We used high level

CORINE ecosystem types as indicated by CLC Level 3 types to assess this service, combining knowledge of ecosystem type with soils data, and drainage.

- **Ecosystem condition**: Depending on the condition of the ecosystem type and underlying soil type (based on condition variables), it may be acting either as a sink (removal) or a source of a number of GHG (greenhouse gases) including methane, carbon dioxide and nitrous oxide.
- **Ecosystem service assessment**: The SEEA-EA (UNSD, 2021) highlights that a complete accounting for all carbon stocks and flows be carried out to support coherence in measurement and wider discussion on climate change and associated policy issues (as follows):
  - The carbon retention component of the service is quantified by recording the stock of carbon retained in ecosystems at the beginning of the accounting period (i.e., the opening stock). This is a proxy indicator for the flow of the service, analogous to the quantification of the services supplied by a storage company in terms of the volume of goods stored, with only the carbon stored to a maximum of 2 metres below the surface to be included (UNSD, 2021).
  - The carbon sequestration component of the service reflects the ability of ecosystems to remove carbon from the atmosphere. An appropriate metric is the net ecosystem carbon balance (UNSD, 2021).

- **Benefits**: The SEEA-EA (UNSD, 2021) highlights the final benefit as being the reduced concentrations of GHG in the atmosphere leading to less climate change and fewer adverse effects (a non-SNA benefit).

We had limited condition data available, so ecosystem type combined with soil type and a knowledge of drainage was the main basis for assessment of potential carbon storage and removals.

Full details of how global climate regulating services were calculated and their results are given in Appendix 4.1.

Soil carbon stocks: For this aspect we used Soil Organic Carbon (SOC) data (Simo et al. 2019) to estimate carbon content to 1m depth for all catchments (no data were available to 2m). Given that there are no national scale SOC data for peatlands in Ireland, we used data from Holden and Connolly (2011) as a proxy for SOC of peat soils. We used a value of 751 tonnes/ha from Holden and Connolly (2011) for blanket bog areas in the Dargle and the Caragh, and industrial peat extraction areas and raised bog remnants in the Figile. The figure of 530 tonnes per hectare was used for peat soils in the Bride catchment, given that these areas were predominantly heathland (less than 30cm peat) and this is the lower value presented by Holden and Connolly (2011) for peat depth less than 30cm (**Figure 4.4**).

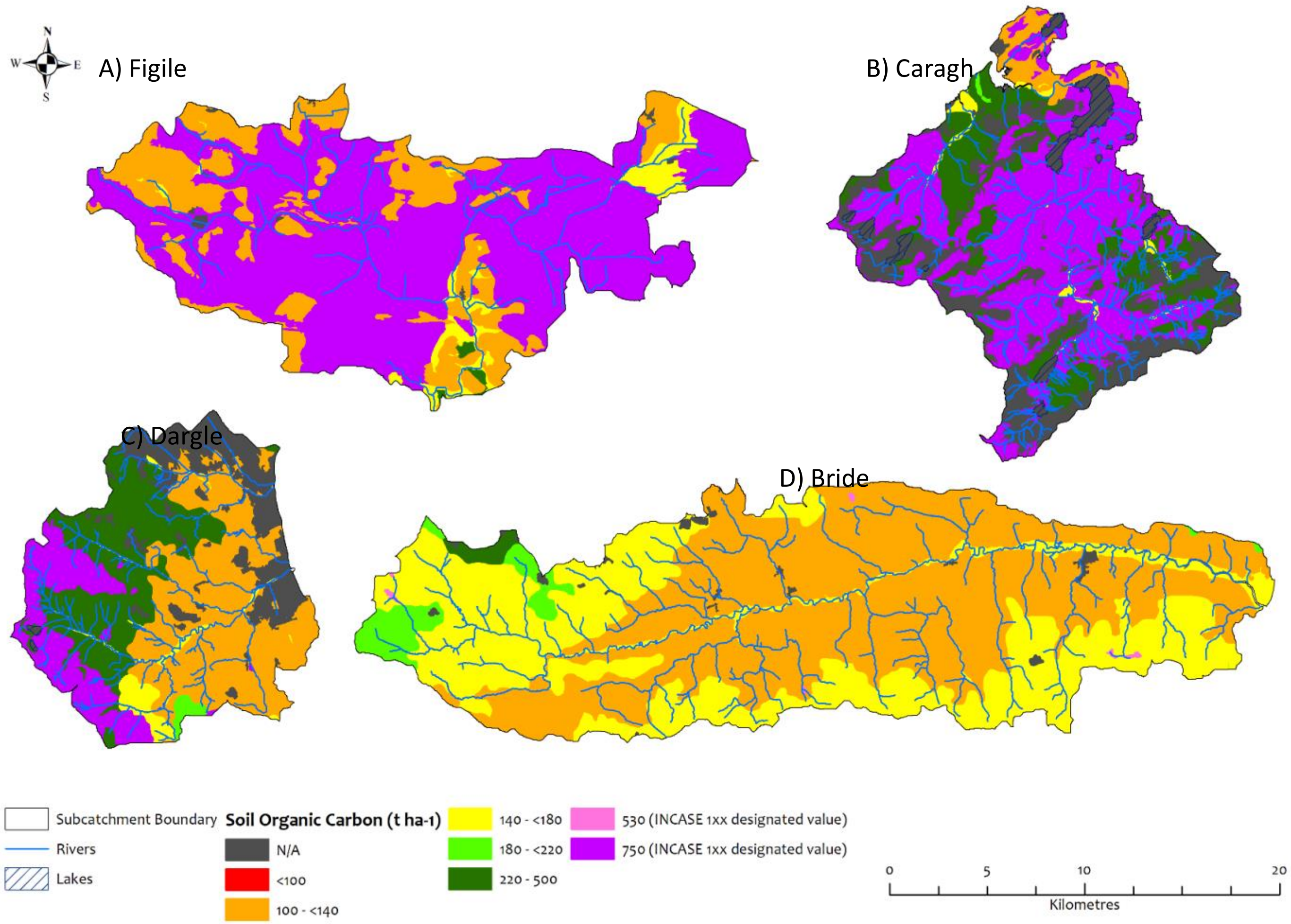


Figure 4.4. SOC maps based on SIS data and other peatland data where relevant for the four INCASE catchments (A Figile, B Caragh, C Dargle and D Bride)

The Dargle has the lowest SOC (Table 4.15.), and this can be attributed in part to the high cover of Urban areas with no data (~25% of the catchment) and also being the smallest of the catchments. The Figile has the highest level of SOC across the catchment, due to the dominance of peatlands and the presence of peat soils under grassland and forestry (>60% of the catchment comprises peat soils). The Bride is the largest catchment and has a high SOC but has the lowest SOC attributed to peatlands due to the dominance of mineral soils. The overall high cover of peat soils in the Caragh (blanket bogs, wet heathland etc.) contributes to the high SOC in catchment. We do not present data for carbon stocks in vegetation (which should be linked to wood biomass, and other vegetation) and/or other organic pools including below ground biomass and dead organic matter. Carbon stocks in vegetation require modelling using data such as, for forests, on yield class, tree type, area, age etc.

Table 4.15. Summary of estimated soil carbon stocks for the INCASE catchments. Note: The analyses are indicative (for demonstration purposes only) and present an overview of how catchment carbon stocks could be presented. Our view is that this requires a GHG expert analysis

	Dargle	Figile	Bride	Caragh
Total catchment area ha	**17,686**	**30,143**	**42,715**	**22,953**
Stocks: tonnes C / ha				
Total SOC to 1m	4,208,746	16,903,915	6,121,786	9,872,358
Area peatlands ha	2,501	20,878	64	10,953
Of which peat soils SOC	*1,876,400*	*15,658,449*	*34,114*	*8,214,441*
Non-peat	*2,332,346*	*1,245,466*	*6,087,672*	*1,657,917*

We estimated soil carbon flows (and nitrous oxide emissions) across three areas as indicative examples of how these flows could be measured (Table 4.16). We also present data on nitrous oxide (responsible for 1/3 of GHG emissions[12] in Ireland), estimated based on CORINE land cover classes and emission factors according to NIR (Duffy *et al.,* 2021) (Table 4.16). Note, we only include carbon flows based on the NIR approach for CORINE Land-cover classes on peat soils in our supply-and-use accounts as this is the most reliable data available at this time. Other assessment approaches can be developed at farm or forest scale with more detailed information.

Table 4.16. Carbon flows (*note*: negative values indicate potential carbon removal or sequestration, positive values indicate carbon emissions or release). *assumes *natural* peatlands

	Dargle	Figile	Bride	Caragh
Total catchment area ha	**17,686**	**30,143**	**42,715**	**22,953**
Flows Carbon				
Soils (combined with CORINE ecosystem type)[1]	25,568	70,578	744	*17,941

[12] We note that nitrous oxide is a much stronger greenhouse gas than CO2 in terms of its 'warming potential'. Over a 100-year timescale, and without considering climate feedbacks, one tonne of nitrous oxide would generate 265 times the amount of warming as one tonne of CO2 (agricultural activity is the main contributor).

Hedgerows, Shrub (SWF)[2]	-11,083	-10,363	-8,072	-5,727
Forest using FERS tool[3]	-8,065	-6,501	-18,338	-2,191
Net flow using available data t C with FERS model	***6,420***	***53,714***	***-25,666***	***10,022***
N2O tonnes	10,973	35,238	467	17,861

[1] To estimate carbon emissions from soils, we combined SOC data (Simo *et al.,* 2019), ecosystem type (based on 2018 CORINE data); and applied carbon emission factors according to NIR and specifically LULUCF emission factors for land use type (a combination of IPCC Tier 1 and Tier 2 factors). We included gaseous emissions and DOC and assumed all peatlands were drained, except for those in the Caragh catchment.

[2] We estimated carbon flows in hedgerows and shrubs, using data of the area of EEA Small Woody Features and Urban Atlas Street Trees combined with emission factors outlined for hedgerows in Ireland (emission factor of -1.9 tonnes C ha-1 hedgerow) (Green *et al.,* 2019).

[3] In 2021, Teagasc published a tool called FERS to estimate carbon emissions from forested areas. Using forest data (dominant tree species), soil types and an estimate of potential yield, we applied this tool to estimate the potential carbon balance of forested areas in each catchment.

Based on our assessments, all catchments are sources of carbon based on estimating emissions from CORINE (ecosystem) landcover classes. The Figile has the highest emissions of carbon, ascribed to the high cover of peat soils and their drainage for peat extraction, agriculture, and forestry. The Dargle and Caragh both have high estimated carbon emissions from ecosystems and corresponding soils, with low levels estimated in the Bride due to lack of peat soils. Including estimated removals of carbon by hedgerows and scrub in each catchment potentially reduces the net carbon emissions from each catchment as shown by the estimates in Table. 4.14., with the highest potential removals in the Dargle and Figile. It is likely that forests in the INCASE catchments are carbon sinks, but this needs to be modelled to reflect the forest age, yield class and soil type. We estimated emissions using the same approach across all four catchments based on commercial plantation data, so the results are relative though the underpinning data are not detailed enough for value judgements. The Bride shows the highest potential removals. In terms of nitrous oxide, the highest emissions are from the Figile (due to high cover of drained peat soils); followed by the Caragh, Dargle and Bride (which shows the least estimated nitrous oxide emissions).

The results are indicative only and rely on a number of high-level assumptions. For example, applying an emission factor for peatlands in the Dargle (as we did in the Caragh) would present a very different result. However, there are limited data on carbon emissions from blanket bogs available (one site for lowland blanket bog for Ireland, no studies on upland blanket bogs). Estimates for hedgerows would need to be subtracted from the overall ecosystem type in CORINE extent accounts to avoid double counting, while estimates from forests require more refinement, incorporating data relating to yield class, age, soils etc. The FERS tool relies on a number of assumptions and data should be validated more thoroughly. In terms of completeness, emissions from livestock in each catchment should also be incorporated to get a full reflection of overall flows.

4.7.3 Cultural services

Cultural services involve an interaction between people and ecosystems, and quantification generally reflects the type, number, and quality of the interaction, such as visitor number to a specific natural location (UNSD, 2021). Congruently, use of a particular ecosystem for recreational purposes is often dependent on a particular location of the ecosystem or other combinations of the attributes of a particular ecosystem rather than a type of ecosystem (Stålhammar and Pedersen, 2017).

4.7.3.1 Recreation-related services (Table 4.17) are the ecosystem contributions, in particular through the biophysical characteristics and qualities of ecosystems, that enable people to use and enjoy the environment through direct, in-situ, physical and experiential interactions with the environment. This includes services to both locals and non-locals (for example, visitors, including tourists). Recreation-related services may also be supplied to those undertaking recreational fishing and hunting. This is a final ecosystem service (UNSD, 2021).

Table 4.17. Recreation related service logic chain

Ecosystem type/s	**Factors determining supply**		**Factors determining use**	**Physical metric/s**	**Benefit**	**Main users and beneficiaries**
	Ecological	**Societal**				
Catchment (geo-landscape; woodlands; uplands; coastal, etc.)	Type and condition of ecosystem; presence of iconic landmarks or species.	Ecosystem management including facilities to support access.	Spatial configuration; population; accessibility of recreation sites; location of users; demand for outdoor recreation.	Number and length (hours) of visits.	Physical and mental health; enjoyment (non-SNA benefit).	Local and global
Urban green space; blue and green corridors; public access amenity (woodlands, forests, coastal; grasslands)	Type and condition of ecosystem; characteristics (e.g., % urban green space, distance to open green space)					Catchment dwellers
Data required				*Visitor numbers per site and type.*	*Volume consumed by type or quality.*	

Context / relationship to other accounts

- **Ecosystem extent / types**: A number of ecosystem types are associated with this service including forest and woodlands, peatlands and heathlands, coastal areas, and grasslands, often linked to landscape or geo-heritage characteristics (from a tourism perspective) and / or accessibility or proximity to high population density areas (local).
- **Ecosystem condition**: Condition can be a subjective assessment by the end-user. There were no condition data available in general, with limited data for waterbodies and peatlands.
- **Ecosystem service assessment**: The SEEA-EA (UNSD, 2021) recommends using the number of visits to a specific natural location. While not a direct quantification of the ecosystem contribution, they are considered a suitable proxy which can be improved by taking into consideration as far as possible the number and length of time of interactions with specific features and characteristics of the ecosystems concerned (UNSD, 2021).
- **Benefits**: The SEEA-EA (UNSD, 2021) highlights the physical and mental health, and enjoyment benefits as the final benefit to users (non-SNA benefit).

Full details of how recreation cultural services were calculated and their results are given in Appendix 4.1.

For INCASE we did not have access to data sufficient to aggregate the level of recreational activity on a quantitative basis (e.g., number of recreational visitors in the catchments). As an alternative, we used location of visits as a qualitative measure of the use of ecosystems within the catchments. Four recreational types were assessed using available qualitative data (Strava data) for walking and running, cycling, swimming and CORINE data (Sport and leisure facilities [CLC code 142]) verified using aerial imagery) to show location of golf courses (Figure 4.5.). Data were also sought on the number of anglers as this was identified in the INCASE catchment workshops as an important recreational activity particularly in the Bride and Caragh, and historically in the Dargle and the Figile. However, data were not available for inclusion in this assessment. Strava data have previously been used for a variety of purposes including transport assessments, estimating travel patterns, and evaluating air pollution exposure risk (Lee and Sener, 2021). However, it is noted that the data may not be representative of all groups within a population. Here it is being used to highlight areas of higher recreational intensity.

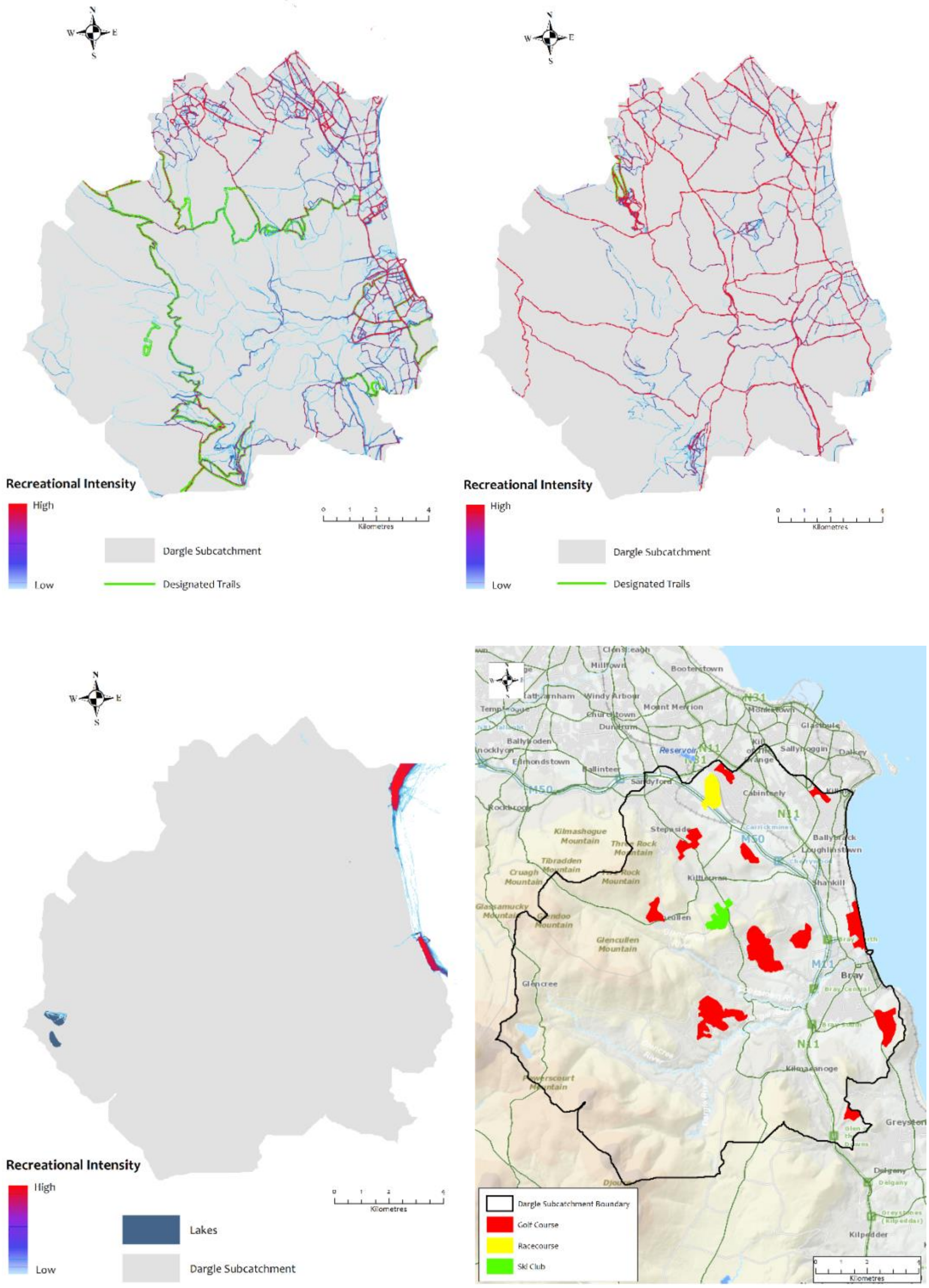


Figure 4.5. Recreational use in the Dargle showing intensity (based on Strava data) of walking and running (top left), cycling (top right), swimming (bottom left) and golf courses (bottom right – using CORINE data)

Modelling approaches for estimation of recreational ecosystem services are not new, with various methods used for estimating this ecosystem service flow. Vallecillo *et al.* (2019) used a model known as ESTIMAP which spatially links potential supply of recreational space from ecosystem with estimated demand (based on human population) to estimate number of visits across various ecosystem types across Europe. For INCASE forests, building on work by Cullen *et al.* (2022), we modelled the potential demand based on proximity of recreational forests to population centres. Note that we include these modelled estimates (Table. 4.18., Figure 4.6) in our supply and use accounts for forests only, as we had no data for other ecosystem types.

Table 4.18. Number of INCASE catchment forest visits based on model of forest visits

INCASE Catchment	Model Estimated Forest Visitors	Estimated Population for Small Areas allocated to Recreational Forests	Average Number of Forest Visits
Dargle	1,122,764	144,063	7.79
Figile	101,885	13,986	7.28
Bride	120,320	15,992	7.52
Caragh	39,269	5,123	7.67

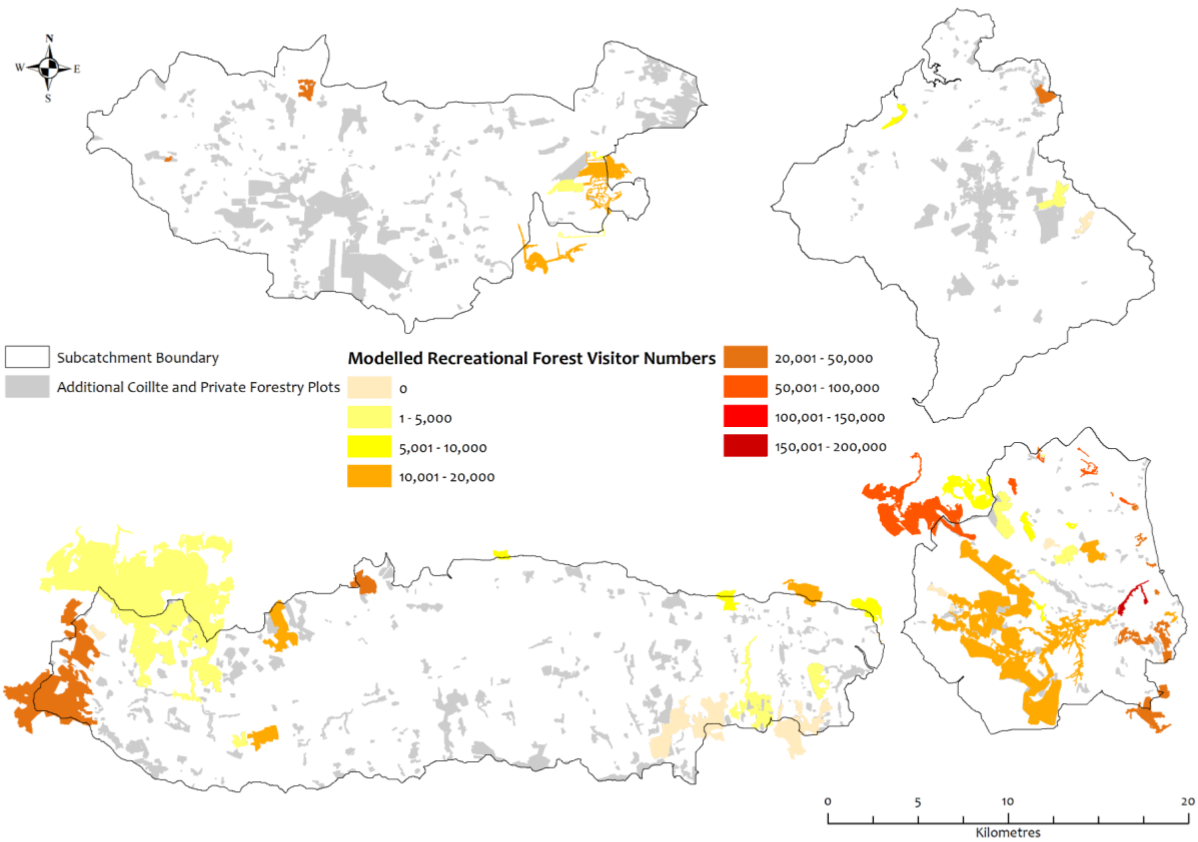


Figure 4.6. Modelled recreational use of forests in the INCASE catchments

The demand for recreational forestry was based on a survey of Coillte forests. Coillte operates a visitor counter in a number of their forests across the country, some of which were located within or near the Dargle catchment (Table 4.19.). No counters were located in or near the other INCASE catchments. The risk of using this modelling approach at catchment scale is highlighted by comparison of the modelled data with real visitor number data (Table 4.19.). While Rathmichael Woods and Crone sites show similar levels to those modelled, with errors of 23% and -38% respectively, the significantly large errors for the other sites show that modelling approaches at catchment scale are not currently able to predict forest visitor numbers.

Table. 4.19. Modelled and actual numbers visiting Coillte forests in the Dargle catchment (for those sites with counters)

Locations	Model Estimate	Coillte Counters by Year (actual visitor numbers by site)					
		2016	2017	2018	2019	2020	Modelled Prediction % (2020)
Rathmichael Woods	12,164			14,826	15,180	14,968	-23%
Glencullen/ Tibradden Wicklow Way[13]	91,621					7,014	+92%
Barnaslingan	3,270	30,045	33,209	34,082	36,663	33,381	-921%
Crone	17,007	30,275	14,614	18,519	21,362	23,261	-38%
Total numbers	***124,062***	***60,320***	***47,823***	***67,427***	***73,205***	***78,624***	***+58%***

Where data are insufficient, modelling approaches may be useful to provide some estimates of ecosystem service use, but recreational use is often related to numbers of residents in the locality, as travel to further sites imposes a cost on recreational users. This is reflected here, where the estimated visitor numbers are correlated with the population numbers within the catchments: > 1.1 million visitors per year in the Dargle, compared to <40,000 visitors in the Caragh catchment. In addition, this approach is based on local populations and does not take into account visitors from outside the catchments. Nor does the model take into account the quality of the forests, the landscape or a variety of other factors that recreational forest visitors take into account in their recreational choice.

4.7.3.2 Eco / geosystem appreciation services concerns the wellbeing that people derive from the existence and preservation of the environment for current and future generations, irrespective of any direct or indirect use (SEEA-EA, Feb 2021). Specifically, this flow relates to non-use values. We note that this service underpins a number of other services such as recreation (quality of the experience), tourism, research and education, food from wild populations, climate regulation, and cultural aspects such as visual amenity. Often the driver of this service relates to the rarity and/or

[13] The nearby Tibradden Dublin Mtns Way counter measured 49,726 visitors in 2020 but is slightly outside the catchment.

complexity of the natural system that is designated for conservation, and level of cultural appreciation (Table 4.20.).

Table 4.20.Ecosystem appreciation logic chain

Ecosystem type/s	**Factors determining supply**		**Factors determining use**	**Physical metric/s**	**Benefit**	**Main users and beneficiaries**
	Ecological	**Societal**				
All ecosystems (particularly habitats and species requiring legal protection) and geosystems	Extent, type and condition; spatial configuration; network connectivity; presence of iconic / rare ecosystems or species; landscape context..	Ecosystem management including conservation measures; monitoring; restoration programmes; education programmes.	EU Nature Directives / Wildlife Act; Legal enforcement; access to ecological sites of interest; education programmes.	Areas designated; (policy relevant) habitats and species conserved (type and area).	Biodiversity, in of itself, and the wellbeing of humans (non-SNA benefit).	Global society
Data required				*Areas designated for habitats and species.*	*Sustainable areas / populations of habitats and species.*	

Context / relationship to other accounts

- **Ecosystem extent**: This service is associated with a number of ecosystem and geosystem types including areas within Natura 2000 sites (SAC, SPA), National Heritage Areas (NHAs) as well as geo-heritage sites and other relevant designations.
- **Ecosystem condition**: data were available for limited areas / survey sample plots across the four catchments (for example, Oldboleys Old Oak Woodland SAC site and a coastal site in the Dargle).
- **Flow assessment**: The SEEA-EA (UNSD, 2021) suggests using areas designated for natural systems (habitats and/or species, landscape forms). There are a number of designated areas in each of the catchments and data were available relating to:
    - Natura 2000 sites (SAC/SPA), Natural Heritage Areas (NHA) and proposed NHA areas (national designation), with some overlap often between both Natura 2000 and NHA designations. Natura 2000 SAC sites are designated for a range of qualifying habitats (Annex I) and species (Annex IV). SPA sites are designated for avifauna.
    - Some more detailed habitat data relating to some Natura 2000 sites, such as the Wicklow Mountains SAC (this habitat map is dated 2006-2007 and shows areas of cutover bog and eroding blanket bog / areas of poor habitat condition).

- There is a range of species in the catchments and their occurrence has been mapped as part of the NPWS MAES project (2016) (see https://www.npws.ie/sites/default/files/publications/pdf/IWM95.pdf)
- Other species records are available, and these are in the main historical records of species of conservation interest (available from National Biodiversity Data Centre). Policy relevant species are most appropriate for consideration.

- **Benefits**: As outlined in SEEA-EA, the inclusion of ecosystem and species appreciation is to address the inclusion of non-use values, despite the recognition that non-use values do not satisfy the definition of an ecosystem service, which requires them to be something that is directly or indirectly used by people (see SEEA-EA para 6.70). However, these non-use flows are hugely important from a policy perspective and of relevance in economic analysis such as cost - benefit analysis. Thus, since the SEEA-EA approach is based on accounting for transactions in line with the SNA, and non-use flows are by definition non-transactional, the SEEA-EA suggests these may be presented in complementary valuations to the main SEEA-EA accounts.

For INCASE, we included areas designated in Natura sites and national designations. We also estimated the cover of each catchment in terms of habitats listed on Annex I and species listed on Annex IV of the EU Habitats Directive (Table 4.21. and 4.22., Figure 4.7).

Table 4.21. Summary areas designated in Natura sites and national designations and Annex I habitats (detailed information in each catchment overview)

	Dargle	Figile	Bride	Caragh
Catchment area ha	**17,686**	**30,143**	**42,175**	**22,953**
Nature designations				
Area* ha	7,214.3	398.4	1,069	19,197
% catchment	23.7	1.4	2.5	83.5
Annex I habitats				
Area* ha	4,345	308	352	9,424
% catchment	24.6	1.0	0.8	41.1

The Caragh has the highest area of nature conservation designation and similarly for Annex I habitats (peatlands, coastal and uplands in general) with a number of Annex IV species present. The Dargle has a relatively high cover of designations with a number of Annex I peatland and coastal habitats designated. The Figile and Bride have relatively low cover of designations. In the Figile the Annex I habitats are largely fragments of raised bog habitats while in the Bride the Blackwater SAC (Bride river and associated marginal habitats) is the main designated feature (**Fig. 4.7)**. A number of Annex IV species are common to all catchments and specific species in the Caragh and Bride. These species have been the focus of a number of conservation projects including the KerryLIFE project and Pearl Mussel Project EIP, both of which focus on freshwater pearl mussel. This species relies on high water quality and consistent water supply throughout the year. The data should be considered in the national conservation status context for habitats and species, but also the local assessment in each catchment.

Table 4.22. Summary Annex I habitats and Annex IV species in each catchment. Note we don't include Annex I habitats demoted by point data here

Annex I habitats	Habitat Name	Dargle	Figile	Bride	Caragh
7110	Raised Bog (active)		X		
91D0	Bog woodland (accounted for in WF section)		X		
4010	Wet Heath			x	x
4030	Dry Heath	x		x	x
4060	Alpine and Subalpine Heath	x		x	x
7130	Blanket Bog (Active)	x			x
7140	Transition mires	x			
Annex IV species					
Common frog (*Rana temporaria*), Irish hare *(Lepus timidus)*, Otter *(Lutra lutra)*, Pine marten *(Martes martes)*		x	X	x	x
White cushion moss *(Leucobryum glaucum)* (a peatland species)		x			x
Marsh fritillary (*Euphydryas aurinia)*			X	x	
White clawed crayfish (*Austropotamobius pallipes*)			X	x	
Desmoulins whorl snail (*Vertigo moulinsiana*)				x	
Natterjack toad (*Epidalea calamita)*					x
Freshwater Pearl Mussel: (*Margaritifera margaritifera*)					x
Kerry slug (*Geomalacus maculosus)*					x

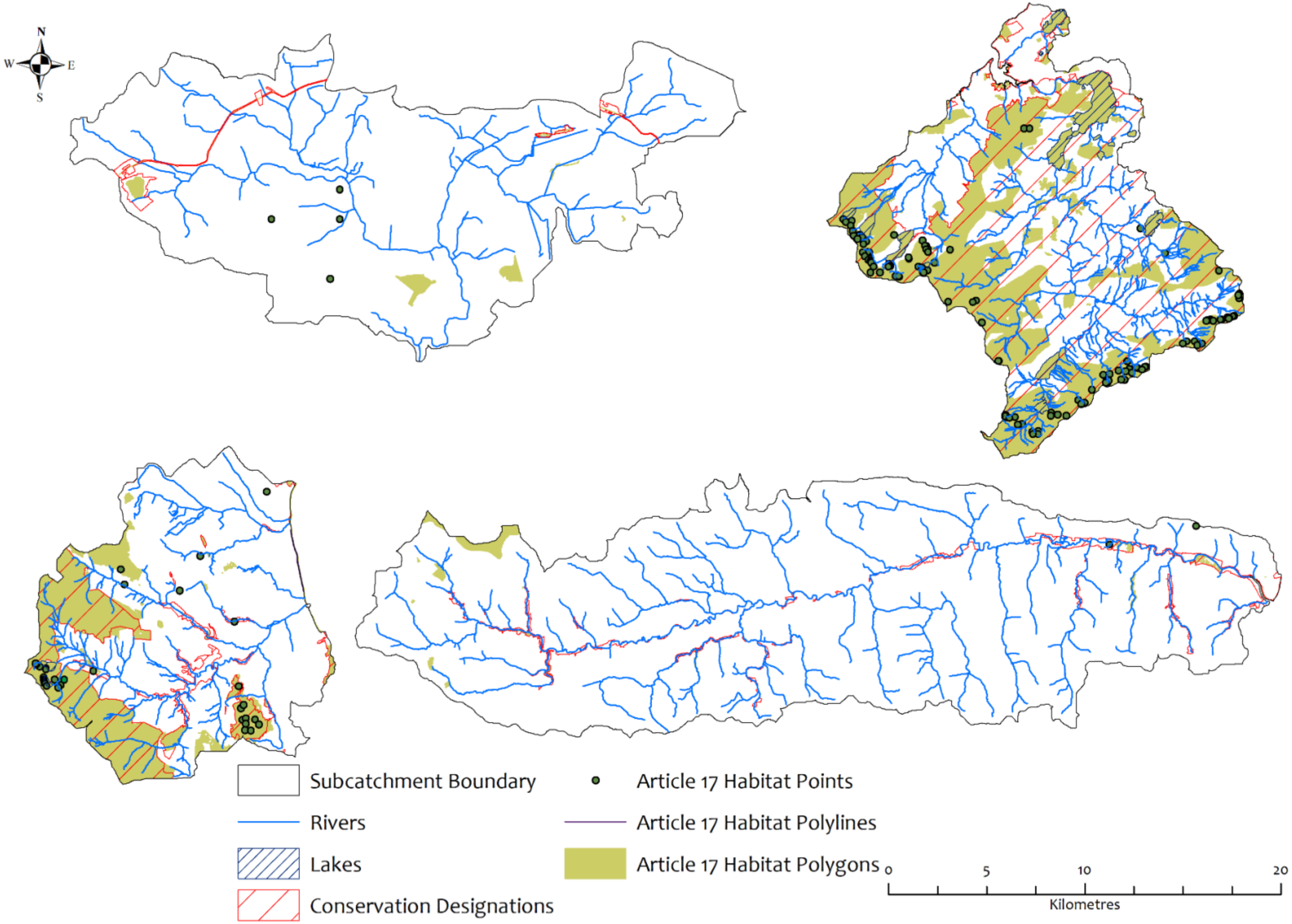


Figure 4.7. All four catchments showing Annex I habitats cover and relative area designated for nature conservation

4.7.4 Abiotic flows

4.7.4.1 Peat (domestic and industrial use)

Peat extracted for fuel purposes is classed as an abiotic flow (UNSD, 2021). This involves extraction of a geological resource (subsoil) and is attributed to geosystems (peat is classified as a subsoil) (Table 4.23.).

Table 4.23. Peat (extracted) logic chain

Geo-system type/s	**Factors determining supply**		**Factors determining use**	**Physical metric/s**	**Benefit**	**Main users and beneficiaries**
	Geological	**Societal**				
Peat deposit	Depth and type of peat.	Spatial configuration; drainage.	Energy policy..	Volume of peat extracted.	Heating for homes; electricity generation.	Households, energy companies
Data required				*Areas used for peat extraction; annual volume extracted.*		

Context / relationship to other accounts

- **Ecosystem and geosystem extent**: This service is associated with peatland ecosystem that have been drained and converted to either domestic cutover bogs (a turf bank and associated spread ground, cutover bog) or industrial extraction areas. The geological resource is the subsoil which can be up to 15m deep in some bog areas in Ireland. There are no mapping data for domestic extraction areas other than mapping of cutover bog habitats on the edge of Annex I peatland habitats. We note that we used commercial data to estimate area of industrial peat extraction as an example of the approach that could be used (relevant in the Figile only).
- **Eco/geo-system condition**: We had limited condition data for degraded cutover peatlands and industrial extraction areas, other than extent data verified by aerial imagery. There are no peat depth data available nationally, with some peat depth data available for Bord na Móna extraction areas.
- **Abiotic flow assessment**: The SEEA-EA (UNSD, 2021) recommends recording of abiotic flows where relevant to the analysis of ecosystem use since there are commonly trade-offs between ecosystem services and abiotic flows.
- **Benefits**: The SEEA-EA does not outline how the final benefit should be measured.

Full details of how abiotic flows (peat) were calculated and their results are given in Appendix 4.1.

For INCASE, we assessed peat use by households and industrially extracted peat as follows.

i) Domestic peat use: Using census data (Small Areas for the 2016 census (CSO, 2017)), we estimated the number of households and the percentage of households in each catchment using peat as their fuel source (Table 4.24.). Based on previous studies[14], we estimated peat use at 60 tonnes per household (**see Appendix 4)**.

Table 4.24. Estimated household use of peat and corresponding wet tonnage

INCASE Catchment	Number of households using peat	% total households in catchment	Estimated annual wet tonnage of peat used based on 60 tonnes / household.
Dargle	52	0.15%	3,120
Figile	1,451	50.52%	87,060
Bride	11	0.24%	660
Caragh	215	23.57%	12,900

Peat for domestic use occurs across the catchments with highest use in the Figile. We note that there are no active areas of domestic cutting in the Dargle or the Bride, so we assume these are imports to the catchment. Using a conservative figure of 10 tonnes of turf and 40% moisture content, the amount of wet peat extracted at 90% moisture content is estimated to be 60 tonnes wet peat per household. However, this assumes no net import of peat and that all peat was produced in the catchment. This is unlikely for the Dargle given there was no evidence of active turf cutting.

ii) Industrial peat extraction: Industrial extraction is active only in the Figile. We used Bord na Móna peat extraction data, estimating 185.325 tonnes (@ 55% moisture) extracted per hectare per annum over a total estimated harvesting area of 4,018 hectare (area of bare peat where active peat extraction was ongoing in 2018, estimated from Bord na Móna 2019 data). This resulted in a total of 744,656 tonnes for the Figile catchment. This corresponds with the total burned in the EPL power station in 2018 which was reported as 648,745tonnes (EPL AER, 2019). We don't include this in our supply and use accounts as it is limited to the Figile. This estimate of annual peat extraction potential was likely to decrease in 2019 and subsequently ceased in 2020. Industrial peat

[14] At an average 10 tonnes of turf and 40% moisture content, the amount of wet peat extracted at 90% moisture content is estimated at 60 tonnes wet peat per household.

extracted in the Figile will continue to be used to fuel an electricity generating station within the catchment (EPL) up until 2023, with the extracted peat transported by rail connection to the point of consumption, while some may also be used for horticultural markets (exported from the catchment).

4.7.5 Other flows

While we assessed a selected limited number of services for INCASE catchments, we identified a number of datasets that could be used as proxies for services in terms of indicators for potential use / supply (Table 4.25). This could guide further research and/or future accounting approaches.

