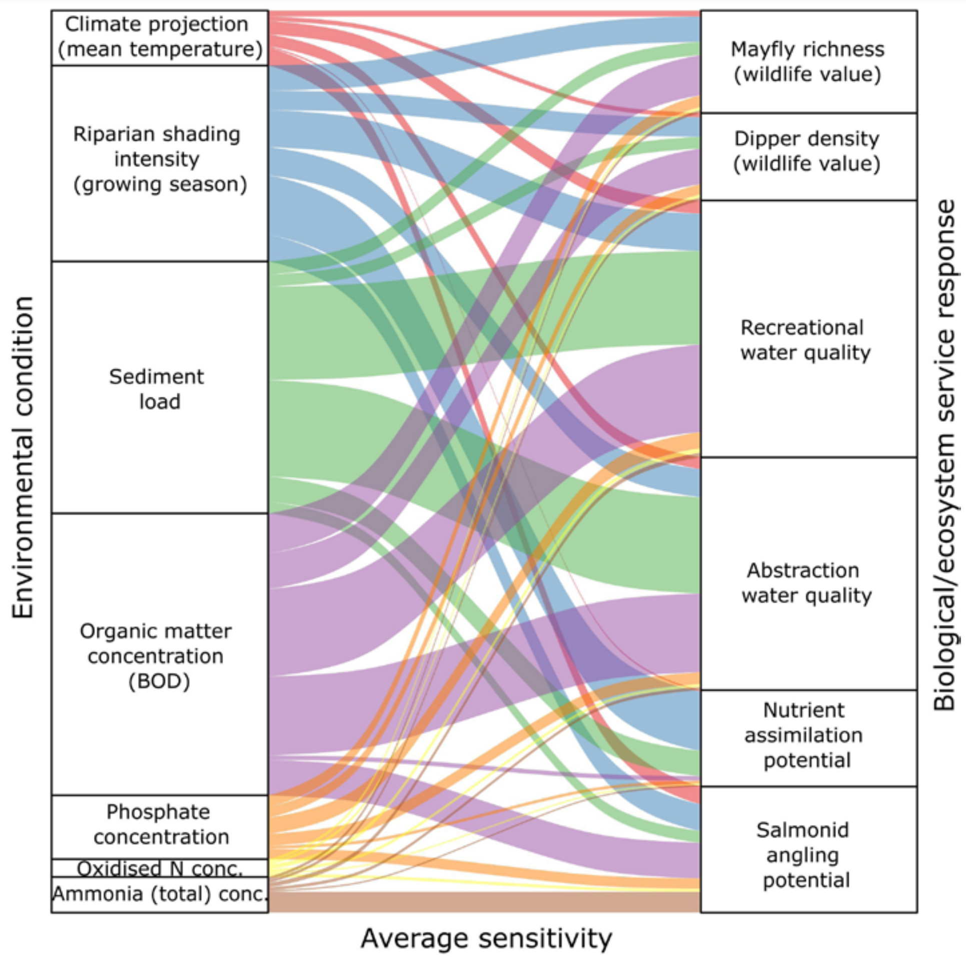
epa Research

Report No.424

ESDecide: From Ecosystem Services Framework to Application for Integrated Freshwater Resources Management

Authors: Mary Kelly-Quinn, Michael Bruen, Craig Bullock, Mike Christie, Christian K. Feld, Jasper Kenter, Marcin Penk and Jeremy Piggott



www.epa.ie

Rialtas na hÉireann
Government of Ireland

Environmental Protection Agency

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

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

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

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

Advocacy: Working with others to advocate for a clean, productive and well protected environment and for sustainable environmental practices.

Our Responsibilities Include:

Licensing

> Large-scale industrial, waste and petrol storage activities;
> Urban waste water discharges;
> The contained use and controlled release of Genetically Modified Organisms;
> Sources of ionising radiation;
> Greenhouse gas emissions from industry and aviation through the EU Emissions Trading Scheme.

National Environmental Enforcement

> Audit and inspection of EPA licensed facilities;
> Drive the implementation of best practice in regulated activities and facilities;
> Oversee local authority responsibilities for environmental protection;
> Regulate the quality of public drinking water and enforce urban waste water discharge authorisations;
> Assess and report on public and private drinking water quality;
> Coordinate a network of public service organisations to support action against environmental crime;
> Prosecute those who flout environmental law and damage the environment.

Waste Management and Chemicals in the Environment

> Implement and enforce waste regulations including national enforcement issues;
> Prepare and publish national waste statistics and the National Hazardous Waste Management Plan;
> Develop and implement the National Waste Prevention Programme;
> Implement and report on legislation on the control of chemicals in the environment.

Water Management

> Engage with national and regional governance and operational structures to implement the Water Framework Directive;
> Monitor, assess and report on the quality of rivers, lakes, transitional and coastal waters, bathing waters and groundwaters, and measurement of water levels and river flows.

Climate Science & Climate Change

> Publish Ireland's greenhouse gas emission inventories and projections;
> Provide the Secretariat to the Climate Change Advisory Council and support to the National Dialogue on Climate Action;
> Support National, EU and UN Climate Science and Policy development activities.

Environmental Monitoring & Assessment

> Design and implement national environmental monitoring systems: technology, data management, analysis and forecasting;
> Produce the State of Ireland's Environment and Indicator Reports;
> Monitor air quality and implement the EU Clean Air for Europe Directive, the Convention on Long Range Transboundary Air Pollution, and the National Emissions Ceiling Directive;
> Oversee the implementation of the Environmental Noise Directive;
> Assess the impact of proposed plans and programmes on the Irish environment.

Environmental Research and Development

> Coordinate and fund national environmental research activity to identify pressures, inform policy and provide solutions;
> Collaborate with national and EU environmental research activity.

Radiological Protection

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

Guidance, Awareness Raising, and Accessible Information

> Provide independent evidence-based reporting, advice and guidance to Government, industry and the public on environmental and radiological protection topics;
> Promote the link between health and wellbeing, the economy and a clean environment;
> Promote environmental awareness including supporting behaviours for resource efficiency and climate transition;
> Promote radon testing in homes and workplaces and encourage remediation where necessary.

Partnership and Networking

> Work with international and national agencies, regional and local authorities, non-governmental organisations, representative bodies and government departments to deliver environmental and radiological protection, research coordination and science-based decision making.

Management and Structure of the EPA

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

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

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

EPA RESEARCH PROGRAMME 2021–2030

ESDecide: From Ecosystem Services Framework to Application for Integrated Freshwater Resources Management

(2018-W-MS-37)

EPA Research Report

Prepared for the Environmental Protection Agency

by

University College Dublin

Authors:

Mary Kelly-Quinn, Michael Bruen, Craig Bullock, Mike Christie, Christian K. Feld, Jasper Kenter, Marcin Penk and Jeremy Piggott

ENVIRONMENTAL PROTECTION AGENCY
An Ghníomhaireacht um Chaomhnú Comhshaoil
PO Box 3000, Johnstown Castle, Co. Wexford, Ireland

Telephone: +353 53 916 0600 Fax: +353 53 916 0699
Email: info@epa.ie Website: www.epa.ie

ACKNOWLEDGEMENTS

This report is published as part of the EPA Research Programme 2021–2030. The EPA Research Programme is a Government of Ireland initiative funded by the Department of the Environment, Climate and Communications. It is administered by the Environmental Protection Agency, which has the statutory function of co-ordinating and promoting environmental research.

The authors would like to acknowledge the members of the project steering committee, namely Hugh Feeley (EPA), Donal Daly (formerly EPA), Iwan Jones (Queen Mary University of London), David Lyons (Department of Housing, Local Government and Heritage), Cormac McConigley (Local Authority Waters Programme, LAWPRO, Blue Dot Programme), Noel Meehan (Teagasc), Marc Metzger (University of Edinburgh), Patrick Morrissey and Lisa Sheils (EPA), for their support and contributions over the duration of the project.

The project partners would also like to acknowledge the valuable contributions to our workshops by EPA staff: Catherine Bradley, Hugh Feeley, Bryan Kennedy, Nessa McDonnell, Patrick Morrissey, Deirdre Tierney, Shane O'Boyle, Wayne Trodd and Martin McGarrigle (formerly EPA); and also Ronan Matson (Inland Fisheries Ireland), Siobhan Atkinson (UCD), Richard O'Callaghan (National Parks & Wildlife Service), Steve Davis (LAWPRO), Katharine Rettig (University of Duisburg-Essen, Germany) and members of the steering committee (Iwan Jones and Mark Metzger).

We are grateful to Darío Fernández-Bellon (University College Cork, School of Biological, Earth and Environmental Science) for his contribution to the decision support tool on the white-throated dipper. Thanks also to Mohammadkarim Saeedghalati (University of Duisburg-Essen, Department of Bioinformatics), who assisted with the software development and implementation of the decision support tool, and to Jean Smith, Hugh Feeley and Bryan Kennedy (EPA), who retrieved physico-chemical data for us.

EPA RESEARCH PROGRAMME 2021–2030

Published by the Environmental Protection Agency, Ireland

ISBN: 978-1-80009-071-2 September 2022

Price: Free Online version

Project Partners

Associate Professor Mary Kelly-Quinn
School of Biology and Environmental Science
University College Dublin
Dublin
Ireland
Tel.: +353 1 716 2337
Email: mary.kelly-quinn@ucd.ie

Professor Michael Bruen
School of Civil Engineering
University College Dublin
Dublin
Ireland
Email: michael.bruen@ucd.ie

Dr Craig Bullock
School of Architecture, Planning and Environmental Policy
University College Dublin
Dublin
Ireland
Tel.: +353 1 716 2677
Email: craig.bullock@ucd.ie

Professor Mike Christie
Aberystwyth Business School
Aberystwyth University
Aberystwyth
UK
Tel.: +44 (0) 1970 622 217
Email: mec@aber.ac.uk

Privatdozent Dr Christian Feld
Department of Aquatic Ecology
Faculty of Biology
University of Duisburg-Essen
Essen
Germany
Tel.: +49 (0) 201 18 34390
Email: christian.feld@uni-due.de

Associate Professor Jasper Kenter
Department of Environment and Geography
University of York
York
and
Ecologos Research Ltd
Borth
UK
Tel.: +44 (0) 7812 560 194
Email: mail@jasperkenter.com

Dr Marcin Penk
School of Natural Sciences
Trinity College Dublin
Dublin
Ireland
Tel.: +353 1 896 1639
Email: penkm@tcd.ie

Assistant Professor Jeremy J. Piggott
School of Natural Sciences
Trinity College Dublin
Dublin
Ireland
Tel.: +353 1 896 1639
Email: piggottjj@tcd.ie

Contents

List of Figures

List of Tables

List of Boxes

Executive Summary

River basin management requires practitioners to take decisions to address key environmental pressures and mitigate impacts on aquatic ecology and ecosystem services. ESDecide built on the outputs of the ESManage project (EPA Research 312) by developing the tools and guidance needed to advance efforts to incorporate ecosystem services and the concept of "nature's contributions to people" (NCP) into decision-making related to the protection and management of freshwater resources. Although the ecosystem services approach has an anthropocentric focus, it is recognised that the approach may help communicate the urgency of addressing declining water quality. Ecosystem services refer to the contributions (goods and benefits) of nature to human well-being. The Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) re-conceptualised the ecosystem services framework to one based on NCP that goes beyond the economic benefits of ecosystem services to include a broader conceptualisation of nature's values. While not always explicitly stated, ecosystem services/NCP protection and restoration are central to many global (Sustainable Development Goals, Convention on Biological Diversity), European (Water Framework Directive, European Green Deal and Biodiversity Strategy) and national (Food Wise 2025, River Basin Management Plan) policies.

ESDecide developed an evidence-based decision support tool (DST) for managing Ireland's freshwater ecosystem services. This was achieved by extending the scope of the original ESManage project through the collection of new evidence on stressor–ecology relationships and incorporating this into the Bayesian belief network (BBN) model, which forms the backbone of the DST. In parallel with this, a short report was published introducing the concept of NCP, the multiple values of nature and the Life Framework of Values. The insights from the report fed into the design of a series of stakeholder workshops to explore the multiple ways in which people value nature and how these values can be captured and fed into policy decisions.

The BBN model was structured to focus on individual stressors, permitting the end user to apply a broad range of generic or bespoke management measures, crafted to individual circumstances. It also incorporated a regulating service (nutrient assimilation) – albeit only qualitatively owing to a knowledge gap in this respect – as well as water quality for abstraction and recreation. While the model was developed for three case study catchments, it is sufficiently robust to capture the responses of the selected ecosystem services/NCP in most other Irish catchments.

The ESDecide DST (ProgRES) provides a graphical user interface to the prognostic ESDecide BBN model. Hence, the DST makes the input nodes of the BBN model selectable through pull-down menus and allows end users to interactively model the probability of biological and ecosystem services/NCP implications of their selection of environmental conditions. The baseline for modelling was the current environmental conditions in three Irish rivers: Dodder, Moy and Suir. Therefore, three slightly different DSTs were implemented, which differ only in the selection of baseline environmental conditions. They can be launched using a web browser, including on tablet computers and smartphones. In addition to the online version of the DST, a stand-alone version has been constructed for application outside the three case study catchments.

The stakeholder workshops demonstrated that rivers have a wide range of intrinsic values, as well as material, non-material and regulating NCP, which may be valued for instrumental, relational and intrinsic justifications. Rivers are also associated with a diversity of overarching transcendental values, from enjoyment and freedom to creativity and protecting the environment. The results demonstrated that the Life Framework of Values provides a useful tool to help people uncover these multiple values and organise them into accessible and inclusive categories. Different management options have wider impacts on, for example, river biodiversity, recreational opportunities and land management practices, which in turn will have varying impacts on different groups of people. Economic approaches that calculate value to society by adding up individual values often mask the values of less dominant groups and often fail to address

value conflict. This research has demonstrated the merits of an approach that uses deliberation to explicitly discuss a broader range of values held by different stakeholders, which, together with the DST, lays a foundation to develop shared visions for future management of rivers that can help reconcile value conflicts and result in policies that are more equitable and more widely accepted.

1 Introduction

1.1 Background

Ecosystem services refer to the contributions (goods and benefits) of nature to human well-being. Freshwaters contribute a disproportionately high level of ecosystem services (as many as 32 have been identified; Vári *et al.*, 2021) and biodiversity, despite covering less than 1% of the Earth's surface (Dudgeon *et al.*, 2006). These services include water for consumption and food production, flood protection, sanitation, sense of place and recreation (MEA, 2005a; Vári *et al.*, 2021). However, freshwaters are among the world's most degraded and threatened ecosystems (Reid *et al.*, 2019). Across Europe water quality is failing to meet Water Framework Directive (WFD; EU, 2000) objectives, with only 40% of surface waters achieving good ecological status or good ecological potential and with only 38% achieving good chemical status (EEA, 2018). The situation is relatively similar in Ireland, where almost half of all water bodies are failing their environmental objectives and, on average, the condition of surface waters across the country has not improved (EPA, 2021). Particularly worrying is the serious decline in the number of pristine river sites (defined as "Q5" using macroinvertebrate metrics) over the last three decades, from over 500 in the 1980s to 22 currently (EPA, 2021). Future land use intensification for food production under initiatives such as Food Wise 2025 (DAFM, 2021), together with climate change, will potentially further put stress on aquatic resources in terms of quality and quantity, and the delivery of ecosystem services (Kelly-Quinn *et al.*, 2020).

Over the past few decades, there has been growing academic and policy interest in assessing the environmental, economic and social impacts of ecosystem degradation and biodiversity loss. The ecosystem services framework in particular has been advocated as a useful tool that provides a holistic and transparent assessment of these impacts on human well-being (MEA, 2005b; TEEB, 2010; IPBES, 2018). This enables decision-making to take proper account of the value of services from ecosystems (Haines-Young and Potschin, 2009). The framework provides evidence to promote the sustainable use of natural resources and the protection of healthy functioning ecosystems. Furthermore, by illustrating the connection between a healthy environment and human well-being, it provides a means to communicate the value of protecting ecosystems to policymakers, resource managers and the general public.

The Millennium Ecosystem Assessment (MEA, 2005b) was fundamental in developing the ecosystem services framework, linking 22 supporting, provisioning, regulating and cultural services to indicators of human well-being. Since then, a number of other frameworks have been developed (Feeley *et al.*, 2016), including the Economics of Ecosystems and Biodiversity (TEEB) (2010) and the Common International Classification of Ecosystem Services (CICES) (Haines-Young and Potschin, 2013). More recently, the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) has re-conceptualised the ecosystem services framework as one of "nature's contributions to people" (NCP), where NCP goes beyond monetary, instrumental values of ecosystem services to include a broader conceptualisation of nature's values. The IPBES framework incorporates *instrumental, relational* and *intrinsic* values, as well as ideas of deep-held *transcendental* values (Christie *et al.*, 2021). Values may also be considered *individual* values, or aggregated to *social* values, or reconciled as *shared* values (Christie *et al.*, 2021). This report presents the findings of research that captures the multiple values of river ecosystem services/NCP and explores how these values can best be incorporated into decision-making for the management of freshwater systems in Ireland.

Despite these recognised benefits, as well as various policies calling for the protection of ecosystem services and biodiversity, the integration of ecosystem services into decision-making is very much in its infancy. Management policy needs to reconcile competing interests across various land uses, set against the costs and benefits of management actions. For example, urbanisation or agricultural intensification needs to consider the full societal costs, including the loss of benefits to other stakeholders. An ecosystem services valuation framework can certainly support this. However, other supports, for instance the use of adaptive management techniques (Williams and Brown, 2014), systematic validation studies (Landyut *et al.*, 2013) and communication techniques focused on ensuring public behavioural change (Choubak *et al.*, 2019), are needed if ecosystem services considerations are to feature in any meaningful way in decision-making relating to the management of freshwater resources.

Previous research on ecosystem services by the ESManage project developed and tested an eight-step methodological framework to help integrate ecosystem services considerations into policy and management of freshwaters (Kelly-Quinn *et al.*, 2020). ESDecide addressed key recommendations of the ESManage project by developing a decision support tool (DST) to not only inform decision-making relating to the management and protection of freshwater ecosystem services, but also help communicate the relationship between water quality degradation and the contribution of freshwaters to human well-being. Furthermore, ESDecide explored the broader concept of NCP (IPBES, 2018) and how this can be used to support decision-making. Thus, where relevant, this report uses the term ecosystem services/NCP to capture this broader concept but the individual terms are also used separately where relevant to ecosystem services and NCP.

1.2 Policy Relevance

Although not always explicitly stated, ecosystem services/NCP protection and restoration are central to many global, European and national policies (Figure 1.1), as well as to the achievement of their goals. At the global level, the Sustainable Development Goals (SDGs) set overarching policy targets in terms of resource management and SDG6 specifically aims, through six targets, to “ensure availability and sustainable management of water and sanitation for all” (UN, 2015). There is a growing body of evidence that ecosystem services/NCP underpin the achievement of the SDG targets. As highlighted by Vörösmarty *et al.* (2018), ecosystem processes and biodiversity that sustain the flow of ecosystem services need to be viewed as “an integral building block of the sustainable development agenda”. Kelly-Quinn

Figure 1.1. Range of legislation and policies for which ecosystem services/NCP are of relevance. CBD, Convention on Biological Diversity.

et al. (2021) further illustrate the range of ecosystem services underpinning the SDG6 targets.

Monitoring of the health of freshwater environments in Europe is driven by the WFD (EEA, 2018). Supporting legislation includes directives relating to nitrates, groundwater and floods. Current river monitoring focuses on the health of biological components, with their supporting physico-chemical and hydromorphological conditions, and on specific chemical pollutants. Restoring and maintaining good ecological status, or high status where it exists, as defined by these readily quantifiable conditions, is the end goal of the WFD. The metrics underpinning the assessment have been chosen because they have established causative relationships with catchment pressures and associated stressors, but they are not necessarily well suited to conveying the ecosystem services value of rivers to society.

Ecosystem services are referred to in policy relating to the protection of biodiversity, such as the Convention on Biological Diversity (CBD) Strategic Plan for Biodiversity 2011–2020.[1] One of its aims is to enhance the benefits to people from biodiversity and ecosystem services. The EU Biodiversity Strategy 2020 set a goal of maintaining and restoring ecosystems and their services. It stated that "By 2050, European Union biodiversity and the ecosystem services it provides – its natural capital – are protected, valued and appropriately restored for biodiversity's intrinsic value, and for their essential contribution to human well-being and economic prosperity." The more recent 2030 Biodiversity Strategy (ECDGE, 2021) builds on this objective to "address the main drivers of biodiversity loss and bring back diverse and resilient nature while ensuring the continued provision of the ecosystem services on which our well-being and prosperity depends". This is also reflected in Ireland's National Biodiversity Action Plan (DAHG, 2016).

One of the overarching EU policies driving change in human activities to improve environmental quality and thereby human well-being is the European Green Deal.[2] A key focus is climate change and sustainability, with a target of a 50% reduction in greenhouse gas emissions by 2030. While most of this has to be achieved by the energy and transport sectors, all major greenhouse gas-emitting sectors are expected to play their part. Ecosystems and their services are therefore affected through changes in agriculture, food consumption, forestry, wetlands and natural peatlands. Thus, among the priorities of the European Green Deal is the aim to protect biodiversity and reduce air, soil and water pollution, and restore the natural environment. It has explicit modelling support for its projections and aspirations using models developed at the International Institute for Applied Systems Analysis (IIASA).

Another EU strategy linked to the European Green Deal is the EU's Farm to Fork Strategy (European Commission, 2020), which aims for fair, healthy and environmentally friendly food production systems that will drive improvements in water quality and aquatic ecosystems services, as well as reduce greenhouse gas emissions. Similarly, the European Commission's Communication on Green Infrastructure[3] emphasises "the important role of natural capital and the value of the ecosystem services concept as providing an integrating and balanced perspective in policy making, planning and management of ecosystems". Indeed, ecosystem services assessments are core elements of natural capital accounting. The World Business Council for Sustainable Development Vision 2050[4] highlights the need to assess the true value and cost of food and other business activities, "factoring in links with ecosystem services and human health", and that "natural systems such as forests, mangroves and wetlands are increasingly valued for providing core infrastructure and ecosystem services". Related to this is a growing awareness of the need for environmental protection schemes that provide payments for protection of ecosystem services (e.g. Bishop and Hill, 2014).

The ESDecide DST, training materials and consideration of the multiple values of nature, together with the project's recommendations, provide support for the aforementioned policy objectives.

1 https://www.cbd.int/sp/ (accessed October 2021).

2 https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal/delivering-european-green-deal_en (accessed October 2021).

3 https://ec.europa.eu/environment/nature/ecosystems/index_en.htm (accessed October 2021).

4 https://www.wbcsd.org/contentwbc/download/11765/177145/1 (accessed October 2021).

1.3 ESDecide – Objectives and Research Approach

The overall aim of ESDecide was to develop an evidence-based DST and the guidance needed to advance efforts to incorporate ecosystem services and the concept of NCP into decision-making related to the protection and management of freshwater resources and other policy goals. This was achieved by extending the scope of the original ESManage project (Kelly-Quinn *et al*., 2020) through the collection of new evidence on stressor–ecology relationships and incorporating this into a Bayesian belief network (BBN) model (Objective 1, Chapter 2) to develop the DST (Objective 2, Chapter 3) and training materials. In parallel with this, a short report was published introducing the concept of NCP, the multiple values of nature and the Life Framework of Values (O'Connor and Kenter, 2019; Christie *et al.,* 2021; Kenter and O'Connor, 2022) (Objective 3). The insights from this report were used to feed into the design of a series of stakeholder workshops to explore the multiple ways in which people value nature and how these values can be captured and fed into policy decisions (Objective 3, Chapter 4). The final chapter (Chapter 5) presents a discussion on the work undertaken and how the two strands of the research may be used to inform decision-making for the protection and management of rivers.

1.3.1 Specific objectives

1. Establish multiple pressure impact–response relationships and use them to strengthen and expand the number of ecosystem services in the existing ESManage BBN model with empirical data quantifying ecosystem functions and services (Chapter 2).
2. Develop a DST (Chapter 3), including training and guidance for stakeholders on the use of the tool.
3. Introduce the concept of Life Frames and NCP, and move beyond traditional monetary valuation of river ecosystem services to explore the multiple ways in which people value nature and how these multiple values might best inform catchment management decisions (Chapter 4).

