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Developing a virtual approach to determine if ecosystem service provision differs between Scottish river corridors with and without nature designations

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Developing a virtual approach to determine if ecosystem service provision differs between Scottish river corridors with and without nature designations

by

VICTORIA ELEANOR KEELE

A thesis submitted to the University of Plymouth in partial fulfilment for the degree of

DOCTOR OF PHILOSOPHY

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Acknowledgments

By grace

This journey to thesis submission has been as sinuous as the rivers I study. Throughout, I have received unmeasurable volumes of support and kindness, subsequently, it feels right to mention each of those who have guided me, listened to me, and laughed with me.

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Victoria Eleanor Keele (December 2021)
Author's Declaration

At no time during the registration for the degree of Doctor of Philosophy has the author been registered for any other University award without prior agreement of the Doctoral College Quality Sub-Committee.

Work submitted for this research degree at the University of Plymouth has not formed part of any other degree either at the University of Plymouth or at another establishment.

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Abstract

Humanity survives because we are graced with nature, or ‘ecosystem services’. In a time of turbulence caused by climate change and increasing population, there is debate surrounding the extent to which areas protected for biodiversity can deliver ecosystem services. Subsequently, the overarching aim of this PhD thesis is to determine if ecosystem service provision differs between Scottish river corridors with and without nature designations. To achieve the primary research aim, this thesis has a secondary aim of developing a methodology which can capture multiple riverine ecosystem services at the reach scale.

Following an extensive review of the methods used to capture river ecosystem services, the Google Earth River Ecosystem Services (GE RES) tool is developed. This method advances the matrix-based Google Earth technique of Large and Gilvear (2015). Significant advancements built into GE RES which are valuable to the river ecosystem service community include: a framework based on empirical evidence, the inclusion of cultural services, confidence scores and appreciation of river corridor area. Of note, the development and analysis of a pilot survey linking river corridor features to cultural service preferences is particularly pioneering. A survey utilises photographs to elicit cultural service preferences for different river corridor features. Preferences are then used to create a preliminary matrix linking river corridor features to ecosystem service potential.

To achieve the overarching research aim, paired analysis comparing four protected (Special Areas of Conservation) and unprotected Scottish rivers occurs. Undertaking GE RES assessments reveals that protected rivers appear to supply higher levels of ecosystem service potentials, and a greater diversity of services. Meanwhile, unprotected rivers are consistently identified to have greater agricultural potential and lower ecosystem service heterogeneity. Additionally, the nature of GE RES facilitates the production of ‘river ecosystem service long-profiles’, of remark, preliminary evidence indicates that nature designation may be associated with a higher prevalence of ecosystem service hotspots. This thesis concludes by discussing the significance of GE RES findings for the management of unprotected rivers, protected rivers, and ecosystem service hotspots.
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Chapter One: Introduction

1.1 Background

Human life is complicated, messy, and unpredictable, but one certainty is that without nature, human life would not be possible. It is in the interest of every soul to protect the environment we have been given dominion over. The ‘ecosystem services’ paradigm brings to the forefront the significance of protecting and enhancing nature because it sustains human wellbeing (Costanza et al., 1997; Gomez-Baggethun et al., 2010; Seppelt et al., 2011). Naturally within this paradigm are multiple research areas. In a time of accelerated climate change, population growth and budgets constraints one particularly significant area of research involves seeking to understand the extent to which areas designated for the protection of biodiversity elements simultaneously supply ecosystem services (Palomo et al., 2014; Willemen et al., 2013). In common parlance this is often posed as the question “what can nature do for us” or is seen as an approach to environmental management of “working with natural processes”. Over a series of eight chapters, this thesis seeks to determine if ecosystem service provision differs between Scottish river corridors with and without nature designations.

Such knowledge is viewed to be important by NatureScot, the Scottish Government Agency which has funded this PhD thesis. Their key mission is to improve the natural environment “so that all nature in Scotland – our key habitats and landscapes, all our green spaces and our native species – is maintained, enhanced and brings us benefits” (https://nature.scot/about-naturescot). NatureScot also emphasise connecting people and nature and the ecosystem service approach is one central tenant of that mission.

To achieve the overarching research aim, a considerable secondary proponent of this thesis involves developing a technique which can be used to capture riverine ecosystem
service potential at the reach-scale. Throughout, this research is underpinned by critical reflectiveness and recommendations for the future of riverine ecosystem service quantification, practice, and management. The rest of this introduction sets out the rationale for the structure of the thesis. Two schematic diagrams, presented below, outline the flow of this thesis. Figure one is a schematic diagram outlining the contents of each thesis chapter and how they connect. Figure two highlights the elements of the ecosystem service concept followed throughout this thesis."
Schematic Diagram of Thesis Contents

Introduction

Chapter One: Introduction

Chapter Two: Literature Review
- 2.2 History of the ecosystem service concept
- 2.3. Protected areas and ecosystem services
- 2.4 Rivers and ecosystem services
- 2.5 Scotland: ecosystem services, protected areas and protected rivers
- 2.7 Proposed Aims and Objectives

Chapter Three: Review of methodologies used to capture river ecosystem services
- 3.2 Reviewing methods used to capture provisioning and regulating services
- 3.3 Cultural service methodologies
- 3.4 Deciding on a methodology

Chapter Four: Methodology Development – Provisioning and Regulating Services
- 4.2 GE RES – Decisions and properties
- 4.3 GE RES – Developing a new matrix

Chapter Five: Cultural services methodology - Development, results, and evaluation
- 5.2 Developing a photo-preference survey
- 5.3 Results of photo-preference survey
- 5.5 Evaluation of photo-preference survey

5.5 Creating an excel tool from ecosystem service capacity matrices
Chapter Six: Results of a paired river comparison

6.2 Study Locations
6.3 Mann-Witney Statistical Comparisons
6.4 River reach morphology, protected status, and potential ecosystem service provision
6.5 Case study: Ecosystem service long-profiles (Dee vs Don comparison)

Chapter Seven: Discussion of GE RES assessments along paired Scottish river corridors

7.2 Exploration of results in context of other research
7.3 Designation, biodiversity status, and ecosystem service potential in Scottish riverine SACs
7.4 Species pressure, status and ecosystem service potential
7.5 Future management recommendations

Figure 1: A schematic diagram outlining the contents of each thesis chapter and how they connect
Chapter Two: Literature Review
- Review of protected area effectiveness.
- Review of protected area ability to provide ecosystem services.

Chapter Three: Review of river ecosystem service quantification
- Discussion: what is being quantified (potential, actual use and demand of services)
- Review: Methodologies used to capture provisioning and regulating river ES
- Review: Methodologies used to capture cultural river ES.

Chapter Four: Provisioning and Regulating Methodology Development
- GE RES Development: Developing a framework for a capacity matrix linking river corridor features to provisioning and regulating service potential.
- GE RES Development: Populating an ecosystem service capacity matrix with empirical evidence
Chapter Five: Cultural Methodology
Development, results, and evaluation

GE RES Development: Designing a photo-preference survey to create a cultural service capacity matrix
Results: Cultural service pilot survey results
Discussion: Evaluation of cultural service pilot survey

Chapter Six: Results of a paired river comparison
Results: Statistical comparisons of ES potential between protected and unprotected rivers
Results: Geomorphology, designation and ecosystem service potential
Results: Ecosystem service long-profile comparison between protected and unprotected river

Chapter Seven: Discussion
Discussion: Exploration of results in context of other research
Discussion: geomorphology, designation, and ES potential
Discussion: Protected areas and ES hotspots
Discussion: Conservation status and ES potential
Discussion: implications of research findings for management of protected and unprotected rivers

Figure 2: Schematic diagram highlighting the flow of focus on ecosystem service elements throughout this thesis
1.2 Research and thesis structure

As most do, this thesis begins with a literature review. The purpose of this chapter is to engage with existing published research which is of significance to the overarching research aim of determining if ecosystem service provision differs between Scottish river corridors with and without nature designations. Logically the starting point of this chapter is the history of the ecosystem service concept. Unravelling the history of the ecosystem service concept involves seeking to define ‘ecosystem services’, exploring arguments for and against the concept, discovering involvement in international and national agendas and exploring the evolution of ecosystem service categories. Moving forward it is necessary to turn attention to inquiring the place of biodiversity within the ecosystem service concept. In particular, there is the question: to what extent do areas protected for biodiversity supply ecosystem services? To gain a foundation block for seeking to answer this question, exploration into the history and effectiveness of protected areas is required. Exploring the academic literature on existing protected area research reveals that in comparison to the terrestrial and marine realms, freshwaters are relatively under researched. A research gap involving river corridor protected areas and ecosystem service potential is evident. Consequently, to assist this thesis in closing this research gap, attention focuses on reviewing literature examining the adoption of the ecosystem service concept within river research. The final proportion of literature review research is then dedicated to exploring why Scotland may be a suitable locality for the investigation of protected areas versus non-protected areas and river ecosystem service potential. To end, the literature review presents the overarching aims and objectives for this thesis.
On completion of a literature review the aims and objectives of this thesis were formulated. This thesis has one overarching aim accompanied by a substantial subsidiary aim. The overarching aim of this thesis is to determine if ecosystem service provision differs between Scottish river corridors with and without nature designations. To fulfil this principle aim, a secondary aim of selecting and developing an appropriate method for capturing river ecosystem potential at a relatively small scale (river reach-scale) is required.

The subsidiary aim of methodology selection and development to capture riverine ecosystem service potential at the reach-scale must be achieved to begin exploration of the overarching aim. As a result, the second chapter of this thesis is a review of existing methodologies used in ecosystem service assessment. Prior to delving into the specific methodologies used to quantify ecosystem services this chapter seeks to determine what exactly researchers are quantifying. On transition into reviewing specific methodologies this chapter uses two broad headings; methods used to capture provisioning and regulating services and methods used to capture cultural services. To maximise relevance, the review of provisioning and regulating methodologies focuses on research conducted on freshwater or riverine ecosystem services. Owing to its dominance within early ecosystem service research this section of review begins with economic valuation. Review then shifts to modelling approaches; these can be divided into computer modelling and capacity matrix-based modelling. Owing to a more limited research base the evaluation of cultural service methodologies draws from all ecosystem service literature. To focus the proceeding review of specific cultural service methodologies attention is given to revealing the cultural services which are supplied by river environments. Subsequently, using this list of services as a structure, a review of cultural service quantification is undertaken. Synthesising the evaluation of methodologies used
to capture provisioning, regulating and cultural services chapter three then cumulates by fulfilling part of the subsidiary aim; selecting a methodological approach suitable for determining if ecosystem service provision differs between Scottish river corridors with and without nature designations.

The selection of an appropriate methodology involves an approach of integration; to capture the three service categories, a cultural service approach is incorporated into a provisioning and regulating methodology. Due to its inability to capture multiple services, morally questionable nature (e.g. commodification of nature) and impracticality, economic valuation is deemed as unsuitable. Similarly, computer-based ecosystem service modelling is also regarded inappropriate due to its ineptitude to capture multiple ecosystem services. Subsequently, owing to its ability to equitably capture multiple services, potential to be used in the absence of existing and appropriate high quality and spatial resolution environmental data sets, and potential for facilitating collaboration, a score-based matrix approach is selected. Large and Gilvear (2015) provide a riverine ecosystem service matrix that forms a basis upon which to build a suitable approach. Their matrix-based approach, known as the Google Earth River Ecosystem Service Assessment Technique (GREAT) produces ecosystem service scores from the analysis of Google Earth imagery. Therefore, chapter three finally concludes by purporting that a matrix and Google Earth based approach will be developed to accomplish the primary research aim. This new model will be known as the GE RES (Google Earth: River Ecosystem Service) tool.

Chapters four and five fulfil the remainder of the secondary aim by developing a methodologic approach suitable for achieving the primary aim of determining if ecosystem service provision differs between Scottish river corridors with and without
nature designations. Through a series of improvements and upgrades these chapters evolve the GREAT model of Large and Gilvear (2015) to the Google Earth: River Ecosystem Services (GE RES) tool.

Chapter four focuses on developing a capacity matrix for provisioning and regulating services. The process of overhauling GREAT to develop a new capacity matrix for provisioning and regulating services begins by critical analysis of framework properties. Properties which require consideration include river system vertical and lateral assessment scale, inclusion of disservice relationships and the admission of uncertainty in river corridor feature - ecosystem service linkages. Attention then turns creating the matrix axes, this involves determining which ecosystem services and river corridor features should be included. Once the framework of services and features exists, the lengthy task of populating the matrix with empirical evidence which supports relationships between services and features commences. Although time consuming, this process of matrix population is deemed worthwhile as it significantly increases matrix robustness.

Chapter five complements chapter four by seeking to develop a cultural service capacity matrix. Cultural service potential is driven by people’s individual preferences, therefore the linkages within the matrix need to reflect these, to achieve this, the population of the cultural service matrix is to be based on the results of a photo-rating survey. To create a robust and reliable survey suitable for eliciting preferences for cultural services arising from Scottish river corridor features many variables require deliberation. Firstly, decisions relating to what data the survey should obtain and the method of survey distribution are made. Next survey design is explored, this involves discussion of the services and features which should be included, the nature of photographs to be used,
and survey usability. Focus then shifts to discussing one of the most fundamental elements of a survey, the questions. Next it is necessary to determine who the survey population should be. Unfortunately, owing to time constraints, it would have been challenging to capture a representative population of those who experience Scottish rivers, as a result a sub-population is sampled, subsequently, the survey should be viewed as pilot in nature with results preliminary.

Chapter five then transitions focus to post-survey completion. A preliminary cultural matrix is presented based on the preference scores obtained. Results to socio-demographic questions are also presented. As highlighted within chapter three, methods used to quantify multiple river cultural services in equitable terms are scant, as a result this chapter presents an evaluation of the photo-preference survey methodology developed. The purpose of evaluation is to progress the approach towards one which is robust and repeatable. Evaluation focuses on limitations and areas for improvement alongside strengths of the developed approached.

Although the survey is pilot in nature and developed for the purpose of fulfilling the primary research aim of determining if ecosystem service potential differs between Scottish river corridors with and without nature designations, a detailed examination of results may be of some significance. Research examining the cultural service potential of river corridor features is limited in extent, subsequently, in the hope of laying some foundations for future projects, discussions surrounding the results of the survey (particularly those from open questions) and potential management implications are presented in appendices seven and eight.

Chapter five ends by outlining how the GE RES tool will be designed within a Microsoft Excel spreadsheet framework.
The creation of the Excel framework means the key can be turned; GE RES is completed, and assessment can begin. The purpose of chapter six is to outline the results collected as a result of undertaking GE RES assessments on eight Scottish rivers. These results seek to peruse the overarching research aim of determining if ecosystem service provision differs between Scottish river corridors with and without nature designations. This chapter begins by describing the paired river corridors which are the chosen study sites. The paired analysis is then initiated by the statistical comparison of ecosystem service scores. Paired statistical analysis is undertaken from two perspectives: one non-weighted by river corridor area and one weighted by river corridor area. A discussion of the significance of river corridor areal extent (i.e. in essence valley floor width) is then undertaken. Next analysis focuses on investigating if river reach geomorphological type exerts a significant influence on ecosystem service potential. The final section of this results chapter involves the comparison and exploration of a pair of ecosystem service main-stem source to mouth long-profiles. This analysis of ecosystem service river long-profiles involves examining downstream trends for provisioning, regulating and cultural services alongside investigating ecosystem service hotspots.