Table 4.25. Potential Irish datasets that could be used to assess services

Provisioning services		**Description**
Biomass	Livestock	Livestock numbers are gathered by the CSO and available for a number of time intervals. These data could be used to assess livestock production in a given year and combined with statistics to assess volume processed and/or consumption. Exports are likely from catchments given that significant volumes of processed meat are exported from Ireland.
	Aquaculture	Aquaculture is a common activity along the Irish coast and less common inland. Proxy data would include fish production in aquaculture units (data reported by BIM) as well as seaweed production data.
	Wild fish and other natural aquatic biomass	Wild fish catch data are gathered by IFI. CSO Environment has published fish landings by port using data provided by the Sea-Fisheries Protection Authority.
	Wild animals, plants, and other biomass.	Data to assess this service includes non-wood forest products (NWFP) and services related to hunting, trapping and bio-prospecting activities; excludes wild fish and other natural aquatic biomass (included in previous class). Data available on gun licenses and regional game councils could be used to assess this service.
Regulating / maintenance services		
Local (micro / meso) climate regulation		Relevant data to assess this service would include the evaporative cooling provided by urban trees ('green space'), the role of urban water bodies ('blue space') and the contribution of trees in providing shade for humans and livestock. This could be provided by data relating to measured temperature effect, and EPA Air Monitoring Stations.
Soil and sediment retention	Soil erosion control	Soil erosion may be inferred from bare peat cover and/or effects of sediment on water quality. Peat texture could be used as an indicator of potential soil texture type eroding.
	Landslide mitigation	Landslide mitigation services may be inferred from historical landslide events (data available from GSI) and/or landslide vulnerability maps developed by GSI.
Water purification (water quality amelioration)	Retention and breakdown of nutrients	There are limited data relating to the retention of nutrients or pollutants, but the ecosystem service could be inferred by data on nutrient and pollutant input, and corresponding levels in draining freshwater and groundwater systems. EPA PIP maps could be used where there is knowledge of nutrient loading; also, knowledge of pressures gathered under WFD.
	Retention and breakdown of other pollutants	

Water flow regulation services	Baseline flow maintenance and peak flow mitigation.	These services require modelling specific ecosystem types and water flows. Hydrology toolset in ArcGIS and elevation are two features that should be explored in assessing these services.
Flood control services	Coastal protection	This service requires data relating to modelling the effects of coral reefs, sand banks, dunes, or mangrove ecosystems along the shore, in protecting the shore and thus mitigating the impacts of tidal surges or storms on local communities. NPWS Article 17 data would indicate presence and OPW gather data relating to flooding and/or erosion.
	River flood mitigation	This service requires data relating to modelling the effects of riparian vegetation which provides structure and a physical barrier to high water levels and thus mitigates the impacts of floods on local communities. Datasets which could be used include LPIS data showing riparian zones, Urban atlas riparian zones, OPW flood maps, and SIS drainage maps.
Storm mitigation		This service requires data relating to modelling the effects of vegetation including linear elements, in mitigating the impacts of wind, sand and other storms (other than water related events) on local communities.
Pollination		This service requires data on pollinators, though using crop production reliant on pollination may be used as a proxy. Pollination service demand from wild plants (an intermediate service in the context of SEEA-EA) is difficult to account for. The NBDC collates data on pollinators nationally.
Nursery population and habitat maintenance		Nursery services provided by freshwater upland streams for salmonids is an example of this service which could be assessed using Inland Fisheries data. WFD protected areas show rivers protected for salmonids.
Cultural services		
Visual amenity		Visual amenity services could be related to landscape characteristics, scenic views (where gathered), and designated landscape data.
Education, scientific and research		Data available for sites could be used here. For example, data were available for visitor numbers to two education centres in the Figile catchment. Lodge Bog managed by IPCC had an average c. 2,300 visitors (2017-2019) while Lullymore Heritage Park (focuses on heritage /use and after-use of peatlands) attracted c. 55,000 paying visitors in 2019 (Stapleton pers. comm. 2021).
Spiritual, symbolic, and artistic		Spiritual artistic and symbolic services could be identified through art workshops, artworks relating to ecosystem types or catchments / landscape scenes. Mass rocks, pilgrim paths, national monument data could all be assessed for relevant use.
Abiotic flows	Geophysical sources	Flows relating to wind could be assessed based on wind energy output from wind farms; geothermal potential data are available from GSI.
	Geological resources	Flows related to extraction of fossil fuel, mineral ores, sand & gravel are recorded by GSI and will depend on catchment (related to bedrock and subsoils).There is also data gathered on sand and gravel and crushed rock aggregate potential, as well as information on historic mines. Bord na Móna data are gathered for regulated industrial peat extraction areas.
Spatial functions		Flows related to the use of the environment for transportation could be assessed by numbers using waterways (data from Waterways Ireland).

4.7.6 INCASE supply and use tables

The available data show a snapshot of selected services and their rudimentary assessment for the INCASE catchments. We note that this is based on available data for those services assessed and 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. We outline a summary of our supply accounts in Table 4.26**.** (Extended supply and use tables in this excel sheet).

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 regards to services in each catchment:

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

ii. **Figile**: Grazing biomass supply / use and water supply / use is high in this catchment. The Figile has the highest SOC stocks and carbon emissions relative to the other catchments (related to high cover of peatlands - >60% peat soils). The area of ecosystem appreciation is the lowest in this catchment.

iii. **Bride**: This has the highest levels of provisioning services supply / use; similarly, for water from groundwater (predominantly demanded by agricultural sector).

iv. **Caragh**: This catchment has the highest flow relating to supply / use of eco/geo-system appreciation with relatively high levels of grazing and carbon stocks supply / use. The main sector benefitting based on s/u tables is the government (global society).

Services (general comments)

Crops: This service was assessed varies across all catchments with 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 area of commercial forest).

Water supply from groundwater: Highest abstraction levels were estimated for the Bride and the Figile, due 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 were no removals of carbon 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 s/u for forests in the Dargle, followed by the Bride (related to high population levels).
Eco/geosystem appreciation: The highest cover of nature designations were recorded in the Caragh with high cover also in Dargle (mostly peatlands and heathlands) along with a more detailed description of geo-heritage features.
Peat (domestic use): highest levels in the Figile and Caragh, 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 in eco 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 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 of the cultural services e.g., visual amenity or certain regulating services e.g., water purification which is more of 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 as well as 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 capital 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.

Table 4.26. Summary services assessments collated for supply/use accounts for the INCASE catchments. C'ment = catchment; IM = import; ES = ecosystem service

		Dargle			Figile			Bride			Caragh		
		C'ment	**Im**	**Total ES**	**C'ment**	**Im**	**Total ES**	**C'ment**	**Im**	**Total ES**	**C'ment**	**Im**	**Total ES**
INCASE services	**Metric**												
Provisioning													
Crops	t DM	3,485		*3,485*	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*
Regulation													
Climate regulation													
SOC to 1m	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	No. people	1,122,764		*1,122,764*	101,885		*101,885*	120,320		*120,320*	39,269		*39,269*
Non use flows													
Eco/Geo-system and species appreciation	Area ha (% c/ment)	7,214 (24%)		*7,214 (24%)*	398 (1.4%)		*398 (1.4%)*	1,069 (2.5%)		*1,069 (2.5%)*	19,197 (84%)		*19,197 (84%)*
Abiotic flows													
Water supply	m3	175,393		*175,393*	907,262		*907,262*	2,379,659		*2,379,659*	116,157		*116,157*
Peat (wet tonnes)	T	0	3,120	*3,120*	87,060		*87,060*	0	660	*660*	12,900		*12,900*

4.9 Valuation methods and approaches

4.9.1 The role of valuation approaches

The fundamental building blocks of the SEEA-EA are the extent and condition accounts, assessment of service supply and use, and identification of the intermediate (which can include a natural capital asset) and end-users of the benefits. These accounts are developed and assessed using bio-physical data, and we note that up to this point monetary valuation has not featured in any part of the accounting framework thus far. Building on the extent, condition, and services (physical) accounts, one of the aspects of the SEEA-EA methodology is that it facilitates the contributions of ecosystems, and broader natural capital assets, to society to be expressed in monetary terms. Thus, allowing for comparison to other goods and services we are more familiar with. Recognising (i) that monetary values cannot reflect a comprehensive and/or 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.

Traditionally, environmentally related valuation approaches have focused on measuring, in monetary terms, the impacts of changes in natural capital assets and services on economic and human welfare. For example, the impacts of reduced pollution on human health (Bollen *et al*.,2009, Hanley *et al*., 2007) or the costs related to climate change. This monetary valuation of impacts can be used to inform cost benefit analysis and the weighing up of trade-offs in relation to natural capital use and human wellbeing (Atkinson *et al*., 2018). However, it does not incorporate the full range of value systems and approaches, as highlighted in the SEEA-EA and others, e.g. IPBES (Diaz *et al*., 2018). Monetary valuation is therefore a tool, providing useful information to assist decision making.

Following from the traditional monetary valuation approaches, natural capital accounting instead focuses on integrating natural capital and the associated service flows to the SNA approach, thus highlighting how natural capital is supporting the current measured economy (previously not integrated in a structured way). As valuation methods are developing over time, new metrics are emerging that can be aligned with those of the SNA (such as GDP) using natural capital approaches. which extends heretofore limited approaches focused on the economy solely, to incorporate the significant role that natural capital plays in underpinning society and economy. A recent example of a new metric is Gross Ecosystem Product or GEP (Ouyang *et al*., 2020).

GEP is equal to the sum of all final ecosystem services (i.e., those used by economic units) at their exchange value, supplied by all ecosystem types located within an ecosystem accounting area over an accounting period, less the imports of ecosystem services from ecosystem assets outside the accounting area (Ouyang *et al.,* 2020). While GEP requires detailed analysis, it is something that could be developed in the Irish context with further supported research focused on NCA. At minimum, reliable biophysical data would be required to assess services and form the basis for any subsequent valuation approach.

4.9.2 Economic valuation approaches

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 framework developed by David Pearce and colleagues (Pearce and Turner, 1990). The word 'total' refers to the sum of use, and non-use values and within the Total Economic Value (TEV) framework, a number of value perspectives including intrinsic values, are gathered together. TEV 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 (Figure 4.8.) and is succinctly described in a summary paper available from the UK Valuing Nature network.

In terms of our discussions, we note that most of the ecosystem services outlined in the SEEA-EA are treated as use values given the benefits revealed through direct or indirect interactions, though 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, 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 given that supporting (or intermediate services in the SEEA-EA) services underpin ecosystem function and therefore all values. Following from this, cultural services can be considered both from a use value and a non-use value perspective. 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.

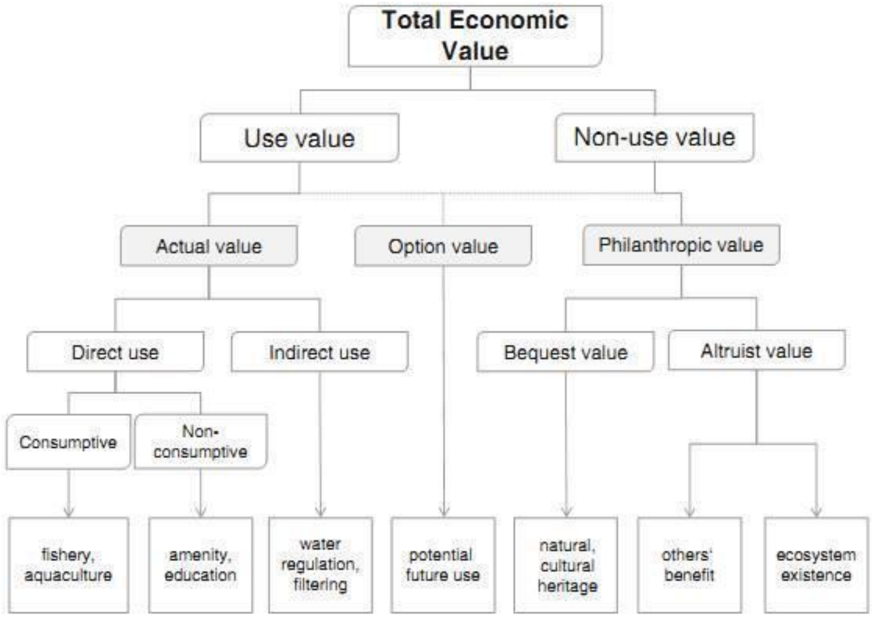


Figure 4.8. The Total Economic Value Framework Source: TEEB, 2010

4.9.3 A note on value versus price

Society expresses some of these TEV framework values through their behaviour as consumers when purchasing environmental goods and services. But the price of something is not the same thing as the value we place on it. The price is determined by demand and supply and reflects the cost of production – which includes what economists refer to as 'consumer surplus'. Equally, price does not often include the cost of environmental damage (such as pollution) resulting from production unless there is a policy requirement (e.g., pollution tax). Moreover, many consumers will derive a benefit greater than the price they are charged ('consumer surplus').

4.9.4 Valuation approaches in the SEEA-EA

Valuation in the SEEA-EA can be broken into two parts: valuation of services and other flows, and valuation of ecosystem assets. While different perspectives on valuation exist, there is wide support for the exchange value-based approach to the monetary valuation of ecosystem services and ecosystem assets in the SEEA-EA (UNSD, 2021); the approach is based on existing theory and concepts in the SNA, which have been adapted to the environmental context.

In national accounting, entries in the accounts in monetary terms reflect their exchange values as defined in the SNA: "Exchange values are the values at which goods, services, labour, or assets are in fact exchanged or else could be exchanged for cash" (2008 SNA, para. 3.118). In the main, exchange values are measured using data from observed transactions involving market prices: "Market prices are defined as amounts of money that willing buyers pay to acquire something from willing sellers"

(2008 SNA, para. 3.119) and assume embodied information about revealed preferences of the economic units involved. However, where exchange values or market prices are unavailable, then SNA allows the other approaches for valuation. These include measurement of the costs incurred or the use of proxy prices for analogous goods or services (for example imputed rent for homeowners).

Given that ecosystem services are distinguished from the benefits to which they contribute, the focus of valuation is on the contribution of the ecosystem asset (i.e., the input of ecosystem services) and not on the valuation of the benefits (UNSD, 2021). For example, in crop biomass, the focus is on disentangling the value contribution of the ecosystem from the labour, fertilisers and other inputs. Depending on the ecosystem service, this will add to overall value added (and GDP) or isolate/identify the ecosystem contribution to value added. For example, air filtration will add to value added while crop provisioning services will identify the contribution. The exchange value approach therefore requires:

i. Determining the prices that would be charged on behalf of the ecosystem asset for the ecosystem services if a market existed.
ii. Estimating the costs to obtain an ecosystem service that would need to be incurred by an economic unit to secure the benefits. Or,
iii. Assessing the loss of benefits to an economic unit that would be incurred if ecosystem services were to be lost.

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:

i. **Availability of direct (observable) price**. For example, stumpage values charged to timber logging businesses or land rental prices (market price).
   We note that generally, the SEEA-EA advises not to use data from payments for ecosystem services schemes in the estimation of prices for ecosystem services, unless there is clear evidence that the scheme does target a specific service. We also note that while there are market prices for carbon, it may be considered appropriate to use measures such as the social cost of carbon[15] (or both for comparison).

[15] The social cost of carbon is an estimate of the economic costs, or damages, of emitting one additional tonne of carbon dioxide into the atmosphere, and thus an estimate of the benefits of reducing emissions.

ii. **Related market prices for similar goods or services.** For example, market prices of fish and/or a non-timber forest product from one water body/forest may be marketed, and not from a similar water body forest.

iii. **Methods where the price for the ecosystem service is embodied in a market transaction.** For example, and for grazing biomass estimated residual value (resource rent). Note, 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.

iv. **Actual costs.** For example, travel costs to recreation sites (travel cost method or TCM).

v. **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 (SEV) method.

Other valuation approaches can be extended to include opportunity costs of alternative uses, stated preference (based on survey), prices developed from economic modelling and/or qualitative methods (Box 4.3). We note that while excluded from monetary aggregates, abiotic flows and spatial functions recorded in supply and use tables in both physical and monetary terms, are essential to support discussions about sustainable use in relation to ecosystems (UNSD, 2021), for example the future extraction and uses of peat in the Irish context.

Box 4.3. Assessing exchange values when a market doesn't exist.

Where no **exchange market prices** presently exist, other economic valuation techniques have been developed to determine values. These are aimed at establishing a person's **willingness to pay (WTP)** for a service. Where there is a use value, then **revealed preference methods** can be used as observed behaviour can be the basis of a person's WTP. Where a non-use value is required, a **stated preference** approach can be used. This involves respondents being directly asked their WTP for an ecosystem service.

Given that the SEEA-EA main accounts only include exchange values, revealed preference techniques are the preferred approach. For complementary accounts such as ecosystem and species appreciation, where the value is considered as entirely consumer surplus, then non-use methods such **contingent valuation** or **choice modelling** may be used. While these values are exchange based, they can still be used within cost benefit analysis and inform policy makers of welfare changes in decisions related to impacts on species or natural capital assets.

For use values while market values or cost approaches most align with the SNA approach, sometimes revealed preference methods which depend on a proxy price or **shadow price** of an ecosystem service may be preferred. Examples of these include the following methods: travel cost method, hedonic pricing, stimulated exchange value, production cost approach, avoided damage cost approach, replacement cost approach and others. These are described well in the literature and each approach must be underpinned by clear data and/or assumptions (UNSD, 2021).

4.9.5 Valuation of ecosystem assets

The approach adopted for ecosystem accounting is to value ecosystem assets using a net present value approach. The net present value (NPV) is the value of an asset determined by estimating the stream of income expected to be earned in the future and then discounting the future income back to the present accounting period (SEEA Central Framework, para. 5.110). In ecosystem accounting it is applied by aggregating the NPV of expected future returns for each ecosystem service supplied by an ecosystem asset (UNSD, 2021). Application of the NPV approach requires measuring the expected future returns for each ecosystem service and applying a discount rate such that the future returns can be expressed in current period values, the selection of which can have a large effect on the estimated monetary values (UNSD, 2021). Together with the discount rate, a number of factors must be considered in combination to yield an estimated NPV for each ecosystem service at a given point in time. These include:

i. The scope of the returns, that is what ecosystem services are included in the accounts.
ii. The likely future patterns of *flow* taking expected degradation and patterns of demand into consideration.
iii. The expected future prices for each ecosystem service
iv. The expected institutional arrangements.
v. The expected asset life. Together with the discount

The NPV of the ecosystem asset is equal to the sum of the NPV for each service. In practice, applying discount rates provides a level of monetary valuation to inform decision making, but only where values for the individual ecosystem services are available and the assumptions are clear in relation to the selection of the appropriate discount rate. There is much discussion of the topic of discounting rates, which we leave to further economic research in this area[16] and we refer to the discussion and recommendations in Chapter 10 of the SEEA-EA (UNSD, 2021).

Key message: Rather than the selection of discounting rates, the more relevant issue is an ecological one 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 is more a question of making reasonable assumptions based on current ecological knowledge and available data. And again, highlights the need for reliable, relevant and robust data to build extent and condition

[16] Use and non-use value of nature and the social cost of carbon | Nature Sustainability https://www.oecd.org/naec/averting-systemic-collapse/Keen2019_Averting_Systemic_Collapse.pdf

accounts alongside services accounts to establish those non-linear relationships to help make decisions to ensure future flows of services and benefits to the society for the future.

4.9.6 Further refinement of valuation approaches

Assessing the importance of ecosystems requires consideration of a wide range of information beyond data on the monetary value of ecosystems and their services, and includes data on the biophysical characteristics of ecosystems, for example of extent and condition, and data on the characteristics of the people, businesses and communities that are dependent on them (UN et al. 2021).

Valuation approaches can help inform decision making around the environment, given that the assumptions monetary estimates are based on are clearly outlined and taken into consideration. For example, following from our previous discussions, the use of value transfer techniques involves a range of assumptions concerning the variation of prices of ecosystem services in different locations, and these must be considered in any further decision-making context. Nonetheless, best available information is better than no information at all.

Further development is ongoing in terms of concepts and methods before the valuation aspects of the SEEA-EA are adopted as a statistical standard (UNSD, 2021) including:

1. The underlying framing for valuation of environmental stocks and flows in the context of the national accounts.
2. The potential of monetary valuation to support decision making.
3. The ability to produce reliable estimates in monetary terms in practice.
4. The role of NSOs in producing fit for purpose statistics in this area of measurement.

4.9.7 INCASE valuation approaches

Given that the INCASE project was intended to explore the use of natural capital accounting 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. By applying a valuation approach that further depends on estimates undoubtedly leads to monetary amounts that do not reflect the actual natural capital value in these catchments. Following from this, for the INCASE catchments, given that the biophysical information and service accounts developed for each catchment did not comprise reliable data (mismatch in data gathering areas shown in Figure 4.9, lack of time series and relevant time period data etc.), 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 4.27.) that could be applied in the Irish context once the approaches to services assessment and overall accounting approach has matured in terms of inclusion and assessment of more services, more detailed landcover mapping (such as the forthcoming OSI-EPA land-use map for Ireland), more robust data and modelling approaches to physical flows and supporting data for valuation.

Table 4.27. Suggested valuation approach as per SEEA-EA highlighted by INCASE

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 three approaches for valuation of carbon: (i) carbon prices from emission trading systems, such as the EU Emission Trading System (ETS), (ii) marginal costs of abatement and (iii) the social cost of carbon.	*DPER shadow carbon price or social cost of carbon.
Recreation	The final benefit is health and well-being with additional benefits to businesses involved in recreational activities	**Travel costs (excluding consumer surplus).
Eco/geo-system appreciation	The SEEA-EA suggests these values may be presented in complementary valuations to the main SEEA-EA accounts	***Non-use stated preference methods
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

*The Irish Department of Public Expenditure and Review (DPER) has revised the approach for valuing carbon price and now recommends the use of carbon shadow price based on estimated marginal abatement cost rather than market value of allowances in the EU ETS. The abatement cost approach was also suggested as more practicable over the use of the social cost of carbon by Horlings et al. (2020) for the Netherlands.

** The TCM is a well-developed non-market valuation approach (Hanley *et al*., 2016) although SEEA-EA (UN et al. 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 SEEA-EA.

***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 contingent valuation method and the choice modelling. 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.

± 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.

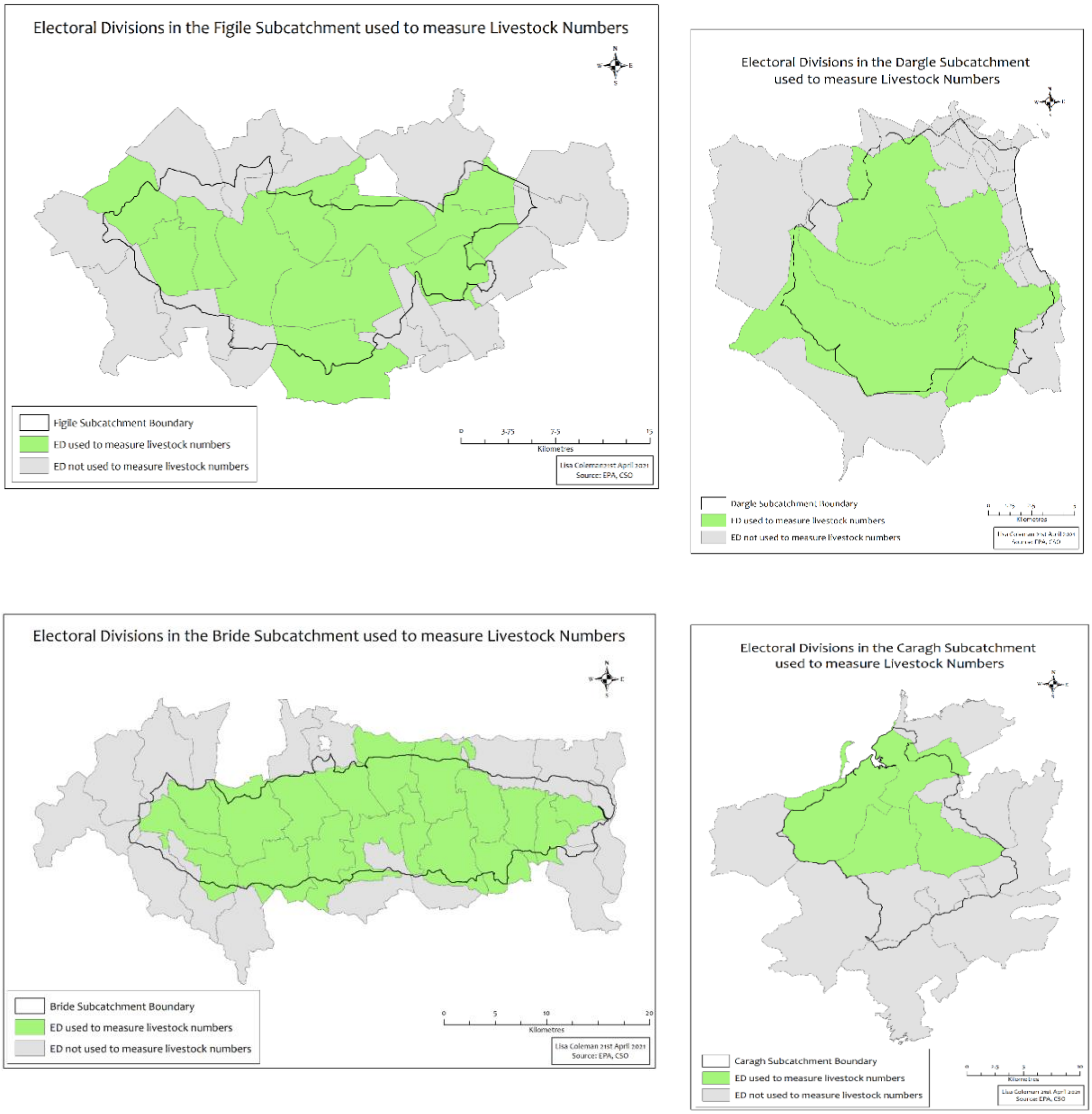


Figure 4.9. INCASE catchment boundaries overlain on electoral divisions (ED): highlight how the data gathered by the CSO for livestock (and water abstraction) at ED level do not align with catchment boundaries

4.10 Economic impact assessment

Summary:

In order to assess the impact of Irish government policy change on natural capital stocks, a national scale modelling approach using input-output models originally created to disaggregate the agri-food and energy sector was taken (Grealis and O'Donoghue, 2015). Given the high proportion of land dedicated to agriculture in Ireland, we chose to focus on food-production policies and their potential impact on terrestrial natural capital. Food-production policies focus on three key environmental issues: climate change, biodiversity loss and water quality. However, these tend to be dealt with separately, and as a result, there are synergies and trade-offs for the economy and for the natural environment. This has the potential to increase carbon emissions, reduce water quality through increased nutrient load, and directly and indirectly negatively impact biodiversity. Input-output modelling, incorporating Life Cycle Analysis, is one way to examine synergies and trade-offs for natural capital. However, natural capital is complex, with many independent dimensions that are difficult to downscale to a single or few indicators, and impacts flow in both directions (from natural capital to agricultural output, and from agricultural activity on natural capital).

We applied Bioeconomy input-output models (BIO and BIO-LCA models) (O'Donoghue *et al.,* 2018), into which feed the Land Model and Animal Model that focus on calculating what changes will occur in land use and animal numbers and type in different scenarios. Various policy documents were reviewed, and some of the main ones were used to assess the impact to 2030 on economic and environmental outcomes.

Policy to mitigate carbon emissions includes increasing efficiency per individual animal, technological innovation (e.g. reducing chemical nitrogen and increasing low emissions slurry spreading), and land use change (e.g. afforestation and increased tillage to reduce crop imports). However, specific policy targets in AgClimatise (the government's roadmap for the agricultural sector (DAFM, 2021) for efficiency and technology are not adequate to meet carbon emission reductions for the sector – it is necessary to manage animal numbers, but current policy levers are weak. Furthermore, Ireland is unlikely to meet its afforestation goals. Thus, meeting climate goals is unlikely without further intervention.

Spatial mapping indicated that underlying soil characteristics and land-use (agriculture vs habitat protection/conservation measures) have the most influence on the proportion of variance in agricultural outcomes. As dairy numbers are likely to continue to increase in the immediate future

because of positive milk prices and an increasing number of female calves already in the system, this is likely to negate any improvements in efficiency.

Key message: Analytically, modelling frameworks currently have limited capacity to incorporate nature or biodiversity impact. This seriously diminishes the capacity of policy to develop legally binding targets in the biodiversity sphere as there is no identification of where gains can be made. As a result, without putting the 'health of our natural capital' to the fore, we are unlikely to lead to improvements in biodiversity.

The full economic impact assessment is given in Appendix 5.2.

5. Conclusions and Recommendations

The INCASE project has advanced understanding and application of natural capital accounting approaches for Ireland. Given our objective was to develop catchment-scale accounts, we used the spatially-explicit UN System of Environmental Economic Accounting – Ecosystem Accounting (SEEA-EA) for four case-study subcatchments – the Dargle, Caragh, Figile and Bride. We developed initial accounts, plus a preliminary data visualisation tool (R-shiny app), as well as a framework for monetisation. Extensive stakeholder consultation and a wide range of communication methods (summarised in Appendix 5.1) has resulted in a high level of engagement with the project and its outputs.

Our work revealed some **key learnings**:

1. Much of the land area in all four catchments was **highly managed**. For example, in the Dargle, ecosystem types are largely grouped in the Intensive Land-use category, T7 (Farrell *et al.,* 2021a) of the IUCN Global Ecosystem Typology (Keith *et al*. 2020,a), including sown pastures, urban areas, and plantations. Only scattered fragments of semi-natural ecosystem types were 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 (Mitchell, 1997). Some areas (e.g. in 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 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, but that most of the peatlands in our catchments were at risk from drainage, disturbance and land conversion pressures.

2. **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 the relevant aspects are included to address the policy question. 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.

3. **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, as well as the availability of data. In the absence of data to inform condition 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 clearly defining, and the purpose of accounting should influence what sort of data, 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 they are compatible, comparable, and their aggregation is ecologically meaningful, enabling comparison across ecosystem types.
4. **Ecosystem services** flows are often estimated via proxies and/or national averages. In advance of 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 to 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. 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.
5. Stakeholder engagement is critical in developing accounts (see INCASE site blog on Changes & Challenges in Land Use within our Dargle Catchment). 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

Accounting Unit, and the work of the INCASE project will inform development of accounts at a national level. In order to move forward,

As a result of the INCASE project work, we make the following **recommendations** for developing Ecosystem Accounts in Ireland:

1. **Developing and using Ecosystem Accounting is a national priority.** To address urgent environmental issues, to develop integrated land use planning, and to make informed decisions, there is no time to lose. Despite gaps in biophysical datasets, ecosystem accounting needs to be not just developed, but actively used to address policy gaps and conflicts. For example, economic impact assessment, focussing 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.

2. **Increased expertise is required for operationalisation of ecosystem accounting in Ireland.** As can be seen from the detail in this 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.

3. **A detailed, high-resolution ecosystem map is required**. CORINE datasets provide contiguous, time-series data and is used for high-level ecosystem and landcover reporting across the EU Region at 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 of peatland and heathland areas, there are limitations of CORINE for catchment scale (Tier III level), and these include:

    a. 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, as well as quantifying flows of services, which vary considerably. For example, biomass provision from improved grassland is likely to be higher compared to 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).

b. Lack of ability to detect linear features: rivers, hedgerows, and landscape features less than the MMU or minimum mapping width of CORINE (such as 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 the available CORINE time series (Farrell *et al*., 2021a).

c. Requirement for ancillary data: bringing in datasets such as soil texture and other indicator maps such as the High Nature Value farming 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, however, 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 (in development for Ireland) (Wall *et al*.,, 2020) due to have a resolution of 10 m, is likely to provide 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 2019).

4. **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 potential to be very useful, providing updated, reliable data, but this approach needs to be implemented nationally.

5. **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 (e.g. see 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.

6. **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 inform how activities (linked to policies) affected 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 data sources (open source) for use data and in general data were limited for service assessment. The regulatory services require further dedicated modelling – particularly services relating to climate, water and biodiversity. Service mapping tools (e.g. SWAT, Aries, EnSym, InVEST etc.) are available and their use should be explored in further research at varying scales.
7. **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 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 INCASE, at catchment level rather than electoral division level. As part of the work by the INCASE team, a Data4Nature workshop convened by Natural Capital Ireland, presented an opportunity to outline shortcomings in data. The key messages are outlined here - NCI Data4Nature. 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.
8. **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 the fact that no monetary accounts were presented. Advancing the understanding of value transfer techniques, that is 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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Acronyms and Annotations

AES	Agri-Environmental Scheme
AER	Annual Environmental Report
ALEW	Ancient & Long Established Woodlands
BD	Birds Directive
BDGP	Beef Data and Genomics Programme
BIM	Bord Iascaigh Mhara (Ireland's Seafood Development Agency)
BRIDE	Biodiversity Regeneration in a Dairying Environment (project)
CAP	Common Agricultural Policy
CC	County Council
CICES	Common International Classification of Ecosystem Services
CLC	Corine Land Cover
CGLS	Copernicus Global Land Service
CORINE	Coordination of Information on the Environment
CSO	Central Statistics Office
CWF	Community Wetlands Forum
DAFM	Department of Agriculture, Food & the Marine
DECC	Department of the Environment, Climate & Communications
DHLGH	Department of Housing, Local Government & Heritage
DHPLG	Department of Housing, Planning & Local Government (now DHLGH, see above)
DLR	Dun Laoghaire Rathdown
DPER	Department of Public Expenditure and Reform
DOM	Dead Organic Matter
EAD	Ecosystem Accounts Division
EC	European Commission
ECT	Ecosystem Condition Typology
EEA	European Environmental Agency
EIP	European Innovation Partnership
EPA	Environmental Protection Agency
EPL	Edenderry Power Limited
ES	Ecosystem Services
ESA	European Space Agency
ESM	Environmental Sensitivity Mapping
ETS	Emissions Trading System
EW-MFA	Economy Wide-Material Flow Accounts
FEGS	Final Ecosystem Goods & Services
FERS	Forest, Environmental Research & Services
FIPS	Federal Information Processing Series (formerly Standards)
GAEC	Good Agricultural and Environmental Condition
GDP	Gross Domestic Product
GHG	Greenhouse Gas
GIS	Geographic Information System
GMT	Greenwich Mean Time
GPS	Global Positioning System
GS	Genuine Savings
GSI	Geological Survey Ireland
Ha	hectare
HAR	Habitat Asset Register
HD	Habitats Directive
HNV	High Nature Value

HNVf	High Nature Value farmland
HRL	High Resolution Layers
ICM	Integrated Catchment Management
IDEEA	Institute for Development of Environmental-Economic Accounting
IED	Industrial Emissions Directive
IFI	Inland Fisheries Ireland
INCASE	Irish Natural Capital Accounting for Sustainable Environments
IPBES	Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Service
IPC	Integrated Pollution Control
IPCC	Intergovernmental Panel on Climate Change
ISBN	International Standard Book Number
IUCN	International Union for Conservation of Nature
IW	Irish Water
KIP INCA	Knowledge Innovation Project on Integrated system for Natural Capital and Ecosystem Services Accounting
LAWPRO	Local Authority Waters Programme
LCA	Life Cycle Analysis
LPIS	Land Parcel Identification System
LULUCF	Land Use Land Use Change and Forestry
LT_LU	Litres per Livestock Unit
MA	Millennium Ecosystem Assessment
MACC	Marginal Abatement Cost Curve
MAES	Mapping and Assessment of Ecosystems and their Services (project)
	mml/g – milligrammes/grammes
g/g	gigagram
MAIA	Mapping & Assessment for Integrated Ecosystem Accounting (portal)
MARS	Managing Aquatic ecosystems and water Resources under multiple Stress (project)
MQI	Morphological Quality Index
MMU	Minimum mapping unit
NBDC	National Biodiversity Data Centre
NC	Natural Capital
NCA	Natural Capital Accounting
NCI	Natural Capital Ireland
NCP	Nature's Contribution to People
NDVI	Normalized Difference Vegetation Index
NHA	Natural Heritage Area
NIR	National Inventory Report
NPWS	National Parks & Wildlife Service
NPV	Net Present Value
NSO	National Statistics Office
NUIG	University of Galway
OPW	Office of Public Works
OSI	Ordnance Survey Ireland
Pa	per annum
PBI	PastureBase Ireland
PIP	Pollutant Impact Potential
PMP	Pearl Mussel Project
RBI	Relative Breeding Index
RBMP	River Basin Management Plan
SAC	Special Areas of Conservation
SDG	Sustainable Development Goal

SEAI	Sustainable Energy
SEEA	System of Environmental Economic Accounting
SEEA-CF	System of Environmental Economic Accounting - Central Framework
SEEA-EA	System of Environmental Economic Accounting - Ecosystem Accounting
SEV	Simulated Exchange Value
SI	Sustainable Intensification
SIS	Soil Information System
SOC	Stocks of Carbon or Soil Organic Carbon
SPA	Special Protection Area
SNA	System of National Accounts
SSRS	Small Streams Risk Score
STL	Street Trees Layer
SWAT	Soil, Water And Topography
SWF	Small Woody Features
T	tonne
T DM	tonnes of Dry Matter
TCD	Trinity College Dublin
TCM	Travel Cost Method
TEV	Total Economic Value
UCD	University College Dublin
UDC	Urban District Council
UAV	Unmanned Aircraft Vehicle
UN	United Nations
UNSD	United Nations Statistics Division
UL	University of Limerick
UWWTP	Urban Waste Water Treatment Plant
VA	Value Added
WCC	Wicklow County Council
WFD	Water Framework Directive
WMNP	Wicklow Mountains National Park
WRBD	Western River Basin District
WTP	Willingness to pay
Yr	year

Glossary

Natural Capital Accounting Language

Ecosystem Accounting: A spatially-based, integrated statistical framework for organising biophysical and monetary information about ecosystem services and linking this information to measures of economic and human activity (adapted from UN 2021).

Environmental-Economic Accounting: a framework that integrates economic and environmental data to provide a more comprehensive, multi-purpose view of the relationships between the economy and the environment and its assets, as they benefit humanity, and how these change over time (UN SEEA).

Green accounting: this is Environmental Accounting (as above) and in a broader sense is accepted as the System of Environmental Economic Accounting approach (see SEEA definition below*)*

Green economy: an economy that aims at reducing environmental risks and ecological scarcities, and that aims for sustainable development without degrading the environment, with a more politically applied focus. (UNEP Green Economy Report, 2011)

Green finance: any structured financial activity that's been created to ensure a better environmental outcome (WEF)

Natural Capital: all the earth's natural environment, including living (plants, animals and microorganisms, and their interactions and functions) and non-living elements (including land, water, and air), considered as assets or stocks that yield a flow of services and benefits to people. Also known as *Natural Assets. (adapted from Natural Capital Protocol via Atkinson and Pearce 1995; Jansson et al. 1994).*

Natural Capital Accounting: a way of organising information about natural capital so that the state of and trends in natural assets can be documented and assessed by decision makers. NCA is often used interchangeably with the terms Environmental and Green Accounting though they have different origins and meanings

SEEA: System of Environmental-Economic Accounting developed by the United Nations also known as the System of Environmental-Economic Accounting-Ecosystem Accounting. This approach to natural capital accounting contains the internationally agreed standard concepts, definitions, classifications, accounting rules and tables for producing internationally comparable statistics and accounts (SEEA)

Natural Systems Language

Abiotic: non-living as in the non-living parts of ecosystems (eg temperature, light, water) (Esmerelda Project)

Atmospheric services: outputs that come from the physical and chemical systems around the planet and contribute to human wellbeing ie wind, sunshine and rainfall

Biodiversity: the variety of all life, including genetic, species and habitat/ecosystem diversity. In most cases, the more biodiverse ecosystems have more resilience to environmental change.

Biotic: relating to or resulting from living organisms; the living parts of ecosystems

Capacity: in the SEEA-EA context, *ecosystem capacity* is the ability of an ecosystem to generate a service under current ecosystem condition, management and uses (UN, 2021)

The ability of a given ecosystem unit to generate a specific ecosystem service in a sustainable way (Czúcz and Condé 2017).

Ecosystem characteristic: Key attributes of an ecosystem unit describing its components, structure, processes, and functionality, frequently closely related to biodiversity (Czúcz and Condé 2017).