ESDecide was also a partner in the first Water Joint Programming Initiative (JPI) Thematic Annual Programming Action on the topic of ecosystem services – the AQUATAP-ES project. Other members were from Finland, the Netherlands and Spain (http://www.waterjpi.eu/implementation/thematic-activities/water-jpi-tap-action/aquatap-es). Key outputs are shown in Figure 1.2.

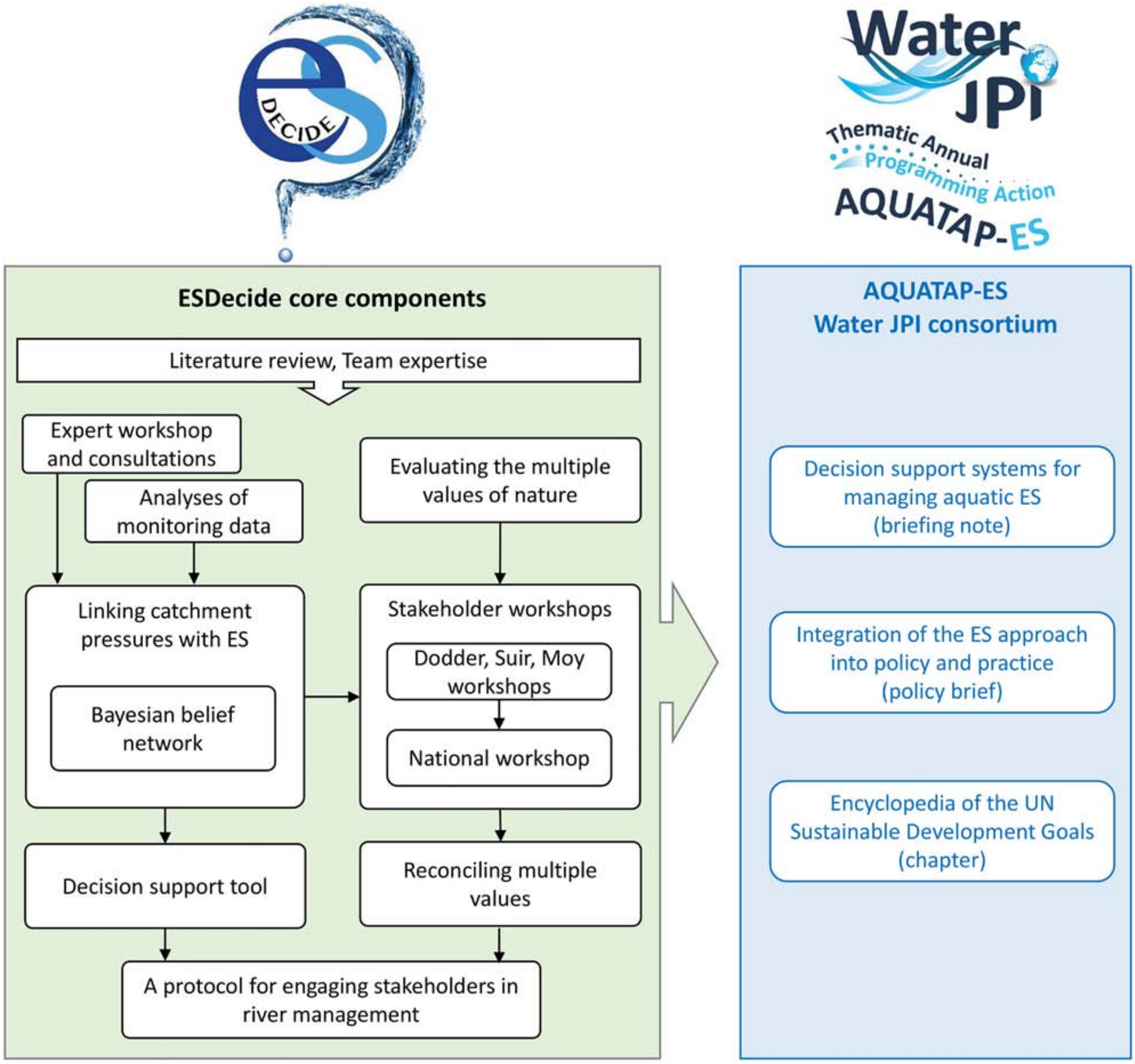


Figure 1.2. Linkages between the various research elements in the ESDecide project and contributions from the ESDecide team to the outputs of the JPI AQUATAP-ES project. ES, ecosystem services.

2 Linking Catchment Pressures with River Ecosystem Services

2.1 Introduction

Rivers are a key part of the global hydrological cycle and a vital conduit of water resources for beneficial human uses and nature alike. They are hotspots of biological activity, supporting disproportionately high biodiversity (Dudgeon *et al.*, 2006). This functionality gives rise to aquatic ecosystem services/NCP that, as mentioned in Chapter 1, benefit human societies in terms of their survival, prosperity and well-being (Christie *et al.*, 2021; Figure 2.1).

River networks connect the landscape, integrating its influences, and they also link lakes and groundwater, eventually reaching the coast. The dissolved and suspended constituents include the fingerprints of human activity, including pollution from agriculture and urbanisation. The morphology and hydrology of river networks themselves are commonly manipulated by humans; together with water pollution, this makes rivers one of the world's most degraded and threatened ecosystems (Reid *et al.*, 2019). Climate change is already adding to these pressures through changes in flow and temperature regimes (Gudmundsson *et al.*, 2021). In Ireland, agriculture is the leading significant pressure, followed by hydromorphological alterations, urban wastewater and forestry (EPA, 2020). Pressures act simultaneously (Lemm *et al.*, 2021) and their interactions present a key challenge for their management. These pressures and associated stressors, such as elevated nutrients and sediment, affect various aspects of river functioning that are responsible for the delivery of ecosystem services/NCP. In such a way, human activities may undercut the capacity of rivers to deliver ecosystem services/NCP and thus broader societal benefits.

Linking pressures with ecosystem services/NCP relies on a series of steps interconnecting abiotic and biological components, and possibly also human perception of their value. This is challenging because these elements tend to be captured using different methods. Abiotic processes are frequently described by physical (process-based) models, whereas ecological dependencies tend to be restricted to empirical (data-driven) models or expert knowledge

Figure 2.1. The River Dodder, which flows through Dublin, provides recreational benefits to a large urban population. Image: Marcin Penk.

and social information is frequently presented only qualitatively. Bringing such diverse information sources together in a common cause–effect chain is difficult (AQUATAP-ES, 2021).

Given the dearth of models of biological responses to pressures that are based on established physical/chemical principles such as conservation of matter, stoichiometry or energy balances involved in homeostasis, BBN models can represent the important cause–effect relationships by conditional probabilities, i.e. a probability of the different outcomes of a state or process, under the different conditions of influencing variables. The subsequent dependencies can then be linked in a feedforward network to form a cause–effect chain between the input and output variables of interest using Bayes' theorem. Implementing BBN models requires defining the variables, their states and connections, and, finally, populating conditional probability tables for each dependent variable (for more detail see Feld *et al.*, 2020, and Kelly-Quinn *et al.*, 2020). Importantly, BBN models can be built using modelled relationships and/or expert judgement, based on qualitative and quantitative information, which can be combined in the same network. Because of this versatility, BBN models have been increasingly used in ecosystem services/NCP frameworks (McVittie *et al.*, 2015; Mantyka-Pringle *et al.*, 2017; Smith *et al.*, 2018; Forio *et al.*, 2020).

The ESDecide project took a BBN model that was initially built by the ESManage project (Kelly-Quinn *et al.*, 2020; Bruen *et al*., 2022) as a starting point, and further developed it to causatively link catchment stressors with ecosystem services/NCP in Irish rivers. The BBN model incorporated information relevant to Irish rivers generally and was then applied to three case study catchments to explore the implications of changes in stressor levels for ecosystem services/NCP in different settings. The BBN model was then implemented using an intuitive graphical user interface as a DST (see Chapter 3).

2.2 The Evidence Base

ESDecide combined information obtained predominantly from experts and from data analyses. This was complemented with information from the literature, legislation and project team expertise.

2.2.1 Expert knowledge

Expert knowledge from national monitoring agencies was an important source of information for the BBN model construction and the associated conditional probability tables. This was collected through a formal workshop followed by personal consultations with selected experts (Figure 2.2).

A 1-day workshop was held on 29 January 2020 at University College Dublin with 17 experts from the Environmental Protection Agency (EPA), Inland Fisheries Ireland (IFI) and the ESDecide steering committee, in addition to the ESDecide team members. The participants were asked to familiarise themselves with the proposed structure of the BBN model in advance of the workshop. On the day of the workshop, the experts were asked to indicate their judgements on the relationships between key nodes in the network. They were split into six teams (typically with three participants per team), with each team providing independent information on the same set of questions about relationships between nodes.

Each expert group was asked to populate six conditional probability tables for intermediate biological variables of the BBN model. These tables define cause–effect relationships in a simple probabilistic format that reflects the likelihood of occurrence of each of the different states of a response variable given

Figure 2.2. The expert workshop was carried out in six breakout groups followed by a plenary discussion. Images: Marcin Penk (left) and Christian Feld (right).

the states of its influencing factors represented in the BBN model. As a simple example, the experts were asked to state the likelihood of "grazer biomass" being low, medium and high (expressed as a percentage, adding up to 100% across the three states) when "oxygen saturation" is either low, medium or high and "instream habitat quality" is either poor, moderate or good (giving a total of nine possible combinations in this case; Table 2.1). The experts then worked through a sequence of conditional probability tables in the order of their increasing complexity. Information from each of the six expert groups was combined using a weighted average to be used in the BBN model. Standard deviations of the results among the groups were further analysed for heterogeneity to identify where the experts agreed or disagreed the most. The expert teams were also asked to state their own confidence level for each of the analysed biological variable responses on a scale from 1 to 10, which was then used as a weighting factor (Table 2.1). Note that the information obtained in this way has an element of subjectivity and was mostly used for nodes that could not be satisfactorily addressed using data or models alone. However, by having multiple groups and assessing the degree of agreement or disagreement between them, the reliability of the results could be assessed. Thus, expert opinions from the workshop were the starting point for these six nodes, and many of their influences were further adjusted using data analyses (section 2.2.2), literature (section 2.2.3) and refinements to the overall BBN model (section 2.3.4).

Finally, the experts were asked to comment on the BBN model structure, in particular if any intermediate variables or links were missing or redundant and if the states of the BBN model variables were adequately defined and quantified. Selected experts were consulted to follow up on the feedback from the workshop, and in relation to any other matters within their expertise.

2.2.2 *Analysis of national monitoring data*

Data from the national river monitoring programme were a key source of quantitative information used to refine the BBN model. These data were provided by the EPA and consisted of:

- benthic invertebrate data 2007–2018; collected once every 3 years from 176 WFD surveillance monitoring sites (Feeley *et al*., 2020);
- WFD hydromorphological data (River Habitat Assessment Technique, RHAT) 2007–2018; usually collected together with the invertebrate data (Morphological Quality Index data were not available for this period);
- WFD phytobenthos data 2016–2018; collected once every year from 200 sites;

Table 2.1. An example of a conditional probability table obtained from the workshop, including mean probabilities of each state of grazer biomass from the six expert groups

Parent nodes/variables		Weighted mean (%)			Standard deviation		
		Grazer biomass			Grazer biomass		
Oxygen saturation	Instream habitat quality	High	Medium	Low	High	Medium	Low
✓ High	✓ Good	93	6	1	7.6	6.1	2.0
✓ High	~ Moderate	68	18	14	34.1	16.7	27.6
✓ High	× Poor	20	26	54	24.7	13.4	31.6
~ Medium	✓ Good	46	29	25	32.5	16.9	25.1
~ Medium	~ Moderate	34	32	34	35.2	19.9	28.3
~ Medium	× Poor	9	32	59	7.8	13.6	19.4
× Low	✓ Good	8	27	65	11.8	20.8	31.6
× Low	~ Moderate	6	21	73	11.9	18.5	29.1
× Low	× Poor	3	11	86	8.1	11.0	15.6

Note: Mean probabilities are weighted by the experts' stated confidence in their own knowledge (mean probabilities add up to 100% across each row). The standard deviation among the estimates of the six expert groups is also shown. Higher standard deviations (darker shading) denote greater disagreement among expert groups. There tended to be more agreement (i.e. lower standard deviations) for the extreme combinations of the parent variables [i.e. the most favourable combination (first row) and the least favourable combination (last row)] than for the intermediate combinations.

- WFD physico-chemical data 2007–2018; collected at varying frequency from 4154 sites, but usually monthly from the biological sites.

The analyses comprised the examination of:

- data distribution, using histograms and summary statistics;
- relationships, using non-linear regression models (generalised additive model, GAM; Wood, 2017);
- thresholds, using classification and regression tree (CART) analysis (Hothorn *et al.*, 2006).

For the analysis of relationships and thresholds, physico-chemical data were screened for those matching biological sites and aggregated over time to match the temporal frequency of the biological data. From this temporal aggregation, the central tendency (mean) and, where relevant, spread (5th and 95th percentiles) and variability (standard deviation) were calculated.

ESDecide took the BBN model developed by the ESManage project as the starting point to benefit from its advances (Kelly-Quinn *et al.*, 2020). The structure of this BBN model was already well defined in many aspects (e.g. wildlife value indicators, angling potential and their influences) and thus a thorough rebuild was not required. However, considerably more data with a wider range of parameters and more detailed analyses were used to refine the ESManage BBN model structure and relationships to produce the new ESDecide BBN model.

These further analyses by ESDecide were used to inform:

- numerical values of the different categories for a given variable – to quantify their states;
- the relative strength of the different influences on a particular target variable – to identify their hierarchy;
- the relative strength of the different intensities (states) of a particular influence on a particular target variable – to identify non-linear relationships.

Variable states were quantified in such a way for biochemical oxygen demand (BOD), summer water temperature and dissolved oxygen. Relationships and thresholds were quantified for dissolved oxygen, filamentous algae cover, mayfly richness and summer water temperature (Figure 2.3).

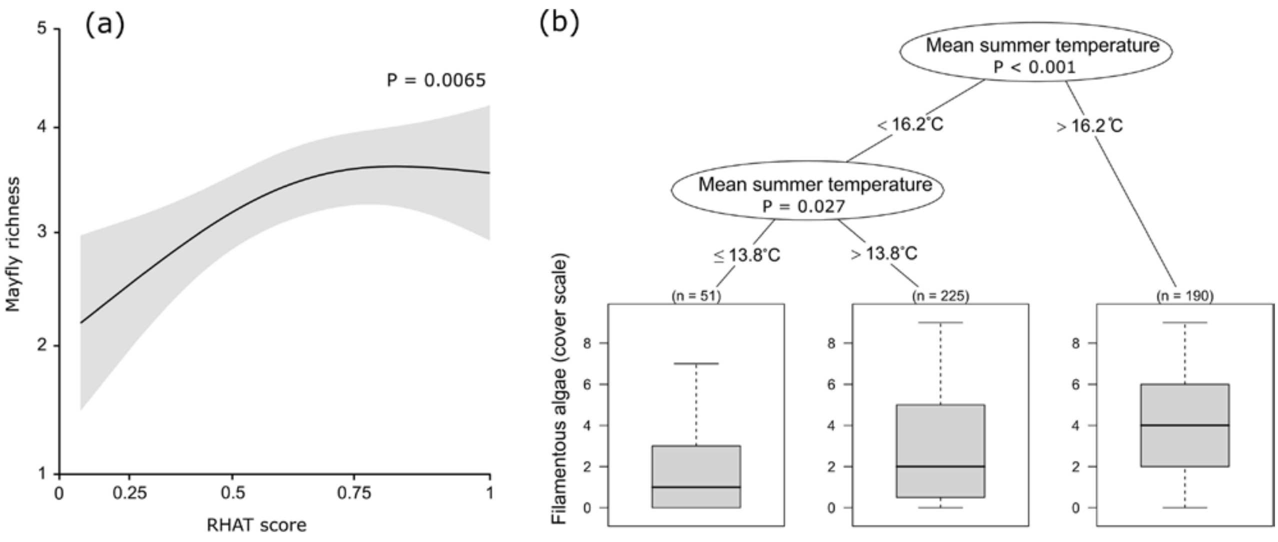


Figure 2.3. Examples of how analysis of monitoring data was used to inform the BBN model. (a) Generalised additive model regression showed that mayfly richness increased with improving hydromorphological quality (RHAT score), reaching maximum at intermediate quality, beyond which it did not change much, so the conditional probability table of the BBN model was adjusted to reflect this non-linearity. (b) CART analysis of filamentous algae abundance (on a 0–9 scale, denoting a range from absent to >75% cover) in relation to mean summer temperature indicated breakpoints at 13.8°C and 16.2°C, which supported the biological relevance of the 14°C and 16°C threshold selected based on the first and third quartiles of the temperature data distribution.

2.2.3 Other information sources

Peer-reviewed scientific papers and published reports were reviewed, specifically from Ireland because of their high relevance and from international studies to fill in any information gaps. Irish studies provided a strong evidence base for the biological effects of sediment in particular, as either a sole or co-occurring stressor (e.g. García-Molinos and Donohue, 2009; Conroy *et al.*, 2016; Davis *et al.*, 2018). International sources were used throughout the work on the BBN model, but in particular to investigate the influences on benthic algae (e.g. Welch *et al.*, 1988; Wagner *et al.*, 2015), fish (e.g. Solomon and Lightfoot, 2008; with references therein), dipper (e.g. Ormerod *et al.*, 1985; Ormerod and Tyler, 1993) and nutrient assimilation (e.g. Hall *et al.*, 2009; Tank *et al.*, 2018; Kikuchi *et al.*, 2020).

Statutory Instrument (S.I.) number 77 of 2019 sets environmental objectives for water protection in Ireland, and any applicable thresholds given in S.I. 77 were used in preference to all other information sources (e.g. nutrient boundary concentrations for moderate, good and high status). This is to link the BBN model state specifications to the legal thresholds and facilitate their use by stakeholders. Findings of the SILTFLUX project (Bruen *et al.*, 2017) were used to inform sediment load values. Team expertise was used throughout, in conjunction with other sources of information.

2.3 Bayesian Belief Network Model

2.3.1 Development of the BBN model

The ESDecide BBN model was initially built in Netica 6.09 (Norsys Software, Vancouver, Canada), consistent with the ESManage BBN model, but then it was migrated to GeNIe Modeler 3.0 (BayesFusion, Pittsburgh, PA, USA) to avail of its additional functionality. The different information sources described in section 2.2 were used to define the BBN model structure (variables/nodes and connections), thresholds for each variable state (e.g. low, medium, high) and knowledge rules (the direction and shape of each relationship) and, finally, to populate the conditional probability tables.

The BBN model underwent multiple iterations of development within the ESDecide project. This was done firstly to encapsulate a broader selection of ecosystem services/NCP, by adding "abstraction water quality", "recreational water quality" and "nutrient assimilation potential". Secondly, owing to concerns that the effect of explicit management options could vary widely between catchments depending on their setting, the resulting individual stressors and general river settings were used instead as inputs to the BBN model. The intermediate nodes and connections were restructured to facilitate these changes. Some variables were changed to be more tangible or quantifiable, e.g. from "food for mayfly" to "algal biofilm abundance" and from "eutrophication potential" to "filamentous algae cover". Further adjustments to the structure of the intermediate part of the BBN model and conditional probability tables were made to incorporate new evidence.

2.3.2 BBN model inputs and outputs

Inputs

After the aforementioned iterations, the ESDecide BBN model provided for six input stressors and riparian shading intensity, which can be mitigated by catchment management. These are given below with a list and definition of the states it can take.

- riparian shading: scarce (< 20%), light (20–50%), moderate (50–70%), heavy (> 70%);
- sediment load: high (> 30 $t\,km^{-2}\,y^{-1}$), medium (10–30 $t\,km^{-2}\,y^{-1}$), low (< 10 $t\,km^{-2}\,y^{-1}$);
- organic matter concentration, quantified by BOD: high (> 1.5 $mg\,O_2\,L^{-1}$), medium (1.3–1.5 $mg\,O_2\,L^{-1}$), low (< 1.3 $mg\,O_2\,L^{-1}$);
- phosphate concentration: high (> 0.035 $mg\,P\,L^{-1}$), medium (0.025–0.035 $mg\,P\,L^{-1}$), low (≤ 0.025 $mg\,P\,L^{-1}$);
- oxidised nitrogen concentration (measured as the sum of nitrate and nitrite, although the latter tends to be negligible in rivers, so oxidised nitrogen and nitrite are sometimes used interchangeably in rivers): high (> 3.0 $mg\,N\,L^{-1}$), medium (0.9–3.0 $mg\,N\,L^{-1}$), low (< 0.9 $mg\,N\,L^{-1}$);
- total ammonia concentration: high (> 0.065 $mg\,N\,L^{-1}$), medium (0.040–0.065 $mg\,N\,L^{-1}$), low (≤ 0.040 $mg\,N\,L^{-1}$).

The BBN model inputs also included three environmental conditions that specify different catchment settings for using the BBN model in different rivers:

- alkalinity: calcifying (visible calcium precipitation), high (>100 mg $CaCO_3$ L^{-1}), medium (10–100 mg $CaCO_3$ L^{-1}), low (5–10 mg $CaCO_3$ L^{-1}), very low (<5 mg $CaCO_3$ L^{-1});
- flow regime: spatey (responds rapidly to rainfall, variable flow), intermediate (substantial flow, no rapid pulses), slow (steady flow);
- coarse fish presence: present, absent.

Finally, the BBN model includes a climate scenario input, distinguishing between baseline climate and Representative Concentration Pathway (RCP) scenarios 4.5 and 8.5 for 2046–2065 (+1.2°C and +2.0°C, respectively). Downscaled predictions of future mean temperatures are available for Ireland (Nolan and Flanagan, 2020); however, downscaled predictions of other climate change impacts, such as temperature extremes and hydrological impacts, are insufficiently conclusive to support robust implementation in the BBN model. Thus, the ESDecide BBN model may underestimate the effect of climate change and this stressor has therefore not been displayed in the online version of the ESDecide DST.

Baseline conditions set for all input variables in each case study catchment are presented in Chapter 3 (see Table 3.1).

Outputs

The ESDecide BBN model produces six output ecosystem service/NCP variables reflecting different groups of societal benefits. Some of these are not directly ecosystem services but, in the absence of relevant data, are biological indicators of ecosystem services. For example, mayfly richness and dipper density are metrics relating to wildlife value appreciated by people (for further description, see Kelly-Quinn *et al.*, 2020). These are given below with a list and definition of the states it can take:

- mayfly richness (wildlife value): very high (8 species), high (6 species, sensitive taxa scarce to common), medium (2 species, sensitive taxa absent), poor (0–1 species);
- dipper density (wildlife value): high (>5 breeding pairs per 10 km), medium (2–5 breeding pairs per 10 km), low (<2 breeding pairs per 10 km);
- recreational water quality (for *in situ* non-consumptive uses): high (suitable for all uses), medium (potential limitations), low (extremely limited);
- abstraction water quality: high (minimal or no treatment required), medium (advanced treatment required), low (low-grade abstraction only);
- nutrient assimilation potential: high (optimal for the river type), medium (underutilised), low (severely compromised);
- salmonid angling potential: high (good density of catchable fish in good condition), medium (some catchable fish in good condition), low (few fish).