Chapter seven seeks to discuss the significance of the findings in relation to the overarching research aim, published literature and riverine management. This discussion chapter begins by exploring the main findings of GE RES assessments in the context of published research. Sub-headings included within this section of discussion are ecosystem service diversity within protected areas, trends for individual services, protected areas, and ecosystem service hotspots, and finally, river geomorphology and ecosystem service potential. Discussion then moves to explore the interactions between designation, biodiversity, and ecosystem service potential. In particular, attention is given to Special Area of Conservation (SAC) designation characteristics, conservation
status, species pressures and the interactions between this triad. Arguably the next segment of discussion is one of the most practically significant, this section focuses on the implications that results may have for the management of Scottish river corridors. Potential management recommendations are viewed from five perspectives; these are the lenses of management for unprotected areas, management for protected areas, management for ecosystem service hotspots, general recommendations (including Green Recovery) and deliberations which should be considered prior to management action.

Finally, this thesis culminates with chapter eight, the concluding chapter. Chapter eight seeks to summarise the main findings of this research conducted with the purpose of determining if ecosystem service provision differs between Scottish river corridors with and without nature designations. Resultantly, this chapter outlines the notable contributions this thesis has made to the fields of river ecosystem quantification, designated area research and river ecosystem service management.
Chapter Two: Literature Review

2.1 Introduction

Life is possible because nature provides us with ‘ecosystem services’. In recent years environmental management, policies and scientific research have become increasingly focused on the ecosystem service concept. This chapter starts by reviewing the history of the ecosystem service concept including categorisation and the place of biodiversity. Elements of biodiversity underpin the provision of ecosystem services. This raises a meaningful question: to what extent do areas protected for biodiversity deliver ecosystem services? The ecosystem service concept is anthropocentric and advocates ecosystem management for human wellbeing, while protected areas focus on conservation objectives. Prior to looking at the relationship between protected areas and ecosystem services, the history of protected areas and their effectiveness for biodiversity conservation is investigated. A review of protected area - ecosystem service literature indicates that freshwater environments, particularly rivers, are under-researched. Subsequently a review is conducted to investigate if the ecosystem service concept is used within river management and to see if there is potential for protected river – ecosystem service research. It emerges that there is the potential for such research, with Scotland providing an excellent study area. The final section of this review discusses why Scotland makes a good study location. Drawing on the review of literature, this chapter finishes with the aims of objectives of this research project.

2.2 History and inclusion of the ecosystem service concept

Humans have always and will always benefit from nature. These benefits are termed ‘ecosystem services’ (MA, 2005). In more detail "ecosystem services are the benefits provided by ecosystems that contribute to making human life both possible and worth
living” (Watson et al., 2011). While Vihervaara et al. (2010a) consider the early idea of ecosystem services to be presented by Odum (1959) in Fundamentals of Ecology, the term ‘ecosystem service’ did not become present in literature until the 1990s (De Groot, 1992; Costanza et al., 1997; Daily, 1997). On Web of Science Costanza et al. (1997) is the most cited ecosystem service paper (cited 9,748 times on 29/11/2021). Costanza et al. is a key paper because the authors consider that if ecosystems benefit human welfare they have economic value, subsequently the authors estimate the value of the total net worth of global ecosystems to be between US$16-45 million a year (in 1997). In valuing ecosystems in economic terms Costanza et al. (1997) reached a wide audience and ignited interest in the value of nature to humans. A large proportion of early ecosystem service work focused on capturing the benefits of nature using economic valuation (McCauley, 2006; Spash, 2008), today methods used are more diverse. A detailed review of methodologies used is presented in the following chapter.

There are arguments both for and against the ecosystem service concept. Vihervaara et al. (2010a) argue the concept is needed to connect humans to ecosystems, to highlight the dependence of human societies on healthy ecosystems, and to help humans understand how we are increasingly impacting the environment. The concept can act as a communication tool between different groups of people facilitating discussion and can be used to guide land management priorities and objectives (Luck et al., 2012). Schröter et al. (2014) discuss the criticisms of the concept arguing that debate is necessary to allow development. One of the dominant criticisms is that the concept is anthropocentric and ignores the intrinsic value of nature (Redform and Adams, 2009; Luck et al., 2012), if we only conserve ecosystems, species and processes which benefit humans then do we lose the incentive to protect those which have no known benefit (Ormerod, 2014)? By only protecting species of direct importance to humans we may lose ‘natural insurance’ (de
Mulder et al., 2008 IN Gordon and Barron, 2013) provided by natural biodiversity and ecosystem functioning. An additionally area of debate (which is discussed below) in the place of biodiversity.

Despite arguments against the concept there are several high-profile documents advocating ecosystem services. The publication of the Millennium Ecosystem Assessment (MA) in 2005 acted as a key catalyst for ecosystem service research. The purpose of the MA was to examine how ecosystem change influenced human wellbeing and to subsequently create a scientific basis for conservation and sustainable use of ecosystems allowing contributions to human wellbeing. The MA revealed that human induced ecosystem degradation was jeopardising current and future human wellbeing. The MA is believed to have aided in the political and scientific acceptance of the ecosystem service concept (De Groot et al., 2010; Vihervaara et al., 2010a). The MA was initially responsible for the categorisation of ecosystem services into supporting, provisioning, regulating, and cultural services. Supporting services are the underpinning biological, physical and chemical processes that facilitate the delivery of provisioning, regulating and cultural services. Provisioning services are the consumable goods that people obtain for ecosystems and include food, water and fuel. Regulating services are the benefits that ecosystems provide through the moderation of natural phenomena, for example upstream areas can store water and prevent downstream flooding. Cultural services are the non-material wellbeing benefits that people obtain from ecosystems through a range of experiences, identities, capacities and activities (Watson et al., 2011).

Following the MA came ‘The Economics of Ecosystems and Biodiversity’ (TEEB). The TEEB is a global initiative focusing on the economic value of biodiversity and biodiversity loss (TEEB, 2008). In the past, the way humans relate to nature has been driven by
dominant economic models and this has resulted in biodiversity loss (Ring et al., 2010). TEEB suggested there needed to be a paradigm shift in the way we take account for biodiversity in economic decisions to limit loss (Ring et al., 2010). To change the way we perceive biodiversity and to mainstream biodiversity into decision making TEEB argue that biodiversity should be economically valued, TEEB describe that having economic frameworks for biodiversity can make pro-biodiversity investment logical (TEEB, 2010). The TEEB is also about bringing together experts from different fields including economics, science and policy.

An important ecosystem service document in the UK is the UK National Ecosystem Assessment (NEA) which was published in 2011 (Watson et al., 2011). The NEA is a UK wide analysis discussing the ecosystem service concept, the status of broad UK habitats and trends of ecosystem service provision. Over the past 60 years, there have significant changes in UK ecosystem service provision. Following the end of the Second World War the UK began a phase of reconstruction, alongside the construction of housing and infrastructure, agricultural production rapidly expanded. The expansion of agriculture occurred at the expense of other ecosystems with land conversion causing significant losses of semi-natural grassland and increased fertiliser use degrading aquatic systems. Additionally, in Scotland increased coniferous timber production replaced other habitat types. The NEA found that over the past 10-20 years there have been improvements in some ecosystems and subsequently ecosystem service provision, however, of all services investigated, around 30% were assessed to be declining. Ecosystem service decline was linked to decreases in habitat condition and extent, and changes in biodiversity. Preventing further decline of ecosystem services was considered challenging as pressure on ecosystems was expected to increase significantly with predicted population growth
and projected changes in climate. The NEA stresses that continued research is fundamental as decisions and actions are going to impact well into the future.

Of international importance is the Common International Classification of Ecosystem Services (CICES). CICES is designed to be a reference classification system which allows the translation between different ecosystem service classifications including those used by the MA and UK NEA. CICES was originally proposed in 2009, following a meeting hosted by the European Environment Agency it became acknowledged that varying groups and organisations were grouping and naming ecosystem services differently (Potschin and Haines-Young, 2011).

Key to the classification of ecosystem services is understanding how ecosystem processes and functions propagate to become services. Fisher et al. (2009) present a three-tier ecosystem service hierarchy in which ecosystem structure and processes contribute to ‘final services’ which lead to ‘benefits’ (figure 3). This ecosystem service hierarchy was then advanced by Potschin and Haines-Young (2011) into a cascade model which is used in the CICES classification (figure 4). The classification of CICES focuses on ‘final services’ with it left to the assessor to decide if a service is final or not depending on context. CICES uses a hierarchical structure for defining ecosystem services, at the highest level are provisioning, regulating and cultural services while moving down the hierarchy services become more specific but remain nested (figure 5).
Figure 3: The conceptual ecosystem service hierarchy of Fisher et al. (2009) showing the relationship between intermediate services, final services and benefits.

Figure 4: The place of CICES in the ecosystem service cascade model of Potschin and Hanies-Young (2011) – Taken from https://cices.eu/content/uploads/sites/8/2018/01/Guidance-V51-01012018.pdf
More recently, the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) published their IPBES 2019 Global Assessment on Biodiversity and Ecosystem Services. IPBES describes itself as an independent intergovernmental body founded to improve science – policy connectivity within the sphere of biodiversity and ecosystem services. By developing deeper connectivity between science and policy, IPBES seek to promote the long-term conservation and sustainable use of biodiversity, human wellbeing, and sustainable development (https://ipbes.net/about). Therefore, to partly fulfil their purpose, IPBES undertake regular assessments of biodiversity and ecosystem services at the global scale. Concerningly, the findings of this most recent IPBES assessment appear to echo that of the MA and UK NEA, at the global scale, biodiversity and ecosystem service decline is both widespread and accelerating at unprecedented rates (Bridgewater et al., 2019).

To address the significant threat of biodiversity decline, IPBES advocate science-policy approaches which seek to reduce the impacts of decline, particularly, these should operate at national and local scales (Ruckelshaus et al., 2020). While IPBES hail assessment as key to protecting biodiversity, crucially, they emphasise the need to turn
assessment into actions (Ruckelshaus et al., 2020). To translate assessments into field action, IBPES call for stronger engagement between scientists and the communities they serve (Ruckelshaus et al., 2020). Furthermore, IBPES identify a need for long-term commitments to biodiversity to be made by multiple stakeholders including governments, NGO’s, scientists, civil society, the private sector, and local communities (Díaz et al., 2018; Ruckelshaus et al., 2020). Despite the stark findings of IPBES, the authors remain positive that there is hope of biodiversity and ecosystem services being restored, conserved, and utilised sustainably, providing transformative science and policy begins immediately (Bridgewater et al., 2019).

Of significance in regard to the history of the ecosystem service concept, IPBES advocate the use of the term ‘nature’s contributions to people’ (NCP). The NCP term is outlined within an article by IPBES science experts titled ‘Assessing nature’s contribution to people’ (Díaz et al., 2018). According to Díaz et al. (2018) the NCP term builds on the ecosystem service concept advocated by the MA. Specifically, Díaz et al. argue that NCP differs from the definition of ‘ecosystem service’ in two distinct ways. Firstly, nature’s contributions to people are considered to recognise the fundamental role culture has in defining relationships between people and nature. Secondly, it is believed that NCP encourages and emphasises the place of local and indigenous knowledge in the understanding of nature’s contribution to human wellbeing. Díaz et al. (2018) argue that the re-framing of ecosystem services to nature’s contribution to people was required because the ecosystem service concept had induced a view of nature-people relationships that frequently excluded perspectives of social scientists, local stakeholders, indigenous communities, and worldviews. Furthermore, Díaz et al. view that the framing of ecosystem services contributed to the exclusion of some cultural services from
quantification and policy (the history, including the exclusion of cultural services from some assessments is discussed below within section 2.2.3).

To frame the NCP term, Díaz *et al.* (2018) identify three main categories for generalising NCP: regulating, material and non-material NCP. These categories are defined by the type of contributions they make to human quality of life. Material contributions are physical elements from nature that sustain physical existence. Nonmaterial contributions are considered to be nature’s impacts on the psychological dimensions that underpin quality of life. Regulating contributions are ecosystem processes which modify or regulate the provision of material and non-material contributions. As outlined above, the MA defined a distinct category of ‘cultural services’, in contrast within the NCP, cultural services permeate through all three broad categories.

Díaz *et al.* (2018) hailed the NCP concept as a paradigm shift within the nature – people sphere and literature suggests that the NCP concept has been accepted by some prolific ecosystem service researchers including Kate Brauman (Brauman *et al.*, 2020) and Berta Martín-López (Martín-López *et al.*, 2019). On review of the approach, Peterson *et al.* (2018) hail there to be two advantages. The approach emphasises the significance of local culture and knowledge in underpinning the benefits we receive from nature. The second advance is outlined to be the ‘maintenance of options’ viewpoint, this recognises that ecosystem potential should be enhanced to keep options open which can support good quality of life.

Coexisting with researchers who advocate the replacement of the ecosystem service paradigm with NCP, are those who consider the approaches complementary. Pires *et al.* (2020) conduct a questionnaire at the 2018 Ecosystem Service Partnership Latin America and Caribbean conference seeking to reveal perceptions of the differences of ecosystem
services and NCP. Results revealed that those researchers who conducted quantitative methodologies tended to use the term ecosystem services whilst those focusing more on qualitative data collection preferred the NCP term, however a large percentage of researchers used both terms. From these results Pires et al. (2020) conclude that the two terms can be complementary, and that using both terms facilitates wider reaching research. Similarly, in their research examining pastoral systems Dean et al. (2021) conclude that owing to the non-material viewpoint of the NCP framework it complements the ecosystem service framework and thus allows for a more complete analysis of complex socio-ecological systems.

Despite the uptake by some researchers and the complementarian view of others, literature indicates that a paradigm shift from ecosystem services to nature’s contributions to people may not be reality. Indeed, right from publication, the ‘nature’s contributions to people’ concept has been subject to fierce debate within the nature – people community (Peterson et al., 2018; Kenter, 2018). The NCP concept has been rejected by some prominent ecosystem service researchers including Joachim Maes, Benjamin Burkhard, Rudolf de Groot and Robert Costanza (De Groot et al., 2018; Maes et al., 2018).

Braat (2018) author an editorial focusing on why the paper of Díaz et al. (2018) would not have been accepted in the journal Ecosystem Services. Braat (2018) argue that in the construction of the NCP concept, the authors significantly neglected important developments within the ecosystem service paradigm, by ignoring documents including the TEEB, CICES and extensive peer-reviewed journal articles, Braat et al. consider that the authors of the NCP concept have an inaccurate view of the ecosystem service concept. Díaz et al. (2018) frame the ecosystem service concept to be heavily characterised by
economic valuation and to have a narrow ecological focus. Drawing from research within Europe, Maes et al. (2018) reject the view that the ecosystem service concept is narrowly framed by economic and ecological principles. In reality, abundant literature exists focusing on incorporating social values into ecosystem service assessments (e.g. de la Rosa-Velazquez and Ruiz-Luna, 2020; Langemeyer and Connolly, 2020; Everard et al., 2021) and much progress has been made to develop non-economic methods for quantifying ecosystem service provision (e.g. Czúcz et al., 2018; Acharya et al., 2019; Chan and Satterfield, 2020; Csurgó and Smith, 2021; Sherrouse et al., 2022).