Carbon sequestration: The process of increasing the carbon content of a reservoir (contained supply) other than the atmosphere (UK NCC)

Catchment: biophysical area of land around water bodies where water naturally collects; natural drainage areas eg a river basin / drainage area

Condition: 'ecosystem condition' is the quality of an ecosystem measured in terms of its abiotic and biotic characteristics. *Quality* is assessed with respect to ecosystem structure, function, and composition which, in turn, underpin the ecological integrity of the ecosystem, and support its capacity to supply ecosystem services (UN, 2021).

Cultural ecosystem services (CES): all the non-material, and normally non-consumptive, outputs of ecosystems that affect physical and mental states of people… they can involve individual species, habitats and whole ecosystems (Czúcz and Condé 2017)

Ecology: the study of interactions between living organisms, and between organisms and the non-living environment

Ecological (adj): concerned with ecology

Ecological community: group of individuals of different species living close enough to interact

Ecological value: non-monetary assessment of ecosystem integrity, health or resilience, all of which are important indicators to determine critical thresholds and minimum requirements for ecosystem service provision

Ecosystem: all the organisms living within a specified community and the non-living factors with which they interact eg. river, hedgerow, ocean, dune system

Ecosystem function/processes: the physical, chemical and biological actions or events that link organisms and their environment

Ecosystem services: the outputs from ecosystems which have a benefit and value to human wellbeing. Defined to categories including: Provisioning Services such as food and water; Regulating Services such as climate and pollination; Supporting Services such as soil nutrient cycling; and Cultural Services such as educational, aesthetic and cultural heritage including recreation and tourism. (MA, 2005)

The contributions of ecosystems to benefits obtained in economic, social, cultural and other human activity (Czúcz and Condé 2017)

Environmental pressure: human-induced process that alters the condition of ecosystems (Maes et al., 2018)

Extent: ecosystem extent is the size of an ecosystem asset, commonly in terms of spatial area (UN, 2021 / SEEA, simplified)

Geological: relating to the physical substance of the earth, on or below the surface e.g. rocks

Geosystem: the underground environment that consists of subsoil, bedrock, minerals, oil, natural gas, and groundwater. Examples include: minerals, energy from fossil fuels, geological heritage sites, groundwater used for drinking and geothermal energy, carbon storage

Geosystem services: the outputs from geosystems that contribute to human wellbeing, specifically resulting from the subsurface, including the flow of natural resources from stocks that have built up over geological time

Habitat: the environment in which an organism can be found. It is characterised by the physical characteristics of the environment and/or the dominant vegetation or other stable biotic characteristics e.g. lakes, woodlands, soil

Heterogeneity: the quality or state of being diverse in character or content

Integrated catchment management: management of catchments based on the concepts of local community and scientific involvement, and appropriate organisational structures and policy objectives

Landcover: the observed physical and biological cover of the Earth's surface, includes natural vegetation and abiotic (non-living) surfaces. (SEEA Central Framework)

Land use: reflects both (a) the activities undertaken and (b) the institutional arrangements put in place for a given area for the purposes of economic production, or the maintenance and restoration of environmental functions. (SEEA Central Framework)

Nature: in the broadest sense, is the natural, physical, or material world or universe. It is often used to describe wildlife and geology, and is analogous with the more strictly defined concept of ecosystems

Natural: used to describe structures and processes that have not been substantially altered by human intervention, or which persist despite human intervention

Natural heritage: usually describes nature and/or biodiversity, together with associated geological structures and formations (geodiversity)

Typology: a classification according to general type

Spatial: relating to the position, area, and size of things

Synthesise: combine and evaluate data (findings of individual studies) in a systematic review process

Systematic: done or acting according to a fixed plan or system

Economics language

Asset: anything that has current or future economic value. Natural assets are assets in the natural environment and consist of biological assets (produced or wild), land and water areas with their ecosystems, subsoil assets and air (OECD 2022)

Benefit: element of goods and services that are ultimately used and enjoyed by people and society (UN, 2021)

Economic (adj): justified in terms of profitability. See also *Uneconomic* (adj): constituting an inefficient use of money or other resources

Economic valuation: the process of expressing a value for a particular good or service in a certain context (e.g. MAES, decision-making) in monetary terms (Czúcz and Condé 2017)

GDP / Gross Domestic Product: the standard measure of the value added created through the production of goods and services in a country during a certain period (OECD 2022)

Value Systems Language

Value: the importance, worth, or usefulness of something (Natural Capital Protocol 2016)

Valuation: the process of estimating the relative importance, worth, or usefulness of natural capital to people (or to a business), in a particular context. Valuation may involve qualitative, quantitative, or monetary approaches, or a combination of these (Natural Capital Protocol 2016)

Types of value:

Bequest value: the value of preserving options for future generations' use of an environmental resource that may be lost irreversibly given expected growth of knowledge / *Option value:* The uses to which ecosystem services may be put in the future (TEEB 2010)

Direct-use value: the benefits provided by the services provided by an ecosystem that are used directly by an economic agent. These include consumptive uses (e.g. harvesting goods) and non-consumptive uses (e.g. enjoyment of scenic beauty).

Exchange value: the values at which goods, services, labour, or assets are in fact exchanged or else could be exchanged for cash (2008 SNA)

Indirect use value: the benefits derived from the goods and services provided by an ecosystem that are used indirectly by an economic agent. For example, an agent at some distance from an ecosystem may derive benefits from drinking water that has been purified as it passed through the ecosystem

Intrinsic (moral) values: the value of non-human living beings for their own sake, regardless of their importance or usefulness to humans

Non-use values /passive use: values that people assign to ecosystems irrespective of whether they use or intend to use the ecosystems (UN 2021) such as *Existence value:* The value that individuals place on knowing that a resource exists, even if they never use that resource (also sometimes known as conservation value), or *Altruistic value:* The importance individuals attach to a resource that can be used by others in the current generation, reflecting selfless concern for the welfare of others (TEEB 2012)

Total Economic Value: the value obtained from the various constituents of utilitarian value, including direct use value, indirect use value, option value, quasi-option value, and existence value (TEEB, 2012)

Appendices

- **1.1** Summary of the overarching policy drivers for NCA at the international, EU and national levels (1980-2023)
- **1.2** Summary of research project outputs in Ireland with a focus on ecosystem services, 2019-2023
- **3.1** Supplementary data relating to rivers for use in condition assessment
- **4.1** INCASE Services Assessment
- **4.2** Economic Impact Assessment
- **5.1** INCASE project communication

Appendix 1.1 Summary of the overarching policy drivers for NCA at the international, EU and national levels (1980-2023)

Policy scope	Policy descriptor	Date	Policy
International	Sustainable development	1987	UN Brundtland Commission (formerly World Commission on Environment and Development) Report *Our Common Future*
	Sustainable development	1992	UN Conference on Environment and Development 'Earth Summit' Rio de Janeiro
	Ecosystems	2000-2005	UN Millennium Ecosystem Assessment
	Biodiversity	2008	UN Environment Programme: The Economics of Ecosystems and Biodiversity
	Biodiversity	2011-2020	UN Environment Programme: Convention on Biological Diversity (CBD) Strategic Plan with Aichi Targets
	Sustainable development	2015	UN Agenda 2030 for Sustainable Development – 17 SDG Goals
	Biodiversity	2020-2030	UN Post-2020 Global Biodiversity Framework
European Union	Biodiversity	2011	Our Life Insurance, our natural capital: an EU Biodiversity Strategy to 2020
	Sustainable development	2014	General Union environment action programme to 2020 : living well, within the limits of our planet
	Climate action, sustainable development and biodiversity	2019	European Green Deal (including EU Circular Economy and EU Bioeconomy and EU Biodiversity Strategies)
	Sustainable activities across public and private sectors	2020	EU Taxonomy
	Agriculture	2023-2027	EU Common Agricultural Policy
National	Biodiversity	2017-2021	Ireland's National Biodiversity Action Plan
	Biodiversity	2022-2027	Ireland's Draft 4th National Biodiversity Action Plan
	General environment	Annual	Environmental Protection Agency State of the Environment Reports
	Sustainable development National Development Plan 2021-2030	2020-2040	Project Ireland 2040 – National Planning Framework
Sectoral	Forestry	2021-2025	Ireland's National Forestry Accounting Plan
	Agriculture	2023-2027	Ireland's Common Agricultural Strategic Plan
	Agriculture	2022-2030	Food Vision 2030
	Bioeconomy	2018	National Policy Statement on the Bioeconomy
	Circular economy	2022-2023	Whole of Government Circular Economy Strategy

Appendix 1.2 Summary of research project outputs in Ireland with a focus on ecosystem services, 2019-2023

Project /Publication	Main features/findings
Bullock, C., Kretsch, C. and Candon, E., 2008. The Economic and Social Aspects of Biodiversity: Benefits and Costs of Biodiversity in Ireland. A Report prepared by the Government of Ireland ISBN: 978-1-4064-2105-7	A preliminary assessment of the benefits of selected Ecosystem Services (ES) in the principal social and economic sectors; estimated ES value at €2.6bn pa to the Irish economy.
Murphy, G., Hynes, S., Doherty, E., Buckley, C. and Corless, R., 2014. What's our water worth? Estimating the Value to Irish Society of Benefits Derived from WaterRelated Ecosystem Services. Report published by the Environmental Protection Agency, Report No. 127	Applied Choice Experiment to explore values of water to Irish people.
Bullock, C. and Hawe, J., 2014. The Natural Capital Values of Ireland's Native Woodland. A Report published by the Woodlands of Ireland.	Outlines the economic value of existing native woodland; value of different uses; potential value of expanding cover; estimated value on NW at €100mn pa. (ES: amenity, tourism, carbon).
Bullock, C., O'Callaghan, C., Ní Dhubháin, A., Iwata, Y., O'Donoghue, C. Ryan, M., Upton, V., Byrne, K., Irwin, S., O'Halloran, J. Kelly-Quinn, M., 2016. A review of the value of ecosystem services from Irish forests. *Irish Forestry* 73.	A review of the value of ecosystem services from Irish forests
Parker, N., Naumann, E-K., Medcalf, K., Haines-Young, R., Potschin, M., Kretsch, C., Parker, J. & Burkhard, B., 2016. National ecosystem and ecosystem service mapping pilot for a suite of prioritised services. Irish Wildlife Manuals, No. 95. National Parks and Wildlife Service, Department of Arts, Heritage, Regional, Rural and Gaeltacht Affairs, Ireland.	Irish MAES project outputs: habitat asset extent (HAR); ES maps (carbon, food, water quality, biodiversity).
Feeley , H.B., Bruen, M., Bullock C. Christie, M. Kelly, F. Kelly-Quinn, M., 2017. ESManage project: Irish Freshwater Resources and Assessment of Ecosystem Services Provision. Report No. 207 Published by the Environmental Protection Agency, Ireland ISBN: 978-1-84095-699-3	Identified ES from water resources; qualitative assessment of relative importance; cultural values stronger than drinking water in stakeholder groups.
Indecon International Economic Consultants, 2017. An Economic Review of the Irish Geoscience Sector. A Report published by the Geological Survey of Ireland.	Established the economic contributions to Irish Economy from geo-sphere
Rolston, A., Jennings, E., Linnane, S. and Getty, D., 2017. Developing the Concept of Catchment Services for Progress Towards Integrated Water Management (Extra TIMe) Report No. 229 Published by the Environmental Protection Agency ISBN: 978-1-84095-746-4	Identified mechanisms for the feasible delivery of the concept of catchment services and disservices in Ireland over the period 2016–2020.
Morrison, R., & Bullock, C., 2018. A National Biodiversity Expenditure Review for Ireland,	Ireland's biodiversity budget is 0.13% GDP - lower than 0.3% IUCN recommends;

University College Dublin.	breakdown: 80% subsidies; DAFM manages 75%; 42% linked to EU funding.
Norton, D., Hynes, S. and Boyd, J., 2018. Valuing Ireland's Coastal, Marine and Estuarine Ecosystem Services. Report No. 239 Published by the Environmental Protection Agency. ISBN: 978-1-84095-760-0	Estimated value of ES: waste, defence, carbon, recreation, fisheries, aquaculture, seaweed, residential values. Developed guidance for ES assessment.
Ryfield, F., Cabana, D., Brannigan, J. and Crowe, T., 2019. Conceptualising 'sense of place' in cultural ecosystem services: A framework for interdisciplinary research. *Ecosystem Services* 36, Article 100907	Developed a conceptual and practical framework for investigating sense of place using maps and stakeholder engagement.
McGrath, L., 2022. Natural capital accounting: Using economic theory to "Green" the national accounts and measure sustainable development. PhD Thesis published by NUI Galway.	Explored used of Genuine Savings (GS) as an indicator for Sustainable Development in Ireland
Stout, J.C., Murphy, J.T. and Kavanagh, S., 2019. Assessing Market and Non-market Values of Pollination Services in Ireland (Pollival) Report 291 Published by the Environmental Protection Agency ISBN: 978-1-84095-856-0	Valued pollination services at €902mn pa; highlights need for integrated decision-making with biophysical data.
Gonzalez Del Campo, A., Kelly, C., Gleeson, J. and McCarthy, E., 2019. Developing and Testing an Environmental Sensitivity Mapping Webtool to Support Strategic Environmental Assessment in Ireland. Report No 278 Published by the Environmental Protection Agency ISBN: 978-1-84095-833-1	Established an online mapping tool bring mapping data together for planners to inform Strategic Environmental Assessment
Norton, D., Hynes, S., Buckley, C., Ryan, M. and Doherty, E., 2020. An initial catchment level assessment of the value of Ireland's agroecosystem services. Biology and Environment: Proceedings of the Royal Irish Academy 2020. DOI: 10.3318/ BIOE.202014..	Used integrated spatial approach to value ES in 46 EPA catchments; ES included food, carbon, cultural and disservices.
Kelly-Quinn, M., Bruen, M., Christie, M., Bullock, C., Feeley, H., Hannigan, E., Hallouin, T., Kelly, F., Matson, R. and Siwicka, E., 2020. Incorporation of Ecosystem Service values in the Integrated Management of Irish Freshwater Resources: ES Manage. Report No. 312 Published by the Environmental Protection Agency ISBN: 978-1-84095-893-5	Used 8-step framework for identification, prediction and valuation of change in 5 river ES; in 3 catchments.
McLoughlin, D., Browne, A. and Sullivan, C.A. 2020. The Delivery of Ecosystem Services through Results-Based Agri-Environment Payment Schemes (RBPS): Three Irish Case Studies. *Biology and Environment: Proceedings of the Royal Irish Academy* 120B, no. 2 (2020): 91–106. https://doi.org/10.3318/bioe.2020.13.	Developing a model by which ecosystem services can be delivered through a results-based agri-environment based approach, using habitat quality, as a result indicator or surrogate for these services to which payments are linked.

Bullock, C., Delargy, O., O'Cinnéide, M., Krisht, S., Aquillina, M., Russ, C., and Rowcroft, P., 2020. Review of options to enhance business contribution to Ireland's national biodiversity objectives. Report to the National Parks and Wildlife Service (NPWS), Department of Housing, Local Government and Heritage (DHLGH), Government of Ireland.	A review of how the private sector can protect biodiversity and ecosystem services. Payments for ecosystem services are reviewed along with awareness among businesses of their impacts and dependencies on biodiversity and ecosystem services.
Christie, M., Kenter, J., Bullock, C., Penk, M., Feld, C. and Kelly-quinn, M., 2021. Evaluating the Multiple Values of Nature – ESDecide: from an Ecosystem Services Framework to Application for Integrated Freshwater Resources Management. Report No. 389. Published by the Environmental Protection Agency. 978-1-80009-012-5	This literature review on the multiple values of nature provides insights into the multiple ways people value rivers and associated ecosystem services/NCPs. These insights can be used to develop frameworks that evaluate the benefits and costs associated with alternative river catchment policies.
McGuinness, S. et al. 2021 Backing Our Bogs: Peatland Finance Ireland to build a new vision for peatland protection. An ongoing collaborative project between the Community Wetlands Forum , Ireland's National Parks and Wildlife Service new vision for landscape (NPWS) and the Landscape Finance Lab.	The Peatlands Finance Ireland project, a collaboration between the Community Wetlands Forum , Ireland's National Parks and Wildlife Service new vision for landscape (NPWS) and the Landscape Finance Lab, will generate a level peatland restoration in Ireland, by strategising government-led assistance with private investment.
Flood, K., Smith, F. and Blanchfield A. 2022. Teaching Natural Capital & Ecosystem Services approaches in Higher Education Institutions in Ireland: Natural Capital Ireland Report on Survey Results. Natural Capital Ireland Report Series, Number 1.	Natural Capital Ireland gathered data on how third-level institutions in Ireland are integrating natural capital and ecosystem services approaches into our curricula. Due to the growing importance of these concepts in international policy, we are working to further their development in Ireland.
Brennan, N. and Sheehy, I. 2022. Addressing the Integration of Forest-Related Ecosystem Services into Non-Forestry Policy Areas and Sectors. Report to the Department of Agriculture, Food and the Marine. Natural Capital Ireland Report Series, Number 2.	This project explores the extent to which forestry related ES are noted in other policy areas in Ireland and the potential for forestry ES to contribute further to national policy objectives, particularly in relation to environmental services, transport objectives, educational and community development objectives and health benefits.
Kelly-Quinn, M., Bruen, M., Bullock,Christie, M., Feld, C., Kenter, J., Penk, M. & Piggott, J. 2022. ESDecide: From Ecosystem Services Framework to Application for Integrated Freshwater Resources Management. Report No. 424. Published by the Environmental Protection Agency. 78-1-80009-071-2	The project developed the interactive decision support tool ProgRES, which helps river resource managers estimate the probability of changes in biological responses and the associated ecosystem services/NCP changes in environmental conditions, with a particular focus on responses to nutrient and sediment stressors.

Appendix 3.1 Supplementary data relating to rivers for use in condition assessment

Morphological Quality Index for Rivers

The MQI (Morphological Quality Index) is due to be available at national scale as a finished product by 2023. The MQI includes an assessment of the waterbody condition which looks at several key indicators such as longitudinal/latitudinal connectivity, hydromorphology and riparian condition and is seen as complementary to existing WFD status as it is essentially an enhancement of how hydromorphology is assessed by the EPA for rivers.

The development of the MQI has involved an assessment of the current river network which has been mapped for larger channels for the whole country i.e., 60,000km of channel. These channels have been based on the current river network with Prime 2 for MQI assessment, with each channel divided into reaches based on type. Reaches and waterbodies do not have 1:1; relationships - a reach is essentially the river channel type, so landscape setting/floodplain interactions/channel setting determine reach type[17].

Hydrometrics

The EPA implements the surface water hydrometric programme for each local authority. These hydrological programmes provide information for the assessment, development and management of water resources and the water-related environment in relation to such things as flow rates at times of water quality sampling and highest water level and related flow rate for use in bridge design and drainage works. In order to make these evaluations, flow records covering a considerable length of time must be available. Of increasing importance in recent years is the use of hydrometric data to estimate nutrient loadings as part of catchment monitoring and management studies involving river, lake, and estuarine systems.

In the wider European context, information on river flows has a supporting role in the WFD. Likewise, long term information on river flows is required to assess any effects of climate change.

The EPA also makes use of the data collected by the OPW which has gauges at strategic locations on rivers and lakes in relation to arterial drainage, navigation, and flood relief and the ESB which operates hydrometric stations to assist in hydroelectric power generation and water level control in relation to dam safety[18].

Currently there are 703 active hydrometric stations in the Republic of Ireland operated by various bodies. Continuous water level records are maintained at 680 of these sites. In most cases, recorders

[17] https://cieem.net/wp-content/uploads/2019/03/Emma-Quinlan.pdf and https://www.slideshare.net/EPAIreland/8-dealing-with-physical-damage-to-rivers-the-morpholo.gical-quality-index-and-restoration-emma-quinlan-epa

[18] https://www.epa.ie/water/wm/hydrometrics/what/

digitally record the water level at 15-minute intervals at Hydrometric stations (set to GMT to avoid the time changes in summer/springtime). The flow is given in cubic metres per second.

The EPA HydroNet site[19] provides access to hydrometric data collected at the network of Local Authority hydrometric stations and processed by the Environmental Protection Agency.

River Flow Estimates – Hydrotool

The EPA Hydronet[20] has flow gauges for the whole country and recently completed an exercise for modelling flow data which provide data on flow levels. This data set contains estimates of naturalised river flow duration percentiles for Irish rivers; estimating flows that could be expected in rivers under naturalised conditions and do not take account of artificial influences of any kind such as water supply abstractions or wastewater discharges.

The aim of the data is to provide naturalised flow estimates for Irish rivers that enable assessment of quantitative impacts relating to hydrological alterations. The data set is to be used in conjunction with the HYDRO Catchments layer[21] to display contributing areas to each flow node. Data results include naturalised flow percentiles (NATQ1-99%), naturalised mean monthly flows (NATMMF1-12) and physical catchment descriptors[22].

From an initial assessment, these data would fit in more with ancillary data, given that they are highly modelled. However, the data could support information relating to potential for flooding in the INCASE catchments.

EPA Macroinvertebrate Data

EPA river macroinvertebrate data[23] collected as part of the annual WFD monitoring and assessments are available. We note that these data are incorporated in the assessment of ecological status but may be used where disaggregation.

Small Streams Risks Scores

The Small Streams Risk Score (SSRS) is a biological risk assessment system for identifying rivers that are definitely 'at risk' of failing to achieve the 'good' water quality status goals of the Water Framework Directive (WFD). It was developed by the Environmental Protection Agency (EPA) in association with

[19] http://www.epa.ie/hydronet/#Water%20Levels

[20] https://www.epa.ie/hydronet/https://www.epa.ie/water/wm/hydronet/

[21] This data set contains segmented catchments for rivers on a national basis and is derived from a digital terrain model (may not be accurate on a field-scale). Data Purpose: To provide high resolution catchment areas for flow modelling applications.

[22] http://www.epa.ie/pubs/reports/water/flows/River%20Flow%20Estimates%20%20HydroTool%20Readme.pdf

[23] https://springernature.figshare.com/collections/A_national_macroinvertebrate_dataset_collected_for_the_biomonitoring_of_Ireland_s_river_network_2007-2018/4966154/1

the Western River Basin District (WRBD) in 2006. The main aim of the SSRS is to support the programme of measures for the WFD which has its main objective to achieve ‘good’ water quality status in all water bodies by 2015.

To date, the use of the SSRS monitoring tool has been widespread in terms of its potential in identifying key plants from EPA authorised wastewater facilities that are currently contributing to river pollution, particularly in the first and second order streams. The SSRS monitoring tool has been expanded and applied by other interested parties e.g., IPC/IED facilities, Fisheries, Local Authorities and LAWPRO as an assessment tool to investigate impacts of point source and/or diffuse discharges from agricultural, industrial etc. sources and is not restricted to assessing discharges from Urban Wastewater Treatment Plants (UWWTPs) only (EPA 2015).

Freshwater Habitats and Species reported under EU Nature Directives

There are data available relating to freshwater habitats (listed in Annex I) and species (Annex II) under Article 17 reporting of the EU Habitats Directive. These data relate to the conservation status of freshwater habitats and species at a national scale. The main Annex I habitats include:

- 3110 Oligotrophic isoetid lake habitat.
- 3130 Mixed *Najas flexilis* lake habitat.
- 3140 Hard-water lake habitat.
- 3150 Rich pondweed lake habitat.
- 3160 Acid oligotrophic lake habitat.
- 3180 Turloughs*.
- 3260 Vegetation of flowing waters.
- 7220 Petrifying springs*

Conservation status is assessed at a national level and the assessment brings together information on four parameters for habitats:

- range,
- area,
- structure and functions, and
- future prospects.

For habitats, the assessment of Structure and Functions includes an assessment of the condition and the typical species that characterise the habitat. These condition assessments are based on sampling points which are spread nationally and may or may not be within a particular catchment, sampling survey data contain detailed non aggregated data.

The assessment brings together information on four parameters for species:

- range,
- population,
- habitats for the species, and
- future prospects.

For species, the extent and quality of suitable habitat is assessed to determine whether the long-term survival of the species is assured.

Under Article 17 reports, conservation measures undertaken for Annex I habitats and Annex II species are listed. The major pressures and threats are also listed for each habitat and species (incorporated in the future prospects assessment). We note that for individual SACs the Natura Standard Data Forms contain useful site assessment data.

Ancillary data

Over the course of the review of the four INCASE catchments we explored the use of other data to infer condition of freshwater habitats (using *ancillary* information available either as a proxy for condition or to inform the identification of data gaps). Some examples (discussed also in detail elsewhere) include:

- **Management and/or land-use datasets:** arterial drainage mapping from OPW has been reviewed for the INCASE catchments. Land-use in the catchment is shown in the broader ecosystem accounts.
- **Protected areas**: there are a number of protection statuses for surface water bodies such as Salmonid and Protected Drinking Water. Designations for Natura 2000 (SAC, SPA) and national designations (National Parks, NHAs, Nature reserves) providing information about the regulatory instruments relating to the freshwater habitats.
- **Pressures:** examples include use of the Pollution Impact Potential Nitrogen and Phosphorus maps and the occurrence of invasive alien species: (available from NBDC).
- **Stable environmental characteristics (environmental variables):** datasets informing elevation can infer headwater streams and rivers.

Appendix 4.1 INCASE Services Assessment

4.1.1 Provisioning services

4.1.1.1 Crop Services

SEEA-EA (UNSD 2021) (Annex 6.1) recommends that the final benefit measure of the harvested biomass be used as a proxy measure of the crop provisioning service, and this was the approach followed for the INCASE catchments.

To provide an estimate of the harvested biomass, the average yield for each crop per hectare (in tonnes of dry matter (t DM)) was multiplied by the total area in hectares of that crop in each catchment. This has the benefit of linking the crop ecosystem service to the extent accounts. To apply this approach, a number of assumptions were made based on the data available:

- The first assumes that supply equals use as in the System of National Accounts (SNA) (UN et al., 2010). Therefore, the reported amounts ignore potential or actual residues in the harvest process.
- The second assumption is that, given national level figures are used, average yields are homogenous across space. This is clearly a shortcoming given that the yields vary both temporally and spatially, for example growth in the Dargle will be different to that in the Caragh catchment. This assumption may be overcome in the future through more detailed reporting at smaller scale and/or through a combination of satellite data and modelling of growth rates (Kasampalis et al., 2018).

The area of each crop per catchment was measured in each INCASE catchment using the 2019 Land Parcel Identification System (LPIS)[24] (**Table A4.1**)

Table A4.1. Area (hectares) of cropland by crop type per INCASE catchment.

LPIS Crop Description	Figile	Dargle	Bride	Caragh
Barley - Spring	448	163	846	
Barley - Winter	420	37	1,244	
Beans		10	15	
Fodder Beet	22		52	
Forage Rape	16	10	10	
Kale	5		17	
Hemp	9			
Loganberries			3	
Maize	14		303	
Miscanthus sinensis		5	9	1
Oats - Spring	7	15	105	
Oats - Winter	20	74	126	
Oilseed Rape - Winter	23		36	
Peas	7		16	
Potatoes			8	
Raspberries		2		
Triticale			14	

[24] Land Parcel Identification System (LPIS) is a spatial database of all agricultural parcels in the EU Member States that is used for Common Agricultural Policy (CAP) purposes including area-based payments (Zimmermann et al., 2016).

Turnips	1			
Vetch	10			
Wheat - Spring	42		16	
Wheat - Winter	464	96	229	
Willow	4			
Fallow	6	19	21	
Fallow - Greening		8	12	
Total Area	**1,517**	**439**	**3,083**	**1**

To obtain yields on a per hectare basis, two sources were used with 2019 as the reference year:

- The first of these was the Central Statistics Office of Ireland (CSO, 2020) which reports annual national yield figures for the six most significant crops in Ireland (barley, wheat, oats, beans and peas, oilseed rape and potatoes). The area of these crops covers 88% of crop area aggregated across the four catchments.
- In order to estimate the yield for the remaining crops, estimates were taken from the Crops Costs and Returns 2019 Report (Collins and Phelan, 2019) for fodder beet, forage rape, kale, turnips, and maize. However, it is noted that these figures are not based on reported yields but are rather static estimates used for forage planting.

These figures are used to estimate yield for crops that cover 9% of aggregated crop area across the four catchments. The yields used are shown in **Table A4.2** and cover 97% of the area of crops across all catchments (crops not covered are shown in italics).

To put the 2019 yields in context, looking solely at those crop yields from the CSO (2019), there was a 3% - 25% increase in yields compared to 2018 (CSO, 2020) due to an extended drought period in Ireland during the summer (Met Éireann, 2020). This demonstrates the value of annual data reporting as these values are able to capture changes in the crop provisioning services. More work needs to be done to have a suitable spatial measurement to allow for variation across catchments.

Looking across the crops, while potatoes have the highest yield, in terms of overall production, barley is the most important crop, followed by winter wheat. However, this does not hold across all catchments with maize a significant crop in the Bride catchment, most likely as supplementary forage for the livestock in that catchment. As the Bride catchment is the largest catchment and dominated by agricultural ecosystems, it is not surprising that it is largest in terms of crop provisioning ecosystem.

Table A4.2. INCASE estimated average yield per hectare and total crop harvest in tonnes DM for 2019. Note that the Caragh catchment is omitted as only one hectare of crop area was grown, and no yield estimate was available for that crop.

			Catchment		
Crop Description	**2019 Estimated yield (tonnes DM hectare^{-1})**	Yield reference	**Figile**	**Dargle**	**Bride**
Barley - Spring	8	(CSO,2020)	3,584	1,304	6,772
Barley - Winter	9.4	(CSO,2020)	3,948	348	11,696
Beans - Spring	5.4	(CSO,2020)	0	54	81
Fodder Beet	13	(Collins and Phelan, 2019)	286	0	674
Forage Rape	3.5	(Collins and Phelan, 2019)	56	35	34
Kale	6	(Collins and Phelan, 2019)	28	0	101
Maize	15	(Collins and Phelan, 2019)	208	0	4,543
Oats - Spring	7.7	(CSO,2020)	54	116	806

Oats - Winter	8.9	(CSO,2020)	178	659	1,125
Oilseed Rape	4.3	(CSO,2020)	97	0	156
Peas	5.4	(CSO,2020)	38	0	86
Potatoes	44.1	(CSO,2020)	0	0	374
Turnips	2.5	(Collins and Phelan, 2019)	3	0	0
Wheat - Spring	8.3	(CSO,2020)	346	0	132
Wheat - Winter	10.1	(CSO,2020)	4,686	970	2,312
Total Crop Harvest			**13,513**	**3,485**	**28,891**

4.1.1.2 Grazed Biomass Services

Land managed for grazing purposes is one of the dominant land use types in Ireland with over 50% of land cover used for this purpose. Within the SEEA-EA (UNSD et al., 2021), there are two different approaches used to measure the ecosystem services directly associated with grazed land.

- This first approach directly links to the extent accounts and is a better measure of the ecosystem input into the livestock sector of the economy. Applying this approach as per Table 6.3. of SEEA-EA (UN et al., 2021) grazed biomass provisioning service is measured as the final ecosystem service. This is the approach taken for INCASE catchments.
- The alternative approach is to measure the livestock production under Livestock provisioning services and classify the grazed biomass provisioning service as intermediate services (UNSD et al., 2021). This approach however significantly crosses the SNA-SEEA EA boundary and section 6.56 (UN et al., 2021) highlights that the key final ecosystem service will be grazed biomass.

Grazed biomass is measured two ways, a supply side approach and a demand side approach following that used for economy-wide material flow accounts (EW-MFA) (Eurostat, 2018). For the former, the area of grazed land is multiplied by grazed area yield to give the potential grazing biomass supply. EW-MFA (Eurostat, 2018) provides yields for three different types of grazing intensity levels.

For each catchment, the area of each grassland type was measured in each INCASE catchment using the 2019 Land Parcel Identification System (LPIS) and classified to an INCASE grassland type based on expert opinion. Expert opinion was also used to classify the INCASE grassland type into EW-MFA (Eurostat, 2018) grazing intensity levels so that the appropriate grazing yield could be used. These are shown below in **Table A4.3**. The yields of different grazing intensities and estimated grazed biomass tonnage produced in each catchment are shown in **Table A4.4**.

Table A4.3. Area and classification of INCASE grassland types

EW-MFA grazing classification (Eurostat, 2018)	INCASE Grassland Classification	Figile (ha)	Dargle (ha)	Bride (ha)	Caragh (ha)
Rough grazing	Commonage	0	2,187	0	7,065
	Rough Grazing	21	28	54	58
		21	**2,215**	**54**	**7,122**

Extensive pasture	Low Input Permanent Pasture	600	238	677	413
	Mixed Grazing	8	0	30	268
	Species Rich Grassland	12	20	14	125
	Traditional Hay Meadow	188	35	286	52
		808	**293**	**1,006**	**858**
Improved pasture	Improved Grassland	422	101	1,077	2
	Permanent Pasture	10,041	2,740	26,603	10,557
		10,463	**2,841**	**27,680**	**10,559**

Table A4.4. Grazing level and grazed biomass produced per catchment.

EW-MFA grazing classification (Eurostat, 2018)	EW-MFA grazing yield (Eurostat, 2018) (tonnes DM hectare^{-1})	Figile (tonnes DM)	Dargle (tonnes DM)	Bride (tonnes DM)	Caragh (tonnes DM)
Rough grazing	0.5	11	1,108	27	3,561
Extensive pasture	2.5	2,020	733	2,516	2,144
Improved pasture	7	73,242	19,887	193,761	73,911
Total		**75,273**	**21,727**	**196,304**	**79,616**

For the demand side approach, Eurostat (2018) prescribes estimating the demand for grazed biomass based on typical roughage requirements of ruminants and other grazing animals and provides annual average roughage intake estimates. Multiplying these estimates by the number and type of livestock in each catchment gives an estimate of the demand for grazed biomass.

- In order to estimate the livestock numbers per catchment, the most appropriate information at the spatial scale of the catchments is **the agriculture census data** which reports at electoral division level.
- Electoral divisions were overlain on the catchments and those over 50% within each catchment were used to aggregate and estimate the livestock numbers per catchment. It is noted that the

latest agriculture census figures are those from the 2010 (CSO, 2012) which may be considered somewhat dated. The agriculture census in Ireland is carried out every 10 years and those figures from 2020 may give a better picture of the demand within the catchments but they have not been released at time of our analysis.

The aggregated numbers of livestock in each catchment by type (based on electoral divisions overlapping with the catchment) is shown in **Table A4.5** and the estimated demand of grazed biomass is shown in **Table A4.6.**

Table A4.5. Aggregated numbers of livestock in each catchment by type.

Catchment	Figile	Dargle	Bride	Caragh
Cattle numbers	26,513	2,468	71,402	3,733
Sheep numbers	12,543	13,888	4,903	22,239
Horse numbers	204	246	1,487	114

Table A4.6. Estimated demand of grazed biomass per catchment.

Livestock Type	EW-MFA average annual roughage intake (tonnes DM)	Figile (tonnes DM)	Dargle (tonnes DM)	Bride (tonnes DM)	Caragh (tonnes DM)
Cattle	4.5	119,309	11,106	321,309	16,799
Sheep	0.5	6,272	6,944	2,452	11,120
Horses	3.7	755	910	5,502	422
Total		**126,335**	**18,960**	**329,262**	**28,340**

Comparing **Tables A4.4** and **A4.6** shows significant disparities between catchments in terms of grazed biomass estimates. This is not without precedent as McEniry et al. (2013) showed in a national assessment that 1.7 million tonnes of dry matter (DM) were available in excess of livestock requirements (a difference of 6.7%). This is considerably less than that observed in the individual catchments.

- The Caragh catchment shows a supply surplus of 181% of demand while on the other end of the scale both the Figile and Bride show demand surpluses of circa 67% over supply.
- The Dargle shows the smallest difference between estimates with supply exceeding demand by 15%.
- This suggests that the assumptions underlying either or both approaches need to be examined.

On the demand side, it was previously noted that the data used was somewhat dated but another issue relates to **the mismatch between the catchment boundaries and the electoral divisions boundaries used to estimate livestock numbers**. The difference between the boundaries is shown **HERE**.

Another reason for the difference is that some of the demand may be supplemented by other forage or imported forage, this was seen in the crop provisioning services where the Bride had circa 12% of cropland area dedicated to forage crops (e.g., maize). The final reason for possibly incorrectly estimating grazed biomass provisioning service through the demand approach is that the average roughage intake estimates provided by EW-MFA (Eurostat, 2018) are incorrect.

Alternative average estimates for cattle and sheep for DM intake by O'Mara (2006) were 3.6 tonnes DM head^{-1} year^{-1} and 0.6 tonnes DM head$_{-1}$ year^{-1} respectively. For cattle, the O'Mara (2006) estimates are 20% lower than the Eurostat (2018) estimate and for sheep, the O'Mara (2006) estimates are 20% higher than Eurostat (2018).

As there are multiple issues using the demand side approach, **it may be more appropriate to only report those estimates from the supply side approach**. However, the supply side approach also has some issues. The first of these is that the average yields per hectare suggested for use by economy-wide material flow accounts (EW-MFA) (Eurostat, 2018) are static, both spatially and temporally. The other issue is similar to that found with the demand side approach in that the yield figures may not be an accurate measurement of the supply of grass produced.

In their study of measuring natural capital for the Netherlands, Remme et al. (2018) also used LPIS to estimate the areas used for grazing and fodder production but additionally were able to more accurately estimate both spatially and temporally the supply of biomass by using net primary productivity (NPP) using remote sensing based on concurrent work by Lorenzo Cruz (2017). Given the lack of suitable data, the INCASE catchments will use the supply side figures shown in **Table A4.4** as estimates for the grazed biomass provisioning ecosystem.

INFORMATION Box A4.1: Estimating grass production in Ireland

There has been some work done in Ireland using remote sensing to examine grass production in Ireland. Green (2019) used an NDVI anomaly approach to estimate deviations of grass growth from previous averages to help farmers with better management of grass use. Askari et al. (2019) used both an unmanned aircraft vehicle (UAV) and the satellite Sentinel-2 to examine aboveground grass biomass for two sites in Ireland and found that models estimating grass biomass using Sentinel-2 was reasonable in terms of prediction.

This bodes well as one option of estimating the spatial and temporal distribution of grass production in Ireland is with another of the Sentinel satellites, Sentinel-3. The Copernicus Global Land Service (CGLS) produces a product – Dry Matter Productivity Collection 300m Version 1.1 which may be used in the future to estimate the grass biomass for Ireland (Wolfs et al., 2020). This product estimates DM production at a resolution of 300m and is updated every 10 days and provided in near-real time.

Current direct use of the data produced from this product is not viable as there are gaps in images that would need to be replaced with suitable estimates and image data would need to be aggregated on an annual basis and validated. However, it provides a possible starting point for future work in estimating grazed biomass provisioning ecosystems at a finer scale.

The future use of remote sensing for estimating the supply of grazed biomass at a finer spatial and temporal scale could also be bolstered by in-situ measurements, particularly as was noted by Green (2019), for some periods satellite grass growth measurements are occluded by clouds, an issue of particular relevance to Ireland.

There are two ongoing complementary programmes managed by the Irish agricultural advisory organisation called Teagasc focused on grass production. The first of these is called GRASS10 and launched in 2017, its aim is to increase grass utilised/ha to 10 tonnes DM (Maher et al., 2021). The second programme is called PastureBase Ireland (PBI) and has been in operation since 2013. The PBI programme is focused on better management of grass production including the regular measurement of grass growth by farmers which are then uploaded to an internet database. Average yearly outputs can be generated from this data (Figure A4.1), which also shows a significant decrease in grass production due to drought in 2018.

Figure A4.1. PBI annual grass growth curve for 2018, 2019 and 5 year average

While useful, these programmes still have some limitations as they are focused on more productive farmers and there is less coverage in the West of Ireland (Maher et al., 2021).

They are also still a minority of farms supplying this information with 3,664 farms using PBI in 2020 (Maher et al., 2021) out of circa 17,000 dairy farms and over 100,000 dry-stock farms in Ireland. PBI reported the mean total grass production in DM tonnes per hectare (range in brackets) in 2019 was 13.6 (20.9-10.6) for dairy farms and 10.2 (16.0-7.0) for dry-stock farms.