2.3.3 Case study catchments

ESDecide used three case study catchments (excluding tidal effects) representing different Irish settings and pressures (Figure 2.4):

- River Dodder, east of Ireland: a steep, flashy and predominantly urban catchment;

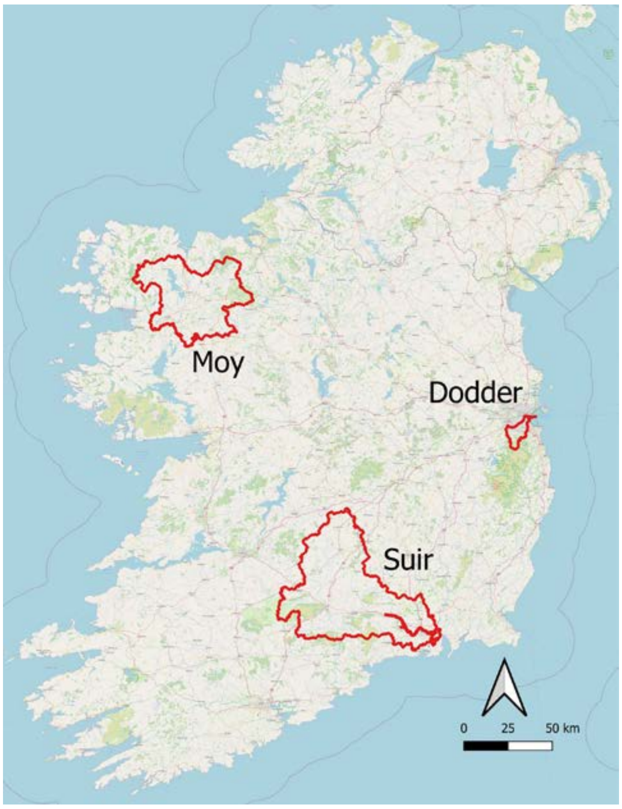


Figure 2.4. Location of the three case study areas in Ireland. Background maps: © OpenStreetMap contributors, licensed under CC BY-SA 2.0 (https://www.openstreetmap.org/copyright). Shapefiles adapted from gis.epa.ie.

- River Suir, south of Ireland: a slow-moving river in an intensive agricultural catchment;
- River Moy (part), west of Ireland: mixed land use with a large proportion of peaty soils.

For the River Moy, owing to the high spatial heterogeneity of pressures, ESDecide focused on the Moy_SC_010 subcatchment, which has a large proportion of coniferous forestry and septic tanks. See Kelly-Quinn *et al.* (2020) for further description of these catchments.

Input states for these three catchments have been defined based on the following:

- EPA water chemistry data;
- aerial photography for riparian shading intensity (by the ESManage project; Kelly-Quinn *et al.*, 2020);
- modelled values for sediment load (from equations developed by the SILTFLUX project; Bruen *et al.*, 2017);
- Inland Fisheries Ireland coarse fish presence data;
- team expertise for flow regime (see section 3.2.2).

2.3.4 Further refinements of the BBN model

The BBN model was checked by the project team to determine if:

- any adjustments of one parent variable had distorted the effect of another, which was plausible in the more complex conditional probability tables; in particular, a change in probabilities of a dominant parent variable may inadvertently distort the effect of a weaker one in some of the combinations of the other parent variables;
- any indirect effects on a particular variable through another was distorting the overall effect; for example, "deposited sediment" has a negative effect on "habitat quality" and consequently on "algal biofilm abundance", but, at the same time, "deposited sediment" subdues "filamentous algae cover", which is one of the stressors on "algal biofilm abundance", so the two mechanisms operate antagonistically;
- the behaviour of the network overall, including strength of influence and sensitivity, aligned with the general understanding of river functioning;
- the outcomes of the network applied to the three case study catchments aligned with the general knowledge of their functioning.

These checks prompted further rounds of adjustments. Finally, the BBN model was incorporated into a DST (see Chapter 3) and was tested by the steering committee, which resulted in one more adjustment concerning the effect of increasing shading intensity.

The final ESDecide BBN model consists of 36 nodes representing variables, 76 links representing relationships between variables and 5018 conditional probabilities quantifying these relationships (Figure 2.5). However, the BBN model can be refined beyond the lifetime of the ESDecide project through wider testing and by using emerging evidence.

2.3.5 General outcomes

Among the different input stressors represented in the BBN model, "organic matter", closely followed by "sediment load" and then "riparian shading" deficit, is predicted to have the strongest effect on the biological/ecosystem services responses examined (Figure 2.6). "Organic matter pollution" depresses "dissolved oxygen", its decomposition contributes to excess nutrients, and it shares sources with *Escherichia coli* contamination (sewage and slurry; Figure 2.5). Sediment smothers riverbed habitats and directly affects water quality for abstraction and recreation. Riparian shading subdues summer stream temperature and filamentous algae growth while promoting better habitat quality and heterogeneity through associated inputs of foliage, coarse woody material, underwater roots, overhangs (which also encourages more food insects), etc. Thus, riparian shading scarcity is considered undesirable. Among inorganic nutrients, phosphate has the strongest effect on riverine biological/ecosystem services responses, followed by ammonia and oxidised nitrogen (nitrate and potentially nitrite). All three contribute to the nutrient excess; in addition, ammonia is toxic to animals as dissolved gas (as opposed to the ionised form). Climate change is predicted to affect biological/ecosystem services responses through increased summer water temperature.

Among the different biological output responses and associated ecosystem services/NCP represented in the BBN model, recreational water quality, closely followed by abstraction water quality, is the most sensitive to input stressors, predominantly to sediment and organic matter (Figures 2.5 and 2.6). Salmonid angling potential is most sensitive to organic matter

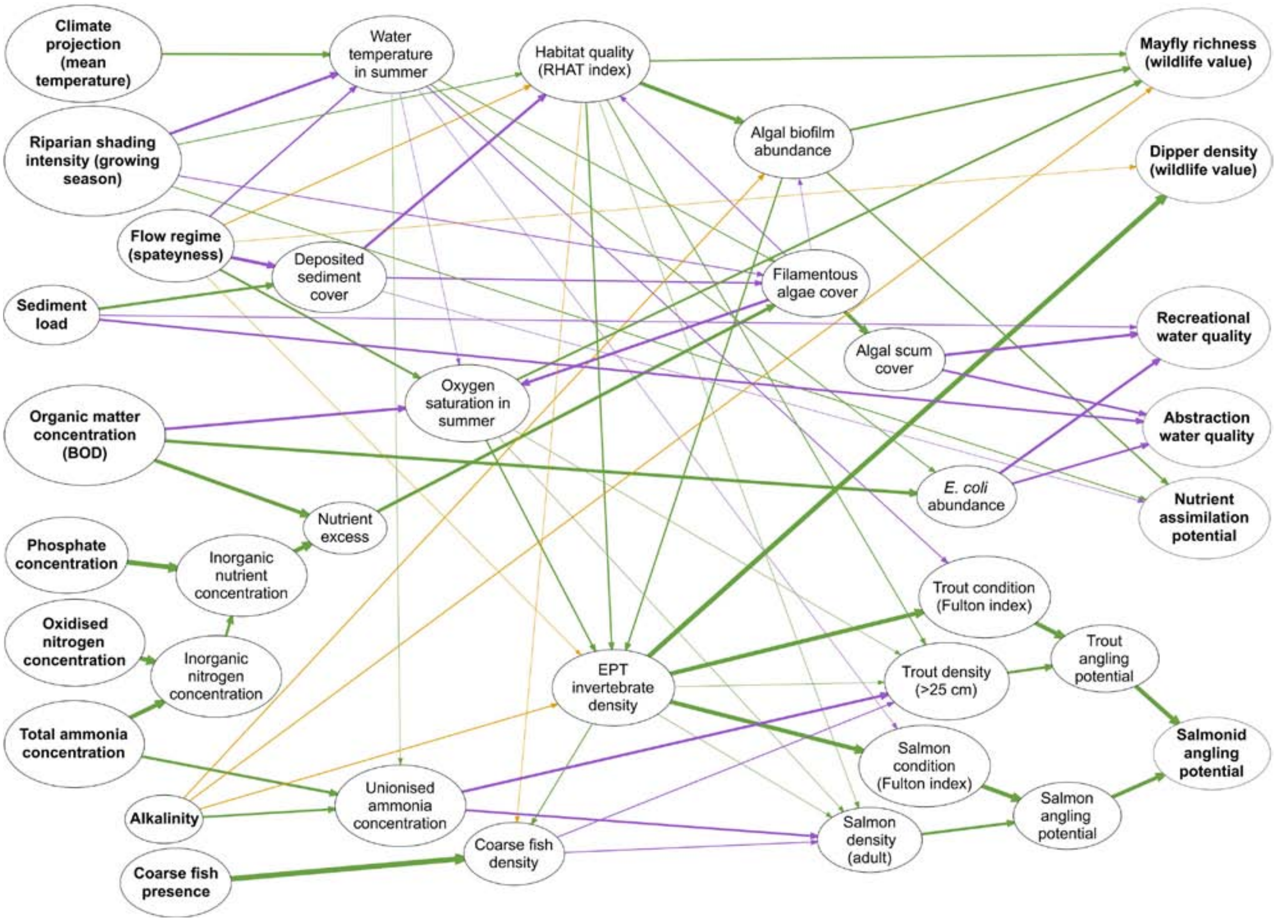


Figure 2.5. The final ESDecide BBN model structure. Nodes in bold are environmental condition inputs (far left), including stressors (left-aligned) and biological/ecosystem service outputs (right). Arrow thickness denotes the strength of influence. Arrow colour denotes the sign of the correlation: green is positive (i.e. an increase in the beginning of the arrow causes an increase in its end), purple is negative (i.e. an increase in the beginning of the arrow causes a decrease in its end) and yellow is changing direction over the parent node gradient (unimodal). *E. coli, Escherichia coli*; EPT, Ephemeroptera, Plecoptera, Trichoptera, i.e. insect orders of mayflies, stoneflies and caddisflies, respectively.

concentrations, followed by riparian shading and ammonia concentrations. Nutrient assimilation potential is most sensitive to riparian shading. The two indicators of wildlife value, mayfly richness and dipper density, have a similar sensitivity, with the strongest reaction to organic matter concentrations.

It should be emphasised that these sensitivities represent average conditions across all the different range of scenarios represented in the BBN model. At the individual locations ranking of sensitivities among ecosystems and the hierarchies of stressors may vary according to site-specific conditions. In particular, the effect of inorganic nutrients may be partly conflated with organic matter, which also contributes nutrients, and has an additional direct effect on oxygen concentration. Thus, nutrients are of higher importance in the absence of organic pollution. Another example is riparian shading, which can have an even stronger effect with high nutrient concentrations and future climate warming because of its increased role in cooling and subduing light for algal productivity. Ammonia toxicity is unlikely to be a problem in low-alkalinity waters, sediment is likely to get flushed out in spatey rivers, and so on. Therefore, specific management advice should always explicitly consider such context dependencies.

2.3.6 *Catchment-specific outcomes*

All three case study catchments have high alkalinity. The Dodder and Moy are spatey, whereas the Suir is

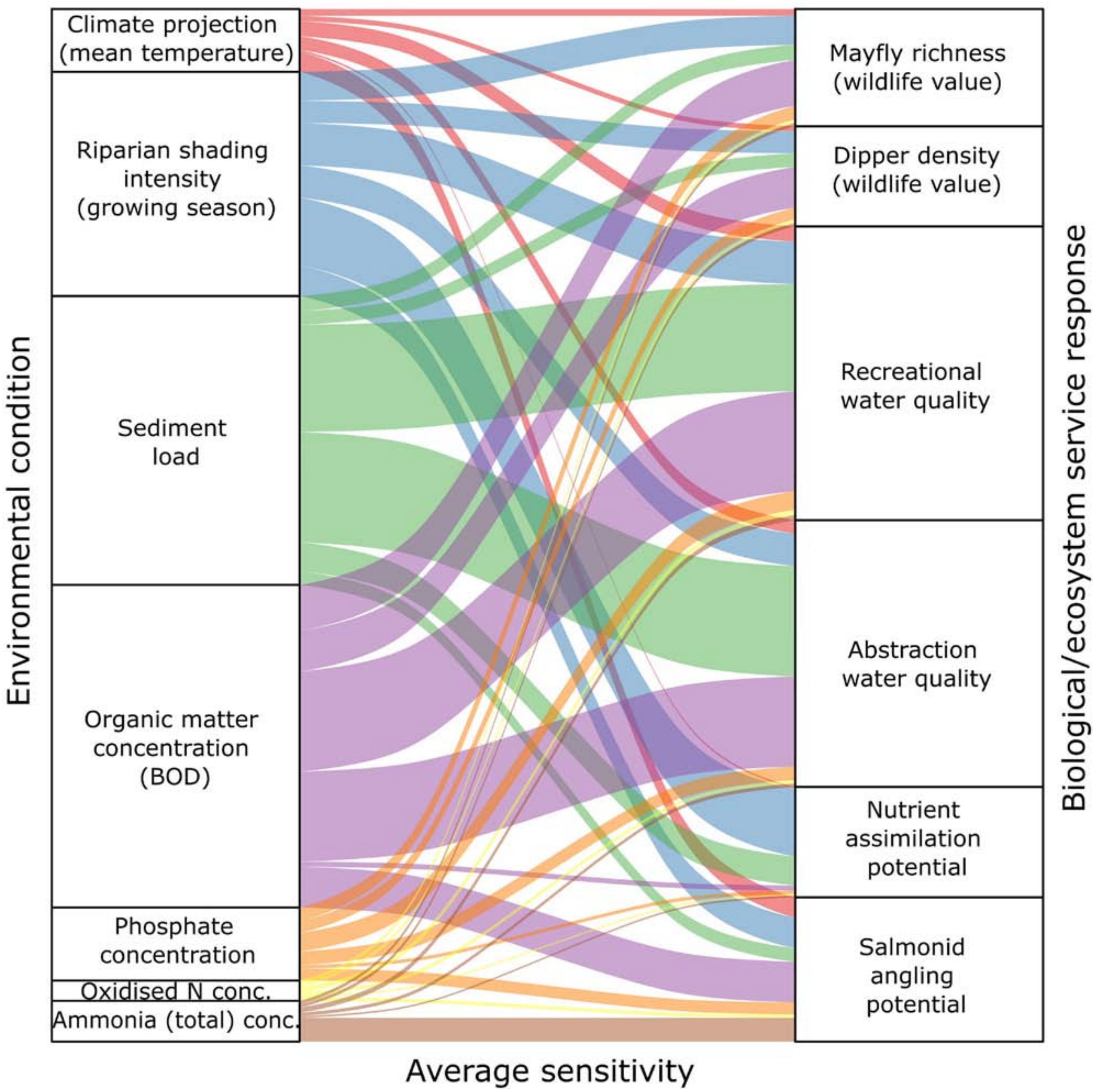


Figure 2.6. Sensitivity of biological responses and associated ecosystem services/NCP to stressors in the ESDecide BBN model represented by the thickness of the connecting shapes. The height of the boxes denotes the overall relative influence of each stressor (left) and the overall relative sensitivity of each ecosystem service (right) across all scenarios represented in the ESDecide BBN model. conc., concentration; N, nitrogen.

slow flowing. The Suir has coarse fish, whereas the Dodder and Moy do not. Thus, the Dodder and Moy are likely to show similar responses to stressors and changes to riparian shading, and their management, whereas the Suir is likely to differ in that regard.

All three catchments have low levels of riparian shading, from “light” in the Dodder (20–50% cover) to “scarce” in the Suir and Moy (< 20% cover). The three catchments vary in the set of acting stressors. The Suir and Moy have medium sediment loads (10–30 $t\,km^{-2}\,y^{-1}$), whereas sediment load is low in the Dodder (< 10 $t\,km^{-2}\,y^{-1}$). The Moy has a medium organic matter concentration (BOD 1.3–1.5 $mg\,O_2\,L^{-1}$), whereas organic matter concentration is low in the other two rivers (BOD < 1.3 $mg\,O_2\,L^{-1}$). Phosphate concentration is high in the Suir (> 0.035 $mg\,P\,L^{-1}$) and medium in the Dodder (0.025–0.035 mg P L^{-1}), but low in the Moy (< 0.025 mg P L^{-1}). Oxidised nitrogen concentration is medium in the Dodder and Suir (0.9–3.0 mg N L^{-1}), but low in the Moy (< 0.9 mg N L^{-1}). Total ammonia concentration is medium in the Dodder and Suir (0.04–0.065 mg N L^{-1}), but low in the Moy (< 0.04 mg N L^{-1}).

Increasing riparian shading is predicted to considerably benefit all biological/ecosystem services responses, more so in the Suir because of its high phosphate levels and slow flow (conducive to high temperature); both favour proliferation of nuisance algae, which can be inhibited by shading. The Dodder catchment, which has a higher shading intensity than the Suir or Moy, is projected to benefit the least from increased shading (Table 2.2). Decreasing sediment load is predicted to considerably improve various aspects of water quality in the Suir and Moy. Decreasing organic matter concentration could bring considerable improvements to all biological/ecosystem services responses in the Moy. Reducing phosphate inputs is predicted to considerably benefit most biological/ecosystem services responses in the Dodder and Suir, more so in the Suir, which has a higher baseline phosphate concentration. In terms of total ammonia alone, a reduction from baseline levels is projected to benefit salmonid angling potential in the Dodder, but not so much in the Suir. This is because multiple other stressors affect salmonids in the Suir, even when ammonia concentrations are low (e.g. phosphate, sediment, oxidised nitrogen, low levels of shading and competition from coarse fish). Decreasing oxidised nitrogen concentration is predicted to have little influence in any of the catchments because it is never higher than “medium”, and phosphate is thought to be a more limiting nutrient for algal productivity than inorganic nitrogen in freshwaters (Schindler, 2006; Table 2.2). Although oxidised nitrogen has the potential to affect transitional and marine waters downstream, the BBN model included only the freshwater sections.

Table 2.2. States of biological and ecosystem service/NCP responses in three river catchments expressed as an index from 0 to 1 (worst to best; in bold) and predicted changes to these services resulting from alterations of catchment stressors

Ecosystem service/NCP		Climate			Shading				Sediment			Organic matter			Phosphate			N (oxidised)			Ammonia (total)		
	Index	Baseline	RCP 4.5	RCP 8.5	Scarce	Light	Moderate	Heavy	Low	Medium	High	Low	Medium	High	Low	Medium	High	Low	Medium	High	Low	Medium	High
Dodder																							
Mayfly richness (wildlife)	**0.51**	Baseline condition	–0.03	–0.04	–0.13	Baseline condition	+0.06	–0.11	Baseline condition	–0.01	–0.02	Baseline condition	–0.12	–0.20	+0.10	Baseline condition	–0.08	+0.02	Baseline condition	–0.02	+0.02	Baseline condition	–0.02
Dipper density (wildlife)	**0.45**	Baseline condition	–0.02	–0.03	–0.09	Baseline condition	+0.05	–0.06	Baseline condition	–0.01	–0.01	Baseline condition	–0.08	–0.13	+0.07	Baseline condition	–0.06	+0.01	Baseline condition	–0.01	+0.01	Baseline condition	–0.01
Abstraction water quality	**0.69**	Baseline condition	–0.03	–0.04	–0.08	Baseline condition	+0.08	+0.08	Baseline condition	–0.32	–0.47	Baseline condition	–0.19	–0.36	+0.08	Baseline condition	–0.08	+0.02	Baseline condition	–0.02	+0.02	Baseline condition	–0.02
Recreational water quality	**0.64**	Baseline condition	–0.02	–0.03	–0.08	Baseline condition	+0.08	+0.09	Baseline condition	–0.15	–0.37	Baseline condition	–0.18	–0.34	+0.09	Baseline condition	–0.10	+0.02	Baseline condition	–0.02	+0.02	Baseline condition	–0.02
Nutrient assimilation potential	**0.68**	Baseline condition	–0.00	–0.00	–0.10	Baseline condition	+0.08	+0.10	Baseline condition	–0.01	–0.02	Baseline condition	–0.01	–0.02	+0.02	Baseline condition	–0.02	+0.00	Baseline condition	–0.00	+0.00	Baseline condition	–0.00
Salmonid angling potential	**0.44**	Baseline condition	–0.05	–0.07	–0.11	Baseline condition	+0.09	+0.01	Baseline condition	–0.01	–0.01	Baseline condition	–0.07	–0.12	+0.06	Baseline condition	–0.05	+0.01	Baseline condition	–0.01	+0.12	Baseline condition	–0.08
Suir																							
Mayfly richness (wildlife)	**0.16**	Baseline condition	–0.02	–0.02	Baseline condition	+0.11	+0.18	+0.08	+0.03	Baseline condition	–0.01	Baseline condition	–0.06	–0.09	+0.13	+0.06	Baseline condition	+0.01	Baseline condition	–0.01	+0.01	Baseline condition	–0.01
Dipper density (wildlife)	**0.19**	Baseline condition	–0.02	–0.02	Baseline condition	+0.08	+0.14	+0.07	+0.03	Baseline condition	–0.01	Baseline condition	–0.05	–0.06	+0.10	+0.04	Baseline condition	+0.01	Baseline condition	–0.01	+0.01	Baseline condition	–0.01
Abstraction water quality	**0.31**	Baseline condition	–0.02	–0.02	Baseline condition	+0.05	+0.09	+0.10	+0.18	Baseline condition	–0.12	Baseline condition	–0.10	–0.19	+0.09	+0.04	Baseline condition	+0.01	Baseline condition	–0.01	+0.01	Baseline condition	–0.01
Recreational water quality	**0.41**	Baseline condition	–0.02	–0.02	Baseline condition	+0.07	+0.12	+0.13	+0.03	Baseline condition	–0.17	Baseline condition	–0.11	–0.23	+0.13	+0.06	Baseline condition	+0.01	Baseline condition	–0.01	+0.01	Baseline condition	–0.01
Nutrient assimilation potential	**0.45**	Baseline condition	–0.00	–0.00	Baseline condition	+0.10	+0.19	+0.24	+0.09	Baseline condition	–0.03	Baseline condition	–0.00	–0.01	+0.03	+0.01	Baseline condition	+0.00	Baseline condition	–0.00	+0.00	Baseline condition	–0.00
Salmonid angling potential	**0.19**	Baseline condition	–0.03	–0.03	Baseline condition	+0.07	+0.13	+0.10	+0.03	Baseline condition	–0.01	Baseline condition	–0.04	–0.05	+0.08	+0.03	Baseline condition	+0.01	Baseline condition	–0.01	+0.03	Baseline condition	–0.02
Moy (part)																							
Mayfly richness (wildlife)	**0.33**	Baseline condition	–0.01	–0.01	Baseline condition	+0.10	+0.16	–0.00	+0.01	Baseline condition	–0.01	+0.25	Baseline condition	–0.13	Baseline condition	–0.04	–0.08	Baseline condition	–0.02	–0.04	Baseline condition	–0.02	–0.04
Dipper density (wildlife)	**0.33**	Baseline condition	–0.01	–0.01	Baseline condition	+0.06	+0.10	–0.00	+0.01	Baseline condition	–0.01	+0.17	Baseline condition	–0.08	Baseline condition	–0.02	–0.05	Baseline condition	–0.01	–0.02	Baseline condition	–0.01	–0.02
Abstraction water quality	**0.27**	Baseline condition	–0.02	–0.02	Baseline condition	+0.04	+0.08	+0.08	+0.24	Baseline condition	–0.12	+0.17	Baseline condition	–0.16	Baseline condition	–0.03	–0.06	Baseline condition	–0.02	–0.03	Baseline condition	–0.02	–0.03
Recreational water quality	**0.38**	Baseline condition	–0.02	–0.03	Baseline condition	+0.05	+0.10	+0.10	+0.11	Baseline condition	–0.16	+0.20	Baseline condition	–0.22	Baseline condition	–0.06	–0.10	Baseline condition	–0.03	–0.05	Baseline condition	–0.03	–0.05
Nutrient assimilation potential	**0.58**	Baseline condition	–0.00	–0.00	Baseline condition	+0.10	+0.18	+0.19	+0.01	Baseline condition	–0.01	+0.03	Baseline condition	–0.03	Baseline condition	–0.01	–0.02	Baseline condition	–0.01	–0.01	Baseline condition	–0.01	–0.01
Salmonid angling potential	**0.40**	Baseline condition	–0.02	–0.03	Baseline condition	+0.10	+0.17	+0.08	+0.01	Baseline condition	–0.01	+0.18	Baseline condition	–0.09	Baseline condition	–0.03	–0.05	Baseline condition	–0.01	–0.03	Baseline condition	–0.10	–0.17

Note: The direction and degree of change are indicated by the colour and intensity of shading: purple denotes a deterioration; green denotes an improvement.