Furthermore, Braat (2018) highlight that Díaz et al. (2018) proposed that the NCP approach was necessary because local knowledge needed to be incorporated into ecosystem services assessments, yet there is evidence of this already beginning to happen within the ecosystem service field (e.g. Zagarola et al., 2014; Lebel et al., 2015; Tarrasón et al., 2016). Similarly, Díaz et al. (2018) believe that the NCP approach can better incorporate the views of stakeholders and policy makers, however Peterson et al. (2018) highlight that this view neglects the progress of those ecosystem service practitioners who have sought to translate and communicate ecosystem service values to many different countries, governments, organisations, and communities (e.g. Albert et al., 2014; Reyers et al., 2015; Beery et al., 2016).

Peterson et al. (2018) present some other perceived shortfalls of the NCP framework. One major shortfall is the replacement of the term ‘ecosystems’ with ‘nature’, Peterson et al. (2018) argue that an emphasis of the term ‘nature’ downplays the extent to which humans interact with ecosystems. Another limitation of the approach is reported to be the neglect of some human-nature relations, these include the role of infrastructure and technology in the production of ecosystem services, a recognition of the dynamic
feedbacks between ecosystems and benefits, and the recognition of spatial and temporal scales.

On concluding, Braat (2018) suggest that a thorough examination of existing ecosystem service literature will reveal all the ‘strengths’ of the NCP approach are already present within the ecosystem service concept. Correspondingly, Kadykalo et al. (2019) seek to disentangle the ‘ecosystem service’ and ‘nature’s contribution to people’ concepts, to do this, the authors investigate the extent to which eleven novel claims of the NCP approach are present within ecosystem service literature. Following their analysis, Kadykalo et al. (2019) conclude that framing ‘NCP’ as a paradigm shift is not necessary since many aspects are already present within ecosystem service research. Furthermore, De Groot et al. (2018) considered the terms ecosystem service and nature's contribution to people to be synonymous. Similarly, Muradian and Gómez-Baggethun (2021) argue that the two approaches share the same core principles.

The advocation of a paradigm shift towards the concept of ‘nature’s contributions to people’ clearly sparked intense debate within the ecosystem service community. Synthesising evidence of the debate indicates that the ecosystem service concept has evolved over time and subsequently, the NCP concept is not viewed as a paradigm shift. That being said, the proposal of the nature’s contributions to people should act as a reminder of the significance of incorporating cultural values, local knowledge, and collaboration between multiple stakeholders. Furthermore, an important lesson should be heralded from the ecosystem service - NCP debate. Whilst debate is healthy, division and tension within the nature – society community can undermine the potential for progress in regard to science, policy and practice (Peterson et al., 2018; Kadykalo et al.,
Key to moving forward within nature–society research, policy and practice is collaboration (Peterson et al., 2018).

2.2.1 The place of abiotic resources

The classification of ecosystem services has induced a question regarding the place of abiotic resources. CICES does not classify abiotic resources from nature as ecosystem services. It is argued that abiotic resources delivered by the environment including river water, mineral flows and non-renewable resources are not the product of ecological functions and therefore not ecosystem services (Van Ree and van Beukering, 2016; Small et al., 2017). Alternative terms such as ‘geosystem services’ have been used to refer to abiotic resources which contribute to human wellbeing (Gray, 2011; Van Ree and van Beukering, 2016). However, some researchers consider that the exclusion of abiotic resources is to the detriment of the ecosystem service concept (van der Meulen et al., 2016). Brouwer et al. (2013) believe that the exclusion of abiotic resources may lead to incomplete economic assessments of environments and the ignoring of potential trade-offs occurring between biotic services and abiotic resources such as valued minerals.

2.2.2 The question of ecosystem status

Another aspect of the ecosystem service definition that needs clarification is status of ecosystems which contribute to service provision. Early research focused on the role of natural ecosystems in providing services while more recent studies include the role of human modified ecosystems (Lovell and Johnson, 2009; Birkhofer et al., 2015). However, humans have been manipulating the environment for hundreds of years, subsequently ecosystem processes and human manipulations are tightly intertwined meaning that services occurring solely from natural ecosystem processes cannot be separated from human modifications (Barot et al., 2017). Ecosystem services can therefore be seen as
functions of both natural processes and anthropogenic systems. Furthermore, in recent research there has been recognition that these natural processes do not have to occur in natural ecosystems but can occur in artificial ones. For example, Beichler et al. (2017) consider that within urban environments man-made structures such green bridges, vertical gardens and canals contribute to ecosystem service provision.

2.2.3 Provisioning, regulating and cultural services

Initially the MA proposed four final ecosystem service categories, however since then the place of supporting services has changed. TEEB, the UK NEA and CICES all consider supporting services to underpin the delivery of provisioning, regulating and cultural services. Potschin and Haines-Young (2011) argue that if we accept the ecosystem service cascade concept (Figure 4) and the notion of different hierarchical layers of ecological processes and structures underpinning ‘final ecosystem services’ then the category ‘supporting services’ proposed by the MA is likely to be unnecessary or synonymous with ecological processes and functions. Of importance, the three categories of final ecosystem services have received unequal attention in both management decisions and ecosystem service quantification.

In land management it appears that there has been a strong focus on the maximisation of provisioning services (Carpenter et al., 2009; Howe et al., 2014). In particular, food, fuel and freshwater which have been subject to management for maximisation (Bennett and Balvanera, 2007). The maximisation of provisioning services leads to trade-offs with regulating and cultural services (Raudsepp-Hearne et al., 2010; Lee and Lautenbach, 2016). Strong trade-offs are reported across the globe for the maximisation of agriculture, in Quebec Raudsepp-Hearne et al. (2010) find intensively managed agricultural land to be negatively correlated with the highest number of other services.
including the regulating services of climate regulation and water quality. The UK NEA also found agricultural production to be negatively related to climate regulation and water quality. Timber production for fuel also causes trade-offs with climate regulation and water quality (Caputo et al., 2016). Globally, dams are important for the provision of freshwater and electricity, however dams are associated with negative effects on multiple ecosystem services including altered downstream water provision (e.g Räsänen et al., 2012), poor water quality (e.g. Wei et al., 2009), damage to fish populations (e.g Liermann et al., 2012) and loss of natural erosion protection (e.g Yang et al., 2011).

The maximisation of provisioning services above other services has occurred due to several reasons. Rodríguez et al. (2006) suggest a focus on provisioning services may result from the way human societies develop. An order of ecosystem service demand from human societies has been identified with the initial focus on provisioning services then regulating and subsequently cultural services, Rodríguez et al. remark that this order of ecosystem service preference pairs with the sequence of events that occur when humans first settle an area which are driven by short-term needs (DeFries et al., 2004 in Rodríguez et al., 2006). Maximisation can also occur through the creation of policies which focus on short-term needs and goals because they are likely to achieve results within political terms (Rodríguez et al., 2006). Another significant reason for the maximisation of provisioning services is that they are of considerable economic value (Paletto et al., 2015; Quintas-Soriano et al., 2016). In their assessment of the value of the Spanish Doñana region’s ecosystem services Martín-López et al. (2014) find provisioning services to account for 65.6% of economic value, cultural services 26.4% and regulating 7.7%, high value for provisioning services is linked to agriculture and fisheries production.
There is also unequal attention given to provisioning, regulating and cultural services in ecosystem service research and quantification. In their review of 405 ecosystem services papers Boerema et al. (2016) found regulating services to be the most studied (48%) compared to provisioning (26%) and cultural (26%), however results may be skewed towards regulating services as nine were considered in comparison to seven provisioning and five cultural. Regulating services have also been identified to be the most commonly mapped with provisioning and then cultural following (Martínez-Harms and Balvanera, 2012). In a review on the methods used to quantify riverine ecosystem services Hanna et al. (2017) find provisioning (37%) and regulating services (33%) to be more frequently quantified than cultural services (24%).

The historic concentration on researching and quantifying provisioning and regulating services is attributed to the fact they are easier to identify and economically value (Rodríguez et al., 2006). Of the two categories provisioning services are easier to identify and economically value as they are tradable. Regulating services are considered somewhat more difficult to identify and in some cases are only noticed when human wellbeing becomes threatened, failure to identify regulating services may lead to trade-offs with provisioning services (Sutherland et al., 2017).

In comparison to provisioning and regulating services, the research and quantification of cultural services has been regarded as the least accomplished and most difficult (Feld et al., 2009; Schaich et al., 2010). The early focus on using economic valuation to capture ecosystem services is considered to be a substantive reason for the neglect of many cultural services (Chan et al., 2012). Recreation is the one cultural service which is easily amenable to economic valuation and therefore has received the most attention (Chan et al., 2012; Hernández-Morcillo et al., 2013; Milcu et al., 2013).
In contrast the economic valuation of other cultural services such as cultural heritage, social relations and spirituality is difficult and controversial, therefore these services have been barely quantified (Kumar and Kumar, 2008; Hernández-Morcillo et al., 2013; Chan et al., 2012; Raymond et al., 2014; Scholte et al., 2015). These services are difficult to capture economically due to their intangible nature (Chan et al., 2011; Milcu et al., 2013; Small et al., 2017). Additionally, these services have proven challenging to economically value because they do not conform to economic theories as their value is dependent on individual and cultural perceptions of their contribution to human wellbeing (Kumar and Kumar, 2008; Eicken et al., 2009; Chan et al., 2011; Scullion et al., 2011 in Milcu et al. 2013).

Significantly, there are also moral objections to the economic valuation of cultural services (Svedsäter, 2003). Some cultural services cannot be economically valued because they are incommensurate, attempts to determine monetary trade-offs fail because individuals believe they will be sacrificing an important principle if begin negotiation (Atran et al., 2007 in Chan et al., 2012). Additionally, individuals reject monetary valuation because they believe it to be morally wrong, in particular this occurs when ecosystems are tied to the past and form part of identity (Sandel, 2012 in Neuteleers and Engelen, 2015; Satz et al., 2013). Furthermore, economically valuing cultural services sets the foundations for commodification (Gómez-Baggettun and Ruiz-Pérez, 2011) which does not reflect the diversity of possible values (Neuteleers, and Engelen, 2015) such as appreciation and love (Anderson, 1993).

Recently the tide appears to be turning with increased interest in cultural services and their inclusion in assessments (Pröpper and Haupts, 2014; Hirons et al., 2016). This increased interest is leading to progress with many new quantification techniques being
developed. New techniques being developed focus on human experiences and preferences, techniques include using data uploaded by the public (Pastur et al., 2016; Gliozzo et al., 2016) and scores obtained from preferences (e.g. Plieninger et al., 2013; Zoderer et al., 2016b). Of importance, in some research looking at preference scores such as Zorrilla-Miras et al. (2014) and Iniesta-Arandia et al. (2014) multiple cultural services are being investigated alongside provisioning and regulating services.

Recent interest in cultural services may reflect heightened demand. Across Europe demand for many river cultural services including education, inspiration, recreation, tourism, aesthetic value and sense of place has increased over past decades and further increase is predicted (Harrison et al., 2010; Gutiérrez and Alonso, 2013). Increase in demand may be linked to economic development, Guo et al. (2010) suggest that as societies economically develop demand for cultural services increases while dependence on provisioning services declines.

Increased interest in cultural services is positive as their exclusion limits the potential of the ecosystem service concept. People are connected to nature through cultural services (Chan et al., 2012; Daniel et al., 2012), these connections can drive ecosystem protection. Hirons et al. (2016) highlight that in India sacred woodlands are conserved as they are dedicated to deities, while in the Amazon indigenous people believe there are forest guardians who harm those who act disrespectfully. Connections with nature can also communicate the need to protect ecosystems (Gobster et al., 2007; Orenstein, 2013). Cultural services in particular require protection because unlike provisioning and regulating services it is believed they cannot be replaced by technical means (Hernández-Morcillo et al., 2013).
2.2.4 Biodiversity and ecosystem services

Following the reclassification of supporting services in the ecosystem service hierarchy there is a debate surrounding the role and place of biodiversity. Mace et al. (2012) discuss how biodiversity, as defined by the Convention of Biological Diversity (CBD) fits into the ecosystem service hierarchy at several levels, they propose that biodiversity can be a supporting and final service. The CBD defines biodiversity as:

“Biological diversity means the variability among living organisms from all sources including, inter alia, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems”

It is evidently clear that elements of biodiversity support the provision of ecosystem services. Harrison et al. (2014a) undertook a literature review of 350 scientific papers to investigate the strength and direction of linkages between 27 biodiversity attributes and 11 ecosystem services. Harrison et al. find that five of the 27 attributes (species abundance, species richness, species weight/size, community/habitat area and community/habitat structure) are important for supporting the provision of at least one service. Other reviews highlighting the positive effect of biodiversity on ecosystem service provision include Balvanera et al. (2006), de Bello et al. (2010) and Quijas et al. (2010). It is important to note that it can often be only specific elements of biodiversity which contribute to ecosystem service provision, for example bees for pollination and wetland reed beds for water purification (Diaz et al., 2005; Ridder, 2008). The relationship between biodiversity and ecosystem service provision can also be inverse with some biodiversity elements negatively influencing provision. In their review of literature looking at biodiversity-ecosystem service relationships in urban areas Schwarz et al. (2017) find 11% of relationships to be negative. Critically, in some cases an element
of biodiversity may support one ecosystem service and have a negative effect on another. For example, Harrison et al. find freshwater provision to be negatively impacted by vegetation characteristics such as stem density and age which take water out of the system but suggest the same characteristics may be important in the provision of other services such as climate regulation and aesthetics.

Despite the evidence linking biodiversity to the provision or reduced provision of ecosystem services there are still considerable uncertainties in linkages (Harrison et al., 2014a). Uncertainties may be the result of limited/unsuitable available data (Balvanera et al., 2014) or may occur because some linkages are under researched compared to others (Ricketts et al., 2016). It is important that we improve our knowledge of these linkages because understanding relationships between biodiversity and ecosystem service provision can be crucial in ecological management decisions (Benayas et al., 2009; Bastian, 2013).

The role of biodiversity as a final ecosystem service is less clear. Mace et al. (2012) argue that biodiversity at the gene and species level constitutes a final ecosystem service as it contributes directly to ‘ecosystem service goods’. This is supported by the latest version of CICES (V5.1) which considers ‘genetic material from all biota’ to be a provisioning ecosystem service. But yet this role as a final service seems strange, is genetic diversity a direct contributor to human wellbeing or does it support the provision of other services, namely agriculture? Indeed, most literature looking at genetic diversity in the ecosystem service context explores its role as a supporting process (e.g. Díaz et al., 2007; Hajjar et al., 2008; Schaberg et al., 2008; Ford-Lloyd et al., 2011).