These figures are far in excess of the EW-MFA grazing yields (Eurostat, 2018) but it is hard to judge national and catchment averages from an elite group of highly productive farmers. Future work integrating remote sensing in conjunction with PBI in-situ measurements and reported on a yearly basis may provide a suitable product for use in natural capital accounting in Ireland at both national and sub-national scale.

4.1.1.3 Wood biomass services

In section 6.55 of SEEA (UN et al. 2021) the most common method suggested to measure this ecosystem service is to measure the gross biomass harvested. This element of the ecosystem service when valued will constitute the benefit derived from wood provisioning services for that year.
However, for forestry stands, growth contribution occurs over a number of years and is continually adding to the stock of standing timber. As nearly all forestry stands in Ireland are cultivated, following section 6.92 of SEEA (UN et al. 2021), growth in forestry stands is adding to the stock (a flow) and is considered an ecosystem service but is not counted as a benefit during this period, contributing instead to future benefits. This is the equivalent of the work in progress approach used in the system of national accounts (UN et al., 2010).
For the INCASE catchment, two wood ecosystem flows were measured, the first is the wood provisioning service which is an estimate of the harvested wood products and the second is the wood growth ecosystem service which is the addition to the overall standing forestry stock by growth of trees. These estimates will also link with other ecosystem services, e.g., carbon where the carbon in harvested wood is subtracted from the carbon stock but growth adds to the carbon stock.

Wood Provisioning Services – Harvested Timber

In order to measure the wood provisioning services, the INCASE project had access to a number of data sources.

- Coillte, the Irish state forest enterprise, provided spatial data on their forestry stands from their FIPS GIS database within each of the INCASE's four catchments. Coillte is the dominant forestry enterprise in Ireland with just over half (50.8%) of forestry lands, with the remainder in private hands (DAFM, 2018).

- Data on private plots in each catchment was accessed from the DAFM private forestry database known as PrivateForests2016[25] (DAFM, REF). Data from this database included forested areas, species of tree and age. This data combined with yield class will allow an estimate of standing stock of timber at time of harvest.

To estimate the harvested areas within catchments, removals identified in each of the catchments by the Tree Cover Density High Resolution Layer Change Map 2015-2018 from the EU Copernicus Land Monitoring Service were used and then checked using Google Earth imagery.
This resulted in two sites being removed from further analysis as there was no forestry identified for those sites. Fifty-two sites where forestry removal had taken place during the period 2016-2018 were identified in the four catchments. This data was then combined with the Coillte and DAFM private forests data to estimate areas, age, species, and year of harvest. Where age was not available, it was estimated based on surrounding stands and historical imagery.

[25] https://datacatalogue.gov.ie/dataset/private-forests-2016. Note: INCASE used the 2019 iteration

Table A4.7. gives a breakdown of species and estimated age by catchment aggregated across all 3 years (2016, 2017, 2018). Sitka spruce (*Picea sitchensis*) is the dominant tree species, particularly in the Bride catchment. Only a small area of broadleaves were harvested, oak in the Dargle and birch and mixed broadleaves in the Figile. The estimated age of harvest was in the range of 30-40 years with private areas tending to be harvested earlier. The Caragh harvested sites were limited in number and area, therefore considerable caution should be exercised with the age estimates from this catchment.

Table A4.7. Species harvested and estimated age by catchment (2016-2018).

Catchment	Sitka Spruce (ha)	Other Conifers (ha)	Broadleaves (ha)	Total (ha)	Area weighted mean estimated age at harvest (years)
Dargle	70.5	17.7	1.2	89.4	37
Figile	48.2	9.1	10	67.3	31
Bride	155.7	14.1	0	169.8	34
Caragh	10	3	0	13	49

Table A4.8. Shows ownership, harvested site number and mean area harvested per site in each catchment. Coillte dominates the area harvested particularly in the Bride catchment: this is expected as private forestry afforestation is a more recent development only starting to match Coillte planting since the 1990's (CSO, 2018). The mean harvested site is quite small in the Dargle and Caragh with the other mean harvested site size in line with the mean site area of 8.13ha for private plots reported by the Phillips et al. (2013).

Table A4.8. Ownership breakdown, harvested site numbers and mean harvested site areas by catchment (2016-2018).

Catchment	Coillte (ha)	Private (ha)	Total (ha)	n	Mean harvested Site Area (ha)
Dargle	53.7	35.7	89.4	19	4.7
Figile	45.8	21.5	67.3	9	7.5
Bride	158.9	10.9	169.8	20	8.5
Caragh	13	0	13	4	3.3

Once the areas of harvested sites were identified with estimated age and species for each site (**Table A4.7),** yield class estimates were needed to estimate the wood volume harvested. Since no data was available for historical thinning for this period (2016-2018), the estimates assume no thinning took place and that the volumes estimated here represent all wood grown on the site and that this was extracted at the time of harvest. This is a significant assumption since it is known that thinning takes place on the majority of sites in Ireland with an estimated 25% of timber removals occurring through thinning although this varies between Coillte and private harvests (DAFM, 2018).

Since the majority of the wood harvested across all catchments (**Table A4.7**.) was Sitka spruce (*P. sitchensis*), yield class for this tree species was estimated based on a spatial model which estimates yield class at townland level in Ireland (O'Donoghue et al., 2021, Farrelly et al., 2011). Additionally, expert opinion on ranges of yield class for Sitka spruce (*P. sitchensis*) in each catchment was obtained (C. Farrell pers. comm. Richard Jack, Coillte). These estimates are shown in **Table A4.9.** Where there was conflict between estimates, the more conservative of the two was used (midpoint estimate used for the expert opinion range). The yield class spatial model was more optimistic than the expert opinion for the Figile and Caragh but the opposite was true for the Dargle catchment. For other species, estimates of yield class was based on figures produced by Gallagher et al. (2004) in **Table A4.10.** For estimation of volumes of timber produced, age was capped at 50 years.

Table A4.9. Spatial model estimates (O'Donoghue et al., 2021, Farrelly et al., 2011) and expert opinion ranges on Sitka spruce (*P. sitchensis*) yield class across the catchments.

Catchment	Model area weighted estimates of yield class ($m^3ha^{-1}yr^{-1}$)	Expert opinion range ($m^3ha^{-1}yr^{-1}$)
Dargle	16.7	18-22
Figile	23.3	16-18
Bride	23.9	22-26
Caragh	21.7	16-18

Table A4.10. Other species yield class estimates reproduced from Gallagher et al. (2004)

FIPS stratum	Yield class ($m^3ha^{-1}yr^{-1}$)
Spruce	16
Pine	10
Larch	8
Other conifers	14
Mature oak and beech	4
Other mature broadleaves	6

Young oak and beech	6
Other young broadleaves	8

The estimated areas and volumes of timber harvested in the INCASE catchments is shown in **Table A4.11.** The amounts are variable with the largest catchment, the Bride, also showing the largest production of timber across all years. The Caragh showed the least and in 2016 was estimated to have produced no timber. Again, it must be emphasised that these are based on timber removals over a 3-year period and despite using best available information, a harvest year for certain sites may not be accurate.

Table A4.11. Estimated areas & volumes of timber harvested broken down by catchment and year.

Catchment and Year	Estimated area harvested (ha)	Estimated timber harvested (m^3)
Dargle		
2016	10.6	7,669
2017	41.6	18,824
2018	37.3	22,818
Figile		
2016	12.3	3,299
2017	12.7	5,739
2018	42.4	21,834
Bride		
2016	86.2	62,256
2017	45	34,201
2018	38.6	36,474
Caragh		
2016	0	0
2017	9	6,052

2018	4	3,075

Wood Provisioning Services – ecosystem contribution

To estimate the annual growth contribution the area, species and yield class were required. The approach followed was similar to that for the harvested timber.

Forested area broken down by ownership and catchment are shown in **Table A4.12**. and forested area broken down by species groupings are shown in **Table A4.10**. Again, as Sitka spruce (*P. sitchensis*) was so common, yield class for this tree species was estimated based on the spatial model described above (O'Donoghue et al., 2021, Farrelly et al., 2011) while for other species, the estimates from Gallagher et al. (2004) were used. Coillte plots identified a very small number of windblown plots in each catchment (<10ha) and these plots were reduced by 20% in yield as noted by Gallagher (1974). Using area of forest and annual growth estimates, we outline the estimated annual growth contribution to forests in **Table A4.12.** The greatest growth was for the Bride, followed by the Figile (less than half growth of Bride), the Dargle and the Caragh (low relative to other catchments).

Table A4.12. Ownership breakdown by area and catchment and estimated annual growth contribution to forest in the INCASE catchments

Catchment	Coillte (ha)	Private (ha)	Total (ha)	Estimated annual growth (m^3 yr^{-1})
Dargle	1,630	1,314	2,944	46,693
Figile	1,620	2,292	3,912	52,658
Bride	4,042	2,339	6,381	125,806
Caragh	679	888	1,567	21,112

4.1.1.4 Water (supply)

For the INCASE project, only sources of groundwater were included as a service as these were the only data available. Due to limitations on data on the actual production, discussed below, a demand approach is taken to estimate the volumes of water used and this approach is also used to allocate the water supply service to the various users in the service use account. Where data allows, a limited supply approach is also demonstrated to link extent of ecosystems to areas used as sources for water supply (Figile and Bride Catchments only).

Permitted extraction

Since 2018 water abstractions in Ireland in excess of 25 m^3 day^{-1} are required to be registered[26]. T**able A4.13** shows the abstractions registered in each sub catchment within the INCASE catchments, taken from the National Abstraction Register up to 1st July 2019 (Quinlan, 2021). The figures are given in m^3s^{-1} and in theory these figures could be aggregated to annual estimates, but they are likely to be over-estimates as they typically represent the highest daily amount.
Additionally, no breakdown by source was provided and for the water supply service in the INCASE project the focus is on water supplied by groundwater. Therefore, the figures provided here are only **an indication of the significant water users within each catchment and are not used to aggregate estimates for the demand within the catchments**. The max abstraction allowed per sector is also shown in **Table A4.13**. per sub catchment.

Table A4.13. Abstractions registered in each sub catchment within the INCASE catchments that were taken from the National Abstraction Register (Quinlan, 2021).

Catchment & sub-catchment (code)	Total Abstractions (m^3 s^{-1})	Sectoral breakdown
Dargle		
Dargle (Dargle_SC_010)	0.0709	49% Public water supply, 51 % commercial
Figile		
Figile (Figile_SC_010)	0.0042	50% Dewatering (removed from groundwater, discharged into drains), 50% Electricity generation.
Figile (Figile_SC_020)	0.1172	95% Public water supply, 5% Electricity generation
Caragh		
Caragh (Caragh_SC_010)	0.0237	100% Public water supply
Bride		
Bride (Bride[Waterford]_SC_010)	0.0012	100% Public water supply
Bride (Bride[Waterford]_SC_020)	0.0154	95% Public water supply, 5% Agriculture
Bride (Bride[Waterford]_SC_030)	0.0164	>99.9% Public water supply, <0.1% Agriculture

Domestic demand

Domestic demand is measured by multiplying the average household usage by the number of households whose water source can be traced to groundwater source. The average household usage is based on the 2018 figures supplied by Irish water to the CSO (2020) which are broken down by county. These are shown in **Table A4.14**.
To estimate the domestic demand for water schemes in the INCASE catchments dependent on groundwater for their water source, data from Geological Survey Ireland (GSI, 2021), was used. This data shows the **Groundwater Source Protection Areas and Source Protection Areas for public water schemes and group water schemes in Ireland**. Only two catchments had data on water schemes with

[26] in accordance with the European Union (Water Policy) (Abstractions Registration) Regulations 2018 (S.I. No. 261 of 2018)

groundwater sources, the Figile and the Bride. Thus, for the other two catchments, the Dargle and the Caragh, only houses with private sources identified by small area census data (CSO, 2017) were used. More information on the water supply in each catchment is detailed below.

Table A4.14. Domestic Metered Public Water Consumption 2018 Table 3B (CSO, 2020)

County/Catchment	Median Household Consumption (litres day^{-1})	Average Household Consumption (litres day^{-1})
Dargle		
Dublin	273	355
Wicklow	263	351
Figile		
Offaly	277	417
Kildare	277	365
Bride		
Cork	257	383
Waterford	248	353
Caragh		
Kerry	229	398
Ireland	255	368

Dargle

As can be seen from the extract from the National Abstraction Register in **Table A4.13**, the maximum allowed abstraction in the Dargle would be c. 125 m^3 per day. Dividing this by average household consumption of 0.355 m^3 day^{-1} and not allowing for leakage, which for Ireland averages 42% of water unaccounted for (CRU, 2020), gives an estimated supply for 352 households in the catchment. However, the estimated number of households in the catchment based on the Small Areas within the Dargle catchment (Appendix A) linked to census data for 2016 (CSO, 2017) shows 35,902 households which is over one hundred times that capable of being supplied by even the most optimistic figures in the National Abstraction Register (Quinlan, 2021).

Most of the catchment water supply is therefore sourced from outside the catchment through the Dublin supply network which sources its water from catchments to the south and west of Dargle catchment in addition to other catchments in the north-west not adjoining the Dargle catchment (Kelly-Quinn et al., 2014). Therefore, to estimate domestic demand for the Dargle based on a groundwater source only, those households served by their own private well were used.

Figile

A map showing the groundwater source protection areas and source protection areas for public water schemes and group water schemes in the Figile is shown in **Figure A4.2. Table A4.15** shows the details of the water schemes in the Figile. All water supply in this catchment was deemed to have source from groundwater so all households within the catchment were aggregated.

Table A4.15. Water schemes and their sources in the Figile catchment.

Figile Water Schemes	Water Source
Walsh Island Public Water Scheme	Groundwater
Toberdaly Public Water Scheme	Groundwater
Daingean Public Water Scheme	Groundwater
Clonbullouge Public Water Scheme	Groundwater
Mountlucas Group Water Scheme	Groundwater
Ballykilleen Group Water Scheme	Groundwater

In an effort to link supply of groundwater to extent, the land-use and land cover for areas (based on CORINE data) covered by groundwater source protection areas and source protection areas for public water schemes and group water schemes in the Figile was extracted (**Figure A4.2.**) and measured (**Table A4.16.**). These show the land-use and landcover that affect the water flowing through the ecosystem and filtering through subsoil before use.

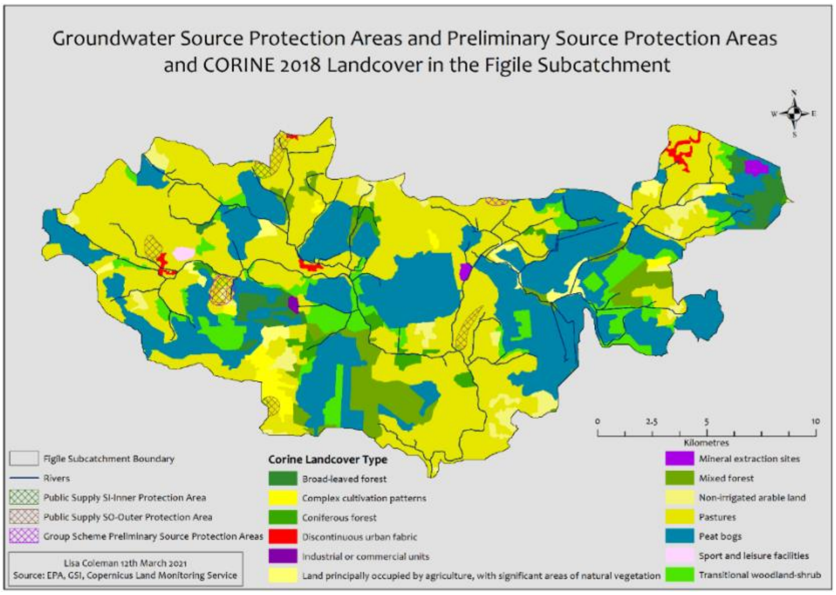


Figure A4.2. Landcover category associated with source protection areas.

Table A4.16. CORINE land-use/landcover contributing to groundwater supply in the Figile.

CLC Code	CORINE Land-use /Landcover description	Area (ha)

211	Non-irrigated arable land	24
231	Pastures	124
412	Peat bogs	7

Bride

A map showing the groundwater source protection areas and source protection areas for public water schemes and group water schemes in the Bride is shown in **Figure A4.3**. **Table A4.17** shows the details of the water schemes in the Bride. All water supply in this catchment was deemed to have source from groundwater bar one, Tallow PWS which was mixed. As all households within the catchment are dependent on groundwater for some or all of their water supply, all households in the catchment were aggregated for estimation of groundwater demand.

Table A4.17. Water schemes and their sources in the Bride catchment.

Bride Water Schemes	Water Source
Tallow Public Water Scheme	Mix
Conna Public Water Scheme	Groundwater
Aghern Bally Daw Group Water Scheme	Groundwater
Blackpool Curraglass Group Water Scheme	Groundwater

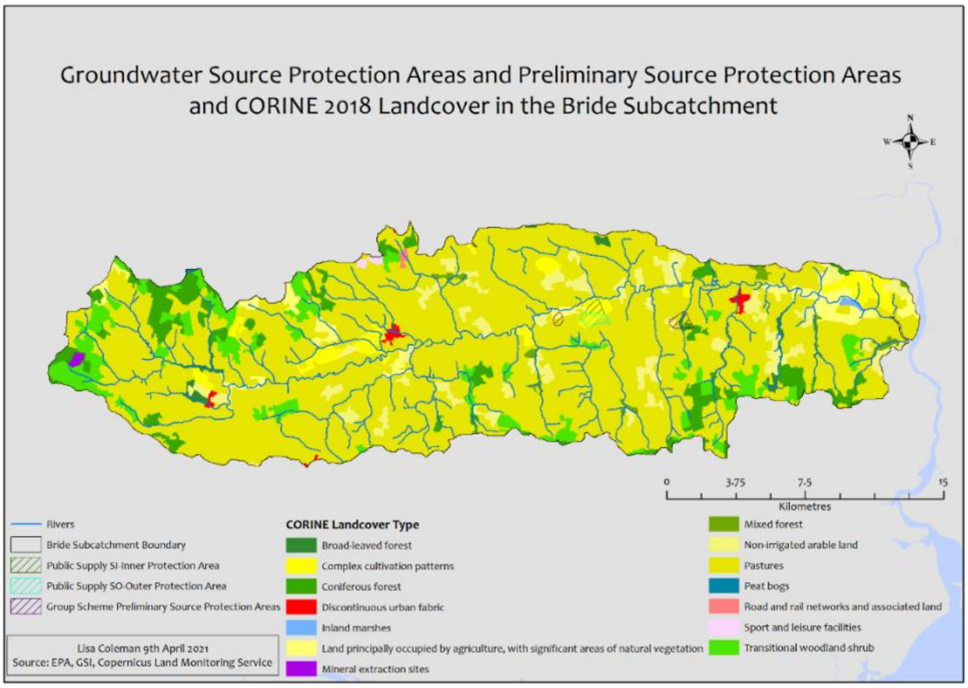


Figure A4.3. Landcover category associated with source protection areas.

Similar to the Figile, in the Bride catchment an effort was made to link supply of groundwater to extent. The land-use and land cover for areas (based on CORINE data) covered by groundwater source protection areas and source protection areas for public water schemes and group water schemes in the Bride was extracted (**Figure A4.3.**) and measured (**Table A4.18).** These show the land-use and landcover that affect the water flowing through the ecosystem and filtering through subsoil before use.

Table A.18. CORINE land-use/landcover contributing to groundwater supply in the Bride.

CLC Code	CORINE Land-use /Landcover description	Area (ha)
211	Non-irrigated arable land	13
231	Pastures	85
242	Complex cultivation patterns	102
243	Land principally occupied by agriculture, with significant areas of natural vegetation	12
312	Coniferous forest	25

Caragh

In the Caragh, water is supplied to a population of 2,272 (estimated 875 households) by the Caragh Lake Public Water Scheme (EPA, 2019). Therefore, to estimate domestic demand for the Caragh based on a groundwater source only those households served by their own private well were used.

Domestic Demand Summary

Table A.19. shows the estimated number of households dependent on groundwater within each county in each catchment. These were then multiplied by the average figures per county. to obtain an estimate for the domestic demand in each catchment.

Table A.19. INCASE catchments estimated annual domestic demand from groundwater.

County/ Catchment	Estimated Number of households	Estimated annual domestic demand by county and catchment (m^3)	Estimated annual domestic demand by catchment (m^3)
Dargle			
Wicklow	610	78,150	
Dublin	221	28,636	106,786 (All Wells)
Figile			
Offaly	1947	296,343	
Kildare	961	128,029	424,372 (46,611 Wells)
Caragh			
Kerry	184	26,730	26,730 (All Wells)
Bride			
Cork	3922	548,276	
Waterford	660	85,038	633,314 (276,592 Wells)

Agricultural demand

To estimate the agriculture demand in each catchment, only grazing livestock numbers were considered, irrigation was not considered as a significant user of water within any catchment. The largest assumption in this section is the allocation of all grazing livestock demand to groundwater within each catchment since bored wells are the most common water sources on farms (Ryan, 2009). To estimate the livestock numbers per catchment, the same approach was taken from estimating grazing biomass demand. The aggregated numbers of livestock in each catchment by type is shown in **Table A4.20.** and the estimated demand of groundwater for water supply for agriculture purposes is shown in **Table A4.21.**

Table A4.20. Aggregated numbers of livestock in each catchment by type.

Livestock Type	Figile	Dargle	Bride	Caragh
Dairy Cows	1,614	356	20,139	155
Other Cattle	24,899	2,112	51,263	3,578
Ewes	5,714	7,033	2,440	12,180
Other sheep	6,685	6,660	2,338	9,820
Horses	204	246	1,487	114

Table A4.21. Estimated annual groundwater demand of grazed livestock per catchment.

Livestock Type	Daily Water Demand (m^3 day^{-1})	Figile (m^3)	Dargle (m^3)	Bride (m^3)	Caragh (m^3)
Dairy Cows	0.125	73,639	16,243	918,842	7,072
Other Cattle	0.035	318,085	26,981	654,885	45,709
Ewes	0.005	10,428	12,835	4,453	22,229
Other sheep	0.0035	8,540	8,508	2,987	12,545
Horses	0.045	3,351	4,041	24,424	1,872
Totals		**414,042**	**68,607**	**1,605,590**	**89,427**

Industrial demand

To estimate industrial users of water within the catchments, data from the EPA was gathered on active Integrated Pollution Control (IPC) sites. The EPA has been licensing certain activities since 1994 and an IPC licence is a single integrated licence which covers all emissions from the facility and more importantly for the purposes here, its environmental management. In order to assess how efficiently each site uses resources, each site is required to return an annual environmental report which details its emissions but also the usage of energy and water. Water use data for the IPC sites in the INCASE catchments is detailed below in **Table A4.22**. This is not an exhaustive list of water demand for industrial use within the catchments, but main users of water overlap with those sectors reported in the abstractions register.

Table A4.22. Estimated Industrial Demand based on Current Integrated Pollution Control (IPC) Licensed Sites Annual Environmental Reports

IPC License Code	IPC Category	Source	Water Used ($m^3 year^{-1}$)	Year
Dargle				
P0674-01	12.2.2: Surface Coatings	Public Supply	364	2020
P0648-02	12.2.2: Surface Coatings	Public Supply	17,999	2020
P0019-02	5.16: Chemicals	Public Supply	96,840	2020
P0567-02	12.2.2: Surface Coatings	Public Supply	17,013	2020
P0366-02	12.2.2: Surface Coatings	Public Supply	1,882	2020
P0366-02	12.2.2: Surface Coatings	Surface Water	60	2020
Figile				
P0430-01	6.2 (a): Intensive Agriculture (Piggery)	Groundwater	19,836[27]	2019
P0614-02	6.2 (a): Intensive Agriculture (Piggery)	Groundwater	1,000	2019
P0482-04	2.1: Energy	Groundwater	48,012	2020
P0482-04	2.1: Energy	Surface Water	1,152,765	2020
Bride				
P0315-01	6.2 (a): Intensive Agriculture (Piggery)	Groundwater	1,170	2020

[27] Water demand based on sow and weaner numbers reported on 28th June 2019.

P0595-02	6.4. (a) Food and drink (Slaughterhouse)	Groundwater	139,585	2020
Caragh				
None				

4.1.2 Regulating services

4.1.2.1 Climate

In order to present indicative values / ranges of carbon stocks and flows, we use the data available to develop some rough estimates of flows within the catchments. We make a number of high-level assumptions and propose that this area requires more detailed attention / research with input for GHG specialists to ensure alignment of emission factors and stock analysis.

Context / relationship to core accounts

- **Ecosystem extent and type**: this account can be used as an indicator of potential carbon stocks. Using the vegetation type – shrubs, wood / timber and graminoids can be an indicator of above ground biomass and potential below ground biomass (dead organic matter and 'living' stocks). Similarly using data available on soil organic carbon stocks informs as to
- **Ecosystem condition**: following from above, depending on the condition of the ecosystem type (based on condition variables), it may be acting either as a source, a sink, or neither for GHG (greenhouse gases) including methane, carbon dioxide and nitrous oxide.
- **Benefits**: to outline and delineate benefits, data primarily on the carbon retained and the flows of GHG, can be linked to the net global warming / cooling effect. Other links can also be made to highlight linkages to the economy, including data relating to carbon markets, carbon credits, carbon offsets etc.

Datasets required depend on the ecosystem type (outlined next in the logic chains) but in general relate to:

- **Flows**: emission factors available at Tier 1/2/3 levels as reported in National Inventory Reporting.
- **Stocks**: data relating to the various pools of carbon stocks (above and belowground biomass, dead organic matter) and Soil Organic Carbon (SOC).

Carbon stocks - Data available

Soils data: attributes relevant to INCASE[28]. More recent SOC data was sourced from Sullivan (2019). Apart from the work of Hammond (1981), the full distribution, depth and associated bulk density data of peat soils have not yet been recorded and the production of a single integrated map that includes both peat soils and the Irish SIS data is recommended for future research (Simo et al. 2019).

Indicative Soil type

- All soil types belong to a Sub-Group and so in turn to one of the 11 soil Great Groups. Great Groups and Sub-Groups are a hierarchical arrangement of soils used for taxonomical classification. At 1:250,000 scale it is impossible to show individual soil types on the map. The soil association concept therefore represents a cartographic grouping of local soils. The polygons on the soil map show soil associations, the groups of soil types that commonly occur together in the landscape. The database that sits behind the map allows you to 'drill down' into the data to

[28] https://www.epa.ie/pubs/reports/research/land/EPA RR 204 final web.pdf

see the soil types linked with a given association and their relative rankings in terms of typical extent.

Indicative Soil depth

- Using a combination of data from the soil profile pits and auger records, the dominant depth was mapped for each association. As this is based on a national soil map, this information is not appropriate for point locations, because the minimum mapping unit is **>250ha in size**. **Note: there are no data for peat soils**.

Indicative Soil texture

- To derive a soil texture map from the third edition soils map and associated database, the lead soil series of each mapped association was used to infer the main textural characteristics for that mapped unit. This was supported by a large number of field observations taken all over the country, where texture was estimated by hand. Samples collected as part of the profile pit campaign had their texture measured in a laboratory. The cut-off for the various texture categories is based upon clay content of the soil (%). In reality, soils will vary in their texture by 1–5% in most fields and by up to 20% in more extreme cases. **Therefore, this map can provide only a broad overview of the range of textural classes found in Ireland, so it is not appropriate for detailed mapping purposes or field-level descriptions**. This map provides only an overview of the range of soil textural classes that occur in conjunction with the main geological landscapes found in Ireland.

Indicative Soil drainage

- The allocation of the drainage class to the lead subgroup of an association for the indicative soil drainage map, means that only a general statement can be made about the drainage class of that mapping unit, based on the dominant subgroup present. While this approach presents a good overview of the range of soil drainage patterns at catchment scale and larger, it should not be applied to specific fields or farms.

Indicative Soil Organic Matter

- This SOC map has been created using a combination of data from modal profiles and bulk density data, as measured in the field, or calculated through PTFs (Reidy et al., 2016) for all modal profiles. SOC levels were calculated for each mapped soil association based on the proportional contribution of each soil series within the association. It should be used only at catchment scale and greater and not at farm/local scale. A second map was created for 0–1m depth; however, this could not be validated for lack of data. More recent SOC data was sourced from Simo, et al. (2019).

Mapping Peatlands and the Derived Irish Peatland Map (DIPMV.2, Connolly and Holden, 2011)

- The Derived Irish Peat Map (DIPM) first published in 2007, estimated the spatial extent of **peat soils** as 13.8% of the national area. The DIPM was derived from the Peatland Map of Ireland, CORINE land cover database (CORINE) 1990 and the General Soil Map of Ireland.
- This initial map was subsequently updated by the DIPMV2 [29] (published in 2009). This estimates that **peat soils** cover 1,466,469 ha, or **20.6%,** of the national land area. Within the DIPMV2 peat soils are classified as Raised Bog, Low-Level Atlantic Blanket Bog, High-Level Montane Blanket Bog or Non-Peat (>30cm peat). For INCASE, we used Version 2 (**DIPMV.2**) to supplement soils mapping, Article 17 habitat mapping and CORINE data(and OSI Landcover mapping when it is available) to determine extent of peatlands and heathlands.

[29] http://erc.epa.ie/safer/iso19115/displayISO19115.jsp?isoID=160

Understanding the contribution of subsoil carbon for climate mitigation (Simo et al. 2019)

This study highlights the need to assess soil carbon stocks below the standard 30 cm depth, applied in many calculations and models, in order to derive sufficiently accurate estimations of soil organic carbon (SOC) stocks and the total quantity of stable SOC at depth. Using empirical data from a national soil survey, SOC measurements from the surface 30 cm, 50 cm and 1 m were compared across all soil types. The results indicate a large variation between soils when comparing the SOC of the first 30 cm only, while the proportion of total SOC stock contained within 0–50 cm was more consistent within subgroups of soil types, and accounts for 90% of the carbon found to 1 m.

This research provides a spatially targeted approach that combines efforts to reduce CO2 emissions from carbon hotspots while also augmenting the sequestration of stable carbon at depth in soils with clay illuviation and wetness (stagnic) diagnostic horizons.

Limitations: no data on SOC in peat soils but there are literature sources that estimate SOC.

INCASE approach:

Soil organic carbon

SOC: for this aspect we used Simo et al. (2019) map to calculate the SOC in each catchment. *Output*: Maps and Tables showing SOC in catchment.

Peatland stocks: We note there were no data in general for peatlands so used data from **SIS/DIPMV.2** to support the overview and a value of **751 tonnes/ha** from Holden and Connolly (2011). We use **530 tonnes per hectare for Peat** in the Bride catchment, given that these areas were predominantly Heathland (less than 30cm peat) and this is the lower value presented by Holden and Connolly (2011) for peat depth less than 30cm.

Overlay SOC with ecosystem types to show the range of SOC in relation to ecosystem type. For example, peat soils have high SOC.

Some issues for discussion:

How does ecosystem type and ecosystem condition relate to stability of the carbon stock, i.e., is the peatland drained and therefore the soil type shows high coincidence between **soil type and soil organic carbon**, i.e. peat soil = high soil organic carbon.

Vegetation stocks

Forest (commercial) biomass: The NIR (2021) outlines the approach to calculating carbon stocks in Forests and a model has been developed by O'Donoghue et al. (2021). There are a number of carbon pools that must be measured, and these are outlined in the NIR (Duffy et al. 2021) as aboveground biomass, below ground biomass and dead organic matter (DOM) (NIR, Table 6.4).

Hedgerow / shrub stocks: nothing available at this time.

Other stocks

Data gaps: Peat depth and SOC peatlands – no data for either. This should be updated by work in progress by Connolly (pers. comm).

Carbon flows - Data available

Emission Factors based on National Inventory Reporting (2021):

The net CO_2 emissions to, or removals from, the atmosphere are to be reported with respect to overall carbon gain or loss for up to five relevant carbon pools for the defined land categories. These pools are

- Living biomass: above-ground biomass and below-ground biomass,
- dead organic matter (litter and dead wood) and
- soils.

For Convention reporting above-ground biomass and below-ground biomass are reported together as living biomass, and litter and deadwood are reported together as dead organic matter (DOM). The 2006 IPCC guidelines provides methodologies for calculating **changes in carbon pools** where land areas form the basic activity data and carbon stock change is determined from a number of other parameters.

Various levels of land subdivision may be used to capture differences due to climate, management system, vegetation type or other factors influencing carbon exchange. As for other sectors of the inventory, the 2006 IPCC guidelines provides higher tiered methods for estimating emissions and removals, where higher tiers may be used if the necessary data are available.

The estimation of emissions and removals also utilises the 2013 Revised Supplementary Methods and Good Practice Guidance Arising from the Kyoto Protocol and 2013 Supplement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories: Wetlands, where appropriate. Those emissions of N_2O and CH_4 associated with land management not reported under Agriculture are reported in the LULUCF sector including such activities as soil disturbance, and the drainage and rewetting of mineral and organic soils.

Emissions of N_2O and CH_4 are reported for biomass burning (and CO_2 emissions from biomass burning in Wetlands).

For peatlands and peat soils (comments from Dr. David Wilson, *Earthy Matters*)

For "natural" peatlands, Tier 1 emission factors from Chapter 3 of the IPCC Wetlands Supplement (WS) would be the most statistically robust values to use. The CO_2 EF may be lower than has been measured for Irish sites (see McVeigh et al. 2014, and the current work by Matt Saunders and Shane Regan at Clara), but the dataset is much larger. CH_4 EF from WS is also twice as large as reported for Glencar by Laine et al. (2007), and for Clara by Regen et al, (2020) – same for DOC.

For degraded peatlands, Tier 1 emission factors from Chapter 2 of the WS are appropriate.

For peat extraction sites, the most recent NIR (Duffy et al. 2020) has used Wilson et al. (2015) as Tier 2 CO_2 values, which are about 1 tonne/ha/yr less than the Tier 1. We used data from Turraun, Bellacorick, Boora, Blackwater, Clara and Glenlahan, so statistically our values are sound. Tier 1 CH_4 (land) EF for peat extraction sites are probably bang on the button (current Moyarwood dataset), but we don't have CH_4 (ditch) data for Ireland.

In terms of **montane BB GHG work**, to my knowledge, there is very little out there. I did a 12-month study at Glenlahan in the BOGLAND project, but I would recommend that you use the Tier 1 value there too.

Agriculture (grassland) is a little trickier as you have to determine the area over organic soils. Again, use Tier 1 values from Chapter 2, but also look at the values published in Renou-Wilson et al. (2014, 2016).

Options available:

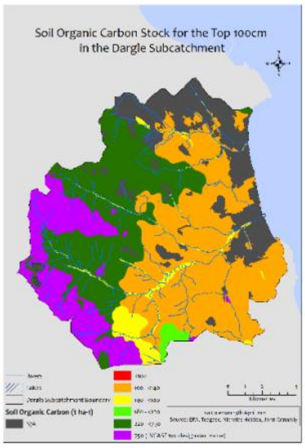
Flows relating to soil emissions: Mapping peat soil texture versus non peat soil texture and applying emission factors for peat soils versus mineral soils; we used peat soil texture to distinguish two categories and calculated the area of each CLC class on peat versus non peat soil texture. Applying relevant EF we calculated the potential flows based on NIR 2020 approach.

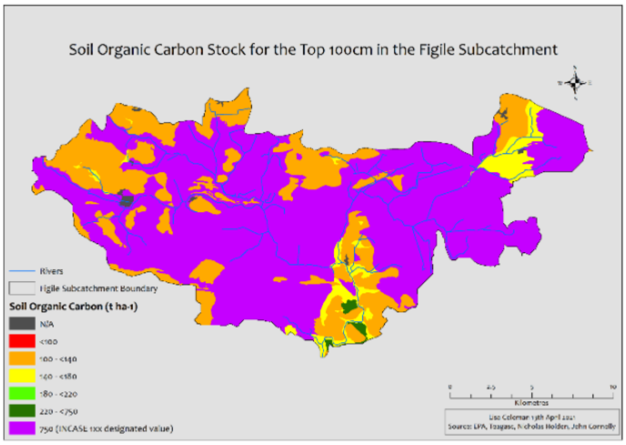
Flows relating to forests: using commercial data and age, to get an estimate of carbon flows in commercial forests we applied the EFs as per Black and Gallagher (2010); assumptions are that all forests are on peat. Obviously there are some forests on mineral soils (in Dargle and Bride); but this

outlines the lowest limit / range of the carbon sink potential. In Caragh and Figile all forests are on peat soils.
Flows based on FERS tool: We applied the species type with knowledge of soils and estimated the forest site sequestration (excluded the HWP and energy substitution),
Flows relating to hedgerows: we used the areas of SWF HRL area of shrubs and linear features and apply the carbon sequestration factors provided in Briar (2019, Table 1.1).
Data gaps for INCASE catchments: Emissions from Livestock, Fertiliser, Liming, Burning.

Carbon stocks are presented in tonnes C per catchment; based on SOC (2019 data). Peatland SOC is estimated using data from Holden and Connolly (2011). Some observations:

- **Dargle**: this catchment has the lowest SOC, and this can be attributed to size, and also the lack of data for Urban areas (~25% of the catchment).
- **Figile**: highest level of SOC across the catchment die to the former dominance of peatlands and the presence of deep peat soils under grassland and forestry.
- **Bride**: this catchment is the largest but has low SOC; largely dominated by mineral soils.
- **Caragh**: there is no data for bare rock (obviously!) and overall, the high cover of peatlands (blanket bogs variable in depth so taking 1m as an average depth) contributes to the high SOC in catchment.
- ***Data gaps***: no data for carbon stocks in vegetation (or other organic pools); this requires modelling data from yield class, tree type, area, age etc.





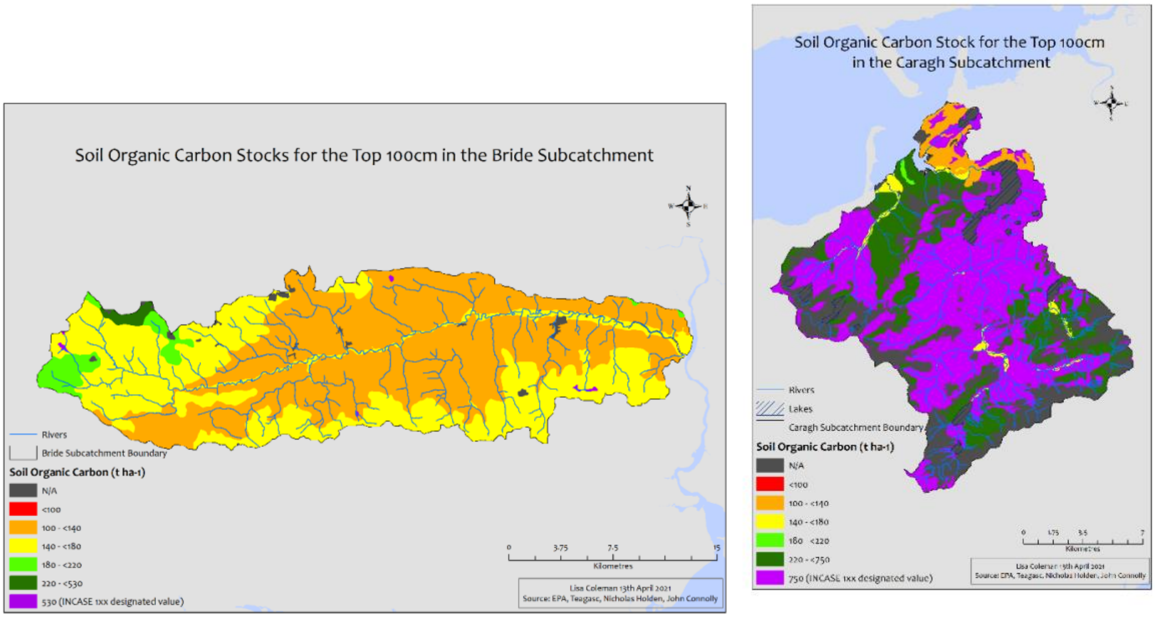


Figure A4.4. Soil organic carbon in the INCASE catchments.