3 The Decision Support Tool

The ESDecide DST is a graphical user interface that allows end users to interactively connect to the ESDecide BBN model as described in section 2.3. The end user can thereby set numerous targeted environmental conditions of selected river reaches, subcatchments or catchments and model the probability of biological responses and associated ecosystem services/NCP depending on the selection. This chapter describes the rationale and the basic functionality of the DST. Further details on its application and the interpretation of results are provided in a separate document, the manual to the ESDecide DST.[5]

3.1 Introduction – Decisions and Support

River basin management requires practitioners to make numerous decisions, such as (1) the decision on which environmental pressures are to be addressed by management options in the first place, (2) the decision on suitable biological indicators to measure the ecological implications of environmental pressures and (3) the decision on appropriate management options to reduce the pressure intensity and to mitigate adverse biological implications and impacts on ecosystem services/NCP. All these decisions may be supported by the ecosystem managers' expertise and knowledge; however, at some point it might be hard to determine the most appropriate decision, in particular in the event of inconsistent or cursory evidence, interacting stressors and potential trade-offs between ecosystem services/NCP. Take, for example, the management of riparian buffers. The huge body of evidence on riverine biological implications of riparian buffers (through riparian shade, organic matter supply or fine sediment retention) predominantly suggests their beneficial effects (Feld *et al.*, 2011, 2018; Ryan *et al.*, 2016; Riis *et al.*, 2020). However, any beneficial effects may depend on the targeted stressors (e.g. nutrient or fine sediment reduction) and on river size, with stronger effects being detectable in upstream reaches and weaker effects further downstream.

Diagnostic DSTs in connection with BBN models have been found to help identify riparian degradation by using numerous biological indicators, and thus support decisions on appropriate riparian and catchment-scale management options (Feld *et al.*, 2020). The same kind of DSTs also allows an end user to (prognostically) estimate the effects of environmental changes on biological indicators and ecosystem services/NCP, and thus support decisions on appropriate management options towards improved riverine biological conditions and good ecological status.

3.2 The ESDecide DST

The ESDecide DST provides a graphical user interface to the prognostic ESDecide BBN model. The DST makes the input nodes of the BBN model selectable by an end user, who can interactively model the probability of biological responses and ecosystem services/NCP implications of their selection of environmental conditions. The baseline for modelling is the current environmental conditions in three Irish rivers: the Dodder, the Moy and the Suir. Therefore, three DSTs have been implemented for the online demonstration version of the tool, which differ only in the selection of baseline environmental conditions. In the future, further catchments could be included by the EPA or Local Authority Waters Programme (LAWPRO) or as part of subsequent projects to test the applicability of the model nationally.

3.2.1 Aims and targeted end user

The main aim of the DST is to answer the following question: "What would be the implication(s) for ecosystem services/NCP if selected riverine and riparian environmental conditions were changed in a targeted river reach/subcatchment?". Because the selection of environmental conditions may directly correspond to certain management options (e.g. hydrological/morphological restoration measures, reduction of point source pollution), the DST can

5 The manual can be obtained from https://cwrr.ucd.ie or by emailing research@epa.ie or mary.kelly-quinn@ucd.ie.

inform and support the decision on appropriate management options in light of particular targeted biological and ecosystem services/NCP implications.

The main end user addressed by the DST is therefore the practitioner, who is in charge of the decision on appropriate river basin management options to achieve targeted ecosystem services/NCP and/or ecological conditions. These conditions may notably differ between policy targets connected to the WFD (2000/60/EC: good ecological status/potential); the CBD and related national targets (UN, 1992: biodiversity, habitat diversity); or socioeconomic targets (MEA, 2005b: ecosystem services; NCP: Diaz *et al.*, 2018). The biological and ecosystem services/NCP-related implications that are addressed by the DST include targets related to these policies.

3.2.2 *Selection of input parameters*

Nine environmental conditions constitute the input parameters of the DST (Table 3.1). These parameters are selectable by the end user through pull-down menus on the left-hand side of the tool (see section 3.4). On start-up of the DST, the environmental conditions of all input parameters are preset according to the current status (year of 2020) of conditions within the three case study rivers (see section 3.4). These default, preset conditions provide the baseline (prior

Table 3.1. Nine input parameters with pre-selected baseline environmental conditions in the DSTs of the three pilot rivers

Parameter name	Ecological meaning	Dodder	Moy	Suir
Predominant flow regime	Flashiness of flow (link to precipitation)	Spatey	Spatey	Slow (steady flow)
Mean alkalinity	Influences the biotic communities and also has implications for toxicity of certain pollutants	High (> 100 mg $CaCO_3$ L^{-1})	High (> 100 mg $CaCO_3$ L^{-1})	High (> 100 mg $CaCO_3$ L^{-1})
Presence of coarse fish	Competes with salmonids	Absent	Absent	Present
Mean nitrate concentration	Diffuse source pollution	Medium (0.9–3 mg L^{-1})	Low (< 0.9 mg L^{-1})	Medium (0.9–3 mg L^{-1})
Mean total ammonia concentration	Point source pollution	Medium (0.04–0.065 mg L^{-1})	Low (< 0.04 mg L^{-1})	Medium (0.04–0.065 mg L^{-1})
Mean phosphate concentration	Point source pollution	Medium (0.025–0.035 mg L^{-1})	Low (< 0.025 mg L^{-1})	High (> 0.035 mg L^{-1})
Annual sediment load	Gives an indication of the potential for elevated deposited sediment	Low (< 10 t km^{-2} y^{-1})	Low (< 10 t km^{-2} y^{-1})	Medium (10–30 t km^{-2} y^{-1})
Mean concentration of organic matter as BOD	Point source pollution (oxygen depletion)	Low (< 1.3 mg O_2 L^{-1})	Medium (1.3–1.5 mg O_2 L^{-1})	Low (< 1.3 mg O_2 L^{-1})
Proportion of sky covered by tree canopy	Riparian conditions (equivalent to percentage of shade)	Light (20–50%)	Scarce (< 20%)	Scarce (< 20%)

model, see section 2.3.6 and Table 3.1) for modelling. The modelling of conditional probabilities of biological and ecosystem services/NCP responses starts with the user's first change of an input parameter. To inform the end user's selection of input parameters, the user should have at least some basic understanding of desirable or achievable environmental conditions, to ensure that they are not mutually exclusive or unachievable within the specific river system.

3.2.3 Selection of output parameters

The six output variables representing the response variables of the ESDecide BBN model are outlined in section 2.3.2, Outputs. They are fixed on the right-hand side of the DST (see Figure 3.2) and cannot be changed by the end user. Any change in the modelled probability of output parameters conditional on the selection of environmental conditions of the input variables is displayed as a horizontal bar in the output section of the DST.

3.2.4 Options and limitations of the DST

The ESDecide DST is meant to support decisions through probability estimates conditional on the end user's input. The tool can help identify ecologically beneficial environmental conditions, as well as distinguish those from rather detrimental conditions. The tool may also inform what environmental conditions are required to obtain a certain biological and ecosystem services/NCP response, such as an increase in water abstraction quality or wildlife value.

For the interpretation of the DST's outcome, however, it is important to acknowledge two limitations. First, the outcome is presented as a probability of change relative to the current (baseline) conditions; however, even the strongest change in the probability of a response does not mean that this response will actually happen. The response may be conditional on other variables, including those covered by neither the DST nor the underlying BBN model (e.g. toxicants and salinisation). Second, the DST is meant to support decisions, but not take them. End users may tend to look for options to automatically connect environmental datasets to the DST to run bulk estimations for tens or even hundreds of river reaches at the same time. Although technically feasible, such an approach would easily run the risk of losing expertise, unless the end user decides to revisit and interpret each individual result in light of their own expertise. It is the end user who has to finally take the decisions, not the DST.

3.3 The DST Web Apps

The DST has been implemented as an interactive web browser-based application. The application is available at https://esdecide.shinyapps.io/ProgRES/ and can be launched using a web browser, including on tablet computers and smartphones. For regular use, however, laptop or desktop screens are recommended to assist a user-friendly application. Full functionality of the tool was tested using Firefox, Google Chrome and Safari browsers.

The online version of the DST consists of three separate web apps representing the three river case studies addressed by the ESDecide project (Dodder, Moy and Suir). In addition to the online demonstration version of the DST, a stand-alone flexible version has been made available for application outside the three case study regions. The stand-alone version requires local installation of the DST onto a desktop computer and offers the user the option to set individual baselines corresponding to any river for the calculation of probabilities (see the input tables in section 3.3.2).

3.3.1 Technical implementation

The core of each web app consists of the BBN model (.net file) and two R scripts that run the calculations (code_for_shiny.R) and the graphical user interface (app.R). As mentioned in Chapter 2, the original BBN model was developed using the software Netica (v.6.09; https://www.norsys.com) and was then exported to a .net file format using the software GeNIe (v.3.0; https://www.bayesfusion.com/genie/). The .net file contains all variables (nodes) and node states, and includes all (conditional) probability entries. Each node and node state were assigned a unique name, which enables further customisation of the web app through translation tables (see section 3.3.3).

The interface between the BBN model and the web apps is provided through the royalty-free software R (R Core Team, 2021) and RStudio (https://rstudio.com/products/rstudio/). An R script (code_for_shiny.R) was developed to import the .net file into R so that Bayesian model calculations can be directly run using R. The three river-specific web apps (app.R) were developed in Shiny (Chang *et al.*, 2019). Shiny provides the technical framework to program the input and output sections of each web app and to display the results and additional information in graphical and tabular form. Because Shiny is also royalty-free for basic applications, any maintenance and further development of the web apps does not require any fees for software or licences. The interplay of the end user's input, the tool's output, the default tool settings, R/Shiny codes and the underlying BBN model is illustrated in Figure 3.1.

3.3.2 Translation tables

To keep all R scripts as generic and handy as possible, all input and output parameter (node) names, their node states, river-specific pre-selections of node states, weighing factors (see section 3.3.4) and links to supplementary text files and pictures were kept separate from the actual script code and were stored in separate translation tables (.csv format). Hence, each river-specific web app links to the following three tables for this purpose:

1. general_prognosis.csv;
2. input_prognosis.csv;
3. output_prognosis.csv.

The general_prognosis.csv table contains, for example, headings and default values for display purposes.

The input_prognosis.csv table defines the variable's names and node states as they are displayed in the input area of the Shiny web apps. The table also contains the values that implement the pre-selection of river-specific environmental states (default settings) on start-up of each of the three web apps. The pre-selected combination of states represents the baseline for the calculation of changes in conditional probabilities, if a user makes changes to one or several of the environmental states. The input table

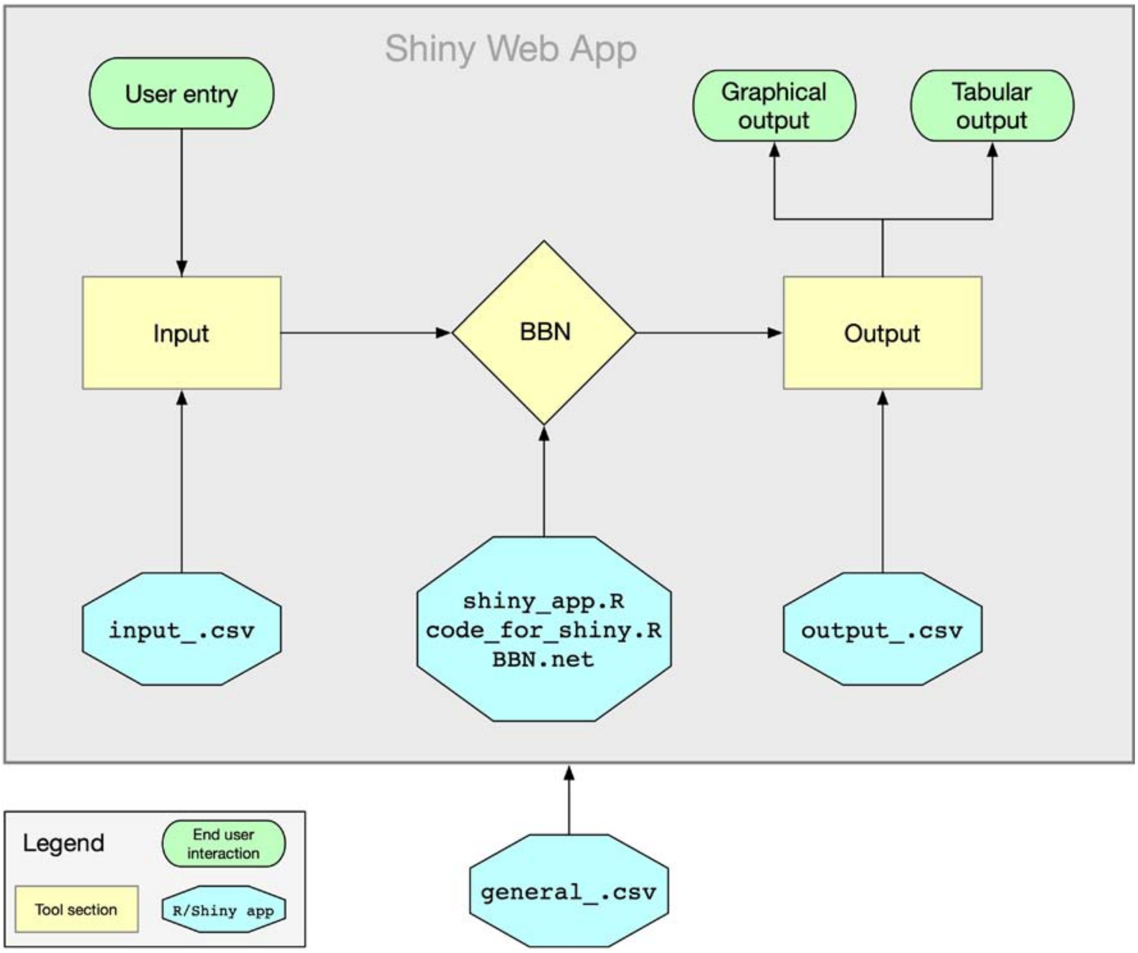


Figure 3.1. Interplay of the BBN model with user entries, model output and translation tables (.csv) in the Shiny web app.

also defines the text that is displayed when the user moves the cursor over the help area of the input variable (blue question marks in Figure 3.2).

To apply the DST outside the three case study regions of Dodder, Moy and Suir, the pre-selection of environmental states on start-up of the DST can be manually set in the input.prognosis.csv table. Therefore, a user need only set the states' IDs (column "Pre-selected class ID" in Table 3.2) as the new baseline for the DST.

The output_prognosis.csv table contains similar information about variable names or codes and states for the output area of the web apps. This table also contains the weighting factors that are used for the calculation of the changes in the probabilities of the output (response) variables.

3.3.3 Weighting factors

Each node within a BBN model has at least two node states (e.g. yes/no, 1/0), but, more commonly, three or four node states are assigned to achieve a reasonable classification of the underlying variable's range of values (gradient). This also applies to the output variables of the DST, i.e. the ecosystem services/NCP (Table 3.3). Hence, the results of a BBN model are expressed as a probability of each individual node state. The comparison of prior probabilities (i.e. before one has changed the input parameters) with posterior probabilities (after one has put evidence on the input parameters) then allows calculation of the changes in the probability of each output parameter's node state. Yet, to be able to express the output of the DST as a *single* probability value, it is necessary to summarise the changes of $n-1$ node states of that particular output parameter. Weighting factors allow for this summary in that they assign a higher weight to more desirable (beneficial) conditions and less/no weight to non-desirable (detrimental) conditions (Table 3.3). The weighted sum of probability changes of all node states of a single node then reflects the overall change in the probability of beneficial/detrimental conditions (see index in Table 2.2, Chapter 2).

3.3.4 Improvement of the draft DST

The draft DST for the Dodder, Moy and Suir was tested by asking stakeholders to access the tool on the web and test whether it was easy to understand

Table 3.2. Pre-selection of input node states (class IDs) as presented on start-up of the River Dodder DST

Input node name	Pre-selected class ID	Class ID = 1	Class ID = 2	Class ID = 3	Class ID = 4	Class ID = 5
Flow regime	1	Spatey	Intermediate	Slow	–	–
Alkalinity	2	High and calcifying	High	Medium	Low	Very low
Coarse fish presence	2	Present	Absent	–	–	–
Nitrate	2	High	Medium	Low	–	–
Total ammonia	2	High	Medium	Low	–	–
Phosphate	2	High	Medium	Low	–	–
Sediment load	3	High	Medium	Low	–	–
Organic matter	3	High	Medium	Low	–	–
Riparian shading	2	Scarce	Light	Moderate	Heavy	–

Note: the pre-selected states translate to a spatey flow regime, high alkalinity, coarse fish absent, medium nutrient content, low sediment load and organic matter content, and light riparian shading. To set any individual combination of input node states as a new baseline on start-up of the DST, the user needs to set the pre-selected class IDs in the table "input_prognosis.csv" of the stand-alone version of the DST.

Table 3.3. Assignment of weighting factors to the output parameters (i.e. biological and ecosystem services/NCP responses) of the DST

	Node state (weight)			
Output parameter	State 1	State 2	State 3	State 4
Salmonid angling potential	High (1)	Medium (0.5)	Low (0)	–
Nutrient assimilation	High (1)	Medium (0.5)	Low (0)	–
Abstraction water quality	High (1)	Medium (0.5)	Low (0)	–
Recreational water quality	High (1)	Medium (0.5)	Low (0)	–
Dipper density	High (1)	Medium (0.5)	Low (0)	–
Mayfly richness	Very high (1)	High (0.666)	Medium (0.333)	Low (0)

Note: the weighting factors summarise the (changes in the) probabilities of individual node states into a single weighted probability value on a range of 0–1 for each output node.

and use, and if its results made sense. After using the tool, stakeholders were asked to complete a questionnaire exploring their experience with it. Responses were generally positive, particularly about the explanatory material; however, some stakeholders suggested that specific training on the use of the tool and the interpretation of the changes expressed as percentages was desirable, and that this would be a learning resource, as well as a practical tool in their work. Subsequently, considerable effort was put into completing the explanatory text for all ecosystems services/NCP in the tool.

Whether the tool, originally implemented for three catchments, could be applied to all river systems in Ireland was also a concern. This was addressed by providing a stand-alone desktop version in which the user could set the baseline conditions for any river for which they had the appropriate data and explore the impact of management options on the biological response and ecosystems services/NCP changes for that river (see section 3.3.2). The extension of the tool to include additional ecosystems services/NCP was also suggested, but this is outside the scope of this project.

3.4 Application of the DST

A prerequisite to reasonably apply the DST is knowledge of the nine environmental (input) parameters that allow the end user to interact with the DST. This knowledge may be obtained through monitoring data or related EPA reports on the three river systems (e.g. nutrient concentrations, BOD, fine sediment load).

The default screen on start-up of the DST is shown in Figure 3.2 and contains an input section on the left-hand side (grey strip), an output section (barplot) on the right-hand side and a brief explanatory text between the sections. Any parameter of the input and output sections is directly connected to the BBN model, which runs in the background of the DST.

When the tool is started, the River Dodder is the default selection. To switch between rivers, the user can select one of the three river tabs at the top of the screen (Figure 3.2). A re-launch of the DST will reset all input parameters to their default states (see Table 3.1).

By changing an input parameter's state (condition), this particular state is selected in the BBN model, i.e. evidence is put on that state. Any change of an input parameter's state then results in a recalculation of conditional probabilities throughout the entire BBN model. The output section of the DST directly connects to the resulting conditional probabilities of the six output variables in the BBN model. These are set to 0 for each river on start-up of the DST (default setting).

Any change in the modelled probability conditional on the selection of input states is displayed in the barplot of the output section (Figure 3.3). Beneficial changes,

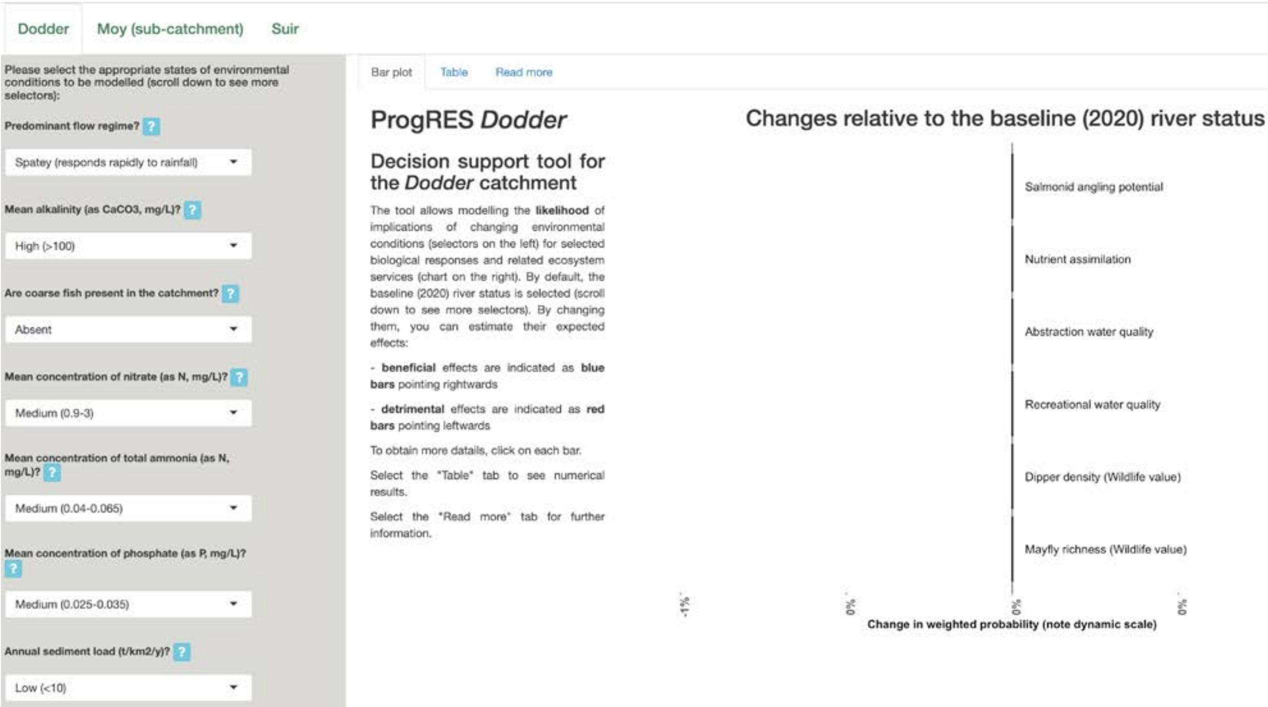


Figure 3.2. Default screen on start-up of the DST (https://esdecide.shinyapps.io/ProgRES/). The environmental conditions (states) in the input section on the left-hand side are preset according to the current conditions in the river system (see Table 3.1). The River Dodder is the default selection on start-up.

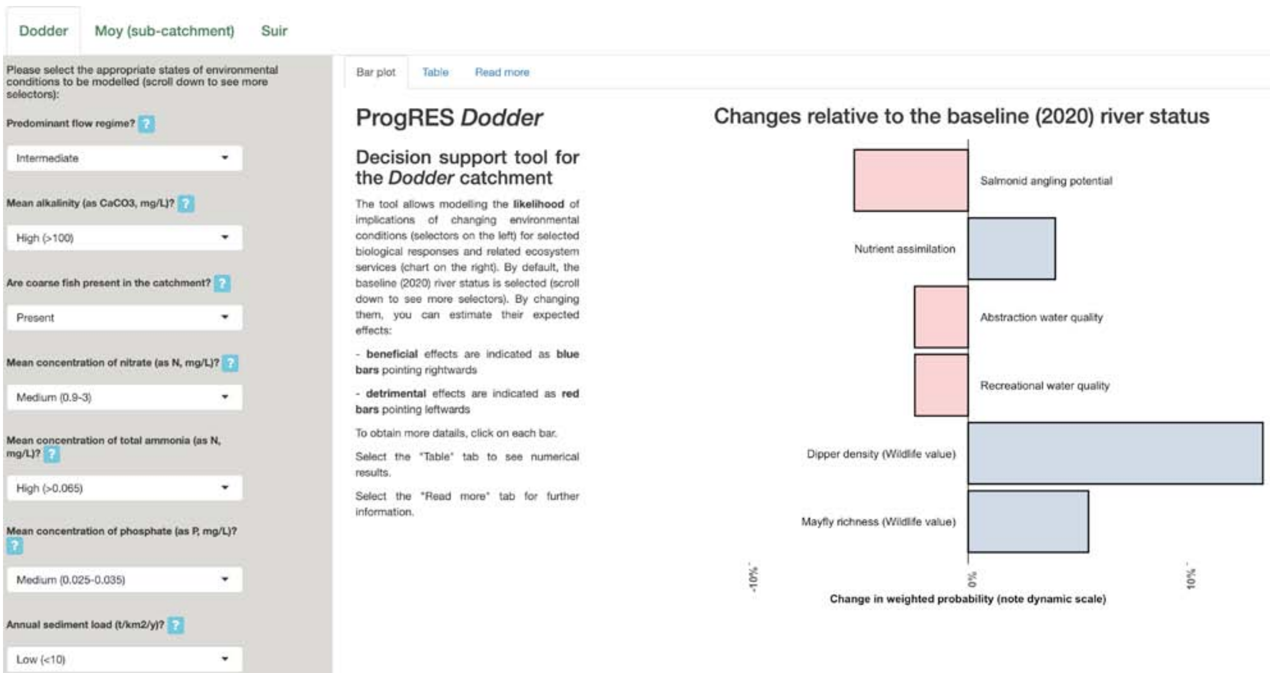


Figure 3.3. Graphical output of biological responses and ecosystem services/NCP conditional on the changes in three input parameters for the River Dodder: (1) spatey → intermediate predominant flow regime; (2) absent → present coarse fish; (3) medium → high mean concentration of total ammonia. Beneficial responses are indicated by blue bars and detrimental changes by red bars.

i.e. increasing probabilities, are shown as blue bars pointing to the right, while detrimental (negative) responses are represented by red bars pointing to the left. The graphical output therefore enables immediate identification of both the strength and direction of biological and ecosystem services/NCP responses to the changing environmental states chosen in the input section.