Mace et al. also suggest that biodiversity itself can be an ecosystem service, in this context biodiversity itself is desired and valued by humans. Humans value diverse environments,
particularly if ‘charismatic’ or aesthetically pleasing animals and plants are present. However, in this context biodiversity seems to support cultural services. Biologically diverse landscapes and characteristic species support aesthetic value, inspiration and recreation and tourism. Tribot et al. (2016) find species richness and functional richness to have positive impacts on the aesthetic value of coralligenous reefs along the French Mediterranean coast. Macadam and Stockan (2015) highlight the role freshwater insects have in inspiring literature, art and music. Charismatic plants and animals across the world support many elements of tourism and recreation including fishing, hunting and wildlife watching (e.g. Butler et al., 2009; O’Garra et al., 2017; Rees et al., 2010). The importance of charismatic species for cultural services has influenced conservation projects to focus on them (Mace et al., 2012; Cimon-Morin et al., 2013; Brambilla et al., 2013). Despite the above examples, in contrast to supporting and regulating services there seems to be less interest in how biodiversity contributes to cultural service provision (Hooper et al., 2005; Cardinale et al., 2012), subsequently, this is flagged as an area for future research.

In summary, it seems as though the majority of literature and evidence indicates that biodiversity is not a final ecosystem service but instead elements underpin the provision of final provisioning, regulating and cultural ecosystem services.

2.3 Protected areas and ecosystem services

It is clear that biodiversity is crucial in supporting the provision of ecosystem services. Across the globe there are thousands of areas designated for the protection of biodiversity elements, the importance of ecosystem services for our wellbeing is leading to one question being relevant to all protected areas. To what extent do protected areas conserve biodiversity and simultaneously provide ecosystem services? Under the
pressure of increasing populations and climate change protecting biodiversity and ecosystem services is going to be key to ensuring our resilience (Keppel et al., 2012; Heller et al., 2015; Biggs et al., 2012). Can protected areas therefore deliver multiple objectives? In this section the history of protected areas is briefly explored before relationships between protected areas and ecosystem services are examined.

2.3.1 History and changing purpose of protected areas

There is evidence that the concept of protected areas has existed in Europe for thousands of years with the Greek philosopher Plato seeking forest recovery on the Attic Peninsula Slopes in the fourth century BC (Jones-Walters and Čivić, 2013). However, it is commonly recognised that protected areas in the way we are familiar with them originate from the designation of Yellowstone National park in 1872 as “a public park or pleasuring ground for the benefit and enjoyment of people” (Hummel et al., 2017). The adoption of protected areas spread across the world, however spatial variation in purposes of designations occurred (Hummel et al., 2017). In North America protected areas were initially established to protect scenery, in Africa protected areas focused on habitat and game with the purpose of maintaining hunting, and in Europe protected areas sought to protect landscapes.

Since the designation of Yellowstone National Park there have been paradigm shifts in the purpose of protected areas. During the 20th century protected areas shifted from focusing on the conservation of landscapes to the biodiversity of species and habitats (Palomo et al., 2014). The recognition of the importance of in-situ conservation in the 1970s led to a significant increase in the area of the Earth subject to statutory protection (Watson et al., 2014). Protecting elements of biodiversity was deemed critical as research uncovered the devastating global effect of human activities on biodiversity (Pereira et al.,
The rationale behind protected areas is that by reducing habitat loss in these areas individuals can survive longer, produce more young and subsequently populations grow (Mora and Sale, 2011). Protected areas are key to preventing further biodiversity loss as research suggests maintaining areas of biodiversity is significantly easier than attempting restoration, indeed in some cases degraded ecosystems can never recover, meaning biodiversity loss is permanent (Mora and Sale, 2011).

In the last few years we have moved into a new paradigm for protected area designation and management. Pressure on limited land under growing populations and projected climate changes means protected areas are required to contribute multiple benefits for human wellbeing (Watson et al., 2014). Protected areas may also be managed for ecosystem services alongside biodiversity as the marketing and sale of ecosystem services could be create return investment (Willemen et al., 2013). Introducing the ecosystem service concept into protected area management is also advantageous because it can act as a common language encouraging multiple stakeholders to be involved in management plans (Palomo et al., 2014). Although it appears apparent that for human wellbeing there is a need for protected areas to provide ecosystem services there is concern than multiple demands and objectives of protected areas will cause trade-offs and conflicts (Watson et al., 2014).

At an international level the ecosystem service concept is integrated into the UN Convention on Biological Diversity (CBD). In 2010 the CBD Vision for the Strategic Plan was decided as “by 2050, biodiversity is valued, conserved, restored and widely used, maintaining ecosystem services, sustaining a healthy planet and delivering benefits essential for all people”. Prip (2018) regard the CBD to be a “global legal framework for action to protect ecosystem services at the national level”. Under the CBD parties are
required to develop National Biodiversity Strategies (NBSAPs). Prip (2018) found that ecosystem services are incorporated into NBSAPs with statements relating to ecosystem services found in overall missions, visions and guiding principles, however the inclusion does not extend further than these statements and commitments to map and value ecosystem services.

### 2.3.2 Are protected areas working for biodiversity?

Before we can consider if protected areas are simultaneously achieving biodiversity and ecosystem service objectives it is important to have an idea of how effective they are at conserving biodiversity. Reviews on the effectiveness of protected areas suggest that well-managed terrestrial and marine protected areas can, and often do make positive contributions to biodiversity conservation. In the marine realm Halpern (2003) found that on average diversity, density biomass and size of organisms is greater within marine protected areas. In the terrestrial realm Geldmann *et al.* (2013) found academic and grey literature to indicate that protected areas are subject to lower rates of habitat loss compared to unprotected areas, however where significant threats are present, protected areas are subject to large losses of border habitats. For species population Geldmann *et al.* found the impact of protected areas to be unclear although literature more frequently reported positive effects. In their review of the performance of terrestrial and marine protected areas Watson *et al.* (2014) find that in most cases well managed and well-designed protected areas decrease rates of habitat loss and maintain species population levels more effectively than alternative approaches. Protected areas have been found to be one of the most cost-effective ways of conserving elements of biodiversity (Balmford *et al.*, 1995).
Freshwaters are considered to be underrepresented in terms of protection, and for the freshwater protected areas that do exist research is limited in comparison to terrestrial and marine protected areas (Abell et al., 2007; Adams et al., 2015). The lack of protection for and knowledge of protection success for freshwater environments is concerning. Freshwaters contain around 6% of known species despite only constituting around 0.8% of the Earth’s surface and are reported to have rates of biodiversity decline far exceeding many terrestrial environments (Dudgeon et al., 2006). Not only are freshwaters underrepresented, sometimes those that are given protection are only protected as a result of their position within or as boundaries of terrestrial protected areas (Saunders et al., 2002; Abell et al., 2007). While there is research suggesting terrestrial protected areas can be effective in the conservation of freshwater fish diversity (Abraham and Kelkar, 2012; Britton et al., 2017), terrestrial protection is not likely to be adequate in all instances as freshwaters have unique properties. Adams et al. (2015) suggest assessing the effectiveness of freshwater protected areas is made challenging by the potential for propagation through systems and high connectivity. Additionally, Adams et al. describe that studies assessing the effectiveness of protected areas for conservation are limited due to the metrics which have been used, typically these have been abundance measures which cannot be obtained remotely making assessments often time consuming and expensive.

Currently the research that does exist for freshwater protected areas reports mixed outcomes for biodiversity (Adams et al., 2015). Hermoso et al. (2016) report that despite the presence of freshwater protected areas, freshwater biodiversity is continuing to decline. Hermoso et al. find reasons for the ineffectiveness of protected areas to result from fewer resources given to freshwater conservation, poor consideration of freshwater conservation needs during design and designation, and limited understanding of the
influence of management outside protected areas. Something important to note is that in their investigation Adams et al. mostly report cases of wetland protected areas with river protected areas seemingly even more under researched. Currently there is very limited evidence available for the success of river protected areas. In South Africa Nel et al. (2007) found a greater percentage of rivers inside of protected areas to be intact compared to those outside.

If well-managed terrestrial and marine protected areas are being found to have positive biodiversity outcomes then it is critical to know what ‘well-managed’ means. Halpern (2003) consider that key to the success of marine protected areas is the requirement to explicitly state conservation goals, goals are essential for assessing effectiveness of protected areas. Indeed, Lundquist and Granek (2005) recognise the need for clear, achievable, and measurable goals when managing protected areas. Involvement of locals has also been found to be key to management success, in their analysis of European protected areas Hirschnitz-Garbers and Stoll-Kleemann (2010) observe that involving local people created a positive attitude towards protected areas and the incorporation of local knowledge allows the facilitation of better management.

Although there is evidence that well managed protected areas positively support biodiversity conservation this is not the complete picture. Watson et al. (2014) find that research suggests that up to 80% of protected areas are not being managed effectively. The ineffective management of protected areas appears to be more relevant in the developing world (Bruner et al., 2001) where there are often significant deficits in the budgets for protected areas (Bruner et al., 2004; Blackman et al., 2015). Funding issues are not limited to developing countries with Watson et al. (2014) describing that inadequate funding is becoming increasingly apparent in developed countries. Alongside
issues with effective management our understanding of the effectiveness of protected areas is also limited by the data we have available. Geldmann et al. (2013) find that our knowledge of species populations is limited by a lack of long-term monitoring inside and outside of protected areas, this is partly a result of such data being time consuming and expensive to produce. Additionally, when data is available it is often of limited usefulness because of a strong focus on ‘charismatic species’ (Geldmann et al., 2013).

When assessing protected areas, it is essential to acknowledge that success and effectiveness is likely to change with projected climate change. Kharobu and Kerr (2010) investigate if long-established Canadian protected areas are robust to climate change by modelling butterfly species distribution, results indicate that existing protected areas are not going to provide a buffer against climate for butterfly species richness. Climate change is predicted to alter conditions within protected areas to those beyond natural ranges for many species meaning protected areas may no longer be suitable for conservation (Hannah et al., 2005; Araújo et al., 2011; Feeley et al., 2016). Furthermore, as the climate changes it may make protected areas more amenable to invasive species which may be better adapted to new climate conditions (Vicente et al., 2013).

2.3.3 Protected areas and ecosystem services

It appears that the future for protected areas is one where they provide both conservation objectives and ecosystem services. Therefore, key to the future of protected area management is understanding to what extent protected areas currently achieve conservation objectives and ecosystem service provision? In the next section the role terrestrial, marine and freshwater protected areas play in providing ecosystem services is explored.
By far the most research has been conducted looking at terrestrial environments. In the UK Eigenbrod et al. (2009) investigate ecosystem service provision from three different types of biodiversity conservation strategy (incentive payments, protected areas and restrictive zoning). Eigenbrod et al. (2009) limit their investigation to ecosystem services which they could obtain high resolution data for all of England; delivery of carbon storage, rural recreation and agricultural production. Through their spatial mapping Eigenbrod et al. (2009) find that protected areas provide little recreation and agricultural production. Eigenbrod et al. note it is not surprising agriculture provision is low as agriculture commonly conflicts with biodiversity conservation (Henle et al., 2008). Eigenbrod et al. do find protected areas to have high carbon storage, however this is deemed to be a result of a larger number of protected areas being located in upland areas. The location of many protected areas in uplands is also considered to explain why recreation is low, upland areas are located away from areas of high population density reducing ease of visitation.

Also in the UK Eastwood et al. (2016) use expert opinion to assess 24 ecosystem services from nine case studies. Eastwood et al. conduct a paired approach comparing service provision from similar areas with and without protection. Overall, for the nine case studies (seven of which are terrestrial) Eastwood et al. find provision for 8 of the 24 services to be greater in protected areas. In particular protected areas seem to deliver higher levels of cultural and regulating services. Protected areas are reported to have no negative effect on the supply of provisioning services which can occur when agricultural activities are restricted, however Eastwood et al. suggest their results may be biased because most case-studies were located in areas with low productivity. Of remark Eastwood et al. found protection to significantly enhance the cultural services of artistic inspiration, education/research and conservation stewardship, however recreation/tourism and cultural heritage were not found to be greater in protected areas.
Regulating services provided to a greater extent in protected areas were pollination, soil quality and water quality.

Outside of the UK Castro et al. (2015) assess the ability of protected areas within the semi-arid region of Spain to provide three regulating ecosystem services (climate regulation, erosion control and water flow maintenance). Overall Castro et al. find the protected area network to supply marginally higher levels of regulating services, protected areas cover 48% of the study area and supply 59% of the total supply of regulating services. In particular climate regulation and water flow maintenance are supplied from protected areas. Additionally, García-Márquez et al. (2017) investigate the ability of protected areas in the Andean high planes of Colombia to simultaneously protect biodiversity and ecosystem services. Three indicators of biodiversity (sensitive species, ecological systems and habitat quality) and two ecosystem services are selected (scenic beauty and water provision). García-Márquez et al. identify multifunctional areas where biodiversity and ecosystem service provision are high however only half of these areas are within protected areas.

There is no strong conclusion to be made from the literature looking at terrestrial protected areas and ecosystem service delivery. While Eastwood et al. suggest protected areas may be associated with increased ecosystem service provision, other studies have mixed results and are limited in scope because they only consider a few ecosystem services.

Are relationships different in the marine and freshwater realms? In comparison to terrestrial environments there appears to be much less research focusing on the provision of multiple and single ecosystem services from marine and freshwater protected areas (Boulton et al., 2016; Steoniewska and Sobczak, 2017). In the marine
realm Lindegren et al. (2018) conduct a global study looking at marine biodiversity (taxonomic, phylogenetic and functional), protected areas and ecosystem services. Overall Lindegren et al. find significant spatial mismatches between protected areas, biodiversity and ecosystem service provision. In particular spatial mismatches are found around the West Coast of South America, Southern Africa, Northwest Pacific and the North Atlantic. Some of these mismatches may be the result of conflict between ecosystem services required for development and conservation objectives. DeFries et al. (2007) describe that in developing countries protected areas often contain resources such as food, timber and space which are required for development, this can lead to non-compliance in order to meet development goals (Peterson and Stead, 2011). However, spatial congruence has been noted on the smaller scale with individual ecosystem services. Rees et al. (2015) find recreation and tourism to be greater within the marine protected area of Lyme Bay, UK compared to outside the protected area.

In the freshwater realm some harmony between ecosystem service provision and protected area status has been identified. Eastwood et al. (2016) compare service delivery from the protected River Dee to the adjacent unprotected River Don in Scotland. Out of 24 services considered Eastwood et al. find seven to be greater in the protected Dee and two in the Don. It is mostly cultural services which are higher in the Dee, these include aesthetics, artistic inspiration, education, environmental stewardship, and tourism and recreation, the provisioning service of genetic resources and the regulating service of water quality are also higher in the Dee. In Cambodia Sáenz et al. (2016) investigate the ability of freshwaters to provide water quantity and water quality, similar to Eastwood et al. protected areas are important for providing water quality. In Eastwood et al. protection does not appear compatible with all provisioning services with energy and food provision provided in greater quantities from the unprotected Don. No
differences in supporting services were identified. For both marine and freshwater protected areas the limited research currently conducted means strong conclusions cannot be drawn. Overall, it appears that our knowledge of harmonies between protected areas and ecosystem service provision is in its infancy for terrestrial, marine and freshwater environments.