Other data available

MAES maps 2016

Areas of land that store carbon developed in 2016 (Figure A4.5)

The map has been created using existing datasets, including the Teagasc national soils and subsoils datasets and the derived habitat map. This does not include information on disturbance, which is particularly relevant on peatlands.

The darkest colours represent areas with high level of organic soil carbon overlain by vegetation which is actively helping the soil to store carbon. Lighter colours represent sandy soils with little organic carbon, which are regularly disturbed where carbon is released into the atmosphere.

INCASE Note: these maps should be used as a guide to carbon stocks and areas with potential to either store or release carbon (most peatland areas are drained and therefore they are not actively sequestering carbon). The darker colours relate to areas with peatlands habitats which may or may not be in good condition – include industrially used peatlands in the Figile for example.

Vegetated land that stores carbon (Figure A4.6)

Data analysis identified areas of significant carbon storage within vegetation. Information derived from existing habitat and land management data. This included a habitat map derived from Corine, FIPS Forest 07 and Forest 12 and NPWS (Article 17, National Survey of Native Woodlands 2003-2008; and Ancient and Long-established Woodland Inventory 2010) datasets. Vegetation is valued high to low according to both its above and below ground likely sequestration of carbon.

The darkest colours represent areas where there is more carbon storage in the vegetation. Lighter colours represent areas of land where vegetated carbon is removed from the land each year.

INCASE Note: these maps are a more reliable guide to areas with standing carbon stocks in vegetation and are considered a valid approach for future updates and accounting. High vegetation carbon stocks relate to forests and woodlands, with permanent pasture also a high carbon stock. Areas with cultivation and intensive grassland management are considered low vegetation carbon stocks.

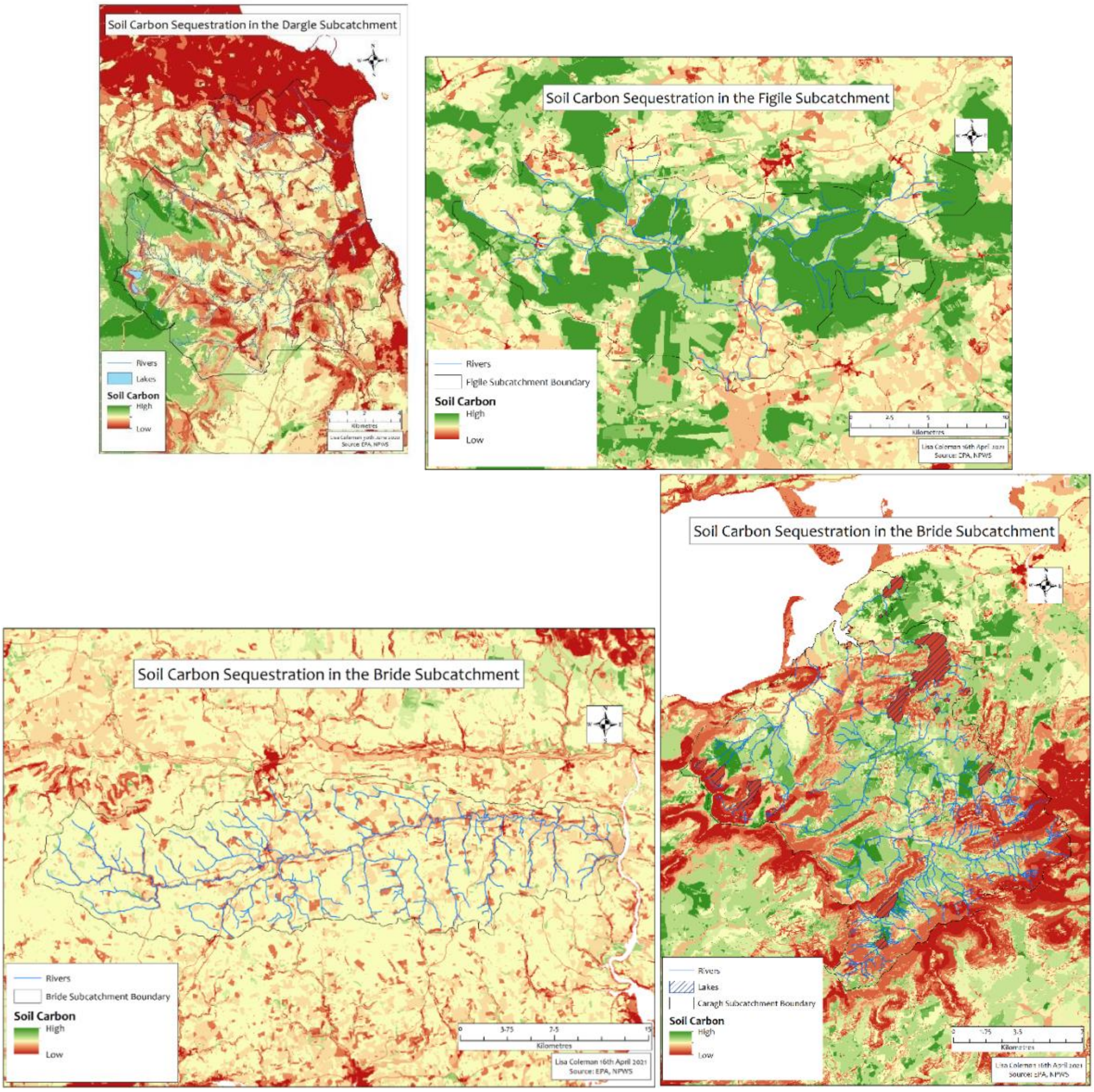


Figure A4.5. Soil organic carbon in the INCASE catchments based in MAES maps developed by NPWS (Parker et al. 2016)

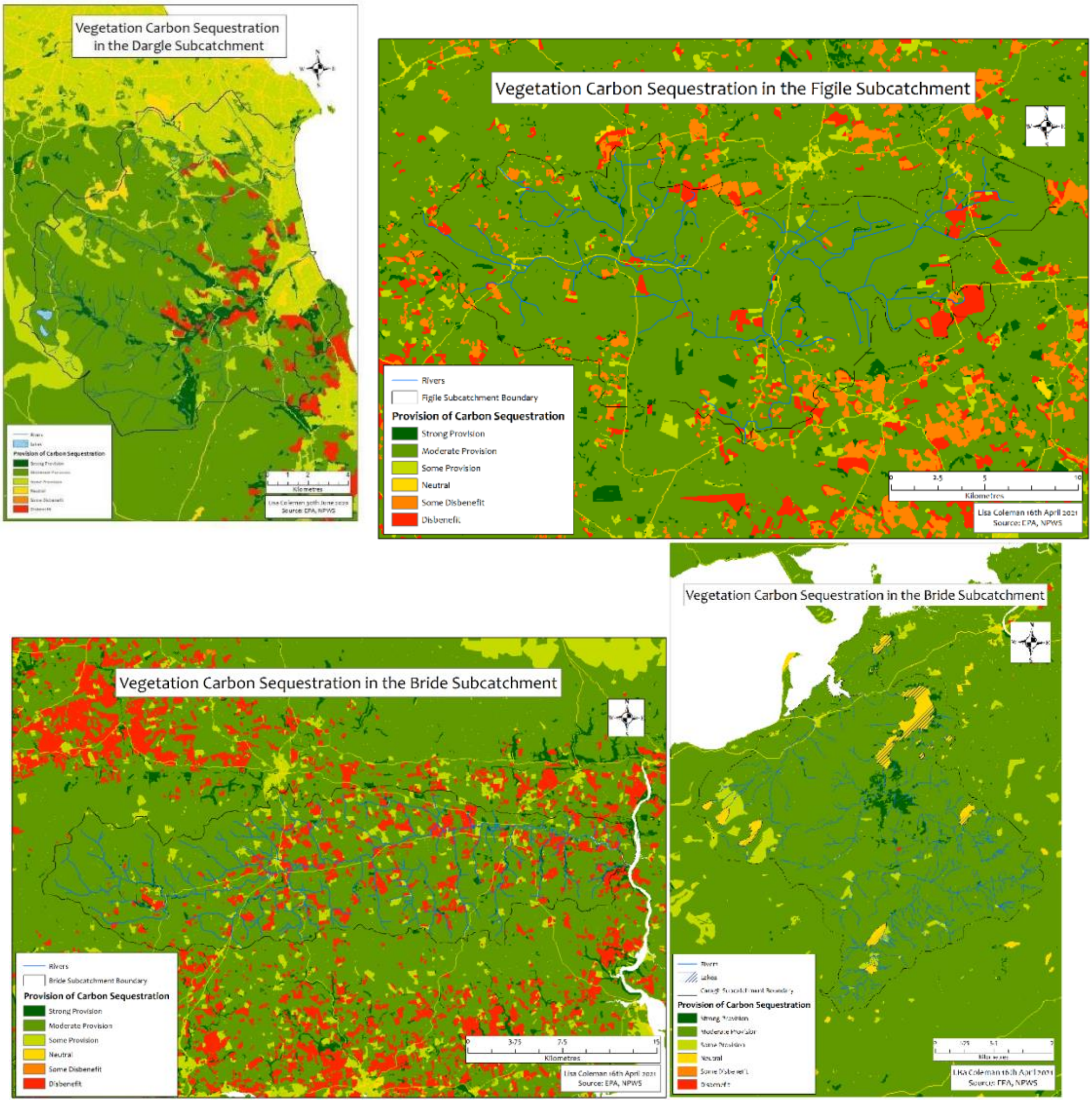


Figure A4.6. Soil organic carbon in the INCASE catchments based in MAES maps developed by NPWS (Parker et al. 2016)

Carbon flows are presented in tonnes of CO2 per catchment **(Table. A4.25)**. Carbon flows from soils: based on 2018 CORINE data (landcover on soil type); we applied the emission factor according to NIR and specifically LULUCF emission factors for land use type (a combination of IPCC Tier 1 and Tier 2 factors). Carbon flows in hedgerows and shrubs following Briar report and assuming all forests on peatlands (needs more analysis). We did not include methane. We do have estimates for nitrous oxide emissions, also applying NIR methodology.

Nitrous oxide is a gaseous form of Nitrogen and is responsible for 1/3 of GHG emissions in Ireland. Nitrous oxide is a much stronger greenhouse gas than CO2 in terms of its 'warming potential'. Over a 100-year timescale, and without considering climate feedbacks, one tonne of nitrous oxide would generate 265 times the amount of warming as one tonne of CO2. Agriculture is the main contributor.

Some observations:

- **Dargle**: this catchment has high CO2 emissions from ***soils***; note we assumed that all peatlands are drained and emitting carbon. We applied the relevant CO2 and DOC emission factors. Applying an emission factor for natural peatlands (as we did in the Caragh) would present a very different result. We note that there are no data on carbon emissions from mountain blanket bogs available. It is likely that ***forests*** are a significant carbon sink, but this needs to be modelled to reflect the age and soil type (we attempted this using the same approach across all four catchments, so the results are relative). The high cover of ***hedgerows and scrub*** in the catchment reduce the potential net emissions from the catchment.
- **Figile**: this catchment has the highest values of CO2 emissions from ***soils*** given the **high cover of peat soils and their drainage for agriculture** and forestry. ***Forests*** present a potential carbon sink, as the ***hedgerow*** network. This requires further modelling based on species, etc.
- **Bride**: this catchment has the lowest potential emissions of CO2 from soils and the highest potential for forests to be a carbon sink. Hedgerow and shrub networks also contribute to the net sink potential of the catchment. Other agri activities of note here are livestock emissions, fertilisers etc.
- **Caragh**: overall high emissions of CO2 from soil; and sink potential in forests and hedgerow / shrub network.
- **Nitrous oxide**: the highest emissions are from the Figile (due to fertiliser applications on drained peat soils); followed by the Caragh, Dargle and Bride (the lease emissions).
- ***Data gaps***: needs a more detailed analysis of forest and land cover types to model data from yield class, tree type, area, age etc. at catchment scale; other GHG sources in the catchments would detail carbon in the economy (livestock) and emissions due to agricultural inputs (fertilisers etc.).

Table. A5.25. Outputs of carbon flows for INCASE catchments. ***Note***: The analyses are indicative (for demonstration purposes only) and present an overview of how catchment carbon flows could be presented. Requires GHG expert view! *Assumes all on peat – need a better approach to forest and carbon modelling; FERS probably a better fit here.**Assumes all drained peatlands (which is true!).

	Dargle	**Figile**	**Bride**	**Caragh**
Total catchment area ha	**17,686**	**30,143**	**42,715**	**22,953**
Flows t CO2				
Soils based on CORINE	25,568**	70,578	744	17,941
Hedgerows, Shrub (SWF)	-11,083	-10,363	-8,072	-5,727
Forests using SS model (CF)	-14,388	-25,340	***-36,591****	-8,817
Forest using FERS tool	*-8,065*	*-6,501*	*-18,338*	*-2,191*
Net flow using available data t CO2 using SS model	**97**	**34,875**	**-43,919**	**3,396**
Net flow using available data t CO2 with FERS model	***6,420***	***53,714***	***-25,666***	***10,022***
Range	97 to 6,420 **source**	34,875 – 53,714 **source**	-43,919 to -25,666 **sink**	3,396 to 10,022 **source**
Methane ?				
N2O tonnes	10,973	35,238	467	17,861

Notes 21/4/2021:

- All catchments are sources of CO_2 based on these calculations mainly due to emissions from soils.
- Dargle, Figile and Caragh catchments are net source of CO_2 despite potential sink in forests and hedgerows.
- Only the Bride is a net CO_2 sink based on low emissions from soils and sinks due to forestry. Note: does not include livestock (consider dairy herd).
- We haven't included emissions from livestock or methane as yet. This would only increase the GHG emissions; methane is not considered to be a strong feature in any catchments but will be in Figile as a result of rewetting post 2020.
- All catchments are net sources of nitrous oxide.

4.1.3 Cultural services

4.1.3.1 Recreation-related

Cultural services are non-material, generally experiential services that occur when ecosystems contribute towards benefits for individuals or society through their existence, functioning and quality. Examples of these benefits vary from spiritual enrichment to cognitive development and learning to recreational and aesthetic experiences (MA, 2005). For many cultural services it is their intangible nature that makes them both less studied and harder to measure relative to other ecosystem services (Milcu et al., 2013).

One of the most studied of the cultural ecosystem services is recreation-related services, those that the SEEA-EA (UNSD, 2021) defines as enabling individuals "*to use and enjoy the environment through direct, in-situ, physical and experiential interactions with the environment*". Often involving travel to the ecosystem to undertake the recreational activity, recreation-related services are supplied to both locals and non-locals (e.g., visitors or tourists) (UN et al. 2021).

Site visits are often used as a quantitative indicator for the use of an ecosystem, which may be difficult or costly to measure. While for other ecosystem services, estimates of the service can be used or transferred from other sites or the literature, this is more difficult (although not impossible) for recreation for a variety of reasons including the fact that use of a particular ecosystem for recreational purposes are often dependent on a particular location of the ecosystem or other combinations of the attributes of a particular ecosystem rather than a type of ecosystem (Stålhammar and Pedersen, 2017).

Some recreational activities such as swimming or running can be carried out in both artificial and natural environments but from the SEEA-EA perspective only those where an ecosystem contributes is of relevance in the ecosystem accounts. Even for those recreational activities occurring within an ecosystem, separating the human component (e.g., fishing tackle or bicycle) from the natural or ecosystem component (location, fish in the stream, water quality, landscape) is still an area of active research.

We use the proxy of visits (or similar proxies) for common recreational activities as our main quantitative measure, and location of visits as a qualitative measure of the use of ecosystems within the INCASE catchments.

Recreation in Ireland

In terms of the most common recreational activities in Ireland, several data sources were identified. QNHS Sport and Physical Exercise (CSO, 2013): this study looked at participation rates for sport and physical exercise. They found 73% of respondents over the age of 15 do physical activity for the purposes of exercise, recreation, or sport. The most popular activity was walking with 59% of respondents over the age of 15 undertaking walking for recreational purposes. The same report also examined participation in other physical activities and sport finding a 38% participation rate for those over the age of 15. These rates of participation for the individual sports are shown **Figure A4.7.**

Sport Ireland (2020) has collected data on participation rates in sport and physical activity. In their report, they found 46% of the population over the age of 15 regularly participate in sport, an increase from 43% in 2017. A breakdown of main sports is shown in **Figure A4.8**. The same report also examined broader physical activity finding 66% of respondents reported walking for recreation.

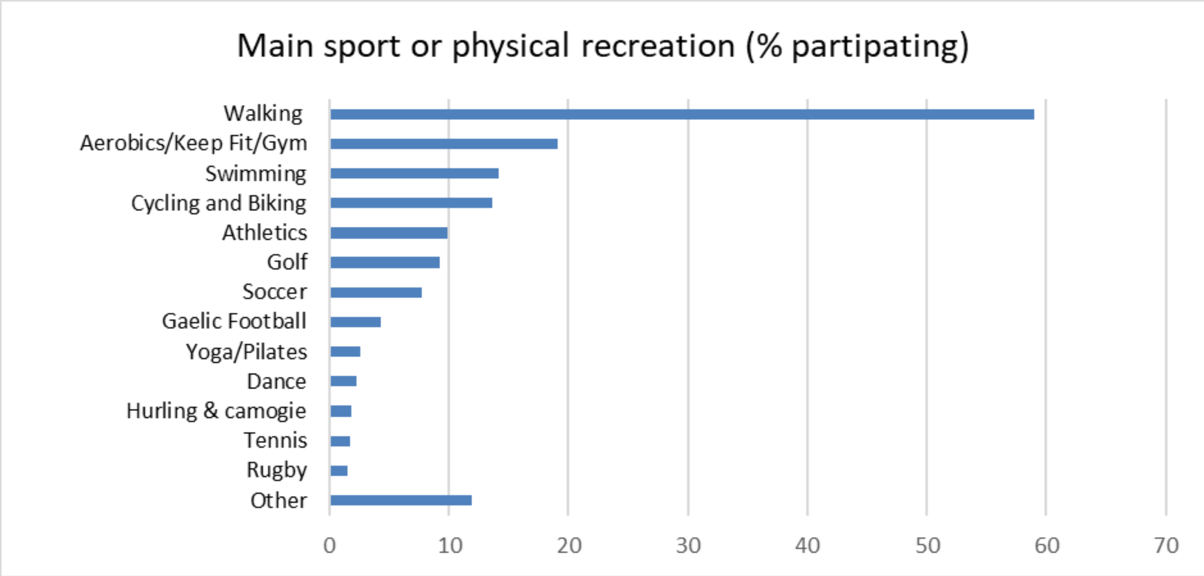


Figure A4.7. Recreational participation rates by adults over 15 in Ireland (CSO, 2013)

Figure A4.8. Sport participation rates by adults over 15 in Ireland (Sport Ireland, 2020)
Different methods and approaches are used in the CSO (2013) and Sport Ireland (2020) reports so they cannot be directly compared but they do highlight the main recreational and sporting activities undertaken in Ireland. The most obvious of these is walking with high participation rates noted by both reports. This can be undertaken within ecosystems with varying degrees of intensity (urban park walking on flat ground compared to hill walking on open heathland) and often does not require significant investment in equipment. Therefore, when people are walking in an ecosystem, a significant portion of the benefit derived is contributed by the natural capital surrounding the walker. The same cannot be said for the next most common activity is personal exercise[30] as this can be done both indoors and outdoors with different levels of equipment (physical capital) required. How to separate out these activities from the levels of natural capital required and its contribution to the recreational activity is a difficult process. The issue of location can also be said for swimming depending on the location of the activity. Swimming outdoors in natural environments is also dependent on the condition of the ecosystem as if the water quality is too poor, swimming can be hazardous to people's health and enjoyment demonstrating the linkages through the SEEA-EA in terms of understanding the final recreational benefits.
To examine recreational activities within the catchments and provide a basis for developing recreational accounts, five popular recreational activities will be included. These were also chosen as they were identified as having more significant contributions from natural capital than other recreational activities and could be linked to ecosystems within the INCASE catchments. The five recreational activities are:

- Walking and running **Figure A4.9.**
- Cycling **Figure A4.10.**
- Swimming **Figure A4.11.**
- Golf **Figure A4.12.**

Recreational fishing was not included in this assessment but should be considered in future studies given its link to aquatic natural capital in all INCASE catchments. Limited data is available on fishing activity despite it being one of the recreational activities that can be easily linked to a certain ecosystem type (such as freshwater rivers and lakes) and is also dependent on ecosystem condition.

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[30] This is termed personal exercise in the Sport Ireland (2020) report and overlaps with aerobics/keep fit/gym in CSO report.

Golf is important from an ecosystem accounts perspective as even though it has relatively small participation rates compared to other recreational activities, it has a land-take in some of the catchments resulting in a mosaic of managed ecosystems. On the CORINE mapping they are classed under Sport and leisure facilities [CLC code 142].

While the aim of the SEEA_EA is to show the linkage between ecosystem extent and the ecosystem service, the project does not have access to data that is sufficient to aggregate the level of recreational activity on a quantitative basis (e.g., number of recreational visitors in the catchments). However, a qualitative approach is used to highlight the locations in the catchments that are used for recreational activities. The source for three of the recreational types is based on Strava data. Strava data has previously been used for a variety of purposes including transport assessments, estimating travel patterns, and evaluating air pollution exposure risk (Lee and Sener, 2021). However, it is noted that the data may not be representative of all groups within a population. Here it is being used to highlight areas of higher recreational intensity. The use of GPS based data for recreation has also previously been used by Byczek et al. (2018) where raw GPS tracks were used to model recreational use within the Grenoble region of France.

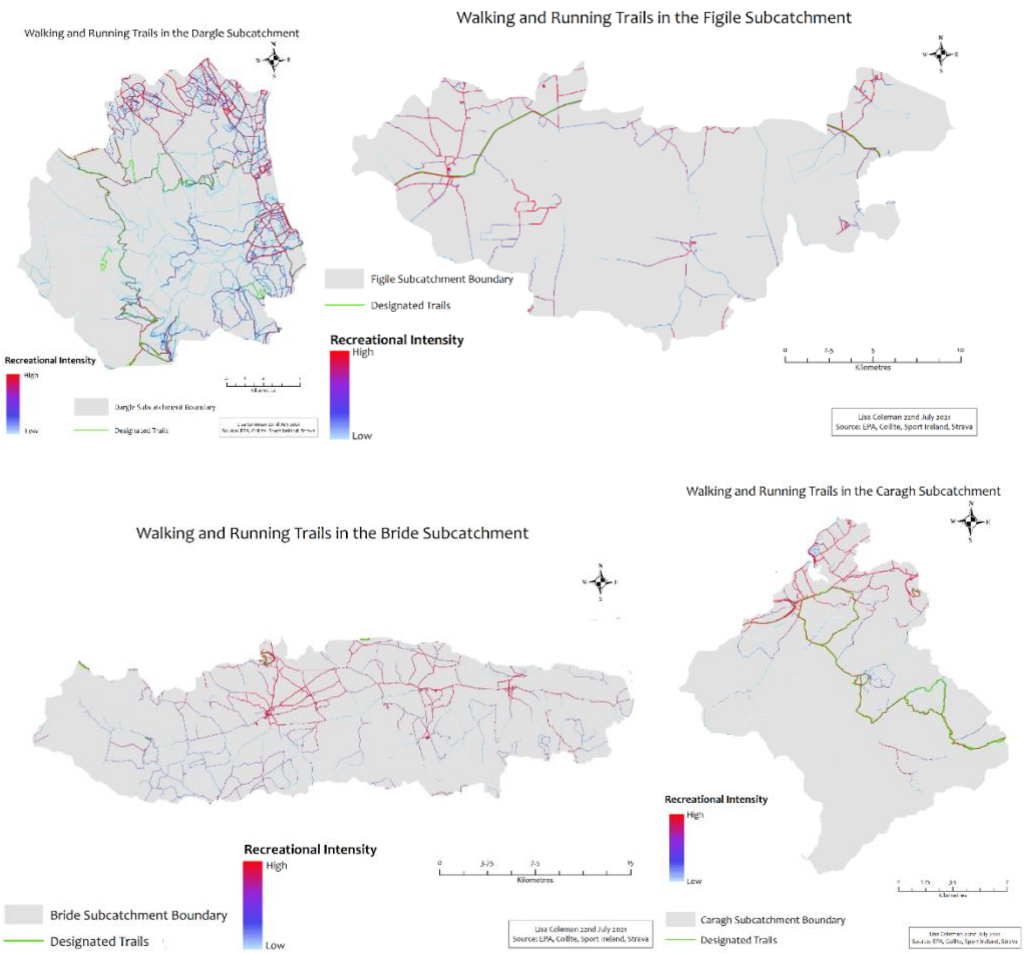

Figure A4.9. Walking and running in the INCASE catchments.

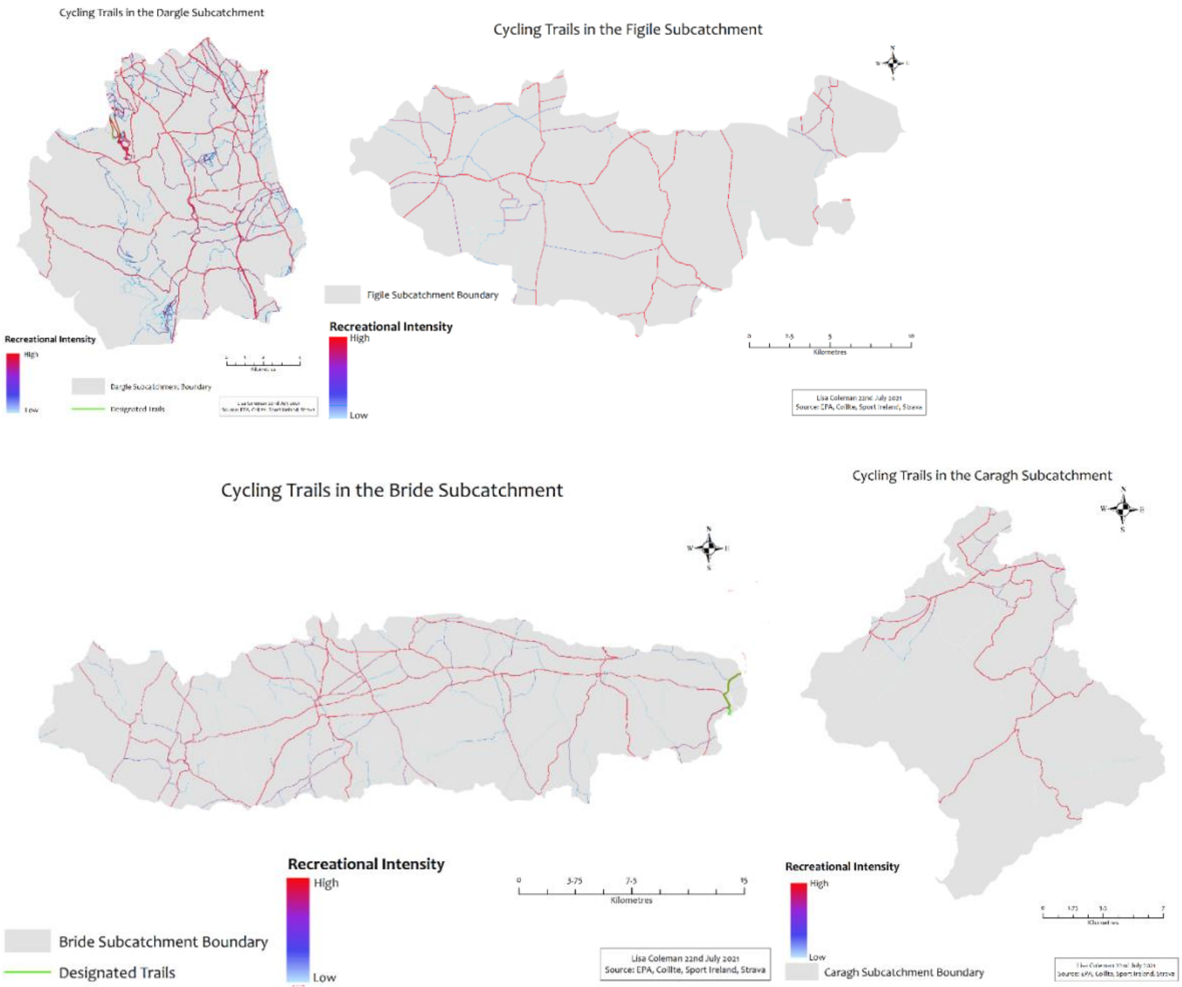

Figure A4.10. Cycling in the INCASE catchments.

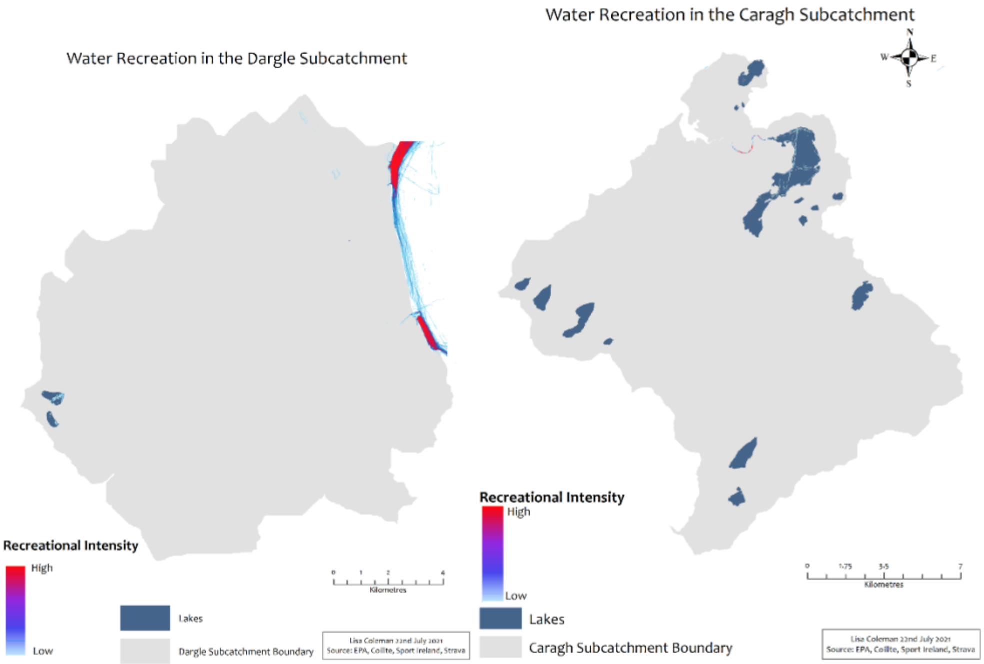

Figure A4.11. Swimming in the INCASE catchments.

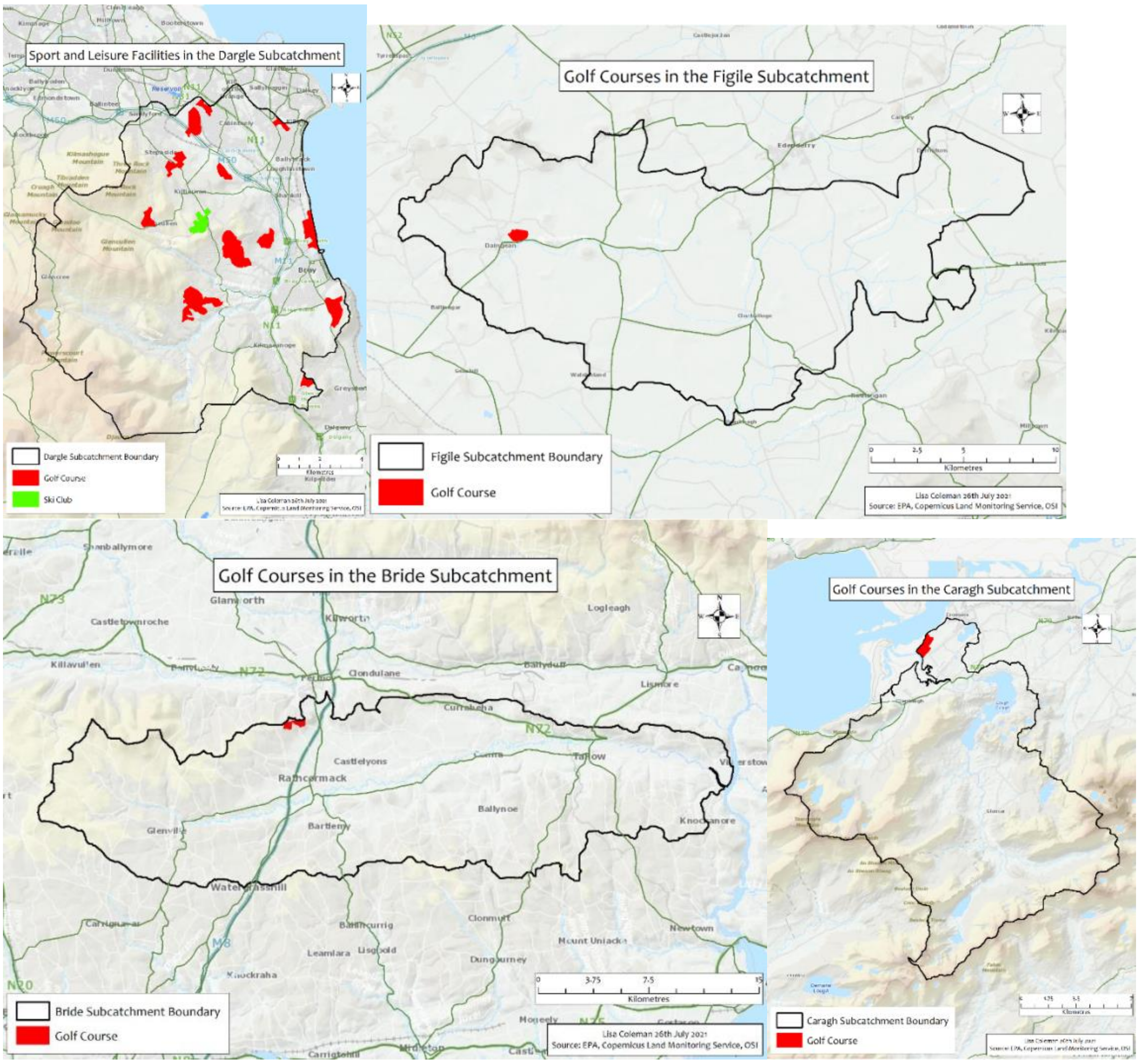

Figure A4.12. Golf in the INCASE catchments

Linking recreational activity to an ecosystem: Walking in INCASE forests

One of the strengths of the SEEA-EA comes from linking between ecosystem and ecosystem service. To further examine this linkage for the INCASE catchments and due to a relative lack of directly observed recreational data, a spatial modelling approach was explored for walking in forests based on work by Cullen *et al.* (2021).

Modelling approaches for estimation of recreational ecosystem services are not new with various methods used for estimating this ecosystem service flow. Vallecillo et al. (2019) used a model known as ESTIMAP which spatially links potential supply of recreational space from ecosystem with estimated demand (based on human population) to estimate number of visits across various ecosystem types across Europe. Another approach advocated by the INVEST model (REF) and demonstrated by Schirpke et al. (2018) is the use of geo-referenced pictures as a proxy for recreational activity allowing spatial estimation of recreational use and intensity in the Alpine regions of Europe.

The model used for the INCASE catchments is based on the work by Cullen et al. (2021). In their work, they initially define the supply for the ecosystem service, a 'recreational forest', based on work by Upton et al. (2015). Briefly, this was achieved by interacting a map of forests and a map of forest paths[31] obtained from OpenStreetMap deeming those inclusive of such paths, recreational forests. Data on the forests, including the level of broadleaf cover was based on use of Copernicus HRL.

The demand for recreational forestry was based on a survey of Coillte, the Irish national forestry company operates a number of visitor counters in their forests across the country and a number of these are located within or near the Dargle catchment. None of their counters are located in or near the other INCASE catchments.

Table A4.26a. Results of model of forest visits

	Coeff.	**St. Err.**
Neg. binomial		
Age	-0.0707**	0.0336
Age squared	0.000746**	0.000357
Access to car	1.402***	0.260
Social group A	1.069***	0.361
Social group B	0.566***	0.209
Social group C	0.395**	0.197
Income (€,000s)	0.0343***	0.00875

[31] Forest paths were based on OSM defined routes within forests which indicated pedestrian or other recreational accessibility. These included footways, tracks, cycleways, bridleways, and paths.

Income squared (€,000s)	-0.000448***	0.000103
Distance to forest	-0.158**	0.0649
Forest size (ha)	0.00237***	0.000799
Forest size squared (ha)	-1.25e-06***	3.75e-07
Mostly broadleaf	0.419***	0.160
Urban area	-0.578***	0.185
Constant	2.200***	0.629
Logit		
Age	0.200***	0.0408
Access to car	-2.488***	0.724
Mostly broadleaf	-1.926***	0.660
Urban area	-2.486***	0.790
Constant	-10.86***	2.826
NTotal	988	
NZero	375	
LL	-2685.54	

Robust standard errors reported, *** p<0.01, ** p<0.05, * p<0.1

Table A4.26b. Results of model of forest visits

INCASE Catchment	Model Estimated Forest Visitors	Estimated Population for Small Areas allocated to Recreational Forests	Average Number of Forest Visits

Dargle	1,122,764	144,063	7.79
Figile	101,885	13,986	7.28
Bride	120,320	15,992	7.52
Caragh	39,269	5,123	7.67

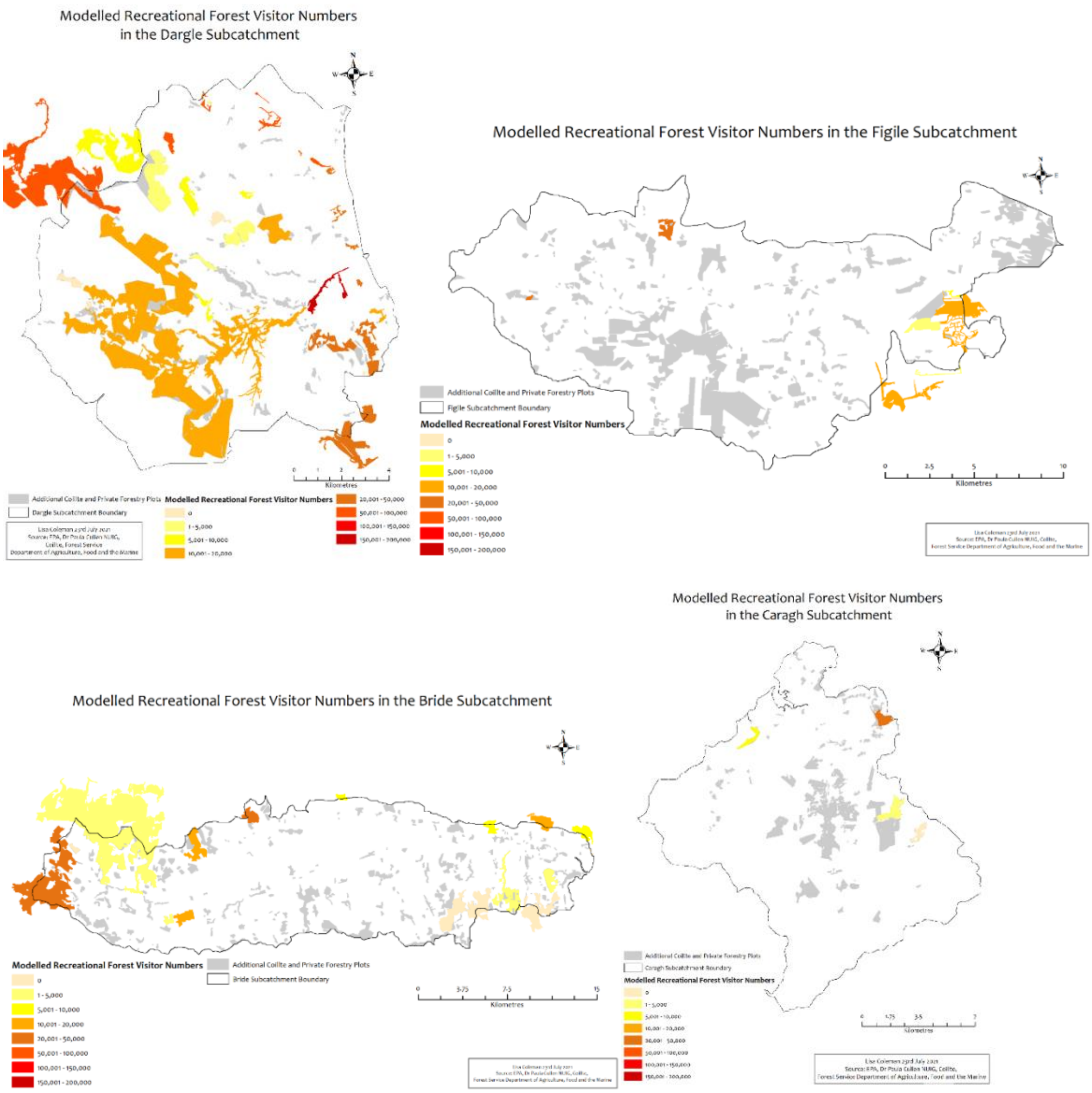

Figure A4.13. Modelled recreation in the INCASE catchments

Table A4.27. Results from Coillte data counters

Locations	Model Est.	Coillte Counters by Year					
		2016	2017	2018	2019	2020	
Rathmichael Woods Total	12164			14826	15180	14968	
Glencullen/Tibradden Wicklow Way	91621					7014	199541
Barnaslingan	3270	30045	33209	34082	36663	33381	
Crone	17007	30275	14614	18519	21362	23261	

Tourism and recreational services

Within the SEEA-EA, it is acknowledged that not only locals enjoy the benefits of recreational ecosystem services generated by the ecosystems within their local area but that some types of ecosystems or certain individual ecosystems may draw in tourists from outside the local area to enjoy recreational activities. In Ireland, Failte Ireland estimated in 2019 that tourists in Ireland accounted for expenditure of €5.6 billion with the sector employing between 170,000 and 260,000 with the former figure representing nearly 8% of employment (Failte Ireland, 2021). The same report also highlighted the top five activities enjoyed by tourists in Ireland as walking/hiking, cycling, golf, equestrian activity and fishing, all recreational activities which have an ecosystem contribution. The numbers taking part in these are significant with nearly 2.4 million visitors undertaking walking and hiking in Ireland.