The interpretation is assisted by a tabular output panel (Figure 3.4) that shows the conditional probabilities of the output variables (biological responses and ecosystem services/NCP) in descending order of change. Hence, the tabular output in particular supports the identification of a response hierarchy. A third tab ("Read more") provides further information and useful web links (Figure 3.5).

3.5 Interpretation of Results

3.5.1 Graphical output

The graphical display of the outcome enables immediate identification of desirable and non-desirable responses given the combination of environmental conditions entered by a user, which renders the interpretation of the outcome fairly straightforward. Beneficial responses are indicated by increasing probabilities pointing to the right (blue bars) and detrimental responses by decreasing probabilities pointing to the left (red bars) (Figure 3.3).

3.5.2 Tabular output

The tabular output provides the same information, i.e. positive (increasing) and negative (decreasing) probabilities, but in numerical order, which allows the user to put the biological and ecosystem services/NCP responses into a hierarchical context. The strongest beneficial effects are put to the top of the table and the strongest detrimental effects to the bottom (Figure 3.4).

3.5.3 Response hierarchy

In order to put the outcome of the DST into a meaningful hierarchical context, the following guidelines may help interpret the changing probabilities correctly.

1. A change of, for example, 20% (either an increase or decrease) in the probability of a biological and

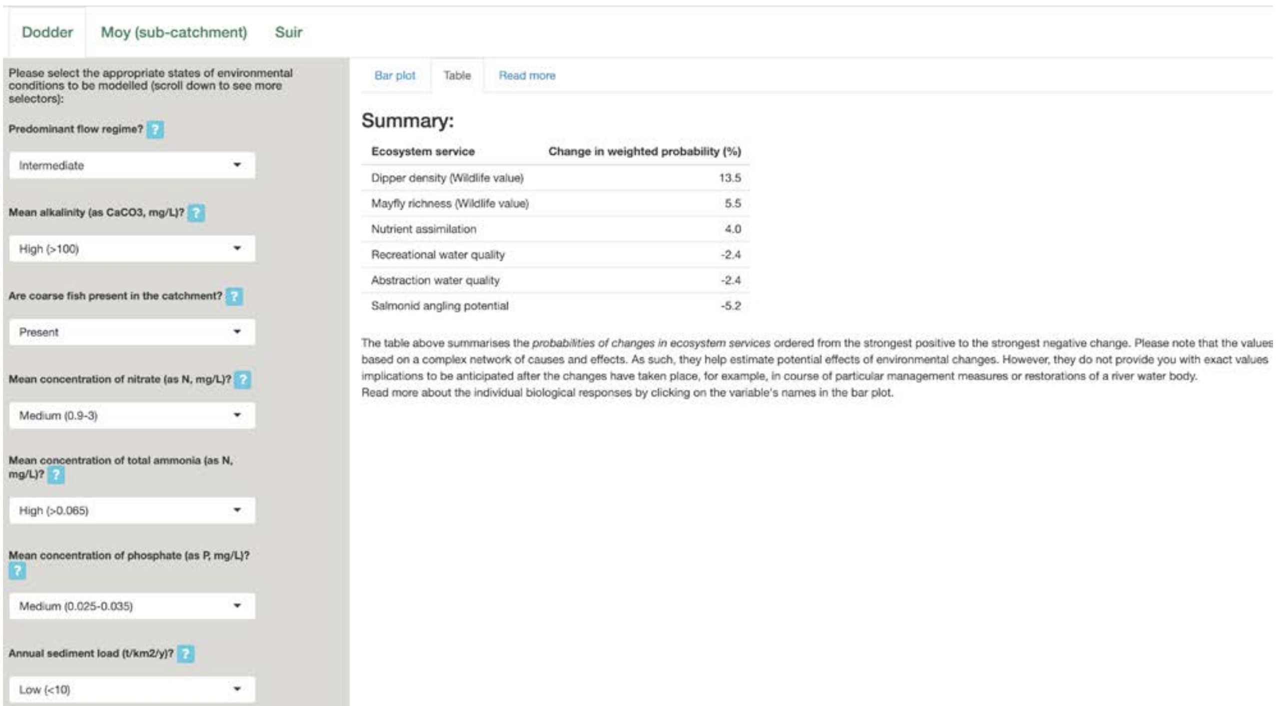


Figure 3.4. Tabular output of biological and ecosystem services/NCP responses according to the example presented in Figure 3.3. The changes in conditional probabilities are given in descending order, which supports the hierarchical classification of results.

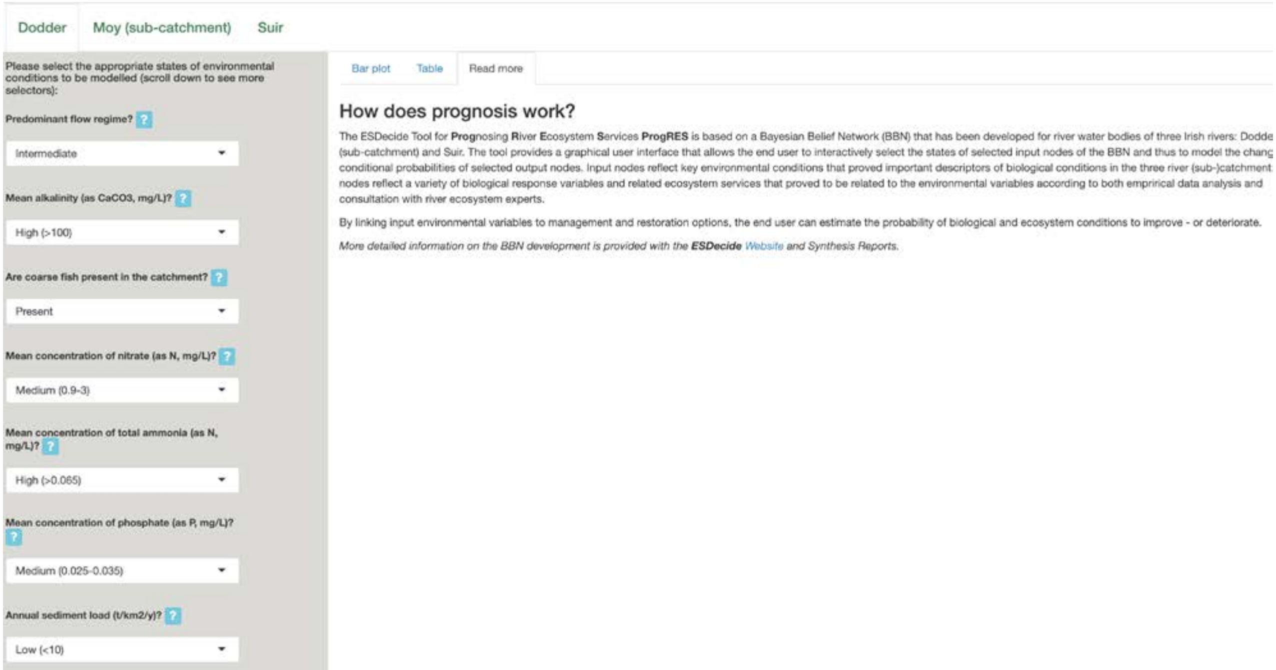


Figure 3.5. Textual description (tab "Read more") of the prognostic modelling using the ESDecide BBN model. This tab of the DST may be populated with additional information and guidance in the future.

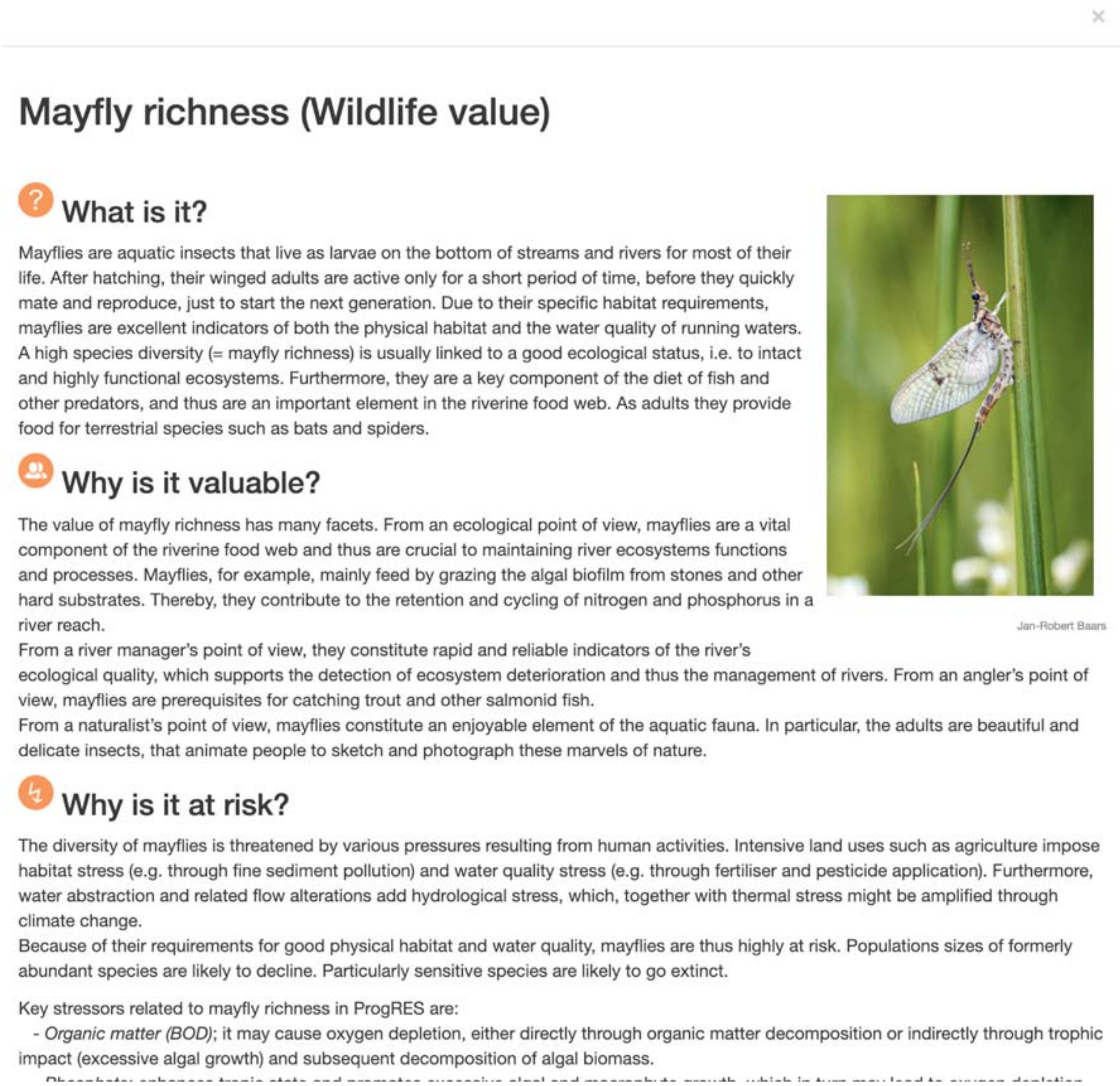
ecosystem services/NCP response means that the probability of attaining beneficial (or detrimental) conditions has changed by 20%. It does not mean, however, that the response (e.g. "mayfly richness") is projected to increase or decrease by the same percentage.

2. Changes of less than 3% (either an increase or decrease) should not be interpreted. They refer to only slight changes in the model and are likely to be subject to high uncertainty. In contrast, changes of more than 10% (increase or decrease) point to strong effects and can be interpreted with confidence. Probabilities between 3% and 10% (any direction) may be interpreted, but with caution owing to their intermediate level of uncertainty.
3. Likewise, differences of less than 3% in the probability between two or more responses should not be put into a hierarchical context. In contrast, differences of more than 10% between responses point to a definite ranking with confidence. Differences between 3% and 10% may be interpreted as giving a relative ranking, but with caution owing to their intermediate level of uncertainty.

These guidelines have been derived from experiences with previously developed DSTs, such as the diagnostic tools that were developed within the MARS project (Feld *et al.*, 2020; http://www.freshwaterplatform.eu/index.php/mars-diagnostic-tools.html). A more analytical approach to quantify the uncertainty of the DST outcome would require additional data (or knowledge) for validation. Data on comparable rivers might help to validate the modelled probabilities of biological and ecosystem services/NCP responses and thus to further quantify the uncertainty of the underlying BBN model. Likewise, expertise and knowledge of river restoration practitioners and river basin managers could provide the foundation for the validation of the DST outcome and eventually for the estimation of the uncertainty of the BBN model.

3.6 Supporting Information

To assist the interpretation of the DST outcome, supporting textual information has been compiled for each of the six biological and ecosystem services/NCP responses. The information becomes available through a click on the response's name in the graphical output section (Figure 3.6). Each text block is divided into six sections and is accompanied by a photo or figure to illustrate the response. The first section explains what the biological and ecosystem services/NCP services response is about. Section 2 refers to the ecological and societal value of the



Mayfly richness (Wildlife value)

What is it?

Mayflies are aquatic insects that live as larvae on the bottom of streams and rivers for most of their life. After hatching, their winged adults are active only for a short period of time, before they quickly mate and reproduce, just to start the next generation. Due to their specific habitat requirements, mayflies are excellent indicators of both the physical habitat and the water quality of running waters. A high species diversity (= mayfly richness) is usually linked to a good ecological status, i.e. to intact and highly functional ecosystems. Furthermore, they are a key component of the diet of fish and other predators, and thus are an important element in the riverine food web. As adults they provide food for terrestrial species such as bats and spiders.

Why is it valuable?

The value of mayfly richness has many facets. From an ecological point of view, mayflies are a vital component of the riverine food web and thus are crucial to maintaining river ecosystems functions and processes. Mayflies, for example, mainly feed by grazing the algal biofilm from stones and other hard substrates. Thereby, they contribute to the retention and cycling of nitrogen and phosphorus in a river reach.

Jan-Robert Baars

From a river manager's point of view, they constitute rapid and reliable indicators of the river's ecological quality, which supports the detection of ecosystem deterioration and thus the management of rivers. From an angler's point of view, mayflies are prerequisites for catching trout and other salmonid fish.

From a naturalist's point of view, mayflies constitute an enjoyable element of the aquatic fauna. In particular, the adults are beautiful and delicate insects, that animate people to sketch and photograph these marvels of nature.

Why is it at risk?

The diversity of mayflies is threatened by various pressures resulting from human activities. Intensive land uses such as agriculture impose habitat stress (e.g. through fine sediment pollution) and water quality stress (e.g. through fertiliser and pesticide application). Furthermore, water abstraction and related flow alterations add hydrological stress, which, together with thermal stress might be amplified through climate change.

Because of their requirements for good physical habitat and water quality, mayflies are thus highly at risk. Populations sizes of formerly abundant species are likely to decline. Particularly sensitive species are likely to go extinct.

Key stressors related to mayfly richness in ProgRES are:

- *Organic matter (BOD)*; it may cause oxygen depletion, either directly through organic matter decomposition or indirectly through trophic impact (excessive algal growth) and subsequent decomposition of algal biomass.

Figure 3.6. Supporting information to assist the interpretation of the DST's outcome. The example shows the information provided on mayfly richness, which is available through a click on the ecosystem services/NCP response's name in the graphical output section of the DST.

response. The third section explains why it can be at risk and the fourth section details how management options might help improve the situation. Section 5 recommends texts for further reading, while the sixth section presents a bar plot with a detailed indication of the changing probabilities for each node state of the respective response node in the BBN model. The plot thus allows the user to derive the original node state-specific probability values before they are summarised into a weighted sum of desirable conditions (see section 3.3.4). A detailed compilation of the supporting information is provided in the manual for the ESDecide DST.

4 Incorporating the Concept of Multiple Benefits of Nature to People into Decision-making

4.1 Introduction

In 2018, IPBES adopted the concept of NCP into its conceptual framework (Figure 4.1) to replace the widely used term “ecosystem services” (Diaz *et al.*, 2018; IPBES, 2018). The introduction of the NCP concept was driven by IPBES’s desire to extend understanding of the multiple ways in which people value and benefit from nature and to feed these values into policy decisions.

Following insights from IPBES, ESDecide evaluated a wide range of rivers’ NCP and approaches that can be used to embed this plurality of values into decision-making. Specifically, Objective 3 of ESDecide was to explore the multiple ways in which people value rivers and assess how these values might best inform catchment management decisions.

To achieve this objective, two tasks were undertaken.

1. A desk review of the multiple ways people value nature. This task provided a synthesis of the recent advances in the literature on the plurality of nature’s values and ways in which these values may be elicited.
2. Valuation of rivers’ NCP. This task involved administering a series of online valuation workshops to (1) develop a deeper understanding of how people value Irish rivers and how any potential conflict between these values might be reconciled and (2) explore how these multiple values might best inform catchment management decisions.

4.2 Review of the Multiple Ways People Value Nature

A review of the state-of-the-art literature that explores the multiple ways in which people value nature was compiled by the ESDecide project and published as a stand-alone report (Christie *et al.*, 2021). Insights from this report fed into the design of the research protocol used in the stakeholder workshops (section 4.3). A brief summary of some of these key messages from the report are reproduced in the following sections to aid understanding of the design and analysis of the stakeholder workshops.

Concept of values		
Transcendental values Overarching principles and life goals	**Contextual values** Objects valued in a particular context	**Value indicator** Measures or indicators of value
Justification of values		
Instrumental values Value as a substitutable means to a human end	**Relational values** Value as a non-substitutable meaningful relationship between nature and people	**Intrinsic values** Something important in and for itself without reference to people as valuers
Scale of values		
Individual values Benefits to an individual	**Social values** Aggregation of individual values	**Shared values** Values held or assigned through our interactions with others that inform narratives of our “common good”

Figure 4.1. Value dimensions.

4.2.1 *Defining and measuring the multiple values of nature*

Recent developments in the valuation literature have extended our understanding of the multiple ways in which people value nature. Authors such as Kenter *et al.* (2019) have synthesised this literature to describe different value dimensions. Figure 4.2 provides a summary of these value dimensions, which include different concepts of value, different justifications of value and different scales of value. Further explanations of each are provided in Kenter *et al.* (2019) and Christie *et al.* (2021). Examination of these dimensions of value can help to better understand the impacts of policy on people's well-being.

Navigating such a complex array of value concepts is clearly challenging. The Life Framework of Values (O'Connor and Kenter, 2019) provides an approach that helps individuals to think more holistically about the multiple ways they connect with nature and allows them to uncover and express multiple dimensions of value. The Framework can be associated with all three value justifications (instrumental, relational and intrinsic values) and can be related in various NCP categories (material, regulation and non-material NCP). O'Connor and Kenter (2019) identify four "Life Frames": living *from*, *in*, *with* and *as* nature (Box 4.1). These four Life Frames can help to translate the often abstract value concepts to provide a simpler way to communicate the diverse values to river users.

4.2.2 *Deliberative approaches to valuing nature*

Exploring the different concepts, justifications and scales of value often requires people to consider their deeper-held, *transcendental* values, their broader *relational* interactions with nature and any *social* and *shared* values that they may have. Some of these values may be pre-formed, while others will be activated, formed or transformed through discussions

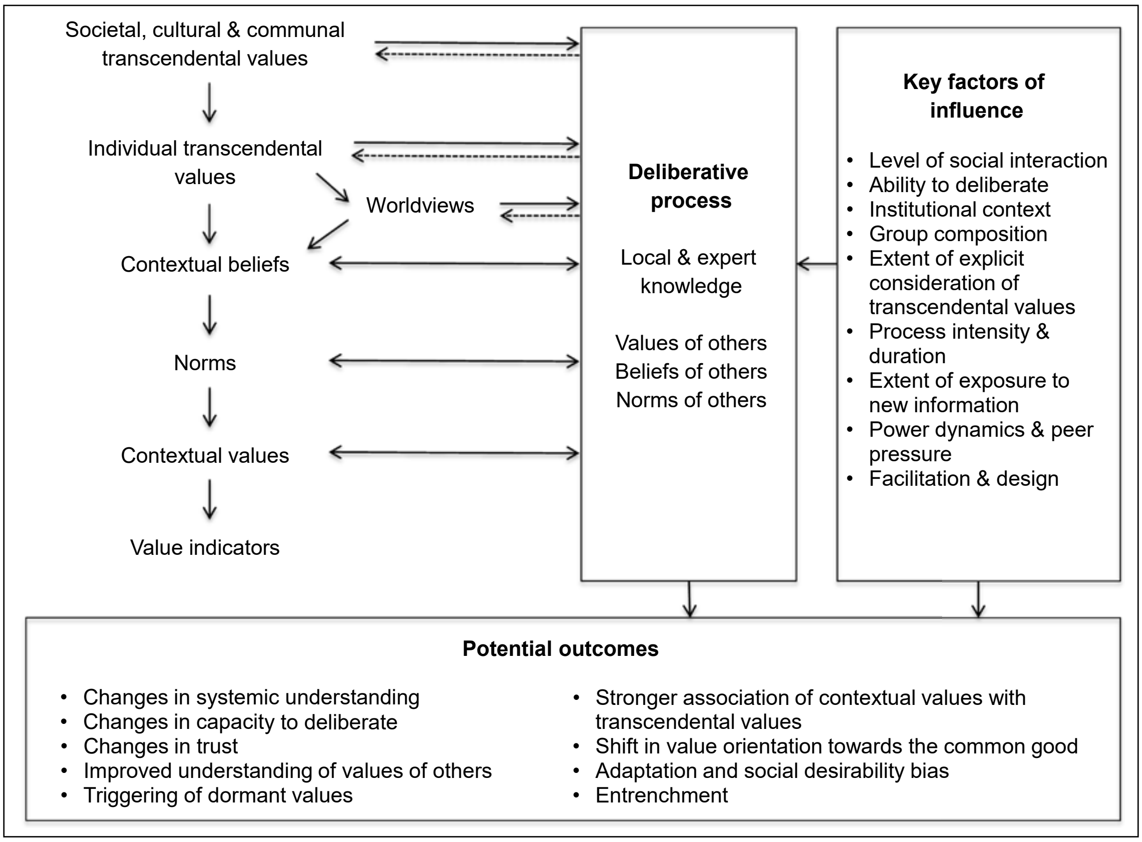


Figure 4.2. The Deliberative Value Formation model. The solid lines indicate progress through these steps and factors influencing value formation, while the dashed lines indicate feedback loops that may influence underlying values. Reproduced from Kenter *et al.* (2016b); licensed under CC BY 4.0 (https://creativecommons.org/licenses/by/4.0/).

Box 4.1. Life Framework of Values

Living from nature points to how we value the world in a provisioning sense and also how it sustains us more broadly.

Living in nature can be seen to map onto the non-material (cultural) contributions of the landscapes and seascapes that help shape (either socially or physically) how cultures, communities and individuals relate to place, forming and supporting cultural and personal identities. It also maps onto material and regulating contributions where they help define the biophysical features contributing to environmental settings.

Living with nature expresses that we share this planet with the more-than-human world, and is enacted in us preserving and creating space dedicated to nature, such as a river catchment designated as a Special Area of Conservation.