Protected area-ecosystem service research in all realms is currently limited by data availability. With the exception of Eastwood et al. (2016) most papers are limited in scope because they only focus on a few ecosystem services, this is in part attributed to a lack of high-resolution spatial data sets (e.g. Eigenbrod et al., 2009). When data sets are available, they may not be suitable as proxies for ecosystem service delivery (Castro et al., 2015). There is also shortage of time series data which is necessary to investigate long-term patterns. Furthermore, there is a lack of pre-protection baseline ecosystem service data (Ferraro et al., 2015), Eastwood et al. use the paired approach as a way to address this issue.

Some of the evidence presented above suggests there may be spatial mismatches between areas protected for conservation and areas important for ecosystem service provision. Mismatches may occur because conservation often focuses on protecting charismatic, iconic, rare, endangered or threatened species, but these species may not be important for the provision of ecosystem services (Cimon-Morin et al., 2013). Xu et al. (2017) find this phenomenon to some extent in China where nature reserves are found to protect mammals and birds but no other taxa or regulating services considered. Xu et al. believe there is a fundamental mismatch in China between the areas important for biodiversity and the provision of ecosystem services. Spatial mismatch can also occur when protection is given to areas of high biodiversity but ecosystem services are actually
delivered in areas of relatively low biodiversity. Lindegren et al. (2018) believe this is occurring in the marine realm with limited protection in areas with low fish biodiversity but high productivity and provision of fish such as the North Atlantic and North-west Pacific.

Critical for future research to recognise is that it is not simply a case of comparing protected and unprotected areas, there is also a need to incorporate the conservation status and type of protected areas. Maes et al. (2012a) mapped biodiversity and ecosystem service indicators across Europe at a 10km resolution, maps were then compared with the conservation status of protected areas. Maes et al. found protected habitats with favourable conservation status to be more likely to deliver regulating services, have higher recreation potential and supply greater amounts of water compared to protected areas with habitats in unfavourable status. Manhães et al. (2016) map the spatial pattern of woody plant diversity and regulating and provisioning services in two types of protected areas in the Brazilian seasonally tropical dry forest of Caatinga. The two types of protected area are strict protection and sustainable use. Overall Manhães et al. find limited spatial convergence between biodiversity and ecosystem service provision with ecosystem service provision differing between the two types of protected area.

2.4 Rivers and Ecosystem Services

The above literature synthesis reveals river environments are underrepresented in terms of ecosystem protection and there is limited research looking at the effectiveness of river protected areas and their ability to provide ecosystem services. Although this niche is unexplored, in parallel with general research, the ecosystem service paradigm is becoming more popular in river focused studies (figure 6). Rivers and their floodplains
are considered to provide provisioning, regulating and cultural services (MA, 2005; Watson et al., 2011). Also akin to general ecosystem service science, there is evidence that not all river ecosystem services have received equal attention. In terms of river management Gilvear et al. (2013) suggest that river environments have been degraded to provide provisioning services and as a result rivers are now unlikely to provide the regulating and cultural services that may have been delivering pre-alteration.

Freshwater ecosystem service research seems to have mirrored the pattern of general research with a strong focus on provisioning and regulating services. Of a sample of 105 studies that discussed freshwater ecosystem services Seppelt et al. (2011) found 60 studies focused on the provision of freshwater, 52 on the regulation of water quantity and 40 on the regulation of water quality. In a recent synthesis looking at ecosystem service quantification within riverine literature Hanna et al. (2017) review 89 studies and find provisioning (37%) and regulating services (33%) to be the most frequently quantified compared to cultural (24%). As has previously been mentioned for provisioning and regulating services, Hanna et al. attribute their heightened quantification to the fact they produce or sustain tradeable goods and are more amenable to economic valuation. Hanna et al. also identify bias within cultural service quantification which has previously been reported, recreation and tourism which are straightforward to economically value were more frequently quantified than other cultural services.
Over the past few decades there have been several paradigms guiding river management, with an increase in different restoration type activities (Hillman, 2009; Wohl et al., 2015). Introducing the ecosystem system service concept into river management has altered project objectives to include emphasis on wellbeing.

When written in 2006, Kondolf (2006) considered the most widely accepted river restoration technique to be the construction of a single-thread channel with managers applying the Rosgen classification system (Rosgen, 1994). Designing rivers this way has been termed ‘form-based’ restoration as managers seek to design stable channels with desired morphology and habitat types (Roni et al., 2008; Beechie et al., 2010). Kondolf (2006) describe that for a long-time form based restoration was popular because it promised stable river conditions, was easy to apply, accessible to those without formal training in fluvial geomorphology, and fulfilled a cultural preference for single-thread meandering channels. Despite the popularity of this paradigm, form-based restoration is not reported to be successful. Kondolf (2006) highlight the failure of the Cuneo Creek and Uvas Creek restoration schemes, where, following restoration to meandering streams, both systems were washed out. The failure of form-based restoration results because the
method neglects our scientific understanding of river systems and does not focus on the processes that create and maintain rivers, it is these processes that lead to river forms (Wohl et al., 2005; Kondolf 2006).

Moving forward, ‘process-based’ river restoration was hailed as the future of river management. Process-based restoration focuses on establishing normative rates and magnitudes of the biological, chemical and physical processes that are responsible for creating and sustaining river environments (Beechie et al., 2010). In contrast to the target of river stability of form-based restoration, process-based restoration seeks to promote river dynamics, habitat recovery and biological diversity (Beechie et al., 2010). Furthermore, unlike form-based restoration, process-based restoration addresses the cause of degradation and aims to create functioning rivers that can adjust to future perturbations (Beechie et al., 2010). Deciding on the processes that should operate can result from historical site analysis, data from reference sites and model predictions (Beechie et al., 2010). However, there is an argument against using past conditions, Dufour and Piégay (2009) describe that past conditions should not be used in restoration schemes because “no former historical state can be justified in preference to another” as it is likely that a past without human modification cannot be identified. There is an argument that ‘river rehabilitation’ is more appropriate than ‘river restoration’ as restoration implies we know the pre-disturbance condition (Dufour and Piégay, 2009). Wohl et al. (2015) describe that several types of process-based restoration have gained prominence including increasing longitudinal connectivity involving water and sediment fluxes, encouraging channel-floodplain connectivity and improving ecological productivity. To evaluate the success of process-based restoration there is a need for long-term post-project monitoring. Erwin et al. (2016) conducted seven years of post-project monitoring following a large scale process-based restoration project on the Provo
River in Utah and found the short duration of the monitoring to be insufficient to identify the long-term geomorphic trajectory following restoration.

While process-based rehabilitation can create ecologically functioning rivers, rehabilitation focused solely on processes may not be the future of river management. The recognition that rivers provide us with multiple benefits is leading to a new emerging paradigm for management where river processes and ecosystems are repaired or improved in order to provide us with services (Dufour and Piégay, 2009; Gilvear et al., 2012; Gilvear et al., 2013). Decisions on which processes and ecosystems are desired depend upon the ecosystem services which are required from the proposed area of rehabilitation (Dufour and Piégay, 2009).

In the initial years following the publication of the MA the uptake of the ecosystem service concept into river rehabilitation was slow (Trabucchi et al., 2012), however in more recent years it appears to have accelerated. Vermaat et al. (2016) conduct research with a wide scope looking at eight paired rehabilitated-unrehabilitated sites across Europe, an extensive range of different rehabilitation measures were included alongside a total of 10 ecosystem services with all three categories represented. Through economic valuation Vermaat et al. find rehabilitated rivers to have significantly greater economic value, on average rehabilitation is estimated to increase value by €1,400 ± 600 ha⁻¹ yr⁻¹. Vermaat et al. attribute the increase in ecosystem service value to an increase in cultural service provision and to a lesser extent an increase in regulating services. Interestingly Vermaat et al. find that rehabilitation to more natural flooding regimes is associated with greater perceived scenic beauty. Compared to Vermaat et al. other research looking at the ecosystem service benefits of river rehabilitation is more niche. In Finland Polizzi et al. (2015) investigate the cultural benefits of rehabilitation of the River Pajakkajoki,
residents and tourists value the recreational benefits of rehabilitation to be between €40 – 144.7 yr\(^{-1}\) per person. In Spain Acuña et al. (2013) find rehabilitation through the addition of deadwood to increase the value of all ecosystem services they considered; recreation fish provision, erosion control and water purification. While current research may suggest river rehabilitation increases the provision of ecosystem services there is evidence that rehabilitation for ecosystem services is not compatible with conservation objectives. In South Africa, Smith-Adao et al. (2011) investigate the potential for ‘win-win’ scenarios for conservation and ecosystem services following river rehabilitation and find such situations would only occur in two of 28 sub-catchments, they suggest that this could be a result of conflicting ecosystem service requirements and conservation priorities.

There is clearly a need for continued research examining how river rehabilitation impacts ecosystem service provision. Research should investigate the effectiveness of different rehabilitation measures for service provision as our current understanding is limited. Gilvear et al. (2013) develop a method for modelling the impact different restoration options have on future ecosystem service delivery, applying their method on the Eddleston Water in Scotland Gilvear et al. find that over the long-term re-meandering, re-introduction of floodplain forest and adoption of less intensive land management provide the most ecosystem service benefits. In summary Gilvear et al. suggest rehabilitation that aims to enhance connectivity, heterogeneity and dynamics is likely to enhance ecosystem function thus creating greater ecosystem service provision. Critically the success of rehabilitation options will depend on scale of rehabilitation activity, location of restoration action within the catchment and pressures currently constraining the river system (Wohl et al., 2005; Gilvear et al., 2013). Essential to understanding the success of
Moving towards an ecosystem service paradigm for river rehabilitation brings several advantages to river management. The ecosystem service approach is by nature cross-disciplinary and encourages the sharing of ideas and information between different branches of science including social science, ecology, economics, and river science (Dufour et al., 2010; Garcia et al., 2016). As well as encouraging interdisciplinary science, the approach can also connects scientists, stakeholders and decision makers. Brauman et al. (2014) find that the ecosystem service concept acted as a common language for the management of the River Dommel in the Netherlands, using the term ‘ecosystem services’ increased communication between stakeholders and decision makers. Additionally, the ecosystem service concept is viewed as a useful tool for communication with the public and education about the benefits and functions of river environments, it can enable people to develop deeper connections with rivers and encourage public support for restoration (Böck et al., 2015; Garcia et al., 2016). Ormerod (2014) highlight that the ecosystem services concept applied to rivers has potential to increase the awareness of the issues that rivers face, potentially placing the need for sustainable rivers alongside the need for sustainable food security and energy security. In practice using the approach and quantifying services allows decision makers to weigh up different restoration options and decide on scenarios that create the most benefits to society (Dufour et al., 2010).

Current literature finds river rehabilitation to increase the value of rivers due to increased ecosystem service provision, if there is potential for the value of a river to increase then this can provide an argument for restoration to go ahead (Gerner et al., 2018). One limitation of using economic valuation is that those cultural services which
are incommensurable cannot be included in assessments of restoration. Cultural services are discussed in more detail in chapters three and five.

2.5 Scotland: Ecosystem Services, Protected Areas and Protected Rivers

2.5.1 Ecosystem Services in Scotland

Scotland is an ideal location to research the relationship between river protected areas and ecosystem service provision. Scotland has actively adopted the ecosystem service approach into policy and management and has many protected rivers.

At the governmental level Scotland has the ‘Natural Assets Theme’ which is part of the Environment, Agriculture and Food Strategic Research Programme of the Scottish Governments Strategic Research Programme 2016-2021. The theme has four work packages: soil, water resource and flood risk management, biodiversity and ecosystems, and integrated and sustainable management of natural assets. Research is to focus on the understanding of physical and biological processes allowing more informed predictions of how assets may change and facilitating the development of approaches and tools for management and policy.

The Governmental organisation SEPA are working on developing a framework to allow ecosystem services to influence and assist in the making of management decisions (SEPA, no date, a). SEPA are using the approach advised by the European Environment Agency under its Mapping and Assessing Ecosystem Services Project (MAES). SEPA describe that key to the success of using an ecosystem service approach is working with other agencies across Scotland because varying agencies hold different data sets which are important in assessing service provision and the health of ecosystems.
One project involving multiple agencies is the Eco-Serv-GIS project (Scottish Wildlife Trust, no date). Jointly SEPA, NatureScot and the Glasgow and Clyde Valley Green Network funded the Eco-Serv-GIS project which is run by The Scottish Wildlife Trust. Eco-Serv-GIS is a GIS toolkit which produces grid-based maps for nine ecosystem services, maps show the potential of the environment to produce ecosystem services, ecosystem service hotspots and societal need for ecosystem services. Maps can be used to assess the ecosystem service impacts of proposed developments, to investigate how different land use patterns would alter ecosystem service provision, and as education tools allowing spatial visualisation of ecosystem services.

Alongside practical projects such as Eco-Serv-GIS, there are forums and groups that bring together organisations and individuals involved in ecosystem services in Scotland. The Scottish Forum on Natural Capital started in 2013 and is an initiative designed to bring together private, public and voluntary organisations with the purpose of protecting and rebuilding the natural capital of Scotland. There is also the Ecosystem Services Community Scotland (ESCom) which is a community of scientists, researchers and practitioners. The purpose of the ESCom is to encourage dialogue between stakeholders, to bring together ecosystem service research in Scotland and to arrange events which support sharing of knowledge.

Of note, Scotland also seems progressive in the inclusion of cultural services in policy and practice. In 2015 NatureScot developed a working paper titled ‘Cultural Ecosystem Services – towards a common framework for developing policy and practice in Scotland’.

Alongside governmental and non-governmental organisations there is also an active interest in Scottish ecosystem services from the academic community. A Web of Science search using the terms ‘Ecosystem Service Scotland’ revealed 103 results (01/05/2018).
In total 52 papers were found discussing ecosystem services, however the number of papers looking at ecosystem services in Scotland is likely to be much greater due to the limited search term used here. Results were categorised into broad topic area. The first thing to note from the retrieved papers is that literature appears diverse with many different aspects of the ecosystem service concept explored. Table one highlights that in particular, there seems to be research interest in biodiversity and ecosystem services, ecosystem service modelling and landscape change/management and ecosystem services. Research produced in Scotland is likely to be of global significance as 12 of the 52 papers have over 20 citations.