The tourism sector is measured by the SNA and the SEEA-EA highlights the use of tourism satellite accounts in developing indicators for measuring recreational benefits in natural capital accounts. However, in Ireland these accounts are still in development (CSO, 2019). If tourists are coming outside the ecosystem, they will be classed as exports under the SEEA-EA (UNSD et al., 2021, section 7.41) while visitor numbers interacting with an ecosystem should form part of the main ecosystem account, a supplementary account for businesses that rely on visitors may be included but businesses should not form part of the main account, only their visitor numbers.

An example of an ecosystem within one of the INCASE catchments that is drawing in tourists is that of peatlands in the Figile catchment. While peatlands as measured under CORINE within this catchment are relatively common covering 32% of the catchment and even within Ireland are a common landcover (c. 20%), these are very rare habitats at global scale accounting for less than 3% of terrestrial landcover internationally.

While CORINE classes peatlands as one ecosystem type, this classification misses the variety of peatland and peatland linked ecosystems in reality. Peatlands in the past were often exploited for fuel or drained for other land use changing them into degraded ecosystems. The INCASE project notes that in the Figile only a small area of intact raised bog remains and one of these sites is at Lodge Bog which is managed by the nearby IPCC and their average visit numbers the period 2017-2019 were c. 2300 annual visitors to the Bog of Allen Nature Centre is beside Lodge Bog (IPPC, 2019, IPPC, 2018).

Two other peatland sites within the catchment also receive recreational visitors and tourists, these are the Lullymore Heritage Park which focuses on peat bog heritage and restoration of peatlands and attracted c. 55,000 paying visitors in 2019 (pers. comm. Ray Stapleton, 2021) while a windfarm built on cutaway peatland at Mount Luca run by Bord na Mona estimated average annual visitor numbers of c. 36,000 for the period 2016-2020 with over 46,000 in 2020 (pers. comm McCorry BNM, 2021). These numbers show a mixture of local and tourist demand and more work is required to estimate the tourist contribution both within the catchments and then to allocate to each ecosystem type.

4.1.4 Abiotic flows

4.1.4.1 Peat

Household peat use for fuel

Peat use for fuel purposes is classed as an abiotic flow. Traditionally peat has been used by many Irish households as a source of fuel, mainly for heating purposes (Kennedy, 2013) with many households having turbary rights to cut their own peat for fuel in nearby peatlands.

Bullock et al. (2012) estimated circa 30 wet tonnes peat use for household per year in their analysis which when adjusted for moisture content (wet peat 90%) to turf (30-40%) (Andriesse, 1988) would give an estimate of circa 5 tonnes of peat a year. This is a lot lower than other estimates of 15 tonnes per household of turf (NPWS) or 10-12 tonnes (Norton, 2021). These figures are slightly higher than the 8 tonnes of turf estimated by Kennedy (2013) for the 19th and early 20th century in Ireland. Using the more conservative modern figures of 10 tonnes of turf and 40% moisture content, the amount of wet peat extracted at 90% moisture content is estimated to be 60 tonnes wet peat per household.

For this analysis we assumed that only households within the catchments use peatlands for domestic fuel extraction. Note that this is a strong assumption and assumes no import or export. Using census data for fuel use per household at Small Areas for the 2016 census (CSO, 2017) level the following number of households and the percentage of households in each catchment were estimated to be using peat as their fuel source (**Table A4.28**).

Table A4.27 INCASE catchment households using peat for domestic use.

INCASE Catchment	Number of households using peat	Percentage of total households in catchment	Estimated annual wet tonnage of peat used based on 60 tonnes per household.
Dargle	52	0.15%	3,120
Figile	1,451	50.52%	87,060
Bride	11	0.24%	660
Caragh	215	23.57%	12,900

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Appendix 4.2 Economic Impact Assessment

The Economic and Environmental Impact of the Agriculture and Climate Strategies to 2030

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Abstract

This paper considers trends in animal growth in Ireland over the period 2010-2020 and considers projections to 2030 based upon current trends to explore the economic and environmental impact of these changes. Some key findings:

- Natural Capital is very complicated – Principal Component Analysis would indicate that there are a lot of independent dimensions – difficult to downscale to a single or few indicators
- An impact both of Natural Capital to Agriculture and from Agriculture on Natural Capital
- Natural Capital indicators explain quite a higher proportion of variance in agricultural outcomes – future work to explain differences in trend
- While there has been improvement in environmental efficiency, the extra 900000 animals have dominated the improved efficiency

The paper reviews various policy documents and evaluates the theoretical drivers of these policies and took some of the main policies to assess the impact to 2030 on economic and environmental outcomes. Some of the main proposed policies are considered.We find that, looking forward, current policies can only have minimal impact. Improved environmental efficiency is good, but to deliver sustainable intensification, it is necessary to be able to manage numbers. However the policy levers currently available are weak.

Analytically modelling frameworks currently have limited capacity to incorporate nature or biodiversity impact. This seriously diminishes the capacity of policy to develop legally binding targets in the biodiversity sphere as there is no identification of where gains can be made. As

a result, without putting the ‘health of our natural capital’ to the fore, we are unlikely to lead to improvements in biodiversity.

The Economic and Environmental Impact of the Agriculture and Climate Strategies to 2030

1. Introduction

Addressing climate change is the focus of an increasing number of international and national policies (Schmidt and Fleig, 2018).. The Paris Agreement set a target to limit the temperature increase to below two degrees Celsius compared to pre-industrial levels. To achieve this, global commitment to a reduction in greenhouse gas emissions (GHGs) is required. The European Union (EU) has committed to a 55% reduction in GHGs by 2030 compared to 1990 levels and a 2050 goal of climate neutrality. Globally, agriculture emits approximately 16.5% of all greenhouse gas emissions (Twine, 2021)(Twine, 2021). Reducing emissions from agriculture to aid in meeting emission reduction goals has become an important part of new agricultural policy particularly within the EU (REF).

Due to the high proportion of global emissions associated with agriculture, a significant portion of climate research has focused on identifying mitigation measures for agriculture to reduce emissions (Fellmann et al., 2021; Panchasara et al., 2021; Sapkota et al., 2019). A number of studies have examined the efficiency of these mitigation measures in terms of emission reductions versus cost with the use of marginal abatement cost curves (Fellmann et al., 2021; Lanigan et al., 2019; Sapkota et al., 2019). Generally win-win methods are favoured where undertaking the measures results in higher profits for farmers as well as low-cost high-impact measures.

Alongside the focus on climate change, other environmental goals are also in place. Two are particularly relevant for agriculture, improving water quality and biodiversity which are a policy focus at both a global level and within the EU (REFS). Previous research has identified both trade-offs and synergies in addressing each of the environmental goals (Frisvold and Konyar, 2013; Ortiz et al., 2021; Wilcock et al., 2008). Also important is understanding the impact that achieving environmental goals will have on the wider economy. Input-output modelling incorporating Life-Cycle Analysis (LCA) is one method that enables examination of both. Input-output models map the flow of economic activity between sectors within an economy and trade outside of the economy. The addition of LCA to an input-output model allows for resource use and pollution to be examined in the context of these flows. REFs re.

simulations.*IO LCA explanation Disaggregation foreign production*. Natural capital gap? This is the gap this paper aims to fill.

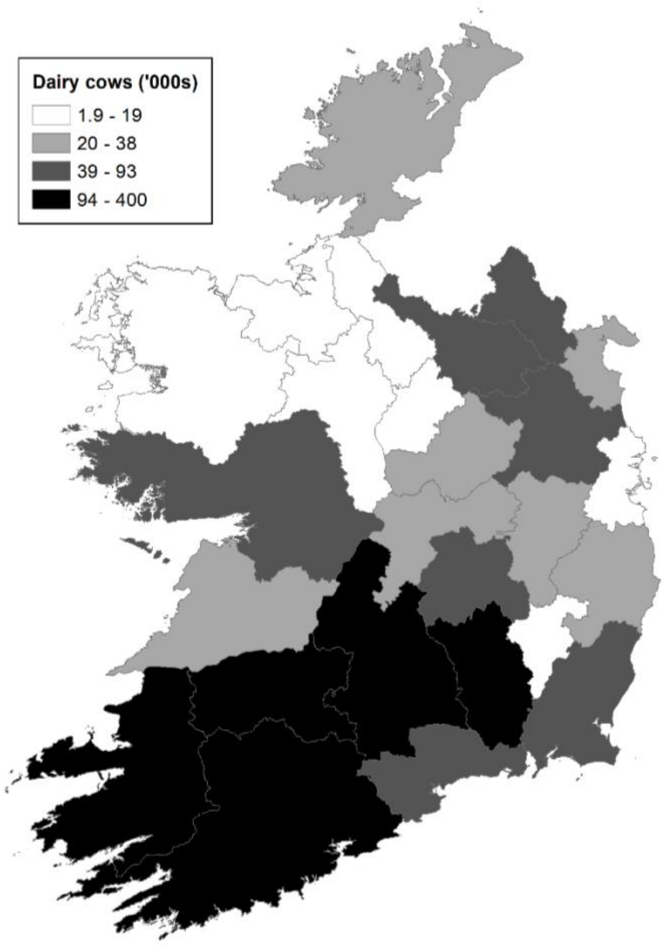
In the context of the Republic of Ireland, the impact of meeting the 2030 climate goals on the economy as well as natural capital is examined. Ireland presents an interesting case study as the ruminant sector is largely grass-based hence has the lowest carbon footprint for dairy products and the fifth lowest in the EU for beef (Leip et al., 2010). At the same time, due to a relatively small manufacturing sector, agriculture contributes a higher proportion of total emissions than other EU member states. Under the Climate Action Plan 2023 Ireland has agreed to reduce emissions by 50% by 2030. To achieve this a 10% reduction in methane emissions has been targeted alongside reductions in other greenhouse gases. This paper employs input-output analysis to examine a scenario where 10% methane reduction is achieved and the impact this will have on both the economy and environment. Input-output modelling is employed to examine the flow on effects of changes in structure or value of the agriculture sector. Information fed into this model includes a land model and animal model in order to disaggregate the agricultural sector for more accurate results.

The remainder of the paper is split into five sections. The next section outlines the context of the research, the agricultural sector in Ireland. This is followed by an examination of the methods proposed to reduce agricultural emissions in section 3. Section 4 outlines the methodology and data used. The results of the scenario modelling are presented in section 5. These are discussed and conclusions drawn in section 6.

2. Agricultural sector in Ireland

The Republic of Ireland has 135 thousand farms with an average farm size of 33.4 hectares (CSO, 2021). The sector is dominated by livestock. The sector has a high reliance on grazing and conserved forage enabled by extensive grasslands that account for 58% of the total land area (Eurostat, 2021. Predominantly the farms are family-owned dairy, beef and sheep farms (CSO, 2021). As of 2020, 55% of farms were beef, 11% dairy, 13% sheep and 3.4% tillage with the remaining split between mixed farming, and other animal farming. The highest animal numbers are in the poultry sector (16.5 million), followed by cattle (7 million), sheep (5.5 million) and pigs (1.6 million).

Figure 1. **Dairy cow numbers by county June 2021 ('000s) (Source: CSO)**



Within the dairy farms, they differ based on the treatment of calves. Predominantly, male calves are sold within a few weeks of birth with sufficient female calves kept and reared as replacements. This represents approximately half of specialist dairy farms (Brock et al., 2022). The remaining farms, in order of commonality, also rear the male calves alongside the females, sell all calves and finally raised female calves on external farms (Brock et al., 2022). Dairy farms are predominantly in the southwest of the country as can be seen in Figure 1.

Beef farms also have variance with the most common being suckler herds numbering approximately 50 thousand. Within suckler herds the most common type is where the calves are raised and sold as weanlings with replacements kept (Brock et al., 2022). The next most common, the calves are kept for longer (between 12 and 20 months). Other variations include suckler herds without replacements kept, herds where the animal is kept from birth until slaughter and beef pedigree herds (Brock et al., 2022). There are also more than 15 thousand store/rearing herds (Brock et al., 2022). These farms are non-breeding and focus on rearing

weanlings from both the beef suckler herds and dairy sector. Finishing herds also represent a significant portion of the beef sector numbering approximately 15,000 (Brock et al., 2022).
Farm size differs significantly between the sectors with dairy and tillage farms being nearly twice as large on average (approximately 65 hectares) compared to specialist beef and sheep farms (CSO, 2021. Geographically the farm systems differ in their locations. Dairy and pig farms tend to be in the south of the country while sheep farms and poultry farms are predominantly in the north and west. Beef farms are split between northern, western and southern parts.

Trends

Figure 6 describes the trend in the main aggregates, total cattle and cows and the number of dairy and other cows. Total cattle numbers declined after the foundation of the state in 1922 by about 10% to a low point in 1948, not reaching the same numbers until 1954. Although total cattle remained relatively static during the economic war, breeding cow numbers increased until 1936. After the Anglo-Irish Agreement in 1938, there was no noticeable recovery due to the onset of the Second World War, with numbers declining further after the war, with a recovery not beginning until 1949.

After blips in 1957 and 1968 total cattle numbers more or less rose each year until peak cattle numbers in 1975 after joining the EEC. The Calved Heifer Subsidy Scheme was an important policy driver during the late 1960's in advance of the higher supported price within the EEC from 1973 and anticipated beforehand. While cattle numbers rose in the 1960's, feed crops did not keep pace, so that bad winter of 1965-66, required additional concentrate feed, resulting in lower cattle the following two years (O'Connor, 1971).

This was followed by a bumpy decline from 1974 to 1984, with slight recovery before a lower point in 1988 from a peak of 7.41m to a low point of 6.46m, a decline of nearly a million animals. After a peak in 1979, dairy cow numbers fell slightly to 1981, before increasing again to a slightly lower peak in 1984 when milk quota was introduced. With milk volumes fixed and rising milk yields, the number of dairy cows began a rapid descent to a low point of just over a million in 2005 or a fall of over half a million cows, approximately one third of the herd. Dairy farmers replaced dairy cows with beef cows, but at a lower rate, so that the total number of breeding cows declined at a similar rate to all cattle to 1988.

There was steady growth numbers after 1988 until a new peak of 7.64million cattle was reached in 1998. Cows increased at more or less the same rate as total cattle until 1993, when the rate of cattle grew faster. The composition of cows however changed radically as the number of dairy cows fell as beef cows grew, so that the new norm for the next decade and a half was similar numbers of dairy and beef cows of about one million each.

However despite the number of beef cows staying relatively flat, total cattle began a downward trend again to a near low point of 6.49m in 2011. The CAP Health Check in 2008, with a gradual increase in quota until its abolition in 2015, saw a gradual growth of dairy cows to 2015 and a rapid rise afterwards, so that the number of dairy cows in 2020 were near the peak in 1979, or 28% above pre quota levels. On the other hand beef cows decreased at a lower rate of 13% over this period.

The number of farms has been decreasing over time. There was a decrease of 3.4% between 2010 and 2020, continuing historical trends. At the same time farm size has been increasing, on average, with a two third hectare increase between 2010 and 2020. This has been driven by a ten hectare increase in size, on average, of dairy farms from 55 hectares to 65 hectares. Tillage farm, mixed crops and livestock farms and mixed livestock farms also grew substantially in size in this period while beef and sheep farms are now smaller on average.

Sheep numbers which had been declining rose in the period between 2010 and 2020 alongside a 10.6% increase in sheep farms. The number of poultry also increased substantially during this time period.

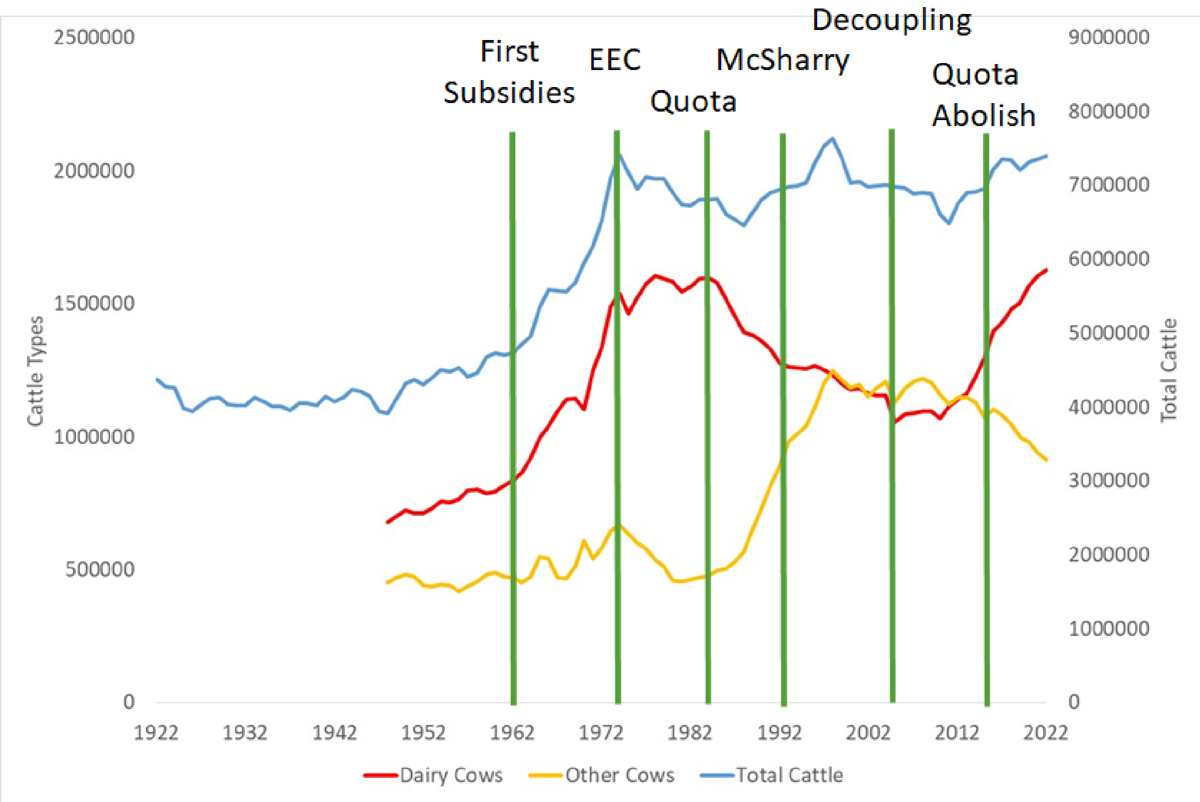


Figure 1. Cattle Numbers 1922-2021 Looking ahead to 2030, it is relevant to see where breeding patterns are indicating. Figure 3 reports the number of male and female calves over time. In the most recent published animal data for June 2022, the number of female calves and so potential breeding animals are continuing to rise and are now higher than the highest from the peak previous number of cattle in 1998. There certainly does not appear to be a change in the trajectory of these animals. It is reasonable to believe, without further mitigation, that cattle numbers will continue to grow and exceed the 1998 peak in coming years.

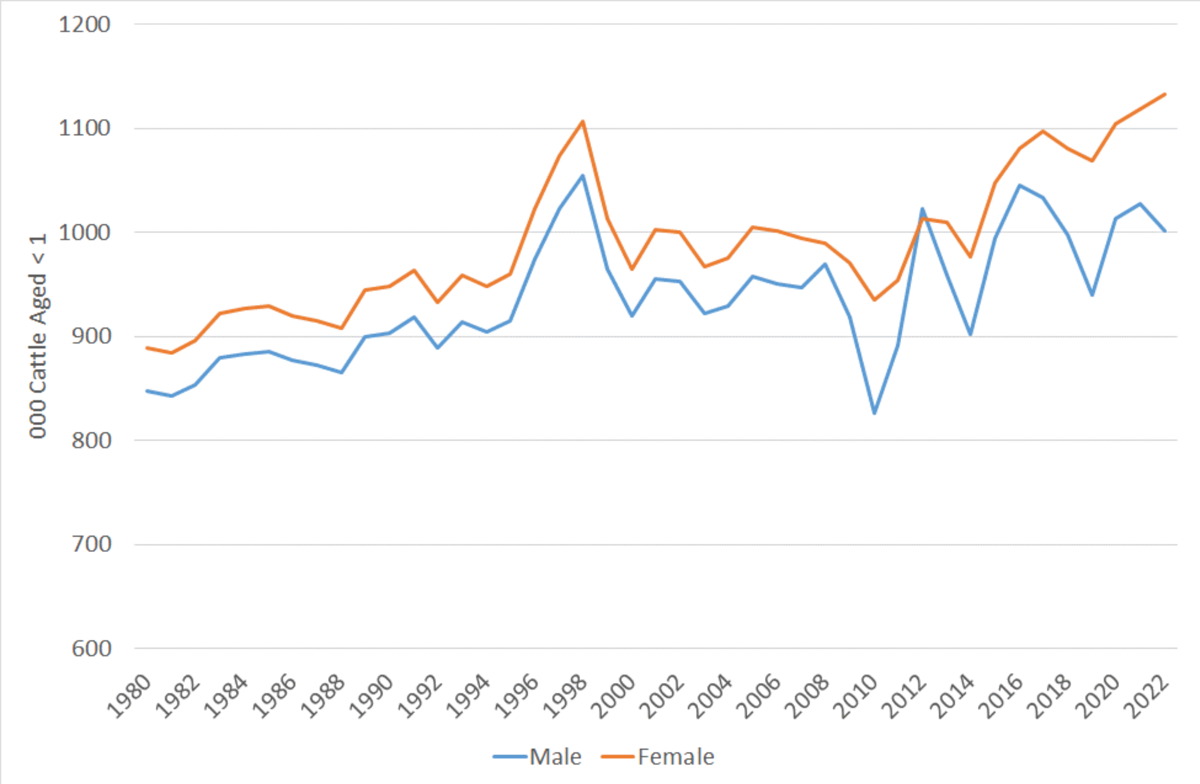


Figure 2. **Male and Female Calf numbers**

Environment and agriculture

Agriculture accounted for 37.1% of Ireland's GHG emissions in 2021[32] (Haughey, 2021) This is high by international standards in the developed world with the European Union average in 2018 being 10.1% (Haughey, 2021). Similar to New Zealand, which also has a high share of agricultural emissions, Ireland has low population density, little heavy industry and a higher importance of agriculture to the economy (O'Mara et al., 2021). Methane emissions from enteric fermentation account for 70% of total agriculture emissions in Ireland. Of the remaining emissions, 30% are of the form nitrous oxide with over a third of these related to chemical nitrogen fertilisers (DAFM, 2020).

3. Reducing agricultural emissions

A number of mitigation measures have been proposed and some implemented to reduce agricultural emissions. Generally these can be classified under three categories: increasing efficiency, replacement of high emitting inputs with lower emitting alternatives and land use change. Reducing the production of the agriculture sector has been discounted as an option

[32] EPA Greenhouse Gas Emission Statistics

due to Ireland's relatively low emissions intensity in relation to other countries (Lanigan et al., 2018; Leip et al., 2010). Reducing production would likely result in higher global emissions if other more emission intensive countries were to increase production to make up the shortfall.

Theoretical Framework

There are a number of competing goals for agriculture. The first is income generation for each farm f,

$$\sum_f Y = \sum_f \left[\sum_s (p_s . f(A_s,\ L_s)) - c.\, g(A, L) + S\right]$$

taking a simple animal based system, where income Y is a function of the number of animals A,[33] the land base L, output drawn from a production function $f(\quad)$ and costs drawn from a cost function $g(\quad)$, incorporating for example, the main direct costs fertiliser, feed and crop protection expenses and overhead costs and respective prices p and c. Within a farm there are can be different systems s such as dairy, beef , sheep, tillage, each with different land use, prices and intensity. Public policy contributes to income via subsidies S.

Income can increase if

- Prices for output increases or where there is a shift from a lower income sector to a higher income sector such as dairy from beef
- The number of animals increase
- The land increases
- The stocking rate increases
- The Yield increases
- The cost price falls relative to output prices
- Cost efficiency rises
- Subsidies increase

Typically the supply curve is upward sloping, so that supply increases with price or margin. Therefore the volume supplied will rise as the margin goes up. The dairy sector with a

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[33] Where $A = \sum_s A_s;\ L = \sum_s L_s$

relatively high margin per hectare and per livestock unit, rapidly increased supply once the supply constraint of milk quota lifted. Ongoing yield increases from improved genetics also increase output volumes. For the cattle sectors, it is not quite as clearcut. Nominally the market net margin per hectare is negative for many farms. However as part of the net margin contains sunk costs such as interest or depreciation that do not decrease as stocking rates decrease, we find that the cash profit, excluding these costs, is mainly positive. With a relatively low return to labour due off-farm employment or the availability of social welfare pensions or payments and the high cost of making a change, farmers are willing to continue production at relatively low cash profits. However more than marginal changes are slow as additional investments are required to scale-up and there are fewer animals on which to cover interest costs or cover replacement assets costs if stocking rates were to be reduced .[To do rephrase a bit]

There are a number of environmental goals. The currently most visible is carbon emissions, which are generated from a number of sources including, methane produced by animals $m(A_s)$, nitrous oxide mainly from fertiliser which depends upon the number of animals and the nature of the land, $n(A_s, L_s)$ carbon emissions from energy use $e(A, L)$.

Total emissions are therefore

$$\sum_f CO2 = \sum_f \left[\sum_s \Big(m(A_s) + n\big(g(A_s, L_s)\big)\Big) + e(A, L)\right]$$

Where each component is adjusted for its global warming potential. Total emissions fall if

- The number of animals reduce
- The emissions per animal reduce
- The amount of fertiliser or feed (which depends upon fertiliser) is reduced
- The energy use is reduced

The emissions per unit product or emission intensity are also relevant, denoted in lower case:

$$co2 = \frac{CO2}{f(A, L)}$$

In terms of a given amount of food demand a lower emissions intensity reduces total emissions. However within the European Union targets are set nationally and with the advent of sectoral carbon budgets in Ireland in 2022, there are sectoral reduction targets to 2030, with agriculture expected to deliver 25%.

While carbon emissions have a national or indeed a global effect, water quality is impacted within a river catchment, c or within the river system. The stocking rate is particularly relevant:

$$sr_c = \frac{\sum_{f,c} A}{\sum_{f,c} L}$$

The nutrient load will depend upon the stocking rate as animals convert feed into wastes and the fertiliser inputs, z_c

$$nl_c = n(sr_c, z_c)$$

Water quality will depend upon the catchment nutrient load, the hydrological system incorporating geology, soils, slope, drainage characteristics H_c , and the rainfall R_c The hydrological characteristics contain quite a complex set of characteristics and complex interactions with rainfall and stocking rate.

$$WQ_f = w(nl, H_c, R_c)$$

Policy measures tend to refer to the farm level stocking rate

$$sr_f = \frac{A_f}{L_f}$$

However, the relationship between the farm stocking rate and water quality depends quite significantly on the setting of the farm relative to water, the hydrological system and the wider catchment stocking rate. A highly stocked farm on a low stocked catchment will have a lower impact than a highly stocked catchment. Having a common Nitrates vulnerable zone for the country is a massive simplification, with a risk that some farms that are compliant with the regulation cause damage, while other farms, given the structure of the catchment, could farm more intensively at catchment level.

The relationship between biodiversity and farming is however much more complex, depending on biodiversity objective and the nature of the agricultural activity. The relevant spatial scope varies. For some issues such as habitats for birds or large mammals, it may be the landscape scale. Water ecology such as the habitats for the freshwater pearl mussel (*Margaritifera margaritifera,* listed on Annex II and Annex V of the Habitats Directive) may be catchment specific. At the other end of the scale, field or more granular scales may be the most relevant scale. Of course in an ecological system, there are synergies between all dimensions. It is challenging therefore to create system wide limits that have relevance at each spatial scale. There may be synergies between what neighbouring farms do in a habitat, depending upon the ecological goal or objective.

Without diminishing the need for solutions for all of these environmental public goods, we draw out some of the implications for carbon and water quality. However, clearly pressures from absolute animal numbers are also relevant for biodiversity.

Proposed Solutions – Sustainable Intensification

One of the most important strategies linking food and the environment at the moments is sustainable intensification which has four pillars (Garnett et al., 2013)

- The need to increase production
- Increased production must be met through higher yields since increasing the area of land in agriculture carries major environmental costs.
- Food security requires as much attention to increasing environmental sustainability as to raising productivity.
- SI denotes a goal but does not specify a priori how it should be attained or which agricultural techniques to deploy.

The approach thus highlights the need to increase protein and energy production via higher yields, while minimising the land or environmental footprint. It emphasises the dual agri and environmental approach while recognising that there are multiple pathways depending upon local conditions on delivering these goals.

Due to the high proportion of GHG's associated with agriculture, reducing the emissions from the sector is integral to Ireland meeting its climate goals. In 2022 the Government, as part of its carbon budgeting strategy has set a target of reducing emissions by 25% between 2018 and 2030, a total reduction of about 6 million tCO2. The Minister for Agriculture indicated that change will be voluntary for farmers.[34] This is quite a challenging target, as in recent times, the largest decline occurred between the peak animal numbers in 1997 and 2011 during the financial crisis of 15.6%.

There are various roadmaps that outline solutions to move in the direction of emission reductions. The Teagasc Marginal Abatement Cost Curve (Lanigan et al., 2019) has been developed to consider the net impact and associated costs of various carbon mitigation

[34] https://www.farmersjournal.ie/emission-reduction-measures-to-be-voluntary-for-farmers-712989

strategies including afforestation.[35] The Teagasc document categorises measures in three dimensions:

- Agricultural Mitigation
- Land-use and Land Management mitigation
- Energy mitigation

The report quantifies the cost per measure of delivering emissions reductions. The report identifies 7.7 mtCO2e per annum potential saving for the periods 2021-2030. These are divided between agricultural mitigation (2.89), land-use mitigation (3.5) and energy mitigation (1.31m). Although the total identified emissions exceed the total required reduction for the sector in the carbon budget, only the agricultural mitigation measures are counted within the agriculture sector as the savings identified in the latter two areas are accounted for in other parts of the carbon budget. The rigidity of the carbon budgeting where carbon reductions that are realised for non-agricultural purposes (which are in effect the majority of feasible reductions) is quite a strong limitation on the budgeting procedure, particularly as many of the goals generate win-wins, especially when the value of the carbon abated is included.

Agricultural mitigation measures are divided into two types:

- Efficiency measures, which indirectly reduce methane by reducing the number of animals required to produce a given amount of meat or milk, with the potential reduction by about 40% of agricultural mitigation.
- Technical measures impact on emission factors and thus reduce the emissions associated with a given activity include fertiliser formulation, crude protein and fats in diets, slurry amendments and land spreading management of animal manures, with the potential reduction by about 60% of agricultural mitigation.
- Agricultural land use change. While many of the land use changes suggest changes to other sectors such as afforestation, land use changes are also proposed to reduce the emissions of the agriculture sector. Particularly, an increase in the tillage area would result in lower importing of foodstuffs for use in the food sector as well as for livestock reducing emission.

[35] https://www.teagasc.ie/media/website/publications/2018/An-Analysis-of-Abatement-Potential-of-Greenhouse-Gas-Emissions-in-Irish-Agriculture-2021-2030.pdf

Efficiency measures

We now discuss in more detail the efficiency measures suggested. Increasing efficiency results in less emissions per unit output, for example lowering the emissions per litre of milk through increasing the output of a dairy cow for the same amount of inputs. A number of measures have been proposed to improve efficiency of the agricultural sector in Ireland.

Improved output yield per animal is the most significant measure within the Teagasc MAC curve analysis. In order to aid this goal, genotyping the national cattle herd is one of the actions proposed in AgClimatise with the goal of improving breeding programs.

The dairy sector has long used breeding indexes. The current system the Economic Breeding Index (EBI) was introduced to replace the Relative Breeding Index (RBI) which was employed for over 20 years. The RBI focused on genetic improvement in milk production at the expense of herd fertility due to an underestimation of the antagonistic relationship between the two (Evans et al., 2006; O'Sullivan et al., 2020). The EBI comprises seven factors related to profitable production. Measures of fertility and milk production are of equal importance with a 33% weighting each with measures of calving performance, beef performance, cow maintenance, cow management and health making up the balance.

The efficiency gains from the use of the index in terms of reducing emissions from the sector come in a number of forms. First, improving the milk production per cow results in lower emissions for the same level of output. Research has shown that herds with an EBI in the top 20% produce 0.14kg less carbon emissions per kilogram of milk than the bottom 20% (corrected for fat and protein content) (ICBF, 2021). Secondly, improving the fertility of the national herd has a number of flow -on effects to carbon emissions. Fertility is the number one reason for involuntary culling of a dairy cow (Dallago et al., 2021) Increasing the fertility of the herd means that cows are kept longer before being culled. This, along with health improvements that can also be achieved through genotyping, means that less replacement cows are needed. This reduces the emissions per unit of output and also increases the profitability of the farm.

The beef sector in Ireland has a shorter history with genomics. The first Beef Data and Genomics Programme (BDGP) began in 2015 and will finish in 2022. There are two indexes for beef cattle, Maternal Replacement (MR) and Terminal, each with different genetic goals with MR focused on maternal traits such as calving difficulty, calving interval etc. as well as the traits that can be passed to offspring while the T index focuses only on offspring traits such as weight and fat levels with the assumption that these offspring will all be sold to slaughter (Quinton et al., 2018). The proposed replacement for the BDGP, the Suckler Carbon Efficiency Programme, is designed to reduce absolute emissions by improving environmental sustainability and genetic merit of the suckler herd. This is in line with Ag Climatise Action 3 which proposes having the entire national herd genotyped by 2030 (DAFM, 2020). The goal is to also record beef weights on 70% of herds increased from the current level of 30% (DAFM, 2020). Quinton et al. (2018) examined the likely impact that the traits contained in the indexes have on emissions. Improvements in some traits were found to increase the emissions per animal and per kilogram of meat while others resulted in a decrease. Overall they found the current trend suggests a 0.4% reduction in annual carbon emissions with a reduction of 34 kilotons (kt) after 5 years assuming the herd size remained stable. Under a scenario with increased use of higher quality AI bulls (30% of pedigree herds and 20% commercial suckler herds) a 1.89% annual reduction in emissions per kilogram of beef is predicted representing a reduction of 229 kt after 5 years (1952 kt after 20 years).

Better integration of the beef and dairy sectors is also promoted as a method to reduce emissions. With improved fertility of dairy cows resulting in a longer time before culling the level of replacement cows can be reduced. The extra calves from this can be integrated into the beef system. This will be aided by the other goal of transitioning away from stock bulls as quality beef sires can be used.

Another focus of the AgClimatise Strategy (DAFM, 2020) to reduce emissions is the improvement of grassland management. A particular focus is on expanding the reach of the Grass10 campaign launched by Teagasc in 2017. The goal of the campaign is to achieve 10 tonnes of grass dry matter per hectare per year and 10 grazings per paddock per year. This aids in emission reduction in a number of ways: higher quality feed reduces the methane emissions due to animal productivity improvements, less methane emissions from a shorter manure storage period and lower use of imported feed.

As efficiency gains, all the efficiency measures within the MACC are identified to be win-wins. For technical measures, about 15% relate to win-wins with 85% relating to additional costs. Typically efficiency measures operate where the amount of produce per animal or per hectare (the yield) increases. The carbon reduction comes from maintaining the same production, while reducing the number of animals to produce it.

In other words for an animal system

$$f(A_s,\ L_s) = f^*(A_S^*,\ L_s)$$

Where $f^*(\quad)$ is the output from animal and land with a higher yield:

$$\frac{f(\quad)}{A} < \frac{f^*(\quad)}{A}$$

Maintaining total output, then

$$A_S^* < A$$

So in effect the efficiency results indirectly reducing animal numbers. However as identified above if the supply curve is positive, a yield increase for a profit making farm with capacity to expand should result in more animals not less. At present, dairy farms that are below the derogation limit within the EU Nitrates Directive can increase their stocking rate, while farms that are at their derogation limit can source more land, mainly through long term leasing. For cattle farms it is more complicated. Where there is a negative cash profit, but positive farm income due to decoupled subsidies, then there is no incentive to increase, nor indeed is there an incentive to decrease. For cattle farms that have a positive cash profit, but a negative net margin once depreciation is taken into account and so have a positive marginal cash return to more animals, their decision will depend upon their constraints. With a negative net margin, if increasing facilities will not be an option given the negative net margin or negative return on new investment, where the stocking rate is within their infrastructure constraints, then the incentive will be to increase animals. Therefore delivering reduced emissions via efficiency will require a policy to reduce numbers.

The Ag Climatise Strategy (DAFM, 2020) published in 2020 prioritised a series of 29 measures that could be utilised to achieve carbon neutrality[36], with a series of sub-measures. The strategy does not set out the potential impact of the potential measures. Of identifiable actions, about one sixth relate to efficiency related actions and a little over half related to technical measures. A number of measures focused on air quality issues and ammonia emissions. Much of the strategy related to enabling actions and infrastructure to facilitate delivery, accounting for 60% of measures. As a result, many of the measures had no associated targets (60%).

[36] https://www.gov.ie/en/publication/07fbe-ag-climatise-a-roadmap-towards-climate-neutrality/

Separately, the government has set targets of reduction of 10% biogenic methane (on the 2018 level) and reduction in emissions of nitrous oxide from chemical fertilisers by 50% by 2030 in the nation's agri-food strategy, Food Vision 2030.

The Climate Action Plan published in 2021[37] identifies a range of measures to achieve carbon neutrality by 2050, identifying the specific delivery of between 3.6 MtCo2 reductions and 4.2 MtCO2 from the agricultural sector. About 70% of the gains are proposed to come from technical measures, with the remainder from efficiency gains. The plan again falls well below the carbon budget set out.