Living as nature reflects notions and experiences of the more-than-human world, rather than non-human nature. It can relate to practices of care, kinship and reciprocal relationships between people and the more-than-human world.

with others. Social deliberation is a key mechanism for the formation of complex values. Examples of approaches that have integrated deliberation within a structured valuation process include deliberative monetary valuation (Niemeyer and Spash, 2001; Orchard-Webb *et al.*, 2016) or participatory multi-criteria analysis (Stirling, 2006; Kenter *et al.*, 2014). Such deliberative processes can inform individual values, but they can also lead to group-based values that can transcend individual concerns and better incorporate broader, shared values (Kenter *et al.*, 2015). Recent work stemming from the UK National Ecosystem Assessment (2014) follow-on report has sought to inventorise the key factors of influence and potential outcomes of value formation processes. This has been summarised in a conceptual framework, the Deliberative Value Formation (DVF) model (Kenter *et al.*, 2016a; Figure 4.2), which underpinned the design of local stakeholder workshops in ESDecide. For more detail see Christie *et al.* (2021).

4.2.3 Concluding comments

Research is uncovering the ever-increasing complexity of the multiple ways in which people value nature. Although this enhanced understanding can help improve decision-making and natural resource policies, it also comes at a cost in terms of resources required to capture and incorporate this evidence into decision-making. The objective of ESDecide is not to tell policymakers which values they need to include in their decision-making, but rather to inform them of the array of values of nature that exist and which therefore may influence their decisions. Accounting for the diversity of values of a wider range of stakeholders in decision-making is likely to promote equity in those decisions.

4.3 Valuation of River NCP – Method

This task involved running a series of online stakeholder workshops addressing Objective 3 to develop a deeper understanding of how people value Irish rivers and explore how these multiple values might best inform catchment management decisions. The workshops included three local stakeholder workshops that explored values relating to the three case study rivers (the Dodder, Suir and Moy) and a national-level stakeholder workshop that explored how the insights of the local workshops might best be embedded into policies.

4.3.1 Methodology – local stakeholder workshops

Three local stakeholder workshops were held in February 2021 to explore how people valued potential enhancements at three case study river catchments: the Dodder, Suir and Moy. Owing to the Department of Health’s COVID-19 restrictions, the workshops were administered online using the video conferencing software Zoom. Google Jamboard (an interactive online whiteboard tool) was also used to facilitate and record discussions. Workshop participants comprised local stakeholders who had a connection with the case study river. Stakeholder network analysis was undertaken to first identify key groups of stakeholders who interact with rivers. These included water quality/river policymakers, landowners within the catchment and different river user groups. Snowballing techniques were used to identify representatives of these stakeholder groups, who were then invited to participate in the workshops. We aimed to include 15 participants in each workshop. In addition to attending the workshops, participants were asked to complete a pre-workshop questionnaire and a post-workshop review. The overall structure of the workshops and the questionnaires reflected the DVF model (Kenter *et al*., 2016b). This meant participants were first asked to reflect on their overarching, transcendental values. They subsequently considered the way they related to the rivers and why rivers were important, having been prompted using the four Life Frames (and implicitly the NCP encapsulated within these). Subsequently, they discussed contextual values around specific management options, which were expressed as value indicators by being ranked and prioritised.

Pre-workshop questionnaire

The aim of the pre-workshop questionnaire was to get participants to start thinking about the case study rivers and then explore their views on alternative management options to enhance water quality. The first set of questions explored how participants valued the rivers. These questions initially focused on participants' overarching, transcendental values, before participants were asked to explore how they interact with the rivers as defined by the four Life Frames (living *from*, *in*, *with* and *as* nature). Participants were then asked to state whether they felt river water quality had improved or declined over the previous 10 years. The final set of questions asked participants to list any concerns they had regarding factors that might affect rivers and river water quality. The results from the pre-workshop questionnaire were presented to participants during the online workshop to help them attain an appreciation of the views and values of the other stakeholders.

Online workshops

The workshops were split into two broad sections: section A explored participants' values and value conflicts, while section B explored their views on alternative river management options. Workshop activities included a mix of short presentations by the research team and breakout group discussions. The breakout discussions were facilitated by a member of the research team and were recorded and later transcribed. During the breakout discussions participants were encouraged to record their views using the virtual whiteboard on Google Jamboard.

Section A aimed to develop a deeper understanding of the multiple ways in which people value the case study rivers and how any potential conflict between these values might be reconciled. Following introductions, the research team presented key findings from the pre-workshop questionnaire. Material presented included participants' ranking of transcendental values and details of the various ways in which participants interacted with and valued the rivers, as elicited using the four Life Frames (living from, in, with and as nature). Participants were then split into three groups and asked to consider the following questions:

- Did the pre-workshop questionnaire capture all the ways in which rivers are important?
- Were you surprised by some of the reasons that others consider the river to be important, or that you were not aware of yet?
- Are there any conflicts between these values? How might they be reconciled to find shared values?

The second half of the workshop (section B) explored participants' views on alternative river management options for improving the environmental quality of the rivers. First, we reported key findings from the pre-workshop questionnaire on participants' views on alternative river management options. Next, we provided information on the "ecological status" of Irish rivers in general and of the case study river, along with information on sources of river pollution (including domestic wastewater and agricultural-based pollution). Detailed information was then presented on potential river management options at the case study river. These options included:

- domestic wastewater pollution prevention/treatment, e.g. increase capacity of overloaded plants; upgrade to tertiary treatment of wastewater; the creation of wetlands to treat

sewage; rain gardens and green roofs; and upgrading septic tanks;
- agricultural waste pollution prevention/treatment, e.g. low-intensity pasture management and the creation of buffer strips.

It should be noted that only a subset of these options were presented for each case study river, depending on local needs. Details of the management options were developed specifically for each river based on local knowledge/information on river condition and pollution sources. The impact of the management options on key river services was assessed using data generated in the expert BBN models. Information on the management options was presented to workshop participants, a summary of which is reproduced in Tables 4.1–4.3.

Following the presentation of the river management options, participants were split into their breakout groups and asked to consider the following questions:

- What are the advantages and disadvantages of the different options? Do they have any positive or negative "side effects"?
- How do you think these management options might affect the values of different stakeholders? Who are the winners and losers?
- Which management options should be prioritised?
- Put on the hat of policymakers: what options are socially most desirable overall?

The transcriptions of the workshop breakout group discussions, along with the notes from Google Jamboard, were analysed using a mix of Braun and Clark's (2006) six-step thematic analysis approach and

Table 4.1. Predicted impact of river management options on the condition of the River Dodder

Option	Increase in dipper numbers	Mayfly richness	Reduction in algal scum	Reduction in *E. coli*	Recreational water quality	Trout angling
Upgrade waste network to separate waste from rainwater	+	++	++	+	+	+
Install screens in sewage overflows	+	++	++		+	+
Create new urban wetlands (including screens) to filter overflow water	+	++	++	+	+	+
Create rain gardens, attenuation ponds and green roofs to reduce occurrence of overflows	+	++	++		+	+
Manage land to prevent pollution from agriculture and forestry entering rivers	+	++	+	++	++	+

Blank cells indicate low influence but not necessarily no influence.

+, small but noticeable improvement on current state; ++, moderate improvement on current state; +++, substantial improvement on current state.

Table 4.2. Predicted impact of river management options on the condition of the River Suir

Option	Increase in dipper numbers	Mayfly richness	Reduction in algal scum	Recreational water quality	Angling
Increase capacity of overloaded wastewater treatment	+	++	++	++	+
Upgrade wastewater treatment plants from secondary to tertiary treatment			+	+	
Create new wetlands to treat sewage from smaller wastewater plants		+	+	+	
Introduce low-intensity pasture management	+	++	++	++	+
Create targeted "buffer strips"	++	+++	+++	+++	++

Blank cells indicate low influence but not necessarily no influence.

+, small but noticeable improvement on current state; ++, moderate improvement on current state; +++, substantial improvement on current state.

Table 4.3. Predicted impact of river management options on the condition of the River Moy (Corsallagh stream)

Option	Increase in dipper numbers	Mayfly richness	Reduction in algal scum	Recreational water quality	Angling
Upgrade septic tanks (30 households)	+	+	+	+	
Introduce low-intensity farming (763 ha)	++	+++	+++	+++	++
Create 16 buffer strips + trees along 1.5 km of riverbank	++	+++	+++	+++	+++

Blank cells indicate low influence but not necessarily no influence.

+, small but noticeable improvement on current state; ++, moderate improvement on current state; +++, substantial improvement on current state.

King's (2004) general template analysis. A hierarchical coding structure was developed that included four "level 1" codes ("Attitudes", "Values", "River management" and "Deliberation") and 28 "level 2" codes (see Appendix 1). The level 1 and level 2 codes centred around key themes of the research. These themes were then split into a series of more detailed level 3 and level 4 codes to allow more nuanced analysis of key themes. The software NVivo was used to systematically apply the coding template across the full dataset. The coded data from the thematic analysis enabled us to organise the qualitative data collected in the workshops to provide analysis of the key questions posed in sections A and B.

In addition, qualitative analysis was used to address a number of higher-level questions relating to the effectiveness of the methodological approach applied:

- To what extent did the Life Frames uncover different types of NCP (material, regulation, non-material) and different value justifications (instrumental, relational and intrinsic)?
- To what extent did deliberation help to move the focus from individual values to shared values?
- To what extent did the consideration of a wider diversity of values and the development of shared values change preferences for the river management options, and did this reduce potential conflict?

4.3.2 Methodology – national stakeholder workshop method

The national stakeholder workshops largely followed the structure of the local stakeholder workshops. Key differences were that the results presented in section A (river values) and section B (management options) are based on the findings from the local workshops (rather than a pre-workshop questionnaire). Two breakout group discussions were held during the national workshop. The first focused on stakeholders' reflections on the values identified in the local workshops. The second focused on discussing the implications of the results from the local workshops on management practices. The workshop ended with a plenary discussion, with national stakeholders asked to reflect on the deliberative process used in the ESDecide project and discuss how such an approach might best be incorporated into river management in practice, to help reconcile potential value conflicts.

4.4 Valuation of River NCP – Results

4.4.1 Results – local stakeholder workshops

The three local river workshops explored the various ways in which people value rivers (section A) and their views on alternative river management options (section B).

How people value the rivers

The results of the qualitative analysis that explored how workshop participants interacted with and valued the three case study rivers based on the Life Framework of Values are presented below. This is followed by an analysis of the prevalence of different types of values in the workshop discussions.

River Dodder

The River Dodder was chosen as a largely urban river; it passes through Dublin. In the workshop, 43% of the values discussed were categorised as the living *from* Life Frame (Table 4.4), including "drinking water" and "recreational fishing". The living *in* frame was also

Table 4.4. Prevalence of comments made during the workshops relating to the different value types in each catchment and across catchments

Value framing	Value type	Dodder	Suir	Moy	Average (%) and total across the three rivers
Life Frames	From	43.7%	43.2%	31.7%	40.5%
	In	21.6%	31.9%	37.5%	29.7%
	With	28.1%	21.1%	29.2%	25.6%
	As	6.6%	3.8%	1.7%	4.2%
	N	167	185	120	472
NCP	Material	12.0%	14.1%	16.5%	14.3%
	Non-material	59.3%	37.6%	35.5%	43.1%
	Regulating	28.7%	48.3%	47.9%	42.6%
	N	108	149	121	378
Value justification	Instrumental	22.4%	42.9%	38.1%	34.7%
	Intrinsic	27.1%	19.5%	19.0%	22.1%
	Relational	50.5%	37.6%	42.9%	43.2%
	N	107	133	63	303

important (21%), with participants describing the river as “A pleasant escape from urban life”, “picturesque”, “peaceful” and “serene”. Another participant stated “I think one of the most valuable things about the river is that it’s one of the few kinds of greenbelts that’s left in Dublin, especially in South Dublin.” Statements coded in the living *with* frame (28%) were focused on observing the environment, for example “The natural resource trail through the urban landscape provides a sense of the earth and the natural environment”, as well as the river wildlife, with statements including references to water birds, such as herons and kingfishers, and to fish, aquatic life, foxes, stoats, deer, badgers, otters, dippers, bats, rabbits, grasses, plants, flowers, mushrooms, trees and biodiversity. In terms of living *as* (6%), one participant stated that the river was like “A lung providing air”. Another stated that “Even when I do not see it, I know it is a vital part of the ecosystem that sustains Dublin.”

The Dodder was also considered important for people’s physical and mental health. Statements included “It’s very relaxing and a break from industrial and car noise. Sometimes I just sit and watch the river. It is very meditative!”. Several participants mentioned that there were more people visiting the river during the COVID-19 pandemic lockdown. These types of benefits were considered to relate to non-material NCP. Relational values were also dominant value justifications (Table 4.4), reflecting how much the river has affected people’s lives: “It is the first and only river I have properly identified with, a bit like an old tree you might gravitate to. I have never really given it much thought before now, but it is a pleasing constant in the back of my mind.”

River Suir

The River Suir is a much more rural river. In the workshop, statements coded in the living *from* frame dominated the discussions (43% of references to Life Frames related to the living *from* frame; Table 4.4). Tourism was seen as an important industry in the area and was seen as “a vital activity for Tipperary and fishing is part of any good holiday. Having the waters of the Suir healthy and full of life supports fishing, walking, kayaking and swimming.” However, another participant stated “Fishing as an occupation and as an income generator has also long gone.” The living *in* frame was also prominent in discussions (32%). In particular, sporting activities were found to be more prominent in the Suir river than in the Dodder and Moy rivers, with people enjoying the river’s natural beauty: “It influenced our decision on where to live. I like water activities and the outdoors, and in that respect, it plays a huge part in my life from a recreational point of view. There is nothing as enjoyable to me as a walk along the banks after a day at work.” The living *with* frame was also considered important (21%): “It’s an entire mini ecosystem that supports the wonderful creatures that we share the space with." Participants also referred to a wide range of wildlife, including fish (especially migrating fish), ducks, herons, swans and other birds, and otters and bats. There were also examples of the living *as* frame: "I feel part of the river, I used to row on the river and now I often walk along it."

Fishing was also seen as a significant activity on the Suir, mainly contributing material and non-material NCP and instrumental value. A unique feature from the Suir workshop was the sense of belonging and the histories of place put forward by participants, which can be considered as non-material NCP and relational values: "The Suir defines Waterford city, where I work. The river is part of the city."

River Moy

The Moy river is also a rural river and is considered important for its fishing. In the workshop, 32% of comments related to the living *from* frame, including the value of tourism and fishing in the catchment. Participants also mentioned the historical importance of renewable energy through the mills on the river, while others mentioned that "The river is used as a source of drinking water for livestock". The living *in* frame accounted for 37% of the comments, for example "It's the centre point of the community" and "It adds beauty to the countryside". The living *with* frame (29%) again focused on the wildlife; wild ducks, cormorants, herons, swallows, kingfishers and other birds, and seals, salmon, pike, trout, seatrout, perch, eel, minnow, crayfish, lamprey and otters were all mentioned in the discussions. One participant stated that the river was "A source of interest to my kids and I … seeing the plant life and animals". Living *as* can be represented by the statements "Keeping an eye on the river level is as innate as talking about the weather" and "I have crossed the river almost every day of my life, it is a part of my identity and who I am, what I am proud of."

The above provides some insights into the many ways in which people interact with and value their local rivers. To further illustrate the diversity of values associated with the case study rivers, Table 4.4 provides a quantitative analysis of the number of times different types of values were discussed in the workshop across all three rivers. The living *from* frame was the most prominent (40%), followed by living *in* (29%) and living *with* (25%). Living *as* was only mentioned 4% of the time, although, as we note from above, many of these values reflect the strong relationships people have with the rivers. In terms of NCP, non-material and regulating NCP were discussed most often across all rivers (of the total number of comments relating to NCP, 43% focused on non-material NCP and 42% on regulating NCP), with material NCP being mentioned 14% of the time. In terms of value justifications, relational values were talked about the most (43% of the discussions relating to value justifications). Instrumental values were also considered important (34%), with intrinsic values discussed only 22% of the time. The finding that relational values were the most popular value justifications is interesting given that relational values are a relatively new concept and tend not to be considered by decision-makers. This finding thus highlights the importance of recognising and acknowledging that people often have close and meaningful relationships with a particular river or stretch of river beyond simply valuing any river for a distinct feature or its ecosystem services outputs.

Workshop participants were also asked to express the relative importance of different transcendental or overarching values. Figure 4.3 illustrates that health, protecting the environment, enjoying life, a varied life, family security and social justice were the most important transcendental values. When asked to consider whether these values reflected values across their wider communities, participants generally felt that this was accurate, except that wealth and tradition may be more important at the community level. Participants' overarching value priorities were remarkably similar between catchments.

Respondent views on potential management options

The second half of the local workshops explored participants' views on alternative management options to improve water quality in the rivers. The management options investigated were developed based on the outputs of the BBN models. Below we report key issues discussed in the workshops.

River Dodder

Five management options were presented for consideration in the Dodder catchment. In the pre-workshop questionnaire, these were ranked in terms of their order of preference: (1) separating sewage

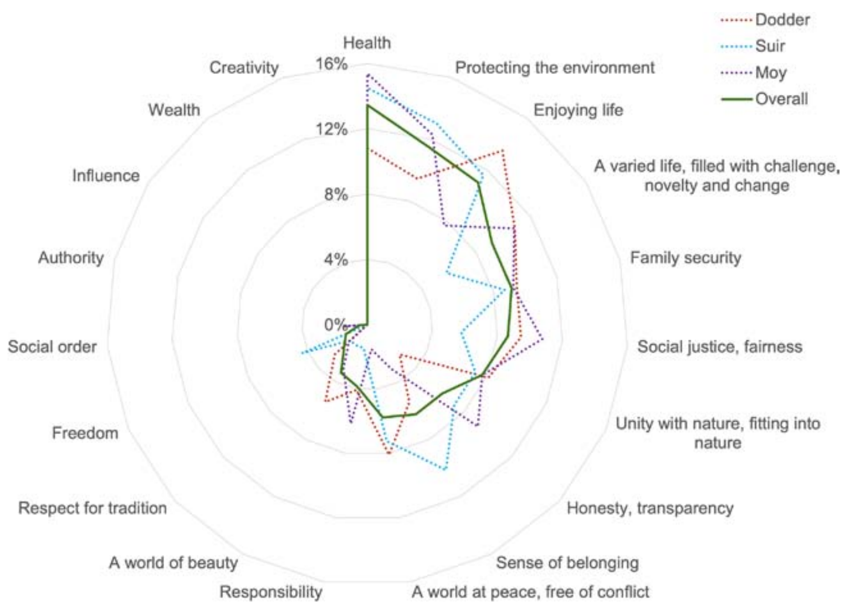


Figure 4.3. Relative importance of different transcendental values by river.

from surface water, (2) urban wetlands, (3) sewage overflow screens, (4) rain gardens and (5) rural land management. Rain gardens, urban wetlands and separating sewage were the three options discussed the most during the workshop. Although many participants supported rain gardens and green roofs as an "efficient and effective" option, others suggested that this option might have some issues with "maintenance": "I always think the green garden thing, or the green roofs are a really nice idea. But I just imagine it'd be a nightmare to organise." Many participants highlighted the "environmental" (including wildlife) benefits associated with the creation of urban wetlands. Furthermore, it was felt that urban wetlands could provide an avenue to increase public awareness of environmental and water quality issues: "Everyone gets involved together. I think one of the things about wetlands and stuff like that is how it can be sold to communities that don't necessarily use the river all the time. It protects the land from other developers as well." Concerns were raised about the costs involved in separating sewage from surface waters in the existing drainage network. At the end of the discussion, urban wetlands was voted the most preferred option, with separate sewage infrastructure dropping to third place because of its high costs.

River Suir

Five management options were also proposed for the Suir. In the pre-workshop questionnaire, these options were ranked in order of preference: (1) increasing capacity of overloaded wastewater treatment plants, (2) new wetland creation, (3) buffer strips, (4) low-intensity pasture management and (5) upgrading wastewater treatment plants. The discussions around buffer strips highlighted potential conflicts with this management option. Some participants were enthusiastic about the water quality and wildlife benefits of buffer strips, along with their cost-effectiveness, while others saw potential issues for farmers in terms of loss of productive land and public access issues. Although initially there were opposing views, deliberation of the values of others resulted in the reconciliation of values, which in turn resulted in buffer strips being voted the most preferred option at the end of the workshop. Increasing capacity of wastewater treatment plants was viewed as an impactful option that could effectively solve some of the pollution issues, but at a cost. Some participants doubted the efficiency of new wetlands to treat sewage, while others were concerned about where they might be located. Given these discussions, the wetlands option dropped from second place before the workshop to fourth place at the end of the workshop.

River Moy

Four management options were presented in the Moy workshop. Of these, two options were the subject of the bulk of the discussions: buffer strips and low-intensity pasture management. This largely reflects the rural nature of the Moy catchment. It was evident that there were conflicting views about these options, particularly between farmers and other stakeholders. Key issues raised included problems with public access to private land, and the fact that both buffer strips and low-intensity pasture management affected farmers' revenues. Following deliberations, there was a clear consensus that farmers would need to be compensated for any loss in agricultural output and that this would make this a viable option.

Key themes emerging from the discussion of management options

Thematic analysis of the discussions of the various management options identified four broad themes: (1) role of authorities, (2) linkages between stakeholders, (3) management options and (4) public engagement. These were further split into 17 subnodes (Appendix 1). Table 4.5 provides a breakdown of the extent to which these themes were discussed during the workshops. In total, 681 comments were made about the management options during the three river workshops. Most comments related to the detail of the management options, with their "efficiency and effectiveness" (13% of comments), the identification of "priority" options (12%) and their "sustainability and maintenance" (10%) most commonly discussed. In terms of the role of authorities in managing rivers, issues relating to "planning" (8%) and the "governance scale" (6%) were the key topics discussed. The discussions also highlighted the need to enhance "cooperation" between stakeholders (5%), as well as the desire to better engage the public in developing river management options through, for example, the provision of "incentives" (6%) and education (5%). The above demonstrates that workshop participants were not only able to express and reconcile their own values for the alternative management options, but were also able to consider how other stakeholders (including authorities and members of the public) should be engaged in the design and implementation of river management options.

Table 4.5. Management option themes discussed in the workshops

Key themes	Sub-themes	Percentage of times topic discussed (%)
Management options	Advanced approaches	2
	Cost–benefit analysis	6
	Efficiency and effectiveness	13
	Environmentally friendly	7
	Priority	12
	Sustainability and maintenance	10
	Trade-off	6
Role of authorities	Agency approaches	2
	Governance scale	6
	Monitoring	2
	Planning	8
Linkages between stakeholders	Communication	2
	Cooperation	5
Public engagement	Education	5
	Incentives	6
	Public perceptions	5
	Public support	5

Total number of mentions: 681.

4.5 Valuation of River NCP – Policy Implications

This research utilised a novel deliberative approach to explore the multiple values associated with rivers and river management options. This section reflects on whether such an approach was capable of uncovering a wider set of nature's values and whether deliberation helped to resolve value conflicts and hence improve policy decisions.

4.5.1 Can deliberative approaches uncover a wider diversity of nature's values?

One novel element of the approach applied was to use the Life Framework of Values as a tool to uncover a wider set of nature's values. During the workshops participants were asked to consider how they interact with, and value, rivers based on the four Life Frames: living *from, in, with* and *as* nature. Table 4.6 presents the results of an exercise that mapped different types of values and NCP to the Life Frames. The relative results need to be considered against the overall prominence of the different Life Frames (Table 4.4), as reflected by the number of comments, which ranged from 41% (living *from*) to only 4% (living *as*).