Table 1: Topics of 52 papers looking at ecosystem services, retrieved from a Web of Science search using the terms ‘Ecosystem Service Scotland’ conducted on 01/05/2018

<table>
<thead>
<tr>
<th>Topic</th>
<th>Number of Papers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biodiversity and Ecosystem Services</td>
<td>10</td>
</tr>
<tr>
<td>Ecosystem Service Modelling</td>
<td>8</td>
</tr>
<tr>
<td>Landscape Change/Management and Ecosystem Services</td>
<td>7</td>
</tr>
<tr>
<td>Review Papers</td>
<td>5</td>
</tr>
<tr>
<td>Economic Valuation of Ecosystem Services</td>
<td>5</td>
</tr>
<tr>
<td>Alternative Cultural Values</td>
<td>5</td>
</tr>
<tr>
<td>Abiotic Variables and Ecosystem Services</td>
<td>5</td>
</tr>
<tr>
<td>Ecosystem Service Mapping/Spatial Patterns</td>
<td>4</td>
</tr>
<tr>
<td>Policy and Ecosystem Services</td>
<td>2</td>
</tr>
<tr>
<td>Humans and Ecosystem Services</td>
<td>1</td>
</tr>
</tbody>
</table>

2.5.2 Scotland, Protected Areas and Protected Rivers

Scotland makes an ideal location to research protected areas and ecosystem services because it has a wide range of different designations. International designations include Biogenetic Reserves, Geoparks, Ramsar Sites, Natura Sites, World Heritage sites, Biosphere Reserves and OSPAR Marine Protected Areas. National designations include National Scenic Areas, National Parks, Marine Protected Areas, National Nature Reserves and Sites of Special Scientific Interest. On the smaller scale, local designations include
Country Parks, Local Nature Reserves, Local Landscape Areas, Regional Parks and Local Nature Conservation Sites.

Off all these designations it is Special Areas of Conservation (SACs) which are the main protection given to Scottish Rivers. SACs are designated under the EC Habitats Directive. Across Europe SACs are designated to protect specific habitats and species listed in the annexes of the Habitats Directive, SACs form a network of high-quality conservation sites. SAC is the only designation given to entire rivers; however, river SACs are only a small proportion of Scottish SACs. Of 241 designated SACs in Scotland, only 20 are rivers (equating to around 1.1% of total Scottish SAC area). Spatially, most SACs are located fully or partially in the Highlands and Islands local authority area. Table two shows the most common primary reasons for designation are the presence of freshwater pearl mussels (12 rivers) and Atlantic salmon (10 rivers). Alongside SAC designations partial lengths of Scottish rivers have other designations. Using the SNH Sitelink Website to identify protected areas with ‘river’ in the title finds 21 Sites of Special Scientific Interest, 2 Ramsar sites, 2 Special Protected Areas and 2 National Scenic Areas.
<table>
<thead>
<tr>
<th>SAC Name</th>
<th>Reasons for Protection</th>
<th>Last Assessed Condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ardnamurchan Burns</td>
<td>Freshwater pearl mussel (P)</td>
<td>Unfavourable declining (2012)</td>
</tr>
<tr>
<td>Berriedale &amp; Langwell Waters</td>
<td>Atlantic salmon (P)</td>
<td>Favourable maintained (2011)</td>
</tr>
<tr>
<td>Endrick Water</td>
<td>Brook lamprey (P)</td>
<td>Favourable maintained (2010)</td>
</tr>
<tr>
<td></td>
<td>River lamprey (P)</td>
<td>Favourable maintained (2010)</td>
</tr>
<tr>
<td></td>
<td>Atlantic Salmon (QF)</td>
<td>Unfavourable recovering (2011)</td>
</tr>
<tr>
<td>Little Gruinard River</td>
<td>Atlantic salmon (P)</td>
<td>Favourable recovered (2011)</td>
</tr>
<tr>
<td>Mingarry Burn</td>
<td>Freshwater pearl mussel (P)</td>
<td>Unfavourable recovering (2014)</td>
</tr>
<tr>
<td>River Bladnoch</td>
<td>Atlantic salmon (P)</td>
<td>Unfavourable recovering (2011)</td>
</tr>
<tr>
<td>River Borgie</td>
<td>Freshwater pearl mussel (P)</td>
<td>Unfavourable non change (2014)</td>
</tr>
<tr>
<td></td>
<td>Atlantic salmon (QF)</td>
<td>Favourable recovered (2011)</td>
</tr>
<tr>
<td></td>
<td>Otter (QF)</td>
<td>Favourable maintained (2012)</td>
</tr>
<tr>
<td>River Dee</td>
<td>Freshwater pearl mussel (P)</td>
<td>Unfavourable no change (2003)</td>
</tr>
<tr>
<td></td>
<td>Atlantic salmon (P)</td>
<td>Favourable maintained (2011)</td>
</tr>
<tr>
<td></td>
<td>Otter (P)</td>
<td>Favourable declining (2012)</td>
</tr>
<tr>
<td>River Evelix</td>
<td>Freshwater pearl mussel (P)</td>
<td>Unfavourable declining (2014)</td>
</tr>
<tr>
<td>River Kerry</td>
<td>Freshwater pearl mussel (P)</td>
<td>Favourable maintained (2002)</td>
</tr>
<tr>
<td>River Moriston</td>
<td>Freshwater pearl mussel (P)</td>
<td>Unfavourable no change (2003)</td>
</tr>
<tr>
<td></td>
<td>Atlantic salmon (QF)</td>
<td>Unfavourable no change (2011)</td>
</tr>
<tr>
<td>River Naver</td>
<td>Freshwater pearl mussel (P)</td>
<td>Unfavourable no change (2015)</td>
</tr>
<tr>
<td></td>
<td>Atlantic salmon (P)</td>
<td>Favourable recovered (2011)</td>
</tr>
<tr>
<td>River Oykel</td>
<td>Freshwater pearl mussel (P)</td>
<td>Unfavourable no change (2015)</td>
</tr>
<tr>
<td></td>
<td>Atlantic salmon (QF)</td>
<td>Favourable recovered (2011)</td>
</tr>
<tr>
<td>River South Esk</td>
<td>Freshwater pearl mussel (P)</td>
<td>Unfavourable no change (2009)</td>
</tr>
<tr>
<td></td>
<td>Atlantic salmon (P)</td>
<td>Unfavourable recovering (2011)</td>
</tr>
<tr>
<td>River Spey</td>
<td>Freshwater pearl mussel (P)</td>
<td>Unfavourable declining (2014)</td>
</tr>
<tr>
<td></td>
<td>Sea lamprey (P)</td>
<td>Favourable maintained (2011)</td>
</tr>
<tr>
<td></td>
<td>Atlantic salmon (P)</td>
<td>Unfavourable recovering (2011)</td>
</tr>
<tr>
<td></td>
<td>Otter (P)</td>
<td>Favourable maintained (2011)</td>
</tr>
<tr>
<td>River Tay</td>
<td>Atlantic salmon (P)</td>
<td>Favourable maintained (2011)</td>
</tr>
<tr>
<td></td>
<td>Oligotrophic to mesotrophic standing waters (QF)</td>
<td>Favourable maintained (2009)</td>
</tr>
<tr>
<td></td>
<td>Sea lamprey (QF)</td>
<td>Favourable maintained (2007)</td>
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<tr>
<td></td>
<td>Brook lamprey (QF)</td>
<td>Favourable maintained (2007)</td>
</tr>
<tr>
<td></td>
<td>River lamprey (QF)</td>
<td>Favourable maintained (2012)</td>
</tr>
<tr>
<td></td>
<td>Otter (QF)</td>
<td>Favourable maintained (2012)</td>
</tr>
<tr>
<td>River Teith</td>
<td>Sea lamprey (P)</td>
<td>Unfavourable declining (2011)</td>
</tr>
<tr>
<td></td>
<td>Brook lamprey (P)</td>
<td>Favourable maintained (2011)</td>
</tr>
<tr>
<td></td>
<td>River lamprey (P)</td>
<td>Favourable maintained (2011)</td>
</tr>
<tr>
<td></td>
<td>Atlantic salmon (QF)</td>
<td>Unfavourable recovering (2011)</td>
</tr>
<tr>
<td>River Thurso</td>
<td>Atlantic salmon (P)</td>
<td>Unfavourable recovering (2011)</td>
</tr>
<tr>
<td>River Tweed</td>
<td>Atlantic salmon (P)</td>
<td>Favourable maintained (2011)</td>
</tr>
<tr>
<td></td>
<td>Otter (P)</td>
<td>Favourable maintained (2011)</td>
</tr>
<tr>
<td></td>
<td>Water courses of plain to montane levels (QF)</td>
<td>Unfavourable no change (2004)</td>
</tr>
<tr>
<td></td>
<td>Sea lamprey (QF)</td>
<td>Unfavourable no change (2011)</td>
</tr>
<tr>
<td></td>
<td>Brook lamprey (QF)</td>
<td>Favourable recovered (2011)</td>
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<tr>
<td></td>
<td>River lamprey (QF)</td>
<td>Favourable recovered (2011)</td>
</tr>
</tbody>
</table>
2.5.3 Scotland’s Rivers and Ecosystem Services

Alongside being important for conservation, Scottish rivers also have significant ecosystem service value. Scottish rivers are national natural assets contributing both to the economy and wellbeing.

In terms of provisioning services, Scottish rivers are particularly important for the supply of water and hydroelectric power. Whilst lochs and reservoirs supply most of the drinking water in Scotland (around 46%), rivers and burns also provide a significant proportion (38%) (The Scottish Government, 2013). River water supply is also very important for industry in Scotland. According to SEPA (no date, b) the industries using the most water are: hydroelectricity generation (3,783 m³ yr⁻¹), aquaculture (1,582 m³ yr⁻¹), chemical manufacturing (315.9 m³ yr⁻¹) and food and drink (260.2 m³ yr⁻¹). Of note, hydropower currently accounts for around 10% of Scotland’s total electricity production, in 2013 this accounted for 33% of Scotland’s energy from renewable sources (Sample et al., 2015).

In terms of cultural services Scottish rivers have particularly high recreational and touristic value. Tourists have been travelling to visit Scottish freshwater features for hundreds of years. Cole (2015) highlight that Scottish waterfalls have been of aesthetic, recreation, and inspirational interest to travellers and those with leisure time since at 1769 AD. Scottish rivers are world-famous for high quality fishing and as a result fishing brings in significant revenue. In 2003 Butler et al. (2009) estimated rod fishing on the River Spey to be worth around £59 million annually. Furthermore, in 2004 it was estimated that freshwater fishing was worth in the region of £113m per annum to the Scottish economy, Atlantic salmon anglers provided the greatest contribution (65%) followed by rainbow and brown trout anglers at 30% (SNH, 2017).
It is not just fishing which is important for the Scottish economy. Riddington et al. (2004) estimated that in 2003 sailing, rafting and canoeing in the Spey catchment generated around £1.7 million per annum. Scottish residents also enjoy river-based recreation. The Scottish Household Survey (2014) found that in 2014 around 6% of outdoor visits were to rivers, however 41% of visits were to local parks/open spaces where rivers may be important landscape elements.

In contrast to provisioning and cultural services there seems to be no statistics relating to regulating services. Regulating services for which European rivers are considered to be important for include natural flood mitigation and water quality regulation (Harrison et al., 2010).

Natural flood mitigation (NFM) has received substantial attention in Scotland. Providing flood mitigation is considered critical in Scotland as SEPA flood maps indicate that around 49,000 homes and 13,000 non-residential properties are at risk of a 1 in 200 year event (SEPA, 2015). In their publication ‘The Natural Flood Management Handbook’ SEPA describe that natural flood mitigation is becoming more important as local authority budgets sink, population and demand for housing increases and as the climate changes. NFM techniques are preferable as they also deliver other benefits including biodiversity, water quality improvement and climate regulation (SEPA, 2015).

Natural flood management projects in Scotland include Braemar floodplain restoration (River Dee), Tarland Catchment (Dee), Logie Burn (Dee), Allt Lorgy (Spey), Eddleston Water (Tweed) and Bowmont Catchment (Tweed). Techniques used within these schemes include planting of riparian vegetation, removal of embankments, re-meandering and meander reconnection, space for flooding, introduction of large woody material and wetland/pond creation (NFM Network Scotland, 2018). The recent
completion of these projects means that data relating to their success is limited, for some techniques such as woodland planting it can take several years before benefits may be seen. Many of the projects were designed with long-term monitoring so they should provide data in the future which will indicate their effectiveness.

The water quality regulation benefits of rivers result from processes relating to riparian, floodplain and wetland vegetation, and bed and bank exchanges. Riparian, floodplain, and wetland vegetation can regulate river water quality by assimilating and trapping pollutants, modifying flow paths, stabilising soils and by providing shading (Mitsch et al., 1995; Lair et al., 2009; Dosskey et al., 2010; Kalny et al., 2017). Exchanges of ions between river water and the bed and bank can lead to buffering and removal of nutrients (Hester et al., 2018; Zaramella et al., 2015). Only a few pieces of literature could be found researching the water quality regulation potential of Scottish rivers. Palumbo-Roe et al. (2017) investigate the ability of the hyporheic zone in attenuating chromium in urban streams and find attenuation to be limited by poor surface water infiltration. In their review of Scottish water systems Novo et al. (2017) find there is limited research into the assimilation capacity for dangerous pollutants such as lead, arsenic and mercury. Novo et al. (2017) find that understandings of water system assimilation capacities is limited by a lack of long-term and consistent data. Scottish water quality research currently seems to have a stronger focus on modelling water quality (e.g. Jackson et al., 2018; Neill et al., 2018; Jonkers et al., 2016), water quality degradation and threats (e.g Worrall et al., 2016; Richards et al., 2016; Millidine et al., 2015) and temporal trends of water quality (e.g. Lathouri and Korree, 2015; Dunn et al., 2014; Muller and Tankéré-Muller, 2012). While there is a lack of research investigating and quantifying the water quality regulation of Scottish rivers it does not mean that these processes are not happening or are unimportant. Indeed, river water quality is generally good in Scotland (SEPA, no date c).
2.6 Conclusion

This chapter starts by reviewing the history of the ecosystem service concept. It appears that the concept is becoming increasingly more prevalent in management, policy and research. The Millennium Ecosystem Assessment (MA) popularised the concept and categorised services. Despite an attempt to re-frame ecosystem services to ‘Nature’s Contributions to People’, the ecosystem service concept remains preferrable. Since the publication of the MA categories have been reduced to provisioning, regulating and cultural with supporting services underpinning them. Research finds that elements of biodiversity support the provision of ecosystem services. This leads to an important question concerning ecosystem management: Do areas protected for biodiversity also deliver ecosystem services?

It appears that the purpose of protected areas is changing, they are now expected to deliver conservation objectives and ecosystem services. In terms of conservation, previous reviews suggest that marine and terrestrial protected areas have positive outcomes for biodiversity. Freshwaters are less frequently protected with the protection that is given found to have mixed outcomes for biodiversity. There is research looking at the relationship between terrestrial protected areas and ecosystem service provision, however studies fail to consider multiple ecosystem services meaning no strong conclusions can be made. In both the marine and freshwater realms there is limited research looking at protected area – ecosystem service relationships, drawing conclusions is therefore not possible. In all realms research on protected area – ecosystem service provision is limited by a lack of appropriate data.

In particular this review highlights that rivers are comparably under protected and that research looking at river protected area – ecosystem service relationships is limited.
Understanding such relationships is important as climate change and population growth are likely to increase the pressure on ecosystems to provide services and areas providing more services may be preferable to protect. River ecosystem service research has increased in parallel with general ecosystem service research. In terms of river management, a new paradigm focusing on ecosystem service provision and human wellbeing is being entered. Many advantages of incorporating ecosystem services into river rehabilitation are recognised including the promotion of interdisciplinary science, improved support from stakeholders/public and education of the public.