Technical measures

Technical measures in the Teagasc MAC Curve analysis and in other strategies reduce emissions via technical changes such as reducingreduce nitrous oxide emissions for example. Reduction in nitrous oxide emissions is intended to occur through the reduction of chemical nitrogen use and the increased use of low emission slurry spreaders. The chemical nitrogen goal is to reduce from the 2018 level of 408,000 tonnes to 325,000 tonnes by 2030. To compensate, liming levels on mineral soils are being targeted to increase to improve nitrogen use efficiency. Alongside this, a target of 90% of farms using low emission slurry spreading by 2027 is set in Ag Climatise. Urea use is also being replaced with protected urea which is intended to require a 12% lower spreading rate for the same effective level of nitrogen. At a European level, Domínguez et al., (2020) considered a suite of mitigation measures that overlapped with the Teagasc MAC. In terms of breed efficiency, they go beyond yield efficiency to incorporate feed efficiency which would reduce emissions per animal.

Technical measures can improve the resource efficiency of agricultural production reducing emissions for a given level of activity. As such they are more likely to realise emissions goals than efficiency measures, which may themselves lead to higher emissions. The challenge relates to adoption. The theory of planned behaviour presents a nice framework to consider adoption and is frequently used in agricultural studies (Senger et al., 2017; Zeweld et al., 2017; Daxini et al., 2019). Behavioural change in this framework relates to personal attitudes, subject norms, perceived behavioural control (or knowhow) and perceived resources (time and money). Another dimension of relevance are transaction costs

$$P(Adoption) = f(pbc, a(l,c), att, sn, tc)$$

[37] https://www.gov.ie/en/publication/6223e-climate-action-plan-2021/

- Perceived behavioural control (PBC). PBC relates to skills or capacity to implement a technical change, know-how .
- Perceived resources. This relates to the time and monetary costs of engagement
- Attitudes. Personal attitudes or values and attitudes to risk that shape an individual's preference function.
- Subjective norms. This relates to social pressure or influence of peers. It is akin to Rogers model of innovation, with a small group of innovators and early adopters, moving before the bulk of the population. It is particularly important for farmers (Daxini et al., 2018).

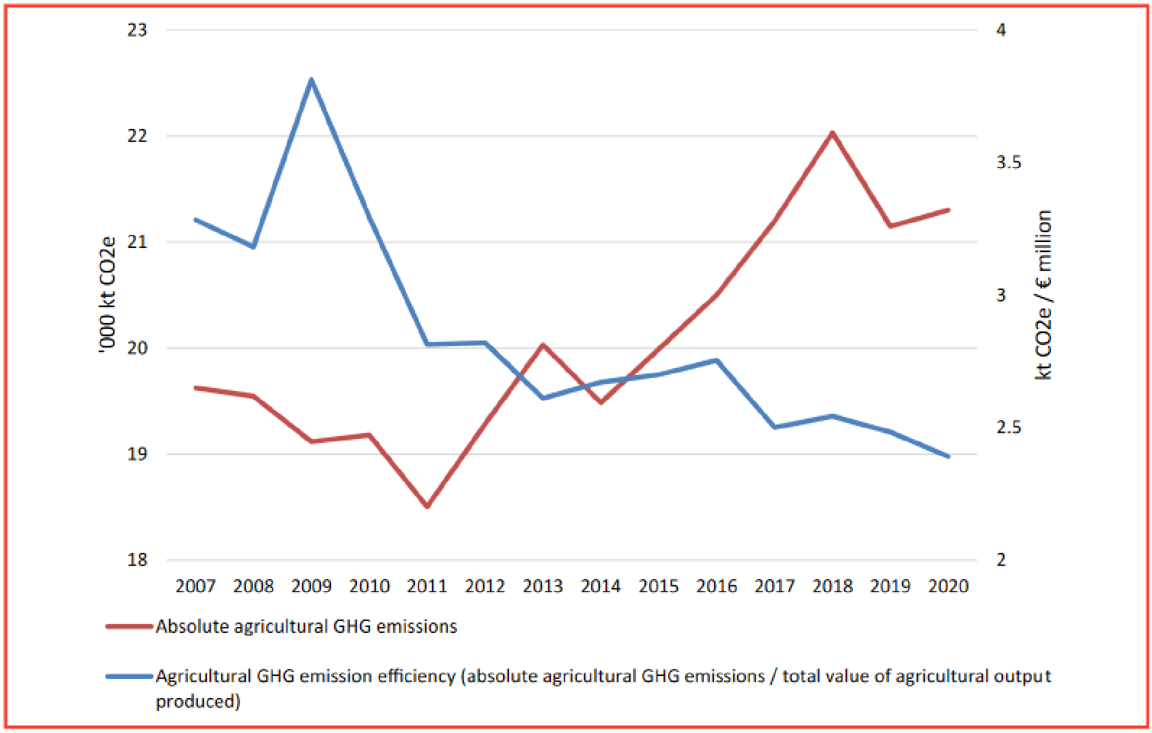


Figure 3. **Total Greenhouse Gas Emissions and GHG Mitigation Efficiency**
Source: TBC

Transaction costs in relation to coordination costs, hassle or inconvenience, diversity in the population, or complexity of the task in relation to adopting technology change are important factors that can influence technology adoption (McCann, 2013; Ugochukwu, & Phillips,2018). Transaction costs like abatement costs increase with the proportion of the population or the scale of change necessary to achieve goals (McCann et al., 2005). Focusing simply on compensating financial losses, while ignoring non-monetary transaction costs are likely to result in a sub-optimal adoption.

In the Teagasc MAC curve, while the efficiency measures are on average win-wins with a negative cost (again indicating the importance of behavioural drivers and transaction costs where it is already financially beneficial to adopt), technical measures typically have a positive cost. Therefore for a given level of farm activity, the financial gap would need to be addressed in addition to factoring in know-how and transaction costs. Depending upon how acceptable the technological change is in terms of subjective norms, the time taken for voluntary adoption will vary.

Relative Carbon Efficiency and National Targets

As a global challenge, influenced by activity globally, the lowest carbon footprint per unit of output will result in a lower total emissions for a given amount of food production. Lorenz et al. (2019) in a meta analysis find that emissions per unit product fall with an increase in milk yield, however for a given yield, pasture based systems had a lower footprint than confinement systems. A recent peer reviewed study by AgResearch New Zealand (Mazzetto et al, 2021) found a similar pattern. However the yields of the pasture systems were in general lower than those of confinement systems, presenting a conflict in terms of sustainable intensification.

There is quite significant variability in relation to Ireland's relative carbon footprint position. Zezza (2017) finds that Ireland has the lowest output per carbon produced within the European Union, so highest carbon per unit output. This is perhaps unsurprising given the composition of the Irish agricultural sector, with high reliance on methane producing beef and dairy cattle as well as sheep. Alternative sources of energy and protein can result in an improved carbon footprint.

However even when one looks at individual product areas, there is quite a variability in conclusions. Lesschen et al. (2011) drawing upon national inventory reports find that emissions in Ireland are amongst the highest per unit product, reflecting the extensive nature of Irish cattle and milk production. However Weiss and Leip (2012) using the CAPRI model to perform a cradle-to-gate life-cycle assessment of the main livestock products found that Ireland had the sixth highest emissions per volume of beef and second highest per litre of milk within the EU. However in a follow up communication with one of the authors Weiss, that the inclusion of carbon sequestration of permanent grassland but which is not part of the IPCC measurement standard would considerably lower the comparative advantage of Ireland's beef and milk production.[38] In a more recent peer study by AgResearch New Zealand (Mazzetto et al, 2021) found a similar pattern to Lorenz et al in relation to milk yield and emissions. Ireland's position for carbon emissions per unit of milk was mid ranked in their global study, with higher emissions than some of the more extensive Southern Hemisphere systems and the Danish confinement system, lower than many developing countries mid table in the EU. Within the EU some confinement systems had a lower footprint such as Denmark,

[38] https://www.irishtimes.com/news/science/where-s-the-beef-outdated-data-leads-to-uncertainty-on-way-forward-1.4262990

while some had higher such as the Netherlands. The pasture based New Zealand system has the lowest emissions. In a comparison of beef carbon footprints with MERCOSUR countries, Alan Matthews, using the FAO GLEAM model found that Irish beef farms had a lower footprint than MERCOSUR Farms.

While extensive arguments are made nationally about Ireland's relative advantage or milk[39] (O'Mara et al., 2021) based upon Weiss and Leip (2012) the general pattern in the wider literature is less positive and are sensitive to calculation assumptions, although on balance Irish Dairy emissions are below average globally and beef emissions are low relative to the Southern Hemisphere. On the face of it, therefore the issue in relation to carbon leakage for beef and in particular dairy products is valid; it is less clear from a system point of view, given the reliance on methane emissions in sheep and livestock production. Other sources of protein and energy would result in a lower carbon footprint for food production, albeit Ireland's soil and climate favour pasture based systems.

Conflicts

While most of these efficiencies could help to reduce emissions in a stable or declining herd, in an increasing herd, improved efficiency may reduce emissions intensity, but depending upon the growth rate of animals, may not result in a fall in total emissions. Public debate has focused on "avoiding a reduction in the herd". For example when carbon budgets to reduce emissions by 25% were introduced, the Minister of Agriculture stated "there will be no instructions issued to farmers to cut Ireland's national herd to meet the emissions targets"[40]. In 2021, he said that "the government's message that maintaining a stable number of animals in the national herd would be done in tandem with reducing the absolute emissions of the sector while improving the carbon footprint of our produce… the focus over the coming decade will be on the increased and early adoption of existing carbon-mitigation measures, while working to develop new abatement measures through research and innovation."[41]. The

[39] https://www.irishtimes.com/sponsored/innovation-partner-profiles/environmental-sustainability-of-irish-dairying-under-spotlight-1.4664248

[40] https://www.irishexaminer.com/news/arid-40929152.html

[41] https://www.agriland.ie/farming-news/national-herd-a-balancing-act-of-new-tech-and-voluntary-diversification/

Taoiseach (Prime Minister) "has dismissed concerns that emission targets will reduce the national herd as "scaremongering".[42]

It comes as the Food Vision Group presented a set of 17 recommendations in its interim report to the Minister for Agriculture Charlie McConalogue. The group, which was established in January 2022, has been tasked with developing and implementing a plan to stabilise and then reduce emissions associated with the dairy sector. However, the IFA said that they will not support exploring a 'cap and trade' model for emissions, and that it was "a quota by another name, which the IFA is completely opposed to".

A Teagasc press release at the Johnstown Open Day in June 2022 said; "The debate is often framed around a cut to the national herd, but there is an alternative, which is the development and deployment of technologies and improvements in the systems of production to reduce emissions. It will be challenging, as the technologies outlined in the 2019 Teagasc MACC are not nearly sufficient. However we have an active research programme and there is a range of additional technologies at various stages in the research pipeline. This includes research to provide more accurate measurements of soil carbon emission and sequestration to help clarify the LULUCF situation and prepare for carbon farming."

Policy Levers

The main policy levers available to manage carbon emissions include

- CAP Basic Payments including compulsory conditional cross compliance measures through Good Agricultural and Environmental Condition (GAEC)
- CAP Voluntary Agri-Environmental Schemes
- Environmental regulations such as the Nitrates Directive

Although it is impossible to summarise the 836 CAP Strategic Plan, which has many diverse goals, there are some common threads relevant to understanding how the policies can influence greenhouse gas emissions.

In relation to conditionality in basic payments, GAEC 1 focuses on maintaining carbon stocks by maintaining the share of permanent grassland, while GAEC 2 focuses on maintaining wetlands and peatlands. Measures when GAEC 10 for arable farmers focus on keeping a share of land non-productive purposes.

[42] https://www.newstalk.com/news/governments-emissions-targets-will-cut-national-herd-predicts-green-senator-1368569

The Eco-scheme for the climate, the environment and animal welfare is a Pillar I measure targeted at with farmers, having the opportunity to opt in or out on an annual basis, where they undertake agricultural practices that will deliver environmental benefits.[43] While there are many measures the most important from a carbon point of view are:

- AP2. Extensive Livestock Production, with an overall limit of 1.4 livestock units per hectare
- AP3. Limiting Chemical Nitrogen Usage, where reduced nitrogen limits are linked to stocking rate
- AP4 Planting of Native Trees, albeit of very small scale, planting a minimum of 3 native trees or 1 metre of hedgerow must be planted per eligible hectare per annum
- AP6 Soil Sampling & Appropriate Liming and thus improving nutrient efficiency

The optional CAP Pillar II scheme, the Agri Climate Rural Environment Scheme (ACRES) is divided into two tiers with measures depending upon their location vis a visvis a via Natura 2000 sites, the presence of specific species or water quality issues. From a carbon sequestration point of view two measures are particularly relevant. Some of the measures have results based payments:

- Low emission slurry spreading
- Low-input grassland;
- Extensively grazed pasture with a maximum nitrogen application
- Tree planting

The Nitrates Directive sets a limit of 170kg/ha of livestock manure. However farmers can apply for derogation conditional on improved management practices of 250 kg/Ha. The Department of Agriculture has indicated that this limit will reduce to 220 kg/Ha in 2023 in areas where water quality worsens. There may also be some other technical requirements.

In general the measures with the programmes incentivise technological changes. However from a behavioural point of view, schemes are merely are costed based on income foregone and costs incurred. They do not incorporate transaction costs or opportunity costs. This has been an issue for agri-environmental schemes for many years and as a result farms that find

[43] If all eligible farmers (c. 129,000 based on 2021 BPS applications) partake in the scheme and bring in all their eligible lands
(c. 4.516 million hectares), the average rate of payment per hectare could be c. €66 (minimum rate of payment). If uptake is only half that (c. 65,000
farmers) bringing in 2.258 million hectares, the average payment rate per hectare could be c. €131 (maximum rate of payment). This maximum rate of
payment will not exceed full compensation for the costs incurred and income foregone regardless of a farmer's choice within the list of available eco-scheme
practices

it cheaper and easier to engage with agri-environmental schemes are the ones to engage, Cullen et al., (2021). As a result, typically extensive beef and sheep farmers are more likely to engage than more intensive dairy farms.

The measures that facilitate efficiency measures include the reduction in the derogation limits and the stocking rate limit on the extensification measure within the Pillar I Eco-scheme. The former is likely to incentivise stick reduction with about half of all dairy farmers currently in the derogation range. For the remainder it provides no additional incentive to achieve efficiency goals. The derogation has been a relatively blunt instrument as there is a flat limit regardless of local water quality or needs. It is also set at a farm level, rather than a catchment level which is the most appropriate for water quality management. For the same reasons as the differential uptake of agri-environmental schemes, the extensification limit is unlikely to directly affect many farms as the farms that have more frequently engaged have lower stocking rates anyway.

4. Methodology

To examine scenarios for meeting emission reduction goals this paper employs input-output modelling. Input-output modelling was developed by Wassily Leontief as a framework for examining the equilibrium behaviour of an economy (Haimes and Jiang, 2001). The model depicts how an output from one industrial sector may become an input to another sector and therefore the dependency between sectors becomes visible (Xu et al., 2020). The structure of an input-output model is a table or matrix representing the flows of products and services between sectors and to the final consumer. Results of changes or scenarios are examined through calculation of multipliers using Leontief inverse matrices.

An analysis of this sort is data heavy and requires a number of interlinking models to understand the impact of changes, such as meeting the methane reduction targets, would have on both the agricultural sector, natural capital and the wider economy. Figure 5 shows the connection between the various models for this analysis.

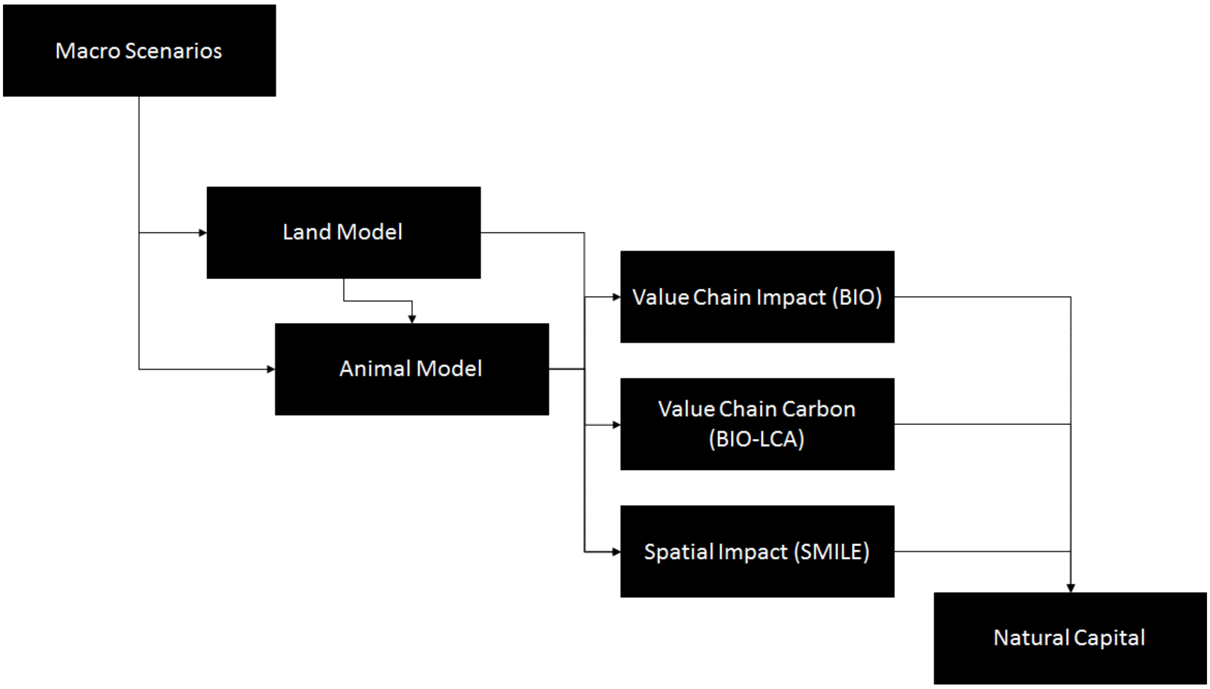


Figure 4. **Model structure**

The input-output model used in this analysis is the BIO model which involves a disaggregation of the Irish bio-economy sector. It was originally created to disaggregate the agri-food and energy sector building on the input-output tables produced by the Irish Central Statistics

Office (Grealis and O'Donoghue, 2015)(Grealis and O'Donoghue, 2015). Since then further sectors have been broken down within the model including the forestry sector and disaggregation of beef sector by animal age to enable more nuanced analysis to be conducted (Ní Dhubháin et al., 2009) (REF for beef). Alongside the BIO model, is an input-output Life-Cycle Analysis (LCA) model named BIO-LCA[44]. An input-output LCA provides an accounting tool for examining environmental issues such as carbon emissions or resource use within the complete supply chain provided by the input-output model (Matthews and Small, 2000). BIO-LCA focuses on greenhouse gases (carbon dioxide, nitrous oxide and methane) from both energy consumption at all stages of the life-cycle as well as process emissions such as animal and soil emissions (O'Donoghue et al., 2018). Emissions are calculated for imports, exports, production including emissions from livestock, energy and transport. Methane emissions from livestock are calculated with simplified emissions factors per unit of livestock based on enteric fermentation and manure management.

Feeding into the input-output models are the Land Model and Animal Model which focus on calculating what changes will occur in land use and animal numbers and type in different scenarios. The land model focuses land use between the different agricultural systems as well as the forage area. Equations used for the land model are found in Appendix A1. The Animal Model is a system of equations used to determine the number of animals and interplay between systems particularly beef and dairy (equations in Appendix A2).

5. **Results**

Historical Changes

As the main sectors within Agriculture, changes in Dairy and Cattle output and their supporting crop based feed inputs drive the economics and environmental implications of Agriculture in Ireland. Table 1 describes the growth rate in land area by system over time. Turning the clock back to 2007, there are a number of periods; the period prior to the financial crisis in 2009 and the bottoming out of cattle numbers in 2011, the period from this low to the abolition milk quota in 2015, the early growth of dairy cows post quota to 2018 and the closer to steady state change post 2018. The period to 2011 is marked by a growth in tillage

[44] For a detailed explanation of the development and structure of the BIO and BIO-LCA model see (O'Donoghue et al., 2018)(O'Donoghue et al., 2018).

area and decline in the area with most animal systems as overall animal numbers fell. Post 2011, after the CAP Health check, the land area of dairy farms started to increase, mainly at the expense of tillage (due to dairy being more competitive for leased land) and as a conversion of mixed farms back to dairy as mixed farms reduced their suckler cows and increased dairy cows. The peak growth rate occurred in the run up to milk quota abolition in 2015 as dairy farms expanded, with the rate of growth declining subsequently. Post 2015, this growth has come at the expense of Tillage and Cattle farms. Total farmed area also declined over this period.

Table 1. **Growth Rate in Land Area over Time by System (2007-2020)**

	Tillage	Dairy	Cattle	Sheep	Mixed	Total
2007-2020	0.005	-0.001	-0.004	0.017	0.002	0.000
2007-2009	0.029	-0.045	-0.093	-0.055	-0.016	-0.060
2007-2011	0.046	-0.040	-0.014	-0.018	0.087	0.001
2009-2020	0.001	0.007	0.013	0.031	0.005	0.011
2011-2020	-0.012	0.017	0.001	0.033	-0.034	-0.003
2011-2015	0.004	0.023	0.017	0.061	-0.043	-0.037
2015-2018	-0.026	0.015	-0.012	0.008	-0.034	0.124
2018-2020	-0.025	0.008	-0.014	0.014	-0.016	-0.007

Source CSO Farm Structures Survey, CSO Census of Agriculture Teagasc National Farm Survey

In order to ground our projections, Tables 2 and 3 describe the trend in factors that influence dairy output. For dairy, the forage area for dairy cows has increased at a growth rate of more than 2% per annum for the entire period between 2011 and 2020. Prior to 2018, the number of dairy animals increased at a faster rate than the increase in forage area resulting in an increased stocking rate over time of about 1% per annum, which is concerning in relation to water quality. Since 2018, the stocking rate reduced very slightly as forage area increased faster than the number of animals. Reflecting higher milk yield, the volume of milk increased faster than the increase in animals. However yields fell in the run up to the abolition of milk quota as farms were still bound by quota while increasing animal numbers in anticipation of quota abolition in 2015. Yield growth of in excess of 2% per annum is very high resulting in Irish dairy production exceeding that of New Zealand over this period. Over time, the land animal concentration has also increased as dairy farms specialised, reducing beef forage and animals and replacing them with dairy cows, with a particular growth in 2016-2018. Another very visible trend is the volatility of the milk price growth with an overall decline in price from a relative high price year in 2011. The 2016-2018 period had high price growth after a very low price in 2016. However in summary, the biggest driver of volume changes and income growth has been land use change, followed by yield gains.

The beef situation is quite different (Table 3). Over the whole period there was a decline in the forage area, with an accelerated decline post quota, albeit with some growth in the period pre-quota abolition. The number of Suckler Cows has decreased at a faster rate than the land area, reflecting the rise in cattle coming from the dairy herd. Overall, there has been a slight decline in the stocking rate between 2011 and 2020, but with a larger decline at the end of the period.

In the absence of major changes such as quotas, volume gaps, trade restrictions or important structural changes in the CAP, it is likely that these trends will continue but at a gradually slower growth rate as some of the initial gains from quota abolition are realised. Given the higher return from dairy than from cattle, the gradual shift of land into dairy is likely to continue, albeit there are limits in relation to the current spatial location of the dairy sector and the land structures. Yield gains are expected to continue as there remains a significant yield gap with other countries in the EU (albeit with different production systems). One would expect growth rates of at least 1% per annum. Changes to derogation rules are likely to limit or reverse growth to the stocking rate.

Table 2. **Dairy Output Components over different periods**

	Dairy Forage	Dairy Cows	Milk Litres	Dairy GO	Stocking Rate	Land Conc	Animal Conc.	Yield	Price
2011-2020*	0.022	0.029	0.046	0.037	0.007	0.016	0.017	0.010	0.007
2011-2015	0.027	0.041	0.065	-0.021	0.013	0.011	0.013	-0.002	-0.037
2016-2018	0.020	0.029	0.043	0.197	0.009	0.039	0.038	0.031	0.124
2018-2020	0.026	0.022	0.037	0.027	-0.004	0.012	0.012	0.020	-0.007

Source: CSO and Teagasc National Farm Survey

Table 3. **Cattle Output Components over different periods**

	Cattle Forage	Other Cows	Non Dairy Cattle	Stocking Rate
2011-2020	-0.006	-0.021	0.001	-0.002
2011-2015	0.009	-0.009	0.008	-0.012
2015-2018	-0.021	-0.030	0.006	0.022
2018-2020	-0.015	-0.033	-0.018	-0.016

Source: CSO and Teagasc National Farm Survey

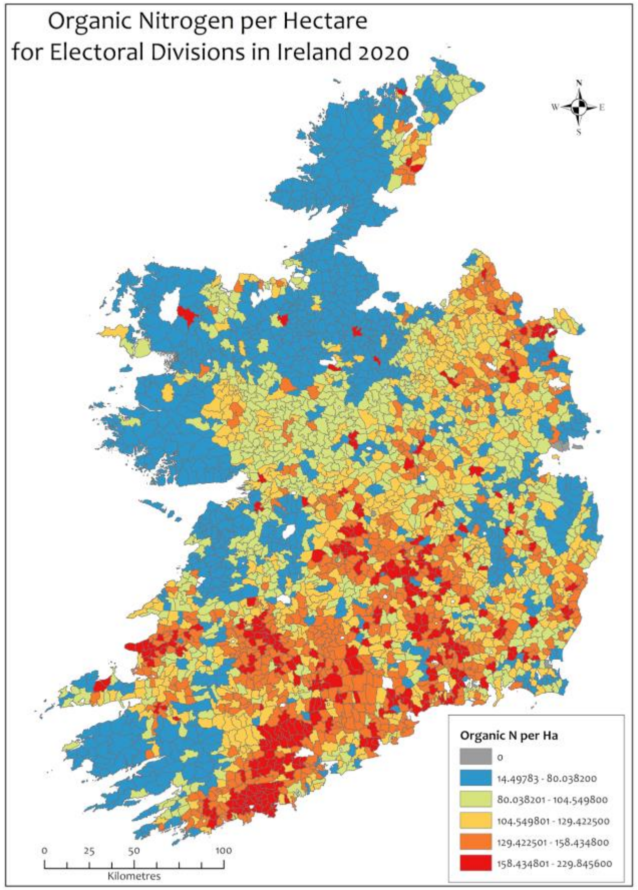
Location of Growth – Natural Capital

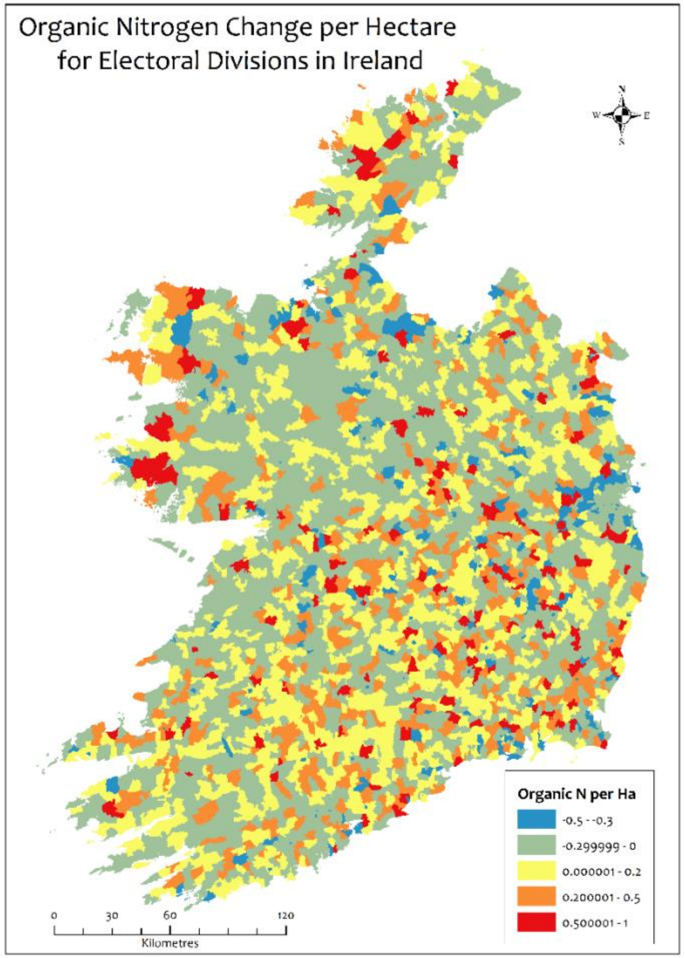
Figure 1 tracked the trend in the number of cattle over time. After a peak in 1998, cattle numbers declined until 2011 and then rose again to a near peak in 2022. Comparing the Census of Agriculture in 2010 with the Census of Agriculture in 2020, we can identify the location of change in this more recent growth period. Natural Capital is a concept defined by the OECD as *natural assets in their role of providing natural resource inputs and environmental services for economic production; comprising three categories: natural resource stocks, land and ecosystems*. All are considered essential to the long-term sustainability of development for their provision of "functions" to the economy, as well as to mankind outside the economy and other living beings.[45]

Figure 5.

Spatial Distribution of Animal Based Organic N per Hectare

[45] https://stats.oecd.org/glossary/detail.asp?ID=1730

(a) Organic N per Ha in 2020	(b) Change in Organic N per Ha 2010 – 2020
	see below



As an important land based industry, the natural capital provided by soils and the environment in general underpins the agricultural sector's ability to realise economic gains, converting. in effect, nutrients in soils via grass and fodder crops in to meat and dairy products via animal production. As the dominant rural land use in a country like Ireland, it also influences the quality of the underpinning natural capital. Nutrient management from the agricultural system influences soil fertility. Insufficient replacement of nutrients extracted from the soil result in diminished soil fertility, the situation in Ireland in the 1950's after decades of under fertilisation (Walsh et al., 1952). The replacement of nutrient losses through the use of chemical and natural fertilisers can improve soil fertility, but once nutrient application exceeds the capacity of the soil to absorb nutrients or if application is applied in inappropriate conditions, losses to ground and surface water can occur, with a consequential impact on water quality. Relatively intensive agriculture also has impacts on flows of other ecosystem services such as biodiversity and habitat provision (due to direct loss of habitat and species) as a result in intensification and land changes for increased productivity.

Figure 5.a reports the distribution of animals in Ireland as measured by the average amount of organic nitrogen per hectare in 2020 as described in the Census of Agriculture. There is a clear spatial pattern reflecting soil and climatic conditions with more intensive agriculture occurring in the South and East. It is however interesting to note in Figure 5.b that the spatial distribution of the change between the low point in 2010 and the higher point in 2020.

The INCASE project (Farrell et al., 2021), while focused on a detailed catchment assessment of natural capital accounting, has also generated a nationwide dataset of some key natural capital statistics at a small area spatial scale. We can use this data to understand the characteristics of both the level and change in animal numbers as a descriptor of the natural characteristics of the local area. The variables used in this analysis come from the following sources

- "Article 17" (of the EU Habitats Directive) Habitat data containing the presence of 58 different habitats which are regarded as threatened[46]

[46] Data gathered for reporting under Article 17 of the Habitats Directive: this data is reported on a six year cycle and outlines the conservation status of habitats considered of high conservation value in the EU and listed under Annex I of the Habitats Directive.

- Biophysical zonal statistics at a district level containing information about conservation status include Special Areas of Conservation, Natural Heritage Areas, Special Protection Areas and their combinations
- Land Parcel Information System (LPIS) describing agricultural areas, containing 165 different land use types
- The Soil Information System containing soil characteristics grouped into Texture (42), Depth (4), Drainage (7), Soil Association (62), Soil Organic Carbon (17)
- Water Quality from 3 periods (2007-09, 2010-12, 2013-18) containing water quality characteristics, Bio-Status (5), Eco-Status (5), Fish-Status (5), General Condition (3), Nitrate (3), Nutrients (3), Oxygenatio (2), pH (2)
- CORINE Land Cover Data for 3 periods (2000-06, 2006-12, 2012-18), containing 19 land cover codes

Iterating through the different variable sets, we report in table 4 the proportion of variation explained in both the level of Organic N per hectare and the change in this variable between 2010 and 2020. In terms of explained variation, the agricultural land use variable unsurprisingly explains the highest share of variation in organic N per hectare accounting for about 50% of variation. Article 17 conservation status is the second most important with over 40% of variation explained. The presence of special conservation areas explain much less variation. This is followed by various soil characteristics, with water quality variables having the weakest relationship, reflecting the impact of complex hydrology. Surprisingly CORINE land cover data has a low explanatory power. This may be driven by a combination of the low spatial resolution and the relatively high aggregation in land cover description.

Turning to the rate of change in Organic N per hectare between 2010 and 2020, explanatory power is much lower at about 15-25% of the explanatory power of the level. The most important explanatory factors are soil characteristics, explaining about 8% of variation. Even LPIS land use descriptors only explain 6.5% of variation. The non-soil characteristics explain less than 3% of the variation in Organic N. This is consistent with the polka dot relatively random nature of the map of change in Organic N. Short term decisions to increase stocking rates also depend upon personal factors such as access to land, age and motivation of the farmer and access to capital to facilitate expansion. Ironically many areas with existing high stocking rates may have less available land to facilitate expansion than other lower stocked areas.

Table 4. **Proportion of variation in Organic N Levels and Change (2010-20) explained by Natural Capital Characteristic (Adjusted R2)**

	Level	Change 2010-20
Conservation Status	0.4162	0.0276
Area Characteristics (SAC/NPA etc)	0.1465	0.006
LPIS Code (Land Use)	0.5366	0.0669
Soil Depth	0.2715	0.037
Soil Drainage	0.254	0.0389
Soil Texture	0.3501	0.0759
Soil Association	0.3985	0.0808
Water Quality (Bio-Status)	0.0511	0.0146
Water Quality (Eco-Status)	0.0546	0.0145
Water Quality (Fish-Status)	0.0072	0.0019
Water Quality (Nitrite-Status)	0.1462	0.0131
Water Quality (Nutrient-Status)	0.0077	0.0073
Water Quality (Ph-Status)	0.001	0.0073
CORINE Land Use Code	0.0751	0.0178

Combining the relative contribution of different natural capital characteristics is challenging given the significant correlation between variables, thus containing similar information. In total there are 432 natural capital characteristics (when using the closest dataset to 2020 when using data from multiple periods). In order to reduce the dimensionality we use a data reduction technique known as principal component analysis (Abdi and Williams, 2010). This technique transforms a set of correlated variables into a set of uncorrelated variables or principal components containing the same information. We select a subset of 315 variables, avoiding almost perfectly correlated variables, but maintaining representatives of each of the datasets using the Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy (Kaiser, 1974). The sample adequacy statistic is 0.67, where a value of over 0.5 is sufficient. We used Cronbach's Alpha to assess internal consistency and reliability, finding a value of 0.6415, where .60 is considered as acceptable (Jolliffe, 2002). Bartlett's test of sphericity had a p-value of 0.0000 rejects the null hypothesis of the correlation matrix being an identity matrix (Jolliffe, 2002).

We select eigenvalues of 1 or higher as our principal components. In total 109 have eigenvalues of 1 or more, accounting for 70% of the total variation. This is quite a large number of principal components or separate information points, reflecting the complexity of integrating aspects of natural capital. It indicates a challenge in drawing simple conclusions using a natural capital approach.

In order to understand the contribution of variation or inequality of individual drivers to driving forces, we use the Fields Decomposition (Fields, 2003). While mainly used in understanding drivers of income inequality, it has been used to decompose drivers of environmental factors, particularly carbon dioxide emissions (Farrell, 2017; Sager, 2019). The Fields approach estimates a single regression equation relating the dependent variable of interest to the explanatory factors of interest. The product of each variable specific estimation parameter and each explanatory variable plus the residual term fully defines the dependent variable. The Shorrocks factor decomposition (Shorrocks, 1982) is then used to decompose the total variation of variation of the dependent variable into these components. Table 5 reports this decomposition. The regression model used relates Organic N per hectare in 2020 to the principal components we derived with eigenvalues of 1 or more. While principal components have a relationship with all of the original variables, we ascribe an underlying dominant driver via the highest correlation coefficients. Following the single group regressions reported in table 5. In the same way as Fields, we report only the observed explanatory variables. The residual term accounts for 33% of the variation in Organic N per hectare in 2020, which is relatively low. There is thus quite a strong association between Organic per hectare and natural capital variables. Soil characteristics and conservation account for over 70% of the variation. Principal components that have the highest correlation with Land Use data are relatively smaller in this model than the single group model, reflecting the strong correlation between soil type and land use. The remainder of the variation is accounted for by water quality and protected area characteristics.

The highest share of factors relate to those that relate to natural capital as inputs to agricultural production (soils and land use) (55%). The lowest share are those that relate to the impact of agriculture in terms of ecosystem condition such as water quality (6.2%). Intermediate variables that relate indirectly to the ecosystem condition that is impacted by agricultural production (protection status and habitat status) (43%).

Table 5. **Fields Decomposition of Organic N per hectare in 2020.**

Row Labels	Share of Observed
Area Characteristics (SAC/NPA)	6.2
Habitat Status	36.4
Land Use (LPIS)	18.0
Soil Characteristics	36.9
Water Quality	2.3
Grand Total	100.0
R2	63.9%

Projected Changes

The trajectory we observe in animal numbers indicates that a trend that may impact on carbon budget targets to reduce carbon emissions from the agricultural sector by 25% in 2030. In this section, we make a number of projections to 2030 to assess potential trends and to assess the potential impact of proposed policy interventions on these trends. Given the rapid changes post milk quota abolition, we assume that the rapid changes seen are not permanent, but rather a response to pent up capacity. We use a simple discount function that reduces the initial rate of change (r_0) using a adjustment factor i as follows :

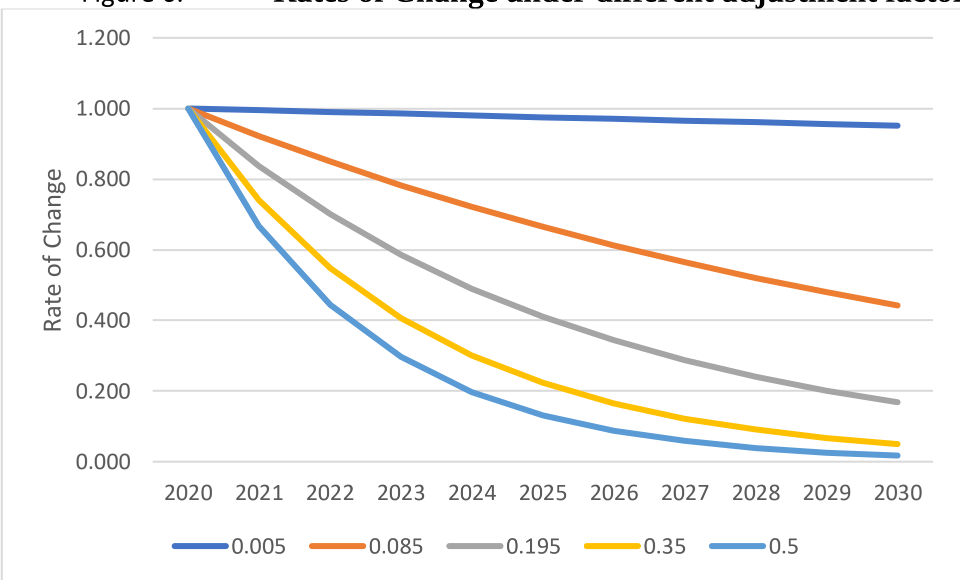
$$r_t = r_0 . \frac{1}{(1+i)^t}$$

The relevant rates of change that are reduced include

- Land Use Area
- The number of farms
- Forage Area Share within a Farm
- Stocking Rate and associated number of animals
- Yield Growth[47]

The short term value of i from the initial growth prior to the abolition of milk quota in 2015 to the 2018-2020 period varied from 0.5% for dairy forage area to 8.5% for the number of dairy cows to 19.5% for milk yield[48].

Figure 6. **Rates of Change under different adjustment factors**



[47] We do however continue to assume a minimum of 1% milk yield growth.