In terms of uncovering NCP (Table 4.6), the living *from* frame highlighted material NCP (67% of comments on material NCP were considered to be linked to

Table 4.6. Mapping of workshop discussions on NCP and values to the Life Frames

Value framing	Value type	Living from (%)	Living in (%)	Living with (%)	Living as (%)	Total
NCP	Material	67.1	17.1	14.5	1.3	76
	Non-material	49.0	32.2	14.3	4.5	245
	Regulating	22.5	29.7	42.1	5.7	209
Value justification	Instrumental	64.0	24.0	10.7	1.3	150
	Intrinsic	12.0	12.0	67.4	8.7	92
	Relational	41.1	35.6	16.8	6.4	202
Transcendental	Transcendental	39.5	31.3	23.7	5.6	342

the living *from* frame) and non-material NCP (49%), while regulating NCP was considered mostly within the living *with* frame (42%). The living *in* frame was also prominent in terms of identifying non-material NCP (32%) and regulating NCP (30%). The living *as* frame highlighted only around 5% of non-material and regulating NCP. In terms of value justifications (Table 4.6), instrumental values were highlighted in the living *from* frame (64%) and living *in* frame (24%). Intrinsic values were mostly highlighted in the living *with* frame (67%), while relational values were linked to both the living *from* (41%) and living *in* (35%) frames. The living *as* frame was again less prominent, but helped to uncover intrinsic (8%) and relational values (6%) more than might be expected on the basis of the low prominence of the frame overall. Finally, transcendental values were linked to the living *from* (39%), living *in* (31%) and living *with* (23%) Life Frames (Table 4.6).

The various elements of transcendental value were also mapped to the Life Frames (Table 4.7). Again, these results need to be considered against the different prominence of the Life Frames overall (Table 4.4). Transcendental values are those deep-held values that often form the basis of societal norms. The transcendental values that were highlighted most often in the workshops were “enjoying life” (150 mentions), “protecting the environment” (81 mentions), “a world of beauty” (73 mentions) and “sense of belonging” (62 mentions). Of these, “enjoying life” (59%), “a world of beauty” (44%) and “a world of peace, free of conflict” (59%) were linked to the living *from* frame, while “a sense of belonging” (53%) was linked to the living *in* frame and “protecting the environment” (48%) was linked to the living *with* frame.

The above analysis highlights that people interact with and value rivers in many different ways. Rivers provide a wide range of material, non-material and regulating NCP (Table 4.6), and are valued for instrumental, intrinsic and relational justifications (Table 4.6); they are also associated with diverse transcendental values (Table 4.7). The results also demonstrate that organising the questionnaires and workshop discussions around the Life Frames values provides a useful mechanism for helping uncover a wide range of values. Living *from* provides a focus for material and non-material NCP, along with instrumental and relational values; living *in* focuses on non-material and regulating NCP and relational values; living *with* relates to regulating NCP and intrinsic values; and living *as*, while less prominent than the other frames, highlights intrinsic and relational values.

4.5.2 Can deliberation help resolve value conflict?

It was clear from the pre-workshop questionnaire and the workshop discussions that stakeholders came to the workshop with their own set of values for rivers and views regarding priorities for the alternative management options, and that this sometimes resulted in conflicting values and views. A key tenet of the workshops was to promote an environment where participants could freely express and deliberate their views and values, as well as reflect on the views and values of others (including overarching, deeper-held transcendental values). The aim, and achieved outcome, of this deliberative process was that value conflicts were often resolved. For example, there were conflicting views in the workshops regarding buffer strips. Several participants highlighted water quality issues associated with “livestock having direct

Table 4.7. Mapping transcendental values to Life Frames

Value	Living from (%)	Living in (%)	Living with (%)	Living as (%)	Total
Enjoying life	59	22	15	4	150
Protecting the environment	19	23	48	10	81
A world of beauty	44	19	33	4	73
Sense of belonging	27	53	8	11	62
A world at peace, free of conflict	59	20	17	4	46
Health	68	20	10	2	41
Respect for tradition	3	55	6	9	33
Unity with nature, fitting into nature	13	26	52	9	23
Social justice, fairness	61	39	0	0	18
Responsibility	15	38	31	15	13
Social order	38	62	0	0	13
Creativity	100	0	0	0	7
Freedom	43	14	29	14	7
Family security	0	100	0	0	1
Average	**44**	**29**	**22**	**6**	

Total number of mentions: 568.

access to rivers", while others supported the creation of buffer strips because of their wildlife, water quality and access benefits. Landowners, on the other hand, were concerned about allowing public access to their land. Following the discussions, buffer strips emerged as one of the priority options; there was consensual support for them in terms of the "increase in wildlife", "good aesthetic values", "improved water quality" and their potential to "enhance the pleasure of walking by the river" and be "cost effective". However, it was also recognised that "farmers would need to be compensated for the loss of productive land" and that "public education of what was not acceptable behaviour [on private land]" was needed. The issue of public access on buffer strips was contentious, and, although the discussions did bring farmers and recreational users closer together in terms of understanding each other's views, the time allocated to discussions was insufficient to resolve this issue. Overall, this example demonstrates how deliberation allowed the reconciliation of conflicting values to provide a pathway to a solution that was seen as acceptable to all stakeholders.

4.5.3 Can deliberation enhance stakeholder engagement with policy decisions?

In the follow-up questionnaire, participants were asked to reflect on the merits of the workshop and the deliberative process. Participants indicated that their experience of the process was overwhelmingly positive across the different workshops and user/stakeholder groups (Figure 4.4). The vast majority enjoyed the process, felt that their views were heard and considered, benefited from discussion with others and thought that the workshops provided somewhere that they could give useful input on river management. Qualitative comments indicated that the workshops felt welcoming and inclusive, and reiterated the importance of participation in river management; for example, one participant stated:

> This was a very interesting and informative evening. I think for any changes to have real impact on the rivers, communities need to be involved in the decisions and the implementation of the changes. If this happens people will learn how to look after the environment at a community level. They will take responsibility for their local areas, and this will then filter into their home life. These actions can improve the health of communities and grow into national health and global health. Education at community level and communities being involved in changes is key.

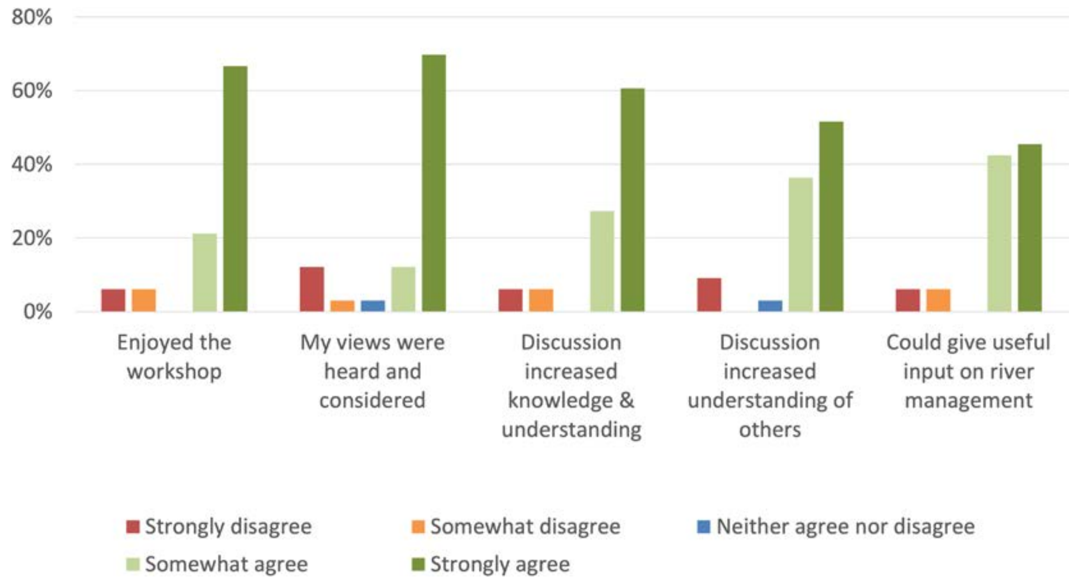


Figure 4.4. Participants' feedback responses across the three local workshops.

4.5.4 Can consideration of the diversity of values improve decision-making?

Participants of the national workshop were asked to discuss the merits of the deliberative approach used in the research and consider whether such an approach could be used to improve decision-making. Key comments emerging from these discussions included:

> I found the approach useful and will apply at least some of it to citizen science projects that we have underway.

> We need to think more carefully about how we engage the public in decisions.

> We will use it as an evidence-base to support our advocacy for effective public engagement in decision-making regarding water management. … I would expect that we shall be advocating for such an approach to be integrated into the State's implementation of the WFD.

Thus, there was evidence that the national stakeholders saw potential in our approach as a mechanism to engage with the wider public in order to help better understand the range of values and value conflicts that may be associated with alternative river management options. They also saw the potential of deliberative processes to reconcile value conflicts and enable the development of policy options based on shared visions. As highlighted by the feedback results, local stakeholders themselves felt highly convinced by the merits of the shared values-based deliberative approach and saw it as an important means of getting their voices heard in river management.

5 General Conclusions and Recommendations

5.1 General Overview

ESDecide set out to build on the outputs of the ESManage project (Kelly-Quinn *et al.*, 2020) by developing the tools and guidance needed to advance efforts to incorporate ecosystem services and the concept of NCP described by IPBES (2018) into decision-making related to the protection and management of freshwater resources and legislation and other policy goals. Although the ecosystem services approach has an anthropocentric focus, it is recognised that this focus may help communicate the urgency of addressing declining water quality. As noted by Rounsevell *et al.* (2019), ecosystem services considerations must be effectively integrated across policy sectors to minimise damage to not only ecosystems, but also human well-being. The same authors also highlighted that decision-makers must engage with communities to gain an understanding of people's awareness of (1) why ecosystem health matters, (2) what ecosystem services are and (3) the relevance of ecosystem services to them, in order to gain insight into shared values and how management might best reconcile conflicting interests and goals. ESDecide took this on board through its engagement with stakeholders to explore the multiple ways in which people value nature and how these values can be captured and fed into policy decisions.

5.2 Linking Pressures/Stressors to Ecosystem Services

Although a good body of information is available to link stressors to biological and hydromorphological changes, including insight into multiple stressor effects (e.g. Lemm *et al.*, 2021), few studies have attempted to make linkages to changes in ecosystem services. This is, in part, due to lack of knowledge on the response of many ecosystem services to stressors and the measuring/monitoring of ecosystem services health/delivery. Thus, any attempt to model these linkages will be heavily reliant on largely expert knowledge and a modelling framework that can use expert opinion and is sufficiently dynamic to incorporate new information as it becomes available. This was the rationale for the selection of BBN model in both the ESManage and ESDecide research projects.

Key advances of the ESDecide BBN model include refined expert knowledge and analyses of large national monitoring data to establish relationships between stressors and biological responses, as well as new evidence from the literature. The BBN model was partly restructured to focus on individual stressors, permitting the end user to apply a broad range of generic or bespoke management measures, crafted to individual circumstances (e.g. NFGWS, 2020). The updated ESDecide BBN model has incorporated a regulating service (albeit only qualitatively owing to a knowledge gap in this respect), as well as water quality for abstraction and recreation. The model was developed using a large physico-chemical dataset with national coverage and the expert opinion of national experts, so it should be sufficiently robust to capture the responses of the selected ecosystem services in most other Irish catchments. It was demonstrated in three catchments for this project but will benefit from testing using baseline data from other catchments.

> **Key message:** The ESDecide BBN model is a robust model that can be adjusted to changing environmental conditions and a range of ecosystem services to reflect conditions in other catchments/subcatchments and to incorporate new information as it becomes available.
> The tool can be parameterised with baseline physico-chemical data for other catchments/subcatchments.

5.3 ESDecide Decision Support Tool – ProgRES (Prognosing River Ecosystem Services)

Various decision support approaches have been developed to aid ecosystem services decision-making. However, most fall short when it comes to directly illustrating the implications of management interventions for biological and ecosystem services/NCP responses. The new ESDecide DST, called

ProgRES (Prognosing River Ecosystem Services), closes this gap and provides a powerful and interactive tool for end users to directly illustrate a river ecosystem's ecological/ecosystem services responses to changing environmental conditions. The ESDecide BBN model and DST together form a unit in which the BBN model provides the backbone model for the estimation of biological and ecosystem services/NCP responses, while the DST provides the graphical user interface to the BBN model. By linking the environmental input variables of the DST to management options, the DST allows the end user to estimate potential beneficial (but also detrimental) effects of individual management scenarios. With this outcome, the DST can greatly support the identification of the management options for a given river that are most likely to achieve the desired improvements in biological and ecosystem services/NCP responses. The open-source architecture of the DST in combination with the use of royalty-free software packages permits a high level of flexibility in terms of tool maintenance and tool advancement. Future advancements, for example, may comprise (1) coverage of further environmental impacts (e.g. river habitat quality variables, emerging pollutants, land use), (2) incorporation of additional socio-ecological responses (e.g. water retention, amenity, ecological status, functional diversity) or (3) provision of an interface to directly link the DST with environmental databases.

Despite this broad potential to inform decisions using the DST, one should not forget, however, that decisions are ultimately to be taken by experts, not by software tools.

> **Key message:** The ESDecide DST (ProgRES) can be used to communicate the consequences of river deterioration on the goods and services that people rely on from rivers, and the benefits of water quality and biodiversity protection.

5.4 Incorporating the Multiple Values of Nature into Decision-making

People interact with and value nature in many different ways. Traditional TEEB-style ecosystem assessments, such as those undertaken in ESManage, have predominantly focused on monetary valuation of ecosystem services. More recently, as previously outlined, IPBES introduced the concept of NCP to highlight a wider range of nature's values. Analysis undertaken in this project demonstrates that rivers provide a wide range of intrinsic values, as well as material, non-material and regulating NCP, which may be valued for instrumental and relational justifications. Rivers are also associated with a diversity of overarching transcendental values, from enjoyment and freedom to creativity and protecting the environment. The results demonstrate that the Life Framework of Values provides a useful tool to help people uncover these multiple values and to organise these values into accessible and inclusive categories.

There is a range of policy options available to enhance river water quality. Selecting the best option can be challenging because of the lack of a shared vision and the poor engagement of stakeholders. These different options also have wider impacts on, for example, river biodiversity, recreational opportunities and land management practices, which in turn will have varying impacts on different groups of people. Economic approaches that aggregate individual values to a social value often mask the values of less dominant groups and often fail to address value conflict. This research has demonstrated the merits of an alternative approach that uses deliberation to explicitly discuss a broader range of values held by different stakeholders. This then provides a foundation to develop shared visions for the future management of rivers that can reconcile value conflicts and result in policies that are more equitable and more widely accepted.

> **Key message:** ESDecide demonstrates that the Life Framework of Values can help identify the multiple values of nature and that deliberation can help reconcile value conflict in order to develop a shared vision for the sustainable management of rivers and associated NCP.

5.5 Key Recommendations

5.5.1 Recommendations for policy and practice

1. Use the DST (ProgRES) to embed the ecosystem services approach in engagement activities undertaken by the LAWPRO and the Agricultural

Sustainability Support and Advisory Programme (ASSAP) to illustrate the benefits to people of improved water quality. This will also allow testing of the model against real-world interventions and outcomes.

2. Extend the use of the DST (ProgRES) to other catchments to investigate changes to ecosystem services/NCP and associated goods and benefits in response to management interventions. This will require initial testing using baseline data for the specific catchments.

3. Freshwater ecosystem management should address the steps defined in the AQUATAP-ES policy brief (expanded here to include reference to integration of the concept into strategic and environmental impacts assessment and consideration of NCP and shared value visions) to effect the changes necessary to support water quality and biodiversity protection efforts and ensure sustainable delivery of essential ecosystem services/NCP.

    (a) Make explicit the wide range of ecosystem services and benefits that are provided to people. An inventory of ecosystem services/NCP should therefore complement the biophysical monitoring of aquatic ecosystems. This will require identification of key attributes of freshwater ecosystem services/NCP for data collection and new data collection initiatives. This should be linked to natural capital accounting initiatives.

    (b) Expand the assessment of "ecological status" of surface waters to include an assessment of "ecosystem services status". The latter will illustrate better to people the connection between water quality and the goods and services that affect their well-being.

    (c) Integrate both "ecological status" and "ecosystem services status" to inform the public of the importance of protecting ecosystems' health (including biodiversity, where appropriate) as a prerequisite for ecosystem services at desired service rates. This should include the often neglected, but important, benefits of regulating services (e.g. water purification, nutrient and water retention) and cultural services (e.g. recreation, sense of place, inspiration) and the wider range of nature's values and NCP.

    (d) Extend monetary assessments of ecosystem services to fully integrate the wider conceptualisations of nature's values and NCP. When values are assessed using metrics other than monetary indicators, such values should be clearly communicated and be considered in alternative assessments. If a full integration is not feasible, for example because of a lack of sound methodology, any services not included should be clearly communicated. This is of particular importance if the benefits of ecosystem protection and management (both to biodiversity and to human health and well-being) are to be justified against the expenditure on the required management measures.

    (e) Complement monetary valuation with non-monetary values assessment structured around the four values of the Life Framework of Values to ensure that a more comprehensive and inclusive set of values is assessed.

    (f) Undertake deliberative and participatory processes to discuss the multiple ways in which people interact with and value rivers; to explore the impacts of policy options on these values; to consider how conflicting values could be bridged; and to develop shared values and integrate those shared values into river management policies. This is of particular importance when there is significant potential for value conflicts (when management measures may benefit some values but to the detriment of others).

    (g) Integrate ecosystem services in strategic environmental assessment (SEA) and environmental impact assessment (EIA), particularly in consideration of mitigation measures, as well as potential ecosystem services trade-offs.

    (h) Identify synergies, disservices and trade-offs that can inform more beneficial, win–win solutions for aquatic ecosystems and water resources management. Synergies may be provided by nature-based solutions to water-related challenges, such as water retention measures in headwaters to reduce flood risk and wetlands for pollutant capture.

(i) Better link the integrated ecological status–ecosystem services status assessment with (1) the Aichi Biodiversity Targets and the global biodiversity targets of the CBD, (2) the EU Biodiversity Strategy for 2030 and (3) the UN SDGs and national biodiversity protection policies.

5.5.2 *Recommendations for future research*

1. Develop indicators/metrics for key ecosystem services that could be assessed on a relative scale from very low (1) to very high (5) service provision, as proposed by Podschun *et al.* (2018), or "benefit-relevant indicators" (either positive or negative) as outlined by Olander *et al.* (2018), in order to integrate both "ecological status" and "ecosystem services status".
2. Address the knowledge gap in regulating services, in particular nutrient assimilation/water purification and how contaminant inputs affect this service.
3. Identify metrics for cultural services and non-material NCP that are sensitive to aquatic ecology changes. This will enable a more comprehensive representation of cultural services in ecosystem services assessments and in natural capital accounting.
4. Undertake research to further validate use of the different Life Frames as a way to organise diverse values and human–nature relations, including by mapping values and NCP to the different Life Frames.
5. Explore how indicators of the multiple values of nature can be best incorporated into decisions, including through adoption of the Life Framework of Values.

References

AQUATAP-ES, 2021. *Briefing Note on Decision Support Systems for Managing Aquatic Ecosystem Services.* AQUATAP-ES Research Network and Water Joint Programming Initiative, Brussels.

Bishop, J. and Hill, C., 2014. *Global Biodiversity Finance: The Case for International Payments for Ecosystem Services*. Edward Elgar, Cheltenham, UK.

Braun, V. and Clarke, V., 2006. Using thematic analysis in psychology. *Qualitative Research in Psychology* 3: 77–101.

Bruen, M., Rymszewicz, A., O'Sullivan, J.J., Turner, J., Lawler, D., Conroy, E. and Kelly-Quinn, M., 2017. *Sediment Flux – Measurement, Impacts, Mitigation and Implications for River Management in Ireland*. Environmental Protection Agency, Johnstown Castle, Ireland. Available online: https://www.epa.ie/publications/research/water/research-230.php (accessed 18 September 2021).

Bruen, M., Hallouin, T., Christie, M., Matson, R., Siwicka, E., Kelly, F., Bullock, C., Feeley, H.B., Hannigan, E. and Kelly-Quinn, M., 2022. A Bayesian modelling framework for integration of ecosystem services into freshwater resources management. *Environmental Management* 69: 781–800. https://doi.org/10.1007/s00267-022-01595-x

Chang, W., Cheng, J., Allaire, J.J., Xie, Y. and McPherson, J., 2019. shiny: Web application framework for R. R package version 1.3.2. Available online: https://CRAN.R-project.org/package=shiny (accessed 18 March 2022).

Choubak, M., Pereira, R. and Sawatzky, A., 2019. *Indicators of Ecological Behaviour Change*. Community Engaged Scholarship Institute, University of Guelph, Guelph, ON, Canada.

Christie, M., Kenter, J., Bullock, C., Bruen, M., 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. Environmental Protection Agency, Johnstown Castle, Ireland.

Conroy, E., Turner, J.N., Rymszewicz, A., Bruen, M., O'Sullivan, J.J., Lawler, D.M., Lally, H. and Kelly-Quinn, M., 2016. Evaluating the relationship between biotic and sediment metrics using mesocosms and field studies. *Science of the Total Environment* 568: 1092–1101.

DAFM (Department of Agriculture, Food and the Marine), 2021. *Food Wise 2025 – A 10-year Vision for the Agri-food Industry in Ireland.* DAFM, Dublin.

DAHG (Department of Arts, Heritage & the Gaeltacht), 2016. *Ireland's National Biodiversity Plan: 2017–2021.* DAHG, Dublin.

Davis, S.J., Ó hUallacháin, D., Mellander, P.-E., Kelly, A.-M., Matthaei, C.D., Piggott, J.J. and Kelly-Quinn, M., 2018. Multiple-stressor effects of sediment, phosphorus and nitrogen on stream macroinvertebrate communities. *Science of the Total Environment* 637–638: 577–587.

Diaz, S., Pascual, U., Stenseke, M., Martin-Lopez, B., Watson, R., Molnar, Z., Hill, R., Chan, K., Baste, I., Brauman, K., Polasky, S., Church, A., Lonsdale, M., Larigauderie, A., Leadley, P., van Oudenhoven, A., van der Plaat, F., Schroter, M., Lavorel, S., Aumeeruddy-Thomas, Y., Bukvareva, E., Davies, K., Demissew, S., Erpul, G., Failler, P., Guerra, C., Hewitt, C., Keune, H., Lindley, S. and Shirayama, Y., 2018. Assessing nature's contributions to people. *Science* 359: 270–272.

Dudgeon, D., Arthington, A., Gessner, M.O., Kawabata, Z., Knowler, D.J., Lévêque, C., Naiman, R.J., Prieur-Richard, A.H., Soto, D., Stiassny, M.L. and Sullivan, C.A., 2006. Freshwater biodiversity importance, threats status and conservation challenges. *Biological Reviews* 81: 163–182.

ECDGE (European Commission and Directorate-General for Environment), 2021. *EU Biodiversity Strategy for 2030: Bringing Nature Back into Our Lives*. Publications Office, Luxembourg. Available online: https://data.europa.eu/doi/10.2779/048 (accessed 20 October 2021).

EEA (European Environment Agency), 2018. *European Waters: Assessment of Status and Pressures 2018.* EEA Report No 7/2018. EEA, Copenhagen.

EPA (Environmental Protection Agency), 2020. *Water Quality in 2019: An Indicators Report*. EPA, Johnstown Castle, Ireland.

EPA (Environmental Protection Agency), 2021. *Ireland's Environment: An Integrated Assessment 2020*. EPA, Johnstown Castle, Ireland.

EU (European Union), 2000. Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy. OJ L 327, 22.12.2000, p. 1–73.

European Commission, 2020. Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions “A Farm to Fork Strategy for a fair, healthy and environmentally-friendly food system”. COM(2020) 381 final, 20.5.2020, Brussels.

Feeley, H.B., Bruen, M., Bullock, C., Christie, M., Kelly, F., Remoundou, K., Siwicka, E. and Kelly-Quinn, M., 2016. *ESManage Literature Review: Ecosystem Services in Freshwaters.* EPA Research Report No. 187. Environmental Protection Agency, Johnstown Castle, Ireland.

Feeley, H.B., Bradley, C., Free, G., Kennedy, B., Little, R., McDonnell, N., Plant, C., Trodd, W., Wynne, C. and Boyle, S.O., 2020. A national macroinvertebrate dataset collected for the biomonitoring of Ireland’s river network, 2007–2018. *Scientific Data* 7: 280.

Feld, C.K., Birk, S., Bradley, D.C., Hering, D., Kail, J., Marzin, A., Melcher, A., Nemitz, D., Petersen, M.L., Pletterbauer, F., Pont, D., Verdonschot, P.F.M. and Friberg, N., 2011. From natural to degraded rivers and back again: a test of restoration ecology theory and practice. *Advances in Ecological Research* 44: 119–209.