For several reasons Scotland provides an ideal study location to investigate ecosystem service - river protected area relationships. Firstly, Scotland has widely adopted the ecosystem paradigm into policy and practice. Secondly, Scotland also has many rivers with protected status, in particular Scottish rivers are given Special Area of Conservation Status under Natura 2000. The most common reasons for rivers to be designated as SACs in Scotland are the presence of Freshwater pearl mussels and/or Atlantic salmon. Finally, protected and unprotected rivers in Scotland have significant ecosystem service value providing water, hydroelectricity and recreation/tourism.

2.7 Proposed Research: Aims and Objectives

The above review has highlighted that there is a gap in research examining the role protected rivers play in providing ecosystem services. Scotland appears to provide a location to investigate such relationships. Therefore, the overarching aim of this research is to determine if ecosystem service provision differs between Scottish river corridors with and without nature designations. To achieve the primary aim, this research has a substantial secondary aim which is to select and develop an appropriate method for capturing river ecosystem service provision at a relatively small scale.
The first step towards the secondary aim is to perform a comprehensive literature review looking at the different methods available for capturing river ecosystem service provision. It has been highlighted above that some studies have failed to capture multiple ecosystem services, and this has limited the usefulness of their findings, it is crucial that the method used in this research is able to capture multiple services including cultural. If necessary, an existing method will be adapted to make it suitable for Scottish rivers. Once a suitable method has been decided the focus will turn to aim one. To investigate if ecosystem service provision varies with protected status, a paired-river approach will be taken. Statistical techniques will then be used to see if there is statistical difference between rivers with and without protected status. Exact statistical techniques will be selected depending on the type of data collected. The results from this comparison will then be discussed in the context of protected area – ecosystem service relationships. This will lead to recommendations for future management of protected and unprotected rivers in Scotland.
Chapter Three: Review of methodologies used to capture river ecosystem services

3.1 Introduction

To determine if ecosystem service provision differs between Scottish river corridors with and without nature designations, the quantification of ecosystem service provision is necessary. This chapter explores the methods which can be used to quantify river ecosystem services in order to select a method appropriate for investigating ecosystem service provision from protected Scottish river corridors.

Prior to delving into specific ecosystem service quantification methods, this chapter explores some fundamental discussions within the ecosystem service quantification sphere. This chapter begins by outlining the elements of the ecosystem service concept which can be quantified. Secondly this chapter discusses the difference between monetary and non-monetary valuation, particular emphasis is given to the history of economic valuation. Attention then turns to outlining the scope of review focus. To achieve the overarching research aim, this methodology review focuses on approaches which can capture multiple ecosystem services.

Owing to their distinct nature, cultural services are often quantified differently to provisioning and regulating services, therefore, to ensure this review is sufficiently detailed, cultural services are reviewed separately. Provisioning and regulating methodologies are reviewed first. Monetary valuation seems the natural starting point for this review as this was the early focus of ecosystem service research. Next review focuses on ecosystem service models which have recently increased in use and application.
Prior to reviewing cultural service quantification, it is necessary to explore the history and inclusion of cultural services within the ecosystem service paradigm. It is also crucial for this research to determine which cultural services are supplied by river corridors. After establishing which cultural services are supplied by Scottish river corridors, attention turns to investigating the methodologies created for their capture. The review of cultural services focuses on general ecosystem service research as papers looking exclusively at river cultural services are elusive.

Following identification of the strengths and weaknesses of individual methods, this chapter culminates by selecting the most appropriate methodology to investigate ecosystem service provision from Scottish rivers.

3.1.1 **Ecosystem services: What are you quantifying?**

Reviewing the methods used to quantify ecosystem services is complicated by the fact that three different aspects of ecosystem services can be measured; potential, flow, and demand (Von Haaren *et al.*, 2014; Hanna *et al.*, 2017; Vigl *et al.*, 2017). Potential refers to the capacity of an ecosystem to deliver services as a result of biophysical functions (Hanna *et al.*, 2017; van Oudenhoven *et al.*, 2012; Schröter *et al.*, 2014). The terms ‘supply’ ‘offered’ and ‘capacity’ are also used to refer to potential (e.g. Villamanga *et al.*, 2013; Burkhard *et al.*, 2014). ‘Flow’, ‘utilised service’ or ‘actual’ is defined as the actual use or experience of the service (Hanna *et al.*, 2017; Schröter *et al.*, 2014; Von Haaren *et al.*, 2014). Demand relates to the amount of a service which is needed or desired by society (Hanna *et al.*, 2017). Demand is different from flow in that it reflects preferences for attributes of the service including location, time of provision, cultural preferences, biophysical characteristics and potential cost of use (Schröter *et al.*, 2014; Villamanga *et al.*, 2013). Of the three measurable elements there has been a preferential focus on
quantifying potential and a noticeable absence of demand capture (Burkhard et al., 2014; Wolff et al., 2015; Vigl et al., 2017). Burkhard et al. (2014) consider that the different ecosystem service elements correspond with components of the ecosystem service cascade of Potschin and Haines-Young (2011). Ecosystem service potential is the function of biophysical processes which cascade to ecosystem service flow and then to ecosystem service demand (figure 7).

Figure 7: The ecosystem service cascade of potential, flow and demand by Burkhard et al. (2014). The cascade shows potential to flow to demand.

It is recommended that ecosystem service assessments should measure all three components (Villamanga et al., 2013; Geijzendorffer et al., 2015; Vigl et al., 2017), however, unfortunately the majority of studies only focus on one or two elements (Tallis et al., 2012). Identifying patterns of components is important in assessing the sustainability of our ecosystem service consumption (Villamanga et al., 2013; Baró et al., 2016). The relationship between potential and flow can demonstrate unsustainable use if flow is greater than potential or underutilisation if significantly lower than potential (Villamanga et al., 2013; Schröter et al., 2014). While identifying relationships between
flow and demand shows if there is ‘unsatisfied demand’ where flow is not at the level required by society (Geijzendorffer et al., 2015). Relationships between potential, flow and demand are not static and can change with demographics, ecosystem management and seasonality (Schröter et al., 2014; Burkhard et al., 2014; Villamanga et al., 2013).

The three aspects of ecosystem service provision are measured using different techniques (Villamanga et al., 2013). Potential is measured and mapped using ecological information relating to properties and functions (Villamanga et al., 2013). Potential is quantified where the service is being supplied. Flow is the most directly measured with quantification focus on the amount of service that is actually delivered, this seems to have a strong economic focus (Villamanga et al., 2013). Flow is not site-specific, processes can occur in one area and the benefits occur in another, for example upstream flood regulation provides downstream benefits (Villamanga et al., 2013). Demand is usually measured using information relating to desired consumption, in particular this also seems to involve monetary valuation.

### 3.1.2 Monetary and non-monetary valuation

As outlined above, in section 2.2, owing to Constanza et al. (1997), the ecosystem service concept emerged shrouded in economic valuation. However, when discussing the production of ecosystem service values, it is necessary to understand that valuation can be either monetary or non-monetary (Christie et al., 2012; Hackbart et al., 2017). Both types of valuation involve quantifying ecosystem service provision, however monetary valuation produces economic values as final figures while non-monetary valuation does not (Hackbart et al., 2017).

Despite later being regarded as a considerable undervaluation of the world’s total ecosystem value, the work of Costanza et al. (1997) acted to significantly raise awareness
of the value of nature and sparked debates regarding the appropriateness of economically valuing nature (Fisher et al., 2009; Tinch et al., 2019). Since then, a variety of diverse methods have been developed to capture the monetary value of ecosystem services, each with their own distinct advantages and disadvantages (Harrison et al., 2018; Selivanov and Hlaváčková, 2021), however some overarching benefits of monetary valuation are perceived.

Foremost, as in 1997, the monetary valuation of ecosystem services is hailed as crucial for demonstrating that functioning ecosystems are of incredible value to human society (Costanza et al., 2014). Money can be viewed as a ‘common language’, and therefore, monetary valuation is seen as a strong communication tool, it allows for stakeholders and local communities to appreciate the value of ecosystems which are threatened (Costanza et al., 2014; Doherty et al., 2014). Subsequently, a widely held view is that monetary valuation is fundamental for guiding environmental decision makers in matters relating to human wellbeing (Laurans et al., 2013; Kieslich and Salles, 2021). Indeed, in their survey focusing on the usefulness of economic valuation, Marre et al. (2016) identifies that amongst Austrian decision-makers, economic valuation is perceived to be useful.

Decision makers utilise economic valuation to determine how best to spend public money in order to achieve conservation targets (Wangai et al., 2016; Azadi et al., 2021). Within UK decision making, the economic valuation of ecosystem services has been utilised to prioritise investments, appraise projects, conduct impact assessments, seek funding, inform planning, and to monitor/review decisions (Curnow, 2019).

Specific limitations of monetary valuation within the context of river ecosystem quantification are discussed in the proceeding methodological reviews focusing on provisioning and regulating service capture (section 3.2.1) and cultural service capture
(section 3.3.4 iii), however, here it is necessary to outline some perceived overarching limitations of monetary valuation. One of the loudest criticisms of monetary valuation is that it can lead to the commodification of ecosystems (Gómez-Baggethun and Ruiz-Pérez, 2011; Luck et al., 2012; Nueteleers and Engelen, 2015; Smessaert et al., 2020). In a broad sense, the commodification of ecosystem services refers to the market trade of previously non-marketed ecosystem components (Luck et al., 2012; Costanza et al. 2014; Hahn et al., 2015; Smessaert et al., 2020). Key to note, commodification is not a synonym for monetary valuation, commodification can occur as a result of monetary valuation (Costanza et al., 2014).

Commodification is rejected by some as they believe it is morally wrong for certain ecosystem services to be sold and traded (Gómez-Baggethun and Ruiz-Pérez, 2011; Hirons et al., 2016). Additionally, by commodifying ecosystem services only those that have ‘purchasing power’ can access them, this is ethically troubling as many services are regarded open access or communal property (Gómez-Baggethun and Ruiz-Pérez, 2011; Kish and Farley, 2021). Indeed Costanza et al. (2014) outline that one criticism is that many ecosystem services are viewed as public goods and therefore should not be traded privately.

Commodification can also lead to ‘motivational corruption’. Motivational corruption is a psychological mechanism where the introduction of money undermines intrinsic desire to protect or uphold good (Luck et al., 2012; Neuteleers, and Engelen, 2015). If extrinsic motivation undermines intrinsic motivation there may be a decrease in environmental moral which may lead to reduced environmental protection (Neuteleers, and Engelen, 2015). Of concern, research has suggested that once motivational corruption has
occurred it is difficult to return to original moral motivation when monetary incentives disappear (Gneezy and Rustichini, 2000; García-Amado et al., 2013).

Furthermore, economic valuation is rejected by some due to its anthropocentric bias (Luck et al., 2012; Washington and Maloney, 2020). Humans associate higher values with certain species and habitats which creates bias. Martín-López et al. (2008) find that people are willing to pay much more to conserve high profile species such as the Giant Panda compared to less well known and more invisible species such as microorganisms.

The limitations of monetary valuation caused some to argue that a transition away from monetary valuation would be beneficial for ecosystem service practice (e.g. García-Llorente et al., 2011; Chan et al., 2012). However, acknowledging the benefits and limitations of monetary valuation has produced a more recent view amongst some practitioners that it may be a ‘necessary evil’, (Martin-Ortega et al., 2019). Conducting research in Mexico, Martin-Ortega et al. (2019) identify that environmental professionals view economic valuation as a ‘necessary evil’ for achieving conservation targets. Professionals recognise that although economic valuation can induce commodification, not attaching economic values to ecosystems can lead to their neglect during conservation schemes.

3.1.3. What is being reviewed?

Of note, prior to beginning this review it is important to outline the scope of focus. The overarching purpose of this research is to determine if ecosystem service provision differs between Scottish river corridors with and without nature designations. Therefore, key to achieving the research purpose is to select a methodology that can capture values for multiple ecosystem services, this is made challenging by the fact that an initial review suggests methodologies have been developed independently for specific services.
In regard to natural flood mitigation, generally, it appears that ecosystem modelling is a popular methodology used to capture natural flood mitigation values (e.g. Nedkov and Burkhard, 2012; Wang et al., 2018; Dang et al., 2021), in many instances, this modelling is followed by economic valuation (e.g. Barth and Döll, 2016; Watson et al., 2016; Gallay et al., 2021). For example, to capture NFM within the Upper Yangtze River Basin Fu et al. (2013) created a natural flood mitigation model adapted from the Soil Conservation Service methodology, model data is utilised to create economic values showing the estimated value of NFM. More recently, within the USA Lawrence et al. (2019) used a combination of Lidar data and GIS modelling to produce estimates of flood extents, economic values for flood mitigation were then calculated based on avoided property losses.

Climate regulation is also a regulating service, yet in comparison to NFM, it appears that a different approach to quantification is dominant. The analysis of literature indicates that many researchers seek to value carbon sequestration based on the collection and extrapolation of biophysical data (Maraseni and Mitchell, 2016; Fernandes et al., 2020; Forogh Nasab et al., 2020). For example, Cierjacks et al. (2010) map carbon sequestration along Danubian floodplains by field sampling carbon stocks for aboveground biomass and soils within the Austrian Donau-Auen National Park. More recently, in India, Kujur et al. (2021) determine carbon stocks within the riparian zone of the Maini River by calculating the carbon stored as biomass within different species and types of vegetation. Of note, the production of biophysical data can then be used to create monetary values for climate regulation. For example, in Northwest China, Aishan et al. (2018) calculate carbon stocks along Tarim River and the convert stocks into monetary value.
In comparison to NFM and climate regulation, there seems more diversity in approaches used to quantify water supply. Several authors use computer models. For example, in China, Jiang et al. (2016) adapt the InVEST (Integrated Valuation of Ecosystem Services and Tradeoffs) model to produce river water yields within the Three-River Headwaters Region. Meanwhile, in Mexico City, Jujnovsky et al. (2012) use the alternative SWAT (Soil & Water Assessment Tool) model to determine drinking water supply. In contrast, other researchers have quantified water supply using monetary valuation. In Illinois, Kozak et al. (2011) value water supply from river wetlands by extrapolating willingness to pay (WTP data). Similarly, in Bangladesh, Rahman et al. (2017) conduct WTP to determine how much households would pay for improved water supply. Additionally, some have sought to use proxies to quantify water supply. Within the Mondego Basin in Portugal, Pinto et al. (2011) use secondary data from the Portuguese National Institution of Statistic to determine water balance.