[48] Albeit comparing 2016-2018 and 2018-2020

Note: These values of *i* are applied in this formula to reduce the value of each growth parameter r_0 $r_t = r_0 . \frac{1}{(1+i)^t}$

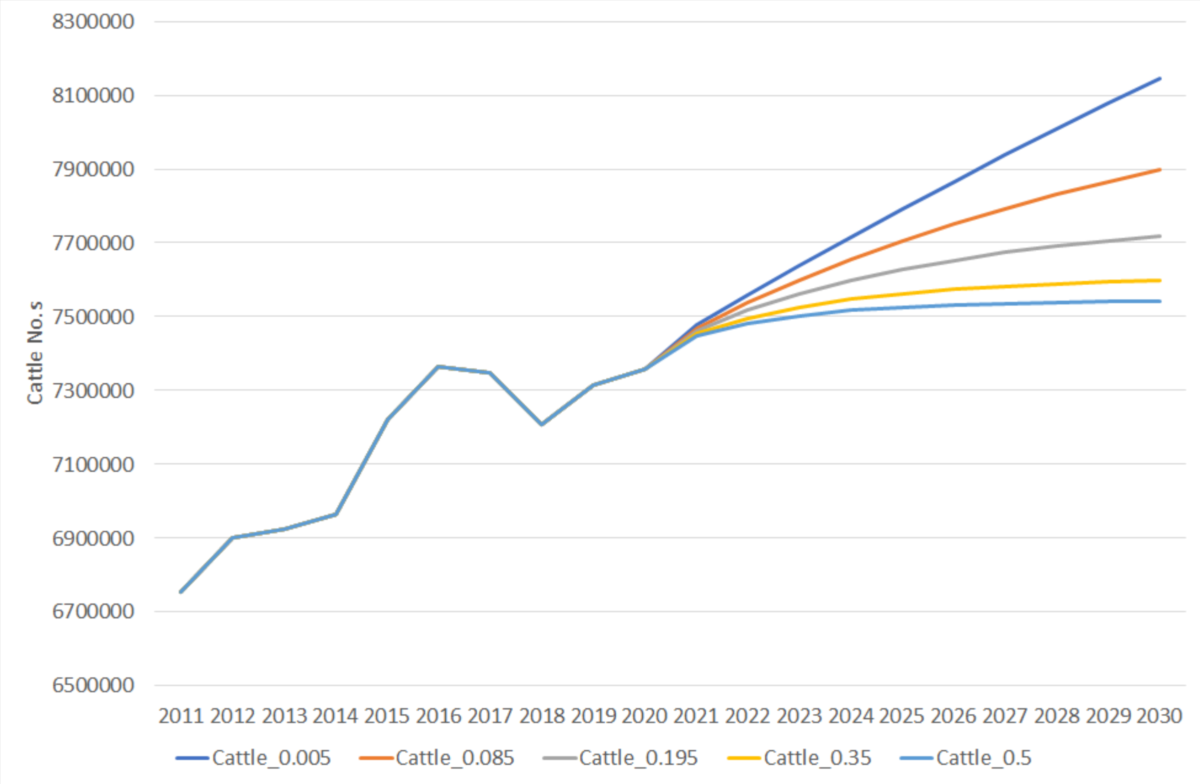
Table 6. **Average Annual Growth Rate Assumptions 2020-30 by "discount" rate (*i*)**

	Dairy	Cattle	Dairy	Cattle	Dairy	Cattle	Dairy	Cattle	Dairy	Cattle
i	0.005	0.005	0.085	0.085	0.195	0.195	0.35	0.35	0.5	0.5
Forage	0.040	-0.031	0.026	-0.019	0.017	-0.012	0.010	-0.007	0.007	-0.005
Cows	0.060	-0.032	0.041	-0.020	0.027	-0.013	0.017	-0.009	0.012	-0.007
Non Dairy Livestock Units		0.022		0.015		0.009		0.006		0.004
Milk Litres	0.076		0.051		0.036		0.027		0.023	
Stocking Rate	0.010	0.045	0.006	0.028	0.004	0.017	0.003	0.011	0.002	0.008
Yield	0.018		0.013		0.011		0.011		0.011	
Beef Going to Processor		0.031		0.022		0.016		0.012		0.010

Note: These values of *i* are applied in this formula to reduce the value of each growth parameter r_0 $r_t = r_0 \cdot \frac{1}{(1+i)^t}$

We report in table 6 the implications of these alternative adjustment factors in the trends of the average annual growth rate in the period 2020-30. For a parameter that had been growing in the in the pre-2020 period such as dairy forage area and stocking rate, the higher the value of i, the lower the value of that growth over the period and v.v. for those that were declining such as cattle forage area. The value of i therefore is a measure of how quickly a component converges to a steady state. The one exception we have is for milk yield. There is a long run increase in milk yields of about 1% per annum from improved breeding. We believe that this would continue to improve in the period to 2030.

Figure 7. **Projected Livestock Units 2014-2030 under different projection assumptions (by adjustment factor *i*)**



Note: These values of *i* are applied in this formula to reduce the value of each growth parameter r_0 $r_t = r_0 \cdot \frac{1}{(1+i)^t}$

Figure 7 takes the animal demographic model contained in the appendix and applies the parameters from table 2, adjusted with the change in the growth rates in table 6 to generate the number of cattle livestock units where cattle are adjusted using the Teagasc National Farm Survey livestock unit parameters. A low value of i would see livestock units increase by 30% over the period 2020-2030, while the highest value of i would see livestock units increase by 4%. As at 2022, as female calves have continued to grow and as a consequence there will be more future progeny, there is no trend that would indicate a reversal in the trend when this analysis occurred in 2022. Economic drivers in terms of milk price are very positive, reinforcing the trend.[49] Reversal in this trend would require an explicit policy intervention.

Table 7. **Growth of Cattle and Dairy Variables with 0.195 adjustment factor**

	Dairy LU's	Dairy Forage	Dairy & Mixed SR	Milk Yield	Milk Volume	Suckler Cow	Total Cattle LU's	Beef Process
2015-20	0.210	0.110	0.090	0.072	0.297	-0.086	0.004	0.044
2015-30	0.280	0.141	0.122	0.210	0.549	-0.144	0.025	0.084

49 https://www.teagasc.ie/publications/2022/situation-and-outlook-for-irish-agriculture---september-2022.php

The trend in dairy expansion after the abolition of milk quota in 2015 involves both a movement from beef cattle to dairy and an intensification of the dairy sector itself. Table 7 reports the actual change 2015-2020 and a projection using a mid-range projection factor of 0.195. As context average farm sizes increased 2015-20, while the number of farms fell and the overall agricultural land area fell by a smaller amount. Total dairy forage increased by 11% 2015-20 and is projected to increase another 6.7% to 2030, driven by increased specialisation on dairy farms and also by mixed dairy and cattle farms as the latter concentrate more on dairy farming. Between 2015-20, dairy livestock units rose faster than the increase in forage area, resulting in a higher overall stocking rate. With Nitrates Directive limits on stocking rates binding on dairy farms, we find a continued growth in the stocking rate of farms with dairy animals coming from mixed farms. Total dairy cows increased by 17% between 2015-20 and are projected in our model to grow a further 15% to 2030. With milk yield improvements total milk volume is projected to grow by 63%.

Table 8 flags the implications of some of these trends in relation to Value Added and GHG emissions. As animal numbers rise, as the share of dairy and suckler beef farming shifts and as milk yields rise, the level of value added at 2015 prices rises over the two periods at both primary and processing levels. However, the increased number of animals and stocking rates sees a rise in total carbon emissions. Given the improved milk yield, total emissions as a share of total value added and in relation to the ratio for primary production falls over time resulting in improved carbon efficiency. However the increase in animal numbers that have occurred and are projected in the baseline to occur dominate, with total emissions rising.

Table 8. **Trends in key economic and environmental drivers 2015, 2020 and 2030 (2015 prices, 0.195 adjustment factor)**

	LT_LU	StockRate	VA (direct) Ag	VA (direct) Proc	Total CO2	Agri CO2	CO2/VA	CO2/VA (Agri)
2015	4606	1.39	3116	1372	18772	17901	4.18	5.74
2020	5459	1.58	3390	1521	20390	19423	4.15	5.73
2030	5971	1.69	3587	1685	21576	20516	4.09	5.72

The economic and environmental impact of these changes require knowledge about the value chain impact such as the output multiplier and an indicator of the carbon footprint such as the emissions per € of output or in terms of ton of energy or protein. Table 9 reports estimates of these taken from the Bio-Economy Input Output model used in this analysis (Grealis and O'Donoghue, 2015; Tsakiridis et al., 2020). The methane emitting food sectors such as beef and sheep meat and dairy products produce more greenhouse gas emissions than food products that do not such as poultry, pigs and fish. The output multipliers are highest for beef and aquaculture followed by pigs, reflecting high domestic input shares, with sea fisheries and poultry havinghave the lowest output multipliers.

Table 9. **Carbon Footprint across Sectors in Ireland**

	ktCO2e per €m of Output	tCO2e per tonne of Protein	tCO2e per kcal Energy	Output Multiplier
Poultry	0.31	4.35	0.38	1.81
Sea Fish	0.34	7.68	1.01	1.75
Aquacult	0.45	10.18	1.34	2.68
Pig	0.75	10.19	0.41	2.40
Dairy	1.03	28.27	1.21	2.21
Sheep	2.44	65.87	3.87	2.15
Beef	3.47	63.18	3.72	2.58

Source: Tsakiridis et al., (2020)

Scenario Analyses

In figure 8 we analyse the trend greenhouse gas emissions using a mid-value of i for different scenarios. Each chart contains an estimate of greenhouse gas emissions associated with

- Enteric Methane
- Manure Management Methane
- Other CO2
- ChemicalN
- Industrial inputs (CO2)

These figures are based upon the 2015 Bio-Economy Input-Output Model, adjusted for animal number changes in the nowcasted period to the present and projected to 2030 using the projection totals above.

In the baseline, we see a steady increase in emissions by about 12% over time across the value chain reflecting the continued rise in animals, milk and beef meat (albeit at an increasing rate from the dairy herd).

4 alternative policy scenarios discussed above are considered in our analysis in Figure 8.

- Derogation
- Extensification
- FarmRetirement
- Protected Urea

We detail here the assumption made for each of the scenarios.

Derogation. Analysing the organic nitrogen per hectare in the Teagasc Farm Survey, 2.9% of the total organic nitrogen is produced on farms with an average of 220 kg of organic N per hectare per year over this limit. This is proposed reduction in dairy cows assumed if the new derogation requirement were implemented. This is an upper bound as the expectation that this new derogation limit would apply only in the case where water quality was sub-standard.

Extensification. The second policy scenario explored is the measure to limit the stocking rate 1.4 in the Eco-scheme within the CAP. We assume the probability of participation is similar to other agri-envronmental schemes, so in other words cattle farms will be more likely to participate, with very few dairy farmers participating. Given the relatively small number of cattle farms with a stocking rate of over 1.4, we project that this measure would reduce cattle numbers by 5.5%, while the lower probability of participation amongst dairy farmers, albeit having a higher stocking rate, sees their cattle numbers fall by 1.5%.

Protected Urea. The next measure is a technical measure to move fertiliser use to Protected Urea which has much lower emissions. We assume the public target of 80% reduction in chemical fertiliser- related Nitrous Oxide through the use of Protected Urea.

Farm Retirement Scheme. We consider the implications of a policy proposal to introduce a significant farm retirement scheme. It has the aim of reducing suckler cow numbers by 700000 and dairy cow numbers by 300000, compensated by a one off payment of €3000 per head, which is equivalent to a €370 per year over a 10 year period at a discount rate of 4%.

Diversification Option. We lastly consider an option where suckler cow numbers returned to 1968 levels (equivalent to the numbers before EEC membership was approved in 1969) and where the lost protein was replaced by pig production that have lower greenhouse gas emissions. We assume the same retirement fee paid as in the farm retirement scheme.

Table 10 reports some summary economic and environmental impacts of various scenarios in terms of impact by 2030 relative to 2020. We see an increase between 2020 and 2030 in the total carbon emissions given our projection assumptions with the 0.195 adjustment factor. As there is a continued shift from suckler cows to dairy cows and the milk yield grows, the average emissions per unit value added falls.

The change in the Nitrates Derogation limit, affecting only a relativelyrelative small number of farms (even assuming the limit applies to all areas), reduces the average stocking rate slightly. The reduction in emissions of just under 2% is less than the total increase in emissions between 2020 and 2030. Value added changes by a similar amount. The extensification measure has a slightly bigger impact as it affects more farms given the numbers that participate in agri-environmental scheme (AES) measures. The impact on value added is not as great. The extensification measure impacts cattle farmers to a greater degree as they are more likely to participate in AES'. The value added impact is lower than for the derogation measure as the value added per animal is lower for cattle than dairy. Protected Urea has a no impact on value added or animal numbers as it has a technical impact with no additional cost as protected urea has a similar. However reduced nitrous oxide emissions see a major reduction in total agricultural emissions and in the agricultural emissions per € value added.

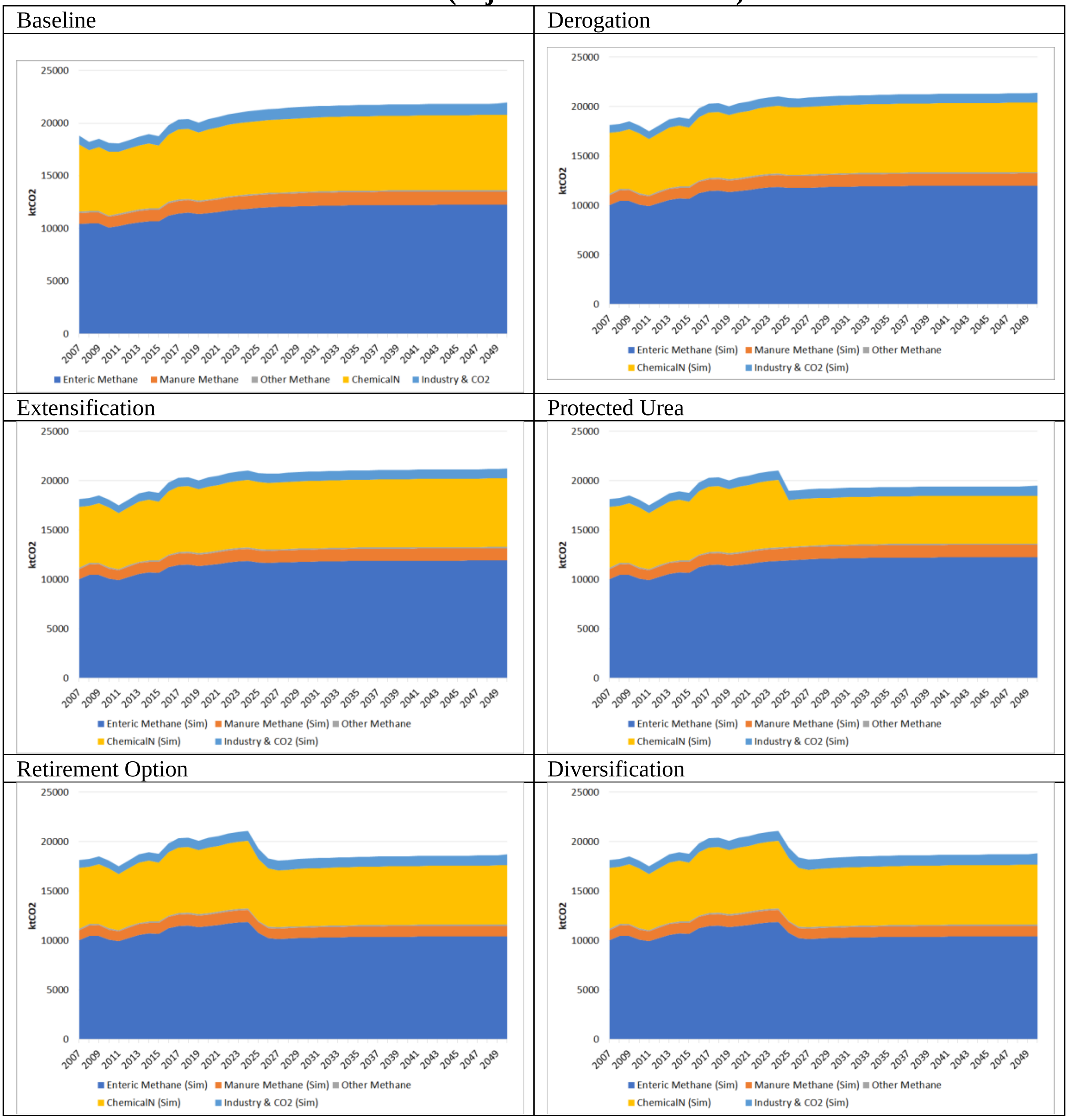
The biggest overall impact is the proposal to facilitate animal number reduction via farm retirements. It delivers in terms of reduced animals and stocking rate, but comes at the cost of the largest loss of value added. However as retirements are focused in the cattle sector, the environmental impact per € of value added is improved.

Table 10. **Economic and Environmental Impact of 2020-2030 (Scenarios)**

	LT_LU	StockRate	VA (direct) Agri	VA (direct) Proc	Total VA	Total CO2	Agri CO2	CO2/VA	CO2/VA (Agri)
Baseline (2015)	4606	1.39	3116	1372	4488	18772	17901	4.18	5.74
Baseline (2020)	5459	1.58	3390	1521	4910	20390	19423	4.15	5.73
Baseline (2030)	5971	1.69	3587	1685	5271	21576	20516	4.09	5.72
Derogation	5971	1.66	3519	1655	5173	21179	20138	4.09	5.72
Extensification	5971	1.65	3525	1660	5185	21009	19965	4.05	5.66
Protected Urea	5971	1.69	3587	1685	5271	19363	18303	3.67	5.10
FarmRetirement (DAFM proposal)	5971	1.17	3143	1361	4504	14239	13383	3.16	4.26
Diversification									
FarmRetirement (EEC)	5971	1.47	3498	1595	5093	18290	17286	3.59	4.94
Pigs Diversification	5971	1.47	3562	1702	5264	18408	17347	3.50	4.87

Note: VA: Value added; LT_LU Litres per livestock unit; Agri – Primary Agriculture; Proc – Processing.

Figure 8. **Total Greenhouse Gas Emissions under different scenarios (adjustment factor 0.195)**

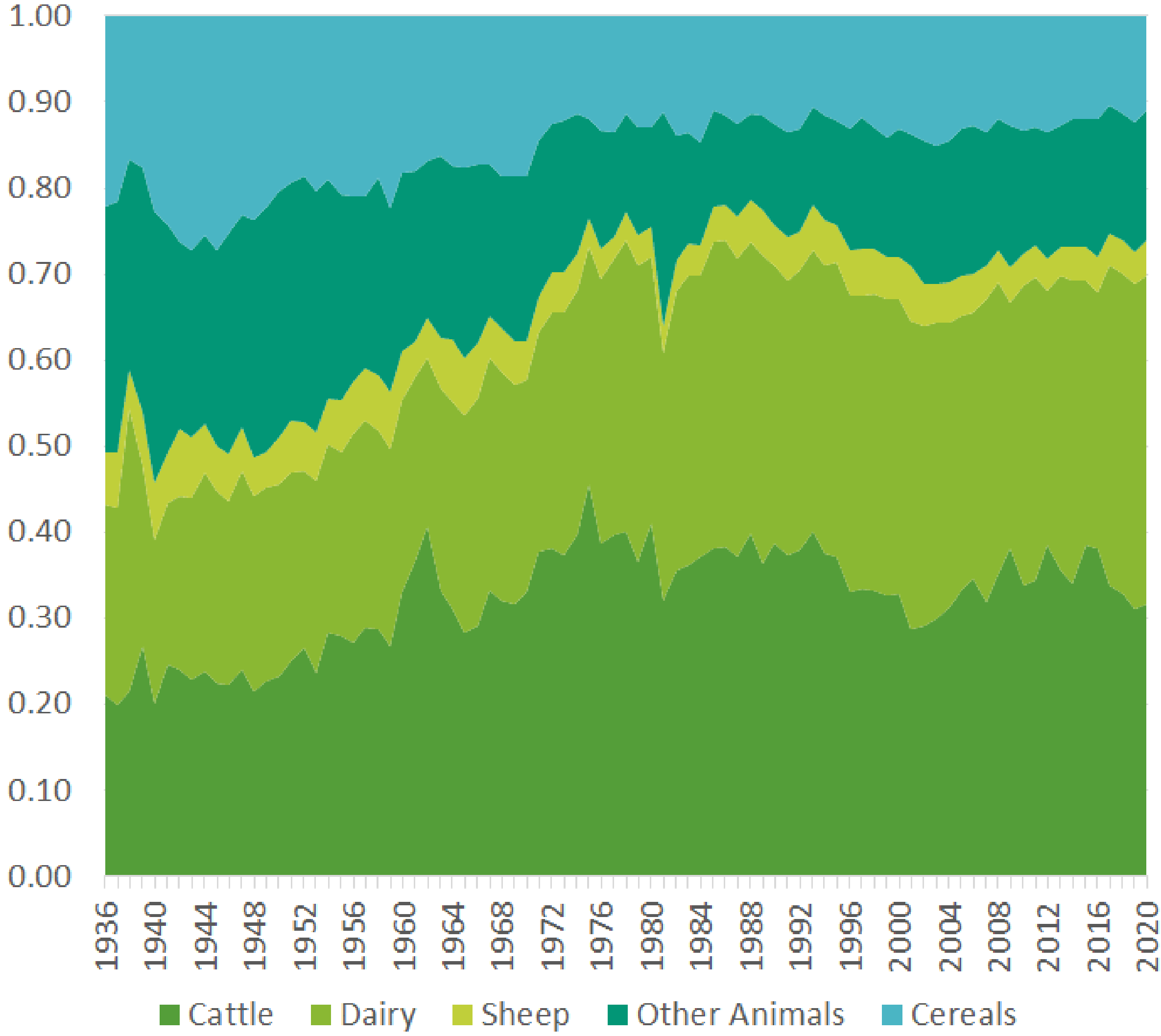


Diversification

Figure 9 describes the distribution of output by sector from the 1930's to 2020 in Ireland. Prior to joining the EEC in the period to the early 1960's, methane emitting sectors accounted for about 50% of the share of total agricultural output. Due to both relatively higher intervention prices for beef, sheep and dairy relative to tillage and pigs or poultry, and later income supports, the share of output of methane emission sectors has risen from 50% to 75%

of total output over the period. Pigs, Poultry and Cereals were more important in the past, all of which have a lower environmental footprint.

Figure 9. **Sectoral Output Share over Time (1936-2020)**



In table 11, we consider a variant of the Farm Retirement scenario reported in table 10. We consider a slightly different variant of the earlier scenario, with a scenario to reduce suckler cow numbers back to the level they were prior to the EEC. A lower number of suckler cattle provides both an opportunity in relation to additional land and a requirement in terms of the need for additional protein. In this scenario we consider the impact of the pig sector meeting the additional protein needs. In essence it is equivalent to unwinding the historical trend towards methane producing food production. Value added increases in the move from beef to pig production. This is in part to the fact that pigs as a cheaper source of protein than beef and has a lower cost base. Emissions are slightly higher than the retirement option as pigs generate N2O emissions in their feed production.

Table 11. **Economic and Environmental Impact of 2020-2030 (Diversification Scenario)**

	LT_LU	StockRate	VA (direct) Agri	VA (direct) Proc	Total VA	Total CO2	Agri CO2	CO2/VA	CO2/VA (Agri)
Baseline (2015)	4606	1.39	3116	1372	4488	18772	17901	4.18	5.74
Baseline (2020)	5459	1.58	3390	1521	4910	20390	19423	4.15	5.73
Baseline (2030)	5971	1.69	3587	1685	5271	21576	20516	4.09	5.72
FarmRetirement (EEC)	5971	1.47	3498	1595	5093	18290	17286	3.59	4.94
Pigs Diversification	5971	1.47	3562	1702	5264	18408	17347	3.50	4.87

Note: VA: Value added; LT_LU Litres per livestock unit; Agri – Primary Agriculture; Proc – Processing.

The direct and indirect feed input requirement, as measured by crop, feed, fertiliser and imported feed input shares, for beef and pig meat is similar, with pigs having a 46% share, compared with 41% for beef (Table 12). However imported feed has a much higher share for the pig meat sector than for the beef sector, reflecting the importance of imported feed. From a life-cycle perspective, emissions may be higher for beef, however from a carbon accounting point of view, the domestic footprint will be lower. Similarly, being reliant on imported feed frees up land for other carbon gains such as in the production of grass for anaerobic digestion, enabling the substitution of fossil fuels.

Table 12. **Feed Input structure for Beef and Pig Meat**

	Beef and veal	Pig meat
Fertiliser	0.032	0.002
Tillage	0.286	0.013
Feed	0.058	0.043
Imports	0.066	0.403
Imports and Feed	0.410	0.460

6. Conclusion

This paper has used an Input-Output and related spatial data analysis to firstly consider the association between recent expansion in agricultural intensity and a series of natural capital variables.

Utilising spatial natural capital attributes from the INCASE project (Farrell et al., 2021), while we try to understand the characteristics of both the level and change in animal numbers as a descriptor of the natural characteristics of the local area. As natural capital is a very complicated concept, the principal component analysis we undertook of the spatial dataset indicates that there are a lot of independent dimensions, so that it is difficult to downscale to a single or few indicators. In terms of association with the spatially varying increase in animal numbers, there is an impact both of natural capital to agriculture and from agriculture on natural capital. Overall natural capital indicators explain quite a higher proportion of variance in agricultural outcomes. The highest share of factors relate to those that relate to natural capital as inputs to agricultural production (soils and land use). The lowest share are those that relate to the impact of agriculture in terms of ecosystem condition such as water quality. Intermediate variables that relate indirectly to the ecosystem condition that is impacted by agricultural production (protection status and habitat status). Future work is however required to explain differences in trends. Utilising a projection framework extrapolating current trends to 2030 at varying convergence factors to steady state in order to assess the implications of achieving the carbon budget target that aims to reduce carbon emissions from the forestry sector by 25% in 2030. Depending upon the convergence to a steady state, the expected change in numbers, given current trajectories, vary from an increase of 4% to an increase of 30%. As of 2022, as female calves have continued to grow and as a consequence there will be more future progeny, there is no trend that would indicate a reversal in the trend when this analysis occurred in 2022.

Dairy expansion is expected to continue, particularly given the relatively positive drivers in terms of milk price are very positive, reinforcing the trend. Reversal in this trend would require an explicit policy intervention. This is likely to be mitigated by Nitrates Directive limits on fertilizer use, however, a continued growth in the stocking rate of farms with dairy animals coming from mixed farms or through the acquisition of new land, particularly leased land. With milk yield improvements, total milk volume is projected to grow by 63%.

The increased number of animals and stocking rates sees a rise in total carbon emissions under current practices. Given the improved milk yield, total emissions as a share of total value added and in relation to the ratio for primary production falls over time resulting in improved carbon efficiency. However the increase in animal numbers that have occurred and are projected in the baseline to occur dominate, with total emissions rising.

From an overall economy perspective, output multipliers are highest for beef and aquaculture, followed by pigs, reflecting high domestic input shares, with sea fisheries and poultry having the lowest output multipliers. Output multipliers are high for both high methane- emitting sectors such as beef and for low- emitting sectors such as pigs and aquaculture.

Predominantly, plans to reduce methane emissions in the agricultural sector in Ireland focus on improving efficiency. In particular, improvements in genetics through use of breeding indexes have been targeted. This has raised questions about the contradictions between an efficiency- led strategy for meeting climate goals and at the same time improving biodiversity and water quality which often benefit from reduced agricultural intensity.

A suggestion for meeting the goals has also been to reduce the stocking rate in some less productive areas which are also important for other environmental factors such as biodiversity and water quality and also areas that have high levels of carbon stored underground.[50] There is, however, no policy currently with which to encourage this change.

Afforestation represents another key strategy for meeting climate goals. Past goals for afforestation in Ireland have not been met. Studies have shown that landowners, particularly farmers are averse to the transition for a number of reasons. In particular, it has been found that they view that it is difficult to revert the land to other uses once it has been planted into forestry.[51] Therefore, it is restrictive of their rights as owners of the land. Predominantly, the land that has been newly forested is state owned. Unless the land is already state owned, future land must be purchased at high expense with competition from other land users particularly dairy farmers. If afforestation goals are not met, a higher reduction in agricultural emissions must be made through the existing avenues.

Four alternative policy scenarios were analysed in this paper including derogation limit changes, extensification, a farm retirement proposal and the use of protected urea. As the change in the Nitrates Derogation limit affects to only a relativelyrelative small number of farms, the average stocking rate is reduced slightly, with emissions reductions of just under 2% relative to the increasing trend. The extensification measure has a slightly bigger impact as it affects more farms given the numbers that participate in agri-environmental scheme

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[50] However this is not always true, as reducing the stocking rate in uplands and low lying coastal areas might reduce the habitat quality. Rather getting the right stocking level and sustaining that for the habitat should be the goal for biodiversity (a good indicator of habitat quality!), water and carbon.

[51] Again – planting targets can have adverse impacts of biodiversity – consider peatlands and species rich wet grasslands – often the key target areas for planting as deemed as low productive land but these are high biodiversity, water quality and high carbon content land. Again highlights the complete lack of integration between agri-forestry targets and setting goals for biodiversity gains (in a world where no further losses can be supported by agriculture – consider Citizens Assembly debate).

(AES) measures. The value added impact is lower than for the derogation measure as the value added per animal is lower in farmers that engage in agri-environmental schemes than dairy farms. The use of protected urea has no impact on value added or animal numbers as it has a technical impact with no additional cost as protected urea has a similar. However reduced nitrous oxide emissions see a major reduction in total agricultural emissions and in the agricultural emissions per € value added.

The biggest overall impact is the proposal to facilitate animal number reduction via farm retirements, delivering in terms of reduced animals and stocking rate, but comes at the cost of the largest loss of value added, but with the environmental impact per € of value added improving. Considering a slightly different variant of the farm retirement scenario to reduce suckler cow numbers back to the level they were prior to the EEC replaced by increasedincrease pig production to have a protein neutral change. Value added increases in the move from beef to pig production, while emissions are slightly higher than the emissions are slightly higher than the retirement option.

One of the concerns about paying farmers for early retirement is that it will have implications for biodiversity as an extensive farming approach is fundamental to diverse grassland areas, peatland, heathland and coastal systems. An alternative approach might be to link retirement to generational renewal to highlight the need for more appropriate payments to farmers for nature rather than just getting rid of them – include the trade-offs for maintaining low intensity agri practices (suckler cows) to maintain high nature value areas (natural capital) and integrate that more explicitly.

One of the key outcomes of this paper is that meeting climate goals is unlikely to occur without intervention. While breeding indices provide a win-win opportunity for farmers and policymakers, the lack of policy or strategy in place to manage animal numbers to meet the 2030 goals and the longer term 2050 goals represents a barrier.

In general also, economic models, because of limited capacity, do not integrate nature as part of their analytical frameworks. As a result the economic and environmental implications of policy changes are not typically considered impacts on biodiversity. So although we can crunch numbers on animal numbers and average emissions with respect to carbon, in order for this to integrate impacts on natural capital, the data needs to be integrated. To some extent, this paper only scratches the surface and shows correlations but to increase biodiversity, we need models to show how we can do this i.e. succeed in biodiversity gain, sustainable agri systems and low carbon impact.

What is shown here is trends and correlations – that there is more intensive agriculture and that the habitat status is inadequate. Biodiversity is de-coupled essentially from carbon (and agriculture) and is considered 'messy'. We need to develop more integrated frameworks that highlight the mismatch in perspective and generate analyses needed to integrate and consider the scope for biodiversity gains rather than track losses if it is to actually address the climate and biodiversity crisis. Essentially, therefore, agriculture and climate can be integrated using these analyses but the challenge is to make it useful and actually integrate effects on nature; as the objective for the Green Deal is.

In summary, any policy changes that don't put the 'health of our natural capital' to the fore (i.e. continues to focus on production led systems) are unlikely to lead to improvements in biodiversity as there is no identification of where gains can be made, and there are currently no targets set in relation to biodiversity gains. The new Nature Restoration Law developed by the EU may influence the setting of clear, legally binding targets other than the relatively weak targets set in the national biodiversity plan.

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Appendix A

Appendix A1: Land model

Land

$$\sum_i \quad Land_{t,i} = \sum_i \quad (1 + \Delta Land_{t,i}) \times Land_{t-1,i}$$

Farms

$$\sum_i \quad \#FarmSys_{t,i} = \sum_i \quad (1 + \Delta \#FarmSys_{t,i}) \times \#FarmSys_{t-1,i}$$

Average Farm Size by System

$$Average\ Farm\ Size_{t,i} = \frac{Land_{t,i}}{\#FarmSys_{t,i}}$$

Dairy Forage Area

$$Dairy\ Forage\ Share_{t,i} = (1 + \Delta Dairy\ Forage_{t,i}) \times Dairy\ Forage_{t-1,i}$$

$$\begin{aligned} Dairy\ Forage_{t} &= Forage\ Share_{t,i} \times Dairy\ Forage\ Share_{t,i} \times \#FarmSys_{t,i} \\ &\times Average\ Farm\ Size_{t,i} \end{aligned}$$

Beef Forage Area

$$\begin{aligned} Beef\ Forage_{t,i} &= Forage\ Share_{i} \times Beef\ Forage\ Share_{i} \times \#FarmSys_{t,i} \\ &\times Average\ Farm\ Size_{t,i} \end{aligned}$$

Sheep Forage Area 0

$$Sheep\ Forage_{t,i} = Sheep\ Forage\ Share_{i} \times \#FarmSys_{t,i} \times Average\ Farm\ Size_{t,i}$$

Appendix A2: Animal Model

Dairy Cows

$$DairyCows_{t,i} = Dairy\ Stocking\ Rate_{t,i} \times Dairy\ Forage_{t,i}$$

Milk Production

$$Yield_{t,i} = (1 + \Delta Yield_{t,i}) \times Yield_{t-1,i}$$

$$Milk(Lt)_{t,i} = DairyCows_{t,i} \times Yield_{t,i}$$

Beef Animals (Other Cows)

$$OtherCows_{t,i} = Other\ Cow\ Stocking\ Rate_{t,i} \times Beef\ Forage_{t,i}$$

Dairy Calves

$$DairyCalves_{t,i} = DairyCows_{t-1,i} \times Dairy\ Ferilty\ Rate_t$$

Dairy Replacements

$$DairyHeifers_{t,i} = DairyCows_{t-1,i} \times Dairy\ Replacement\ Rate_t$$

$$Dairy\ Replacement\ Rate_t = 20\%$$

Beef Calves

$$OtherCalves_{t,i} = OtherCows_{t-1,i} \times Other\ Ferilty\ Rate_t$$

$$NonReplacementDairyCalves_{t,i} = DairyCalves_{t,i} - DairyHeifers_{t,i}$$

Beef Animals (Aged 1-2)

$$BeefAnimals1\_2_t = \sum_i \left(OtherCalves_{t,i} + NonReplacementDairyCalves_{t,i}\right) \times SurvivalRate1\_2_t \sum \quad (\quad)$$

$$BeefAnimals1\_2_{t,i} = \frac{Beef\ Forage_{t,i}}{\sum_i \quad Beef\ Forage_{t,i}} \times BeefAnimals1\_2_t \frac{}{\sum}$$

Beef Animals (Aged 2+)

$$BeefAnimals2p_t = \sum_i \quad (BeefAnimals1\_2_t) \times SurvivalRate2p_t \sum \quad (\quad)$$

$$BeefAnimals2p_{t,i} = \frac{Beef\ Forage_{t,i}}{\sum_i \quad Beef\ Forage_{t,i}} \times BeefAnimals2p_t \frac{}{\sum}$$

$$MaleBeefAnimals2p_{t,i} = MaleShare2p \times BeefAnimals2p_{t,i}$$

$$FemaleBeefAnimals2p_{t,i} = BeefAnimals2p_{t,i} - BeefAnimals2p_{t,i}$$

$$Bulls_t = \Delta Bulls_t \times Bulls_{t-1}$$

Sheep Livestock Units

$$SheepLivestockUnits_{t,i} = Sheep\ Forage_{t,i} \times SheepLUStockingRate_i$$

Total Livestock Units

$$\begin{aligned} TotalLivestockUnits_{t,i} & \\ &= DairyCows_{t,i} + A \times \left(DairyCalves_{t,i} + OtherCalves_{t,i}\right) \\ &+ B \times \left(DairyHeifers_{t,i} + BeefAnimals1_{2_{t,i}}\right) \\ &+ C \times \left(OtherCows_{t,i} + FemaleBeefAnimals2p_{t,i}\right) \\ &+ MaleBeefAnimals2p_{t,i} + Bulls_t + Sheep\ LivestockUnits_{t,i} \end{aligned}$$

Where

- A – 0.4
- B – 0.7
- C – 0.8

$$
\begin{aligned}
&DomesticBeefProcessing_{t,i} \\
&\quad = 0.20 \times \left(DairyCows_{t,i} + OtherCows_{t,i} + Bulls_t\right) \\
&\quad + \left(BeefAnimals1\_2_{t,i} - BeefAnimals2p_{t+1,i} - DairyHeifers_{t,i}\right) \\
&\quad + FemaleBeefAnimals2p_{t,i} + MaleBeefAnimals2p_{t,i}
\end{aligned}
$$

Dairy Expansion Spatial Model

Probability of being a Dairy Farmer

$$P(HasMilk) = f(M, L, F, R, E)$$

Where

- M – Management Characteristics
- F – Farm Characteristics
- L – Farmer Characteristics
- R – Region
- E – Environmental Characteristics

Farm level Yield (Litres per Livestock Unit)

$$Milk\ per\ LU = f(M, L, F, R, E)$$

Farm level Stocking Rate (Livestock Unit per Hectare)

$$LU\ per\ Ha = f(M, L, F, R, E)$$

Target Milk Growth

Apppendix 5.1 INCASE project communications summary

Presentations		
Jan 2020	INCASE project stakeholder workshop	Slides
Oct 2020	The Contribution of Limestones in Ireland to our Natural Capital	Link
Feb 2021	INCASE project stakeholder workshop	Link
Apr 2021	Nature Based Solutions Conference (CIEEM)	
May 2021	Data 4 Nature (Natural Capital Ireland) Conference	Link
May 2021	Environment Ireland Conference	
Jun 2021	Annual meeting Ecosystem Services Partnership (Europe)	Posters
Jun 2021	Global Society of Ecological Restoration Conference	
Jun 2021	NCA approaches (World Bank) Workshop	
Jun 2021	EPA Climate Conference	
Jun 2021	EPA Water Conference	
Peer-reviewed publications		
Apr 2021	Applying the System of Environmental Economic Accounting-Ecosystem Accounting (SEEA-EA) framework at catchment scale to develop ecosystem extent and condition accounts	Link
Dec 2021	Natural capital approaches: shifting the UN Decade on Ecosystem Restoration from aspiration to reality	Link
Dec 2021	Developing peatland ecosystem accounts to guide targets for restoration	Link
Jan 2022	Applying ecosystem accounting to develop a risk register for peatlands and inform restoration targets at catchment scale: a case study from the European region	Link
Reports		
Dec 2019	Irish Natural Capital Accounting for Sustainable Environments Literature review	Link
Jul 2020	Irish Natural Capital Accounting for Sustainable Environments: Stage 1 Feasibility Report	Link

Other outputs		
Sep 2019	Ireland needs needs more detailed land-use maps (Irish Times)	Link
May 2020	Putting a price on natural capital (Irish Farmers Journal)	Link
Jun 2020	Introduction to Natural Capital Accounting animated video	Link
Jun 2020	Pioneering research project explains “Natural Capital Accounting” (TCD News and Events)	Link
Oct 2020	MAP: Natural capital – the foundation of the Bioeconomy	Link
Nov 2020	Irish Natural Capital Accounting for Sustainable Environments (INCASE) (EPA Catchment News)	Link
Social Media		
2019 - 2022	27 blogs published online	Link
2020 - 2022	8 newsletters published	Link
2019-2023	Twitter - 5,280 Tweets to 1,580 Followers	Link