Feld, C.K., Fernandes, M.R., Ferreira, M.T., Hering, D., Ormerod, S.J., Venohr, M. and Gutiérrez-Cánovas, C., 2018. Evaluating riparian solutions to multiple stressor problems in river ecosystems – a conceptual study. *Water Research* 139: 381–394.

Feld, C.K., Saeedghalati, M. and Hering, D. 2020. A framework to diagnose the causes of river ecosystem deterioration using biological symptoms. *Journal of Applied Ecology* 57: 2271–2284.

Forio, M.A.E., Villa-Cox, G., Van Echelpoel, W., Ryckebusch, H., Lock, K., Spanoghe, P., Deknock, A., De Troyer, N., Nolivos-Alvarez, I., Dominguez-Granda, L., Speelman, S. and Goethals, P.L.M., 2020. Bayesian belief network models as trade-off tools of ecosystem services in the Guayas River basin in Ecuador. *Ecosystem Services* 44: 101124.

García-Molinos, J. and Donohue, I., 2009. Differential contribution of concentration and exposure time to sediment dose effects on stream biota. *Journal of the North American Benthological Society* 28: 110–121.

Gudmundsson, L., Boulange, J., Do, H.X., Gosling, S.N., Grillakis, M.G., Koutroulis, A.G., Leonard, M., Liu, J., Müller Schmied, H., Papadimitriou, L., Pokhrel, Y., Seneviratne, S.I., Satoh, Y., Thiery, W., Westra, S., Zhang, X. and Zhao, F., 2021. Globally observed trends in mean and extreme river flow attributed to climate change. *Science* 6534: 1159–1162.

Haines-Young, R.H. and Potschin, M.B., 2009. *Methodologies for Defining and Assessing Ecosystem Services.* Final Report for the Joint Nature Conservation Committee. Centre for Environmental Management, University of Nottingham, Nottingham, UK.

Haines-Young, R. and Potschin, M., 2013. *Common International Classification of Ecosystem Services (CICES).* Report to the European Environment Agency. Contract No EEA/BSS/07/007. European Environment Agency, Copenhagen.

Hall, R.J.O., Baker, M.A., Arp, C.D. and Koch, B.J., 2009. Hydrologic control of nitrogen removal, storage, and export in a mountain stream. *Limnology and Oceanography* 54: 2128–2142.

Hothorn, T., Hornik, K. and Zeileis, A., 2006. Unbiased recursive partitioning: a conditional inference framework. *Journal of Computational and Graphical Statistics* 15: 651–674.

IPBES (Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services), 2018. *Summary for Policymakers of the Regional Assessment Report on Biodiversity and Ecosystem Services for Europe and Central Asia of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services.* IPBES Secretariat, Bonn, Germany.

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 Services Values in the Integrated Management of Irish Freshwater Resources – ESManage*. Report No. 312. Environmental Protection Agency, Johnstown Castle, Ireland.

Kelly-Quinn, M., Christie, M., Bodoque, J.M. and Schoenrock, K., 2021. Ecosystem services approach and natures contributions to people (NCP) help achieve SDG6. In Leal Filho, W., Azul, A.M., Brandli, L., Lange Salvia, A. and Wall, T. (eds), *Clean Water and Sanitation. Encyclopedia of the UN Sustainable Development Goals.* Springer, Cham, Switzerland.

Kenter, J.O. and O’Connor, S., 2022. The Life Framework of Values and living as nature; towards a full recognition of holistic and relational ontologies. *Sustainability Science*. In press.

Kenter, J.O., Reed, M.S., Irvine, K.N., O’Brien, L., Brady, E., Bryce, R., Christie, M., Church, A., Cooper, N., Davies, A., Hockley, N., Fazey, I., Jobstvogt, N., Molloy, C., Orchard-Webb, J., Ravenscroft, N., Ryan, M. and Watson, V., 2014. *UK National Ecosystem Assessment Follow-on Phase*. Work Package Report 6: Shared, Plural and Cultural Values of Ecosystems. United Nations Environment Programme World Conservation Monitoring Centre, Cambridge, UK.

Kenter, J.O., O'Brien, L., Hockley, N., Ravenscroft, N., Fazey, I., Irvine, K.N., Reed, M.S., Christie, M., Brady, E., Bryce, R., Church, A., Cooper, N., Davies, A., Evely, A., Everard, M., Fish, R., Fisher, J.A., Jobstvogt, N., Molloy, C., Orchard-Webb, J., Ranger, S., Ryan, M., Watson, V. and Williams, S., 2015. What are shared and social values of ecosystems? *Ecological Economics* 111: 86–99.

Kenter, J.O., Jobstvogt, N., Watson, V., Irvine, K.N., Christie, M. and Bryce, R., 2016a. The impact of information, value-deliberation and group-based decision-making on values for ecosystem services: integrating deliberative monetary valuation and storytelling. *Ecosystem Services* 21: 270–290.

Kenter, J., Reed, M. and Fazey, I., 2016b. The Deliberative Value Formation model. *Ecosystem Services* 21: 194–207.

Kenter, J.O., Raymond, C.M., van Riper, C.J., Azzopardi, E., Brear, M.R., Calcagni, F., Christie, I., Christie, M., Fordham, A., Gould, R.K., Ives, C.D., Hejnowicz, A.P., Gunton, R., Horcea-Milcu, A.I., Kendal, D., Kronenberg, J., Massenberg, J.R., O'Connor, S., Ravenscroft, N., Rawluk, A., Raymond, I.J., Rodriguez-Morales, J. and Thankappan, S., 2019. Loving the mess: navigating diversity and conflict in social values for sustainability. *Sustainability Science* 14: 1439–1461.

Kikuchi, T., Kohzu, A., Ouchi, T. and Fukushima, T., 2020. Quantifying the sources and removal of nitrate in riparian and lotic environments based on land use and topographic parameters of the watershed. *Ecological Indicators* 116: 106535.

King, N., 2004. Using templates in the thematic analysis of text. In Cassell, C. and Symon, G. (eds), *Essential Guide to Qualitative Methods in Organizational Research*. Sage, London.

Landuyt, D., Broekx, S., D'Hondt, R., Engelen, G., Aertsens, J. and Goethals, P.L.M., 2013. A review of Bayesian belief networks in ecosystem service modelling. *Environmental Modelling and Software* 46: 1–11.

Lemm, J.U., Venohr, M., Globevnik, L., Stefanidis, K., Panagopoulos, Y., van Gils, J., Posthuma, L., Kristensen, P., Feld, C.K., Mahnkopf, J., Hering, D. and Birk, S., 2021. Multiple stressors determine river ecological status at the European scale: towards an integrated understanding of river status deterioration. *Global Change Biology* 27: 1962–1975.

Mantyka-Pringle, C.S., Jardine, T.D., Bradford, L., Bharadwaj, L., Kythreotis, A.P., Fresque-Baxter, J., Kelly, E., Somers, G., Doig, L.E., Jones, P.D. and Lindenschmidt, K.E., 2017. Bridging science and traditional knowledge to assess cumulative impacts of stressors on ecosystem health. *Environment International* 102: 125–137.

McVittie, A., Norton, L., Martin-Ortega, J., Siameti, I., Glenk, K. and Aalders, I., 2015. Operationalizing an ecosystem services-based approach using Bayesian belief networks: an application to riparian buffer strips. *Ecological Economics* 110: 15–27.

MEA (Millennium Ecosystem Assessment), 2005a. *Ecosystems and Human Well-being: Wetlands and Water Synthesis*. World Resources Institute, Washington, DC.

MEA (Millennium Ecosystem Assessment), 2005b. *Ecosystems and Human Well-being: A Framework for Assessment*. Island Press, Washington, DC.

NFGWS (National Federation of Group Water Schemes), 2020. *A Handbook of Source Protection and Mitigation Actions for Farming. National Federation of Group Water Schemes*. Available online: https://nfgws.ie/wp-content/uploads/2019/06/Handbook-mitigation-actions-November-2020.pdf (accessed 22 October 2021).

Niemeyer, S. and Spashm, C.L., 2001. Environmental valuation analysis, public deliberation, and their pragmatic syntheses: a critical appraisal. *Environment and Planning C-Government and Policy* 19: 567–585.

Nolan, P. and Flanagan, J., 2020. *High Resolution Climate Change Projections for Ireland – A Multi-Model Ensemble Approach*. EPA Research Report No. 339. Environmental Protection Agency, Johnstown Castle, Ireland.

O'Connor, S. and Kenter, J.O., 2019. Making intrinsic values work; integrating intrinsic values of the more-than-human world through the Life Framework of Values. *Sustainability Science* 14: 1247–1265.

Olander, L.P., Johnston, P.I., Tallis, H., Kagan, J., Maguire, L.A., Polasky, S., Urban, D., Boyd, J., Wainger, L. and Palmer, M., 2018. Benefit relevant indicators: ecosystem services measures that link ecological and social outcomes. *Ecological Indicators* 85: 1262–1272.

Orchard-Webb, J., Kenter, J.O., Bryce, R. and Church, A., 2016. Deliberative democratic monetary valuation to implement the Ecosystem Approach. *Ecosystem Services* 21: 308–318.

Ormerod, S.J. and Tyler, S.J., 1993. Birds as indicators of changes in water quality. In Furness, R.W. and Greenwood, J.J.D. (eds), *Birds as Monitors of Environmental Change*. Chapman & Hall, London.

Ormerod, S.J., Boilstone, M.A. and Tyler, S.J., 1985. Factors influencing the abundance of breeding Dippers *Cinclus cinclus* in the catchment of the River Wye, mid-Wales. *Ibis* 127: 332–340.

Podschun, S.A., Thiele, J., Dehnhardt, A., Mehl, D., Hoffmann, T.G., Albert, C., von Haaren, C., Deutschmann, K., Fischer, C., Scholz, M., Costea, G. and Pusch, M.T., 2018. Das Konzept der Ökosystemleistungen – Eine Chance für integratives Gewässermanagement. *Hydrologie & Wasserbewirtschaftung* 62: 453–468

R Core Team, 2021. *R: A Language and Environment for Statistical Computing*. R Foundation for Statistical Computing, Vienna. Available online: https://www.R-project.org/ (accessed 14 September 2021).

Reid, A.J., Carlson, A.K., Creed, I.F., Eliason, E.J., Gell, P.A., Johnson, P.T.J., Kidd, K.A., MacCormack, T.J., Olden, J.D., Ormerod, S.J., Smol, J.P., Taylor, W.W., Tockner, K., Vermaire, J.C., Dudgeon, D. and Cooke, S.J., 2019. Emerging threats and persistent conservation challenges for freshwater biodiversity. *Biological Reviews* 94: 849–873.

Riis, T., Kelly-Quinn, M., Aguiar, F.C., Manolaki, P., Bruno, D., Bejarano, M.D. and Dufour, S., 2020. Global overview of ecosystem services provided by riparian vegetation. *BioScience* 70: 501–514.

Rounsevell, M.D.A., Metzger, M.J. and Walz, A., 2018. Operationalising ecosystem services in Europe. *Regional Environmental Change* 19: 2143–2149.

Ryan, D.K. and Kelly-Quinn, M., 2016. Riparian vegetation management for water temperature regulation: implications for the production of macroinvertebrate prey of salmonids. *Fisheries Management and Ecology* 23: 519–530.

Schindler, D.W., 2006. Recent advances in the understanding and management of eutrophication. *Limnology and Oceanography* 51: 356–363.

Smith, R.I., Barton, D.N., Dick, J., Haines-Young, R., Madsen, A.L., Rusch, G.M., Termansen, M., Woods, H., Carvalho, L., Giuca, R.C., Luque, S., Odee, D., Rusch, V., Saarikoski, H., Adamescu, C.M., Dunford, R., Ochieng, J., Gonzalez-Redin, J., Stange, E., Vadineanu, A., Verweij, P. and Vikstrom, S., 2018. Operationalising ecosystem service assessment in Bayesian belief networks: experiences within the OPENNESS project. *Ecosystem Services* 29: 452–464.

Solomon, D.J. and Lightfoot, G.W., 2008. *The Thermal Biology of Brown Trout and Atlantic Salmon*. Environment Agency, Bristol, UK.

Stirling, A., 2006. Analysis, participation and power: justification and closure in participatory multi-criteria analysis. *Land Use Policy* 23: 95–107.

Tank, J.L., Martí, E., Riis, T., von Schiller, D., Reisinger, A.J., Dodds, W.K., Whiles, M.R., Ashkenas, L.R., Bowden, W.B., Collins, S.M., Crenshaw, C.L., Crowl, T.A., Griffiths, N.A., Grimm, N.B., Hamilton, S.K., Johnson, S.L., McDowell, W.H., Norman, B.M., Rosi, E.J., Simon, K.S., Thomas, S.A. and Webster, J.R., 2018. Partitioning assimilatory nitrogen uptake in streams: an analysis of stable isotope tracer additions across continents. *Ecological Monographs* 88: 120–138.

TEEB (The Economics of Ecosystems and Biodiversity), 2010. *The Economics of Ecosystems and Biodiversity Ecological and Economic Foundations*. Earthscan, London.

UK National Ecosystem Assessment, 2014. *The UK National Ecosystem Assessment Follow-on: Synthesis of the Key Findings.* United Nations Environment Programme World Conservation Monitoring Centre, Cambridge, UK.

UN (United Nations), 1992. *Convention on Biological Diversity*. Available online: http://www.cbd.int/doc/legal/cbd-en.pdf (accessed 21 September 2021).

UN (United Nations), 2015. General Assembly Resolution A/RES/70/224 – Towards global partnerships: a principle-based approach to enhanced cooperation between the United Nations and all relevant partners. Available online: http://undocs.org/A/RES/70/224 (accessed 12 December 2019).

Vári, Á., Podschun, S.A., Erős, T., Hein, T., Pataki, B., Ioja, I., Adamescu, C.M., Gerhardt, A., Gruber, T., Dedic, A., Ciric, M., Gavrilovic, B. and Baldi, A., 2022. Freshwater systems and ecosystem services: challenges and chances for cross-fertilization of disciplines. *Ambio* 51: 135–151.

Vörösmarty, C.J., Osuna, V.R., Cak, A.D., Bhaduri, A., Bunn, S.E., Corsi, F., Gastelumendi, J., Green, P., Harrison, I., Lawford, R. and Marcotullio, P.J., 2018. Ecosystem-based water security and the sustainable development goals (SDGs). *Ecohydrology & Hydrobiology* 18: 317–333.

Wagner, K., Besemer, K., Burns, N.R., Battin, T.J. and Bengtsson, M.M., 2015. Light availability affects stream biofilm bacterial community composition and function, but not diversity. *Environmental Microbiology* 17: 5036–5047.

Welch, E.B., Jacoby, J.M., Horner, R.R. and Seeley, M.R., 1988. Nuisance biomass levels of periphytic algae in streams. *Hydrobiologia* 157: 161–168.

Williams, B.K. and Brown, E.D. 2014. Adaptive management: from more talk to real action. *Environmental Management* 53: 465–479.

Wood, S.N., 2017. *Generalized Additive Models: An Introduction with R*. Second edition. CRC Press, Boca Raton, FL.

Abbreviations

BBN	Bayesian belief network
BOD	Biochemical oxygen demand
CART	Classification and regression tree analysis
CBD	Convention on Biological Diversity
DST	Decision support tool
EPA	Environmental Protection Agency
IPBES	Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services
JPI	Joint Programming Initiative
LAWPRO	Local Authority Waters Programme
NCP	Nature's contributions to people
RHAT	River Habitat Assessment Technique
SDG	Sustainable Development Goal
TEEB	The Economics of Ecosystems and Biodiversity
WFD	Water Framework Directive

Glossary

Bayesian belief network	Probabilistic model of acyclic cause–effect relationships among variables propagated using Bayes' theorem
Conditional probability	The likelihood of a state/event conditional upon its influencing factor(s)
Contextual value	Objects valued in a particular context
Ecosystem services	Contributions (goods and benefits) of nature to human well-being
Instrumental value	Value as a substitutable means to a human end
Intrinsic values	Something important in and for itself without reference to people as valuers
Material NCP	Water, food and energy, for example
Mayfly richness	The number of mayfly species
Non-material NCP	Physical and psychological experiences
Oxidised nitrogen	The sum of nitrate and nitrite (typically measured in combination owing to the analytical procedure, although nitrite tends to be negligible in rivers)
Parent node	An element of a BBN model representing a variable being modelled
Regulating NCP	Habitat maintenance, regulation of water flows and quality, for example
Relational values	Value as a non-substitutable meaningful relationship between nature and people
Shared values	Values held or assigned through our interactions with others that inform narratives of our "common good"
Social values	Aggregation of individual values
Transcendental values	Values that relate to overarching principles and/or life goals
Value indicator	Measure of benefit to an individual

Appendix 1 Coding Structure Used in the Qualitative Analysis of the Workshop Discussions

1 Attitudes
- 1 Unspecified
- 2 Negative
- 3 Positive

2 Values
- **1 Transcendental Values**
  - 1 Health
  - 2 Family security
  - 3 Enjoying life
  - 4 A varied life, filled with challenge, novelty
  - 5 Social justice, fairness
  - 6 A world at peace, free of conflict
  - 7 Unity with nature, fitting into nature
  - 8 Protecting the environment
  - 9 A world of beauty
  - 10 Sense of belonging
  - 11 Responsibility
  - 12 Honesty, transparency
  - 13 Creativity
  - 14 Respect for tradition
  - 15 Social order
  - 16 Freedom
  - 17 Others
- **2 Life Frames**
  - 1 Living in
  - 2 Living from
  - 3 Living as
  - 4 Living with
- **3 NCP**
  - 1 Material
  - 2 Non-material
  - 3 Regulating
- **4 Value Justifications**
  - 1 Instrumental Values
  - 2 Relational Values
  - 3 Intrinsic Values
- **5 Other Things of Values**
  - **1 Biodiversity and wildlife**
    - 1 General
    - 2 Birds
    - 3 Fish
    - 4 Mammals
    - 5 Insects
    - 6 Other
- **6 Issues**
  - 1 Water health
  - 2 Water quality
  - 3 Fish stocks
  - 4 Other wildlife
  - 5 Flooding
  - 6 Access
  - 7 Personal safety
  - 8 Others
- **7 Conflicts**

3 River Management

- **1 Dodder**
  - 1 Separate sewage water from rainwater
  - 2 New urban wetlands
  - 3 Rain gardens ponds, green roofs
  - 4 Sewage overflow screens
  - 5 Rural land management
  - 6 Others
- **2 Moy**
  - 1 Creation of "butter strips" along river banks
  - 2 Increase capacity of overload water treatment
  - 3 Low intensity pasture management
  - 4 Upgrade septic tanks
- **3 Suir**
  - 1 Creation of "butter strips"
  - 2 Creation of new wetlands to treat sewage from smaller waste water plants
  - 3 Increase capacity of overloaded waste water treatment plants
  - 4 Low intensity pasture management
  - 5 Upgrade waste water treatment plants from secondary to tertiary treatment
- **4 Management Aspects**
  - **1 Authority**
    - 1 Agency approaches
    - 2 Governance scale
    - 3 Monitoring
    - 4 Planning
  - **2 Links**
    - 1 Communication
    - 2 Cooperation
  - **3 Options**
    - 1 Advanced approaches
    - 2 Cost-benefit
    - 3 Efficiency & effectiveness
    - 4 Environmental friendly
    - 5 Priority
    - 6 Sustrainable & maintenance
    - 7 Trade-offs
  - **4 Public**
    - 1 Education
    - 2 Incentives
    - 3 Public perception
    - 4 Public support

4 Deliberation

- 1 Learning from the project presentations
- 2 Learning from other participants
- 3 Influencing
- 4 Reference to social status
- 5 Social norms
- 6 Questions of trust
- 7 Acknowledgement of others' values
- 8 Triggering or making explicit of dormant/implicit/tacit values
- 9 Explicit associations of trascendental and contextual values
- 10 Apparent entrenchment of views or values
- 11 Apparent shifts in value orientation towards the common good
- 12 Apparent adaptation of values in response to others
- 13 Peer pressure
- 14 Dominance of certain individuals

An Ghníomhaireacht Um Chaomhnú Comhshaoil

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

Is féidir obair na Gníomhaireachta a roinnt ina trí phríomhréimse:

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

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

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

I measc ár gcuid freagrachtaí tá:

Ceadúnú

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

Forfheidhmiú Náisiúnta i leith Cúrsaí Comhshaoil

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

Bainistíocht Dramhaíola agus Ceimiceáin sa Chomhshaol

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

Bainistíocht Uisce

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

Eolaíocht Aeráide & Athrú Aeráide

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

Monatóireacht & Measúnú ar an gComhshaol

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

Taighde agus Forbairt Comhshaoil

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

Cosaint Raideolaíoch

- Monatóireacht a dhéanamh ar leibhéil radaíochta agus nochtadh an phobail do radaíocht ianúcháin agus do réimsí leictreamaighnéadacha a mheas;
- Cabhrú le pleananna náisiúnta a fhorbairt le haghaidh éigeandálaí ag eascairt as taismí núicléacha;
- Monatóireacht a dhéanamh ar fhorbairtí thar lear a bhaineann le saoráidí núicléacha agus leis an tsábháilteacht raideolaíochta;
- Sainseirbhísí um chosaint ar an radaíocht a sholáthar, nó maoirsiú a dhéanamh ar sholáthar na seirbhísí sin.

Treoir, Ardú Feasachta agus Faisnéis Inrochtana

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

Comhpháirtíocht agus Líonrú

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

Bainistíocht agus struchtúr na Gníomhaireachta um Chaomhnú Comhshaoil

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

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

Tugann coistí comhairleacha cabhair don Ghníomhaireacht agus tagann siad le chéile go rialta le plé a dhéanamh ar ábhair imní agus le comhairle a chur ar an mBord.

EPA Research Report 424

ESDecide: From Ecosystem Services Framework to Application for Integrated Freshwater Resources Management

Authors: Mary Kelly-Quinn, Michael Bruen, Craig Bullock, Mike Christie, Christian K. Feld, Jasper Kenter, Marcin Penk and Jeremy Piggott

Identifying Pressures

Ecosystem services are commonly defined as "the benefits people obtain from ecosystems" (Millennium Ecosystem Assessment) or "the contributions that ecosystems make to human well-being" (Common International Classification of Ecosystem Services – CICES). The ESDecide project set out to build on the outputs of the ESManage project by developing the tools and guidance needed to advance the incorporation of ecosystem services and the concept of "nature's contribution to people" (NCP) into decision-making for the protection and management of freshwater resources and other related policy goals. The inclusion of ecosystem services/NCP in decision support tools helps to evaluate the impacts of water quality pressures and related stressors on the freshwater biodiversity and biological processes underpinning the delivery of the goods, services and benefits that people depend on from freshwaters. Nutrients (phosphorus and nitrogen) and fine sediments are among the primary stressors on freshwater quality. Habitat degradation due to hydromorphological alterations (e.g. flow alteration, barriers or loss of riparian vegetation) is also a prominent stressor. River basin management requires tools that help inform strategies for protecting water quality and maintaining the flow and quality of ecosystem services/NCP.

Informing Policy

The ESDecide project, through its focus on the links between ecosystem services/NCP and environmental quality, highlighted the need to incorporate these considerations into water resources monitoring and management, including river basin management plans. Although not always explicitly stated, ecosystem services/NCP protection and restoration are central to many global, European and national policies, including the Sustainable Development Goals, biodiversity strategies and the European Green Deal. Our research demonstrated that an approach that uses deliberation to explicitly discuss a broader range of values associated with rivers, nature and ecosystem services/NCP held by different stakeholders can lead to shared visions for future river management that can help reconcile value conflicts and result in policies that are more equitable and more widely accepted.

Developing Solutions

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. The tool can help estimate the effects of stressor reductions or increases to identify suitable protection measures for the biological processes underpinning ecosystem services/NCP. An online demonstration version of ProgRES is based on current conditions in three rivers: the Dodder, Suir and Moy. A separate, stand-alone version of the tool can be applied and tested with baseline data for other rivers. This tool supports the integration of ecosystem services/NCP considerations into policy and practice relating to river resource management in Ireland.

EPA Research: McCumiskey House, Richiew, Clonskeagh, Dublin 14.

Phone: 01 268 0100
Twitter: @EPAResearchNews
Email: research@epa.ie

www.epa.ie

EPA Research Webpages
www.epa.ie/our-services/research/