Conducting a brief review into the different methods used to quantify the three services of natural flood mitigation, climate regulation and water supply clearly demonstrates that a variety of different approaches are available for the valuation of river ecosystem services. Indeed, the revelation that niche approaches are developed for individual services echoes the findings of Croci et al. (2021) in their review of urban ecosystem services. However, in order to achieve the overarching research aim of determining if ecosystem service provision differs between Scottish river corridors with and without nature designations it is necessary to capture multiple services simultaneously, therefore, the following review of methodologies used to capture river ecosystem services will be limited to approaches which can capture value for multiple services.
It is widely accepted within the ecosystem service community that the quantification of cultural services is distinct from provisioning and regulating services owing to their value being driven by individual and societal preferences and the perceived intangibility for some services (Satz et al., 2013; Hirons et al. 2016; Dickinson and Hobbs, 2017; Small et al., 2017). Subsequently, this section of review focuses jointly on methodologies used to capture provisioning and regulating services before attention is given solely to cultural service quantification.

3.2 Reviewing methods used to capture provisioning and regulating services

3.2.1 Monetary valuation

Economic valuation is a popular technique for river ecosystem services quantification, in their review of riverine ecosystem service quantification Hanna et al. (2017) found 45% of 89 used economic valuation. Provisioning and regulating river services quantified using economic valuation include; freshwater provision (Elsin et al., 2009), fish for sustenance (Morton et al., 2017), flood protection (Gerner et al., 2018), hydropower (Yu, 2017; Yang and Chen, 2014) and water quality regulation (Gerner et al., 2018; La Notte et al., 2015; Fang et al., 2015). The economic valuation of river ecosystem services is considered to prevent the neglect of river environments in decision making and lead to improved river management (Brauman et al., 2007; Brauman et al., 2014).

A common use of economic valuation in the river ecosystem service field seems to be in research focusing on restoration. These studies mostly focus on how much people would pay for proposed restoration actions with willingness-to-pay as the valuation technique (Bergstrom and Loomis, 2017). Indeed, the most cited river ecosystem service paper is Loomis et al. (2000) who use willingness-to-pay to determine the value people place on restoring five ecosystem services (erosion control, natural water purification,
wastewater dilution, habitat provision and recreation) along a 45-mile reach of the Nebraskan Platte River. Loomis et al. found 100% of respondents were willing to pay the minimum value presented but as the value increase WTP decreased. One of the main concerns of WTP is the reliability of responses, would people actually pay the amount they stated? To determine the validity of their results Loomis et al. adopted the 10 point-scale of Champ et al. (1997) which suggested that their WTP results are robust. Loomis et al. consider that their WTP research was successful because they provided detailed descriptions of the ecosystem services being valued, used extensive visual aids and conducted in-person interviews.

Valuing the potential ecosystem service improvements of restoration assists cost-benefit analysis and can guide the type of restoration that takes place. Droste and Meya (2017) evaluate the cost-benefit potential of deepening the Lower Weser River in Northwestern Germany. Traditional cost-benefit analyses in Germany do not account for improvements in ecosystem services, however, in their valuation exercise Droste and Meya (2017) find that the inclusion of freshwater supply and habitat protection reduces the cost benefit ratio significantly. The inclusion of ecosystem services in the cost benefit analysis of river restoration schemes is seen to allow more efficient spending of public money (Droste and Meya, 2017). Economic valuation can also be used to evaluate restoration schemes. Vermaat et al. (2016) quantify 11 ecosystem services for eight pairs of restored-unrestored reaches across Europe, overall restoration is found to have increased the ecosystem service value of restored reaches by $1400 \pm 600 \, € \, h^{-1} a^{-1} \, y^{-1}$.

Despite the advantages of economically valuing river ecosystem services, the approach has limitations. Practically, the monetary valuation of river services is considered expensive and time consuming with valuations for every catchment regarded beyond the
resources of most water management authorities (Hanley et al., 2006). Furthermore, the data required to economically capture services is spatially inconsistent (Gerner et al., 2018). To save time and money ‘benefits transfer’ is proposed (Hanley et al., 2006; Bergstrom and Loomis, 2017), ‘benefits transfer’ is the process of taking valuation estimates from one catchment and adjusting them for another. Hanley et al. (2006) test the potential of benefits transfer for rivers in England and Scotland. WTP is used to value potential methods to improve ecological status of the River Wear in County Durham and the River Clyde in Scotland. Results find that people living near the Clyde place higher values on identical improvements to water ecology than those living in Durham despite the fact Durham residents have higher average incomes. Results therefore reject the idea of benefits transfer. Rejection occurs because WTP is related to individual preferences which cannot be easily predicted.

There is also concern that WTP is not as robust as previously thought because it poorly captures individual preferences and motivations. Spash et al. (2009) investigate the value of restoring ecosystem function and species diversity on the Scottish River Tummel using a combination of psychology methods and WTP. Psychology methods focus on ethical variables as opposed to the socio-economic variables of WTP. Spash et al. (2009) find the four ethical variables considered to explain as much variance in WTP as the 10 socio-economic variables. Thus Spash et al. (2009) conclude that WTP intentions cannot simply be interpreted as ‘trade prices’ for ecosystem services as they have complexity driven by psychology and social factors. Additionally, there is concern that individuals are uncertain about the WTP values they give. Lehtoranta et al. (2017) undertake a WTP assessment for the restoration of Finnish forested catchments and find that of 450 respondents who indicated they would pay for restoration, only 15% were completely certain in their preferences. WTP uncertainty has been linked to younger age, low
incomes, negative feelings towards paying for nature conservation and low environmental knowledge (Brouwer, 2011; Voltaire et al., 2013). Another criticism of WTP is that it focuses on individual preferences. People state the amount they are willing to pay for what they personally want but not necessarily what they believe might be best for society (Howley et al., 2010). This creates an issue for policy makers as decisions should be made based on what is best for society.

If researchers seek to capture multiple services then different methods may be required which can make economic valuation challenging. In their multi-service valuation of restored-unrestored river pairs, Vermatt et al. (2016) conduct several approaches including WTP, local market pricing and sporting licence fees and report that using a wide range of data sources leads to a degree of error which could not be quantified. Boithias et al. (2016) also ascertain that uncertainty increases with the number of river ecosystem services which are valued. Minimising uncertainty in ecosystem service valuations is important as results are used to inform management (Naeem et al., 2015). Uncertainty can be reduced by ensuring services, benefits and metrics selected for valuation are relevant to the context and purpose of assessment (Boithias et al., 2016). However, Boithias et al. (2016) describe that some uncertainty will always remain and a measure of uncertainty should always be presented in economic studies.

3.2.2 Modelling used to capture river provisioning and regulating services

Modelling refers to the use of a programme or tool to produce data relating to ecosystem service potential, flow or demand. Ecosystem service models use a combination of input data and algorithms/rules representing ecological processes to quantify elements of ecosystem services. The incorporation of ecological processes within models is partly responsible for their recent increase in popularity. Initially ecosystem service research
focused on the trends and status of services, but recently there has been a transition to understanding processes and developing models which connect processes to human wellbeing (Small et al., 2017). Within ecosystem service research models are most commonly used to investigate how land management and changes in climate may influence service provision (Duku et al., 2015; Marqués et al., 2013; Sharps et al., 2017; Lüke and Hack, 2018). Two types of model have been identified and are reviewed here; computer-based modelling and capacity matrix based modelling.

One major advantage that many of the computer and matrix models discussed below have over methods of economic valuation is that they are designed to spatially represent elements of ecosystem services. Ecosystem service maps are invaluable to decision makers and scientists. Maps can identify trade-offs and synergies between ecosystem services (Haase et al., 2012; Zarandian et al., 2016). Bennett et al. (2009) consider that without knowledge of these relationships opportunities to make the most of synergies may be missed and unwanted trade-offs may occur. Maps can also identify trade-offs and synergies between ecosystem services and elements of biodiversity (Anderson et al., 2009; Nelson et al., 2009), such maps are invaluable in the development of management plans that strive to meet ecosystem service and conservation goals simultaneously. Additionally, mapping enables the identification of relationships between ecosystem service potential, flow and demand (Nedkov and Burkhard, 2012; Stürck et al., 2014; Vigl et al., 2017). Historically the mapping of demand has been neglected, however interest has recently increased (Wolff et al., 2015). Demand is challenging to map as it changes frequently due to changes in population, wealth, lifestyle, urbanisation, land management, increased pressure on natural resources and climate (Zasada, 2011; Wolff et al., 2015). Ecosystem service maps are also seen as important communication tools. Hauck et al. (2013) conducted a focus group looking at ecosystem service maps and found
participants considered maps to be valuable in helping to educate the public about the value of ecosystem services and their flows to beneficiaries. Maps are also seen as important for initiating discussions such as those relating to different proposed management scenarios (Hauck et al., 2013).

(i) Computer Programme Modelling of River Ecosystem Services

There are a number of computer models available for capturing freshwater ecosystem services. Model comparisons assist researchers in selecting models appropriate for research questions. Table three highlights the comparison papers used to form this review.

Table 3: Table describing the research papers used in the investigation of computer-based river ecosystem service modelling

<table>
<thead>
<tr>
<th>Paper</th>
<th>Models Compared</th>
<th>Nature of Comparison - conducted through literature review or model runs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vigerstol and Aukema (2011)</td>
<td>SWAT, VIC, InVEST, ARIES</td>
<td>Use literature to undertake comparison. Models were selected as they are publicly available, being actively supported and are free to use</td>
</tr>
<tr>
<td>Bagstad et al. (2013)</td>
<td>17 Models in total</td>
<td>Conduct a larger scale literature review looking at 17 ecosystem service models, here the focus is not solely on freshwater services</td>
</tr>
<tr>
<td>Vorstius and Spray (2015),</td>
<td>SENCE, InVEST and Eco-Serv-GIS.</td>
<td>Focused comparison looking only at ecosystem service models. Models used to map carbon storage, water purification and pollination in a small Scottish Borders catchment (Eddleston Water).</td>
</tr>
<tr>
<td>Sharps et al. (2017)</td>
<td>InVEST, ARIES and LUCI</td>
<td>Also look only at ecosystem service models. Comparison focuses on the ability of the models to capture water supply, carbon storage and nutrient retention in a temperate catchment of North Wales</td>
</tr>
<tr>
<td>Lüke and Hack (2018)</td>
<td>SWAT, InVEST and RIOS</td>
<td>Comparison of Open Source models. Models are compared theoretically and in practice in a case study in a Nicaraguan urban catchment where water flow regulation and sediment retention are modelled</td>
</tr>
<tr>
<td>Hallouin et al. (2018).</td>
<td>Review literature not individual models</td>
<td>Literature review of models focusing on quantifying one or more freshwater ecosystem service.</td>
</tr>
</tbody>
</table>

Model Acronyms

- SWAT – Soil and Water Assessment Tool
- VIC – Variable Infiltration Capacity Model
- InVEST, Integrated Valuation of Ecosystem Services
- ARIES - Artificial Intelligence for Ecosystem Services
- SENCE - Spatial Evaluation for Natural Capital Evidence
- LUCI - Land Utilisation and Capability Indicator
- RIOS - Resource Investment Optimization System model
Models used to capture freshwater ecosystem services come from two branches of science; hydrological and ecosystem service (Vigerstol and Aukema, 2011). The development through different branches of science produces some inherent differences. Hydrological models have been developed over a longer timeframe and thus have been subject to years of testing, improvement and peer review (Vigerstol and Aukema, 2011; Guswa et al., 2014). Hydrological models are based on accepted hydrological knowledge which is seen as an advantage (Lüke and Hack, 2018). Furthermore, within the ecosystem service modelling community there is a preference for tools which have been subject to extensive development and have abundant documentation (Bagstad et al., 2013). However, the choice between hydrological or ecosystem service model depends on several considerations including research question, data availability, output resolution, user expertise and resources available.

Ecosystem service models are better for research investigating multiple services (Vigerstol and Aukema, 2011). Hydrological models were not developed for capturing ecosystem services meaning they can only model a few services, this makes them a poor choice for seeking trade-offs and synergies (Vigerstol and Aukema, 2011). SWAT can only assess water supply and flood risk (Vigerstol and Aukema, 2011) while VIC focuses on water supply (Maurer, 2007; Hurkmans et al., 2009; Elsner et al., 2010). In contrast the ecosystem service model of InVEST currently has the potential to model water purification, reservoir hydropower production, reservoir sedimentation, carbon storage, pollination and is subject to continual development (Vigerstol and Aukema, 2011; Guswa et al., 2014; Vorstius and Spray, 2015). ARIES can currently model sediment regulation, flood control, fishing yields, water supply and nutrient filtration (Vigerstol and Aukema, 2011).
Ecosystem service models are designed with more functions than hydrological models. ARIES can identify elements that may reduce provision (Villa et al., 2014) and areas where people benefit from ecosystem services (Vigerstol and Aukema, 2011). EcoServ-GIS originally developed by the Durham Wildlife Trust focuses on mapping ecosystem potential and demand at the county scale (Bellamy et al., 2014). InVEST can incorporate economic valuation (Vorstius and Spray, 2015; Lüke and Hack, 2018). Meanwhile LUCI models ecosystem services condition and can identify where land use change may improve ecosystem service provision (Sharps et al., 2017). RIOS the opensource tool developed by NatCap seeks to identify management actions including protection, maintenance and restoration of ecosystem services, focus is on identifying where the greatest benefits could be generated for the lowest costs (Lüke and Hack, 2018).

Models have varying data requirements which influence their suitability for research. In their comparison of SWAT, InVEST and RIOS, Lüke and Hack (2018) find the SWAT model to require greater input data because it is more complex and models more physically-based processes. In comparison the ecosystem service models of InVEST and ARIES are more flexible in regards to data input (Vorstius and Spray, 2015; Sharps et al., 2017). InVEST is able to operate at different levels of complexity depending on data availability (Vorstius and Spray, 2015). ARIES can model biophysical relationships if abundant data is available, however if not then probabilistic relationships from data of other sites is used (Lüke and Hack, 2018). While the varying data requirements of models makes them suitable for different projects it also hampers comparisons which are necessary for informed modelling choices (Lüke and Hack, 2018).

Data requirements determine where the model can be used. The high data demand of SWAT means it is challenging to use in less developed countries where data is unavailable.
or costly to obtain (Lüke and Hack, 2018). On the contrary, InVEST and RIOS are designed for use in developing counties and use commonly available data (Lüke and Hack, 2018). Sharps et al. (2017) find ARIES to be a good model in data scarce areas as the probabilistic nature means that data gaps can be dealt with, and uncertainty scores given. Ecosystem service models that use commonly available data can be used to conduct comparisons of studies from different climates (Hallouin et al., 2018). It is worth noting that abundant data does not necessarily equate to easy ecosystem service modelling. In the San Pedro river catchment, Bagstad et al. (2013) find that much of the pre-existing data did not meet the input requirements of models.

Input data and model mechanics determine the spatial and temporal resolution of model outputs. Because the hydrological VIC and SWAT models focus on complex patterns of water movement through catchments they model down to the hourly or daily scales respectively (Hallouin et al., 2018). In comparison ecosystem service models including InVEST, ARIES, LUCI and RIOS operate at annual scales (Sharps et al., 2017; Lüke and Hack, 2018). While hydrological models operate at high temporal resolutions their spatial resolutions are comparably larger. SWAT models at the sub-basin scale while VIC can model grid cells from 1km$^2$ to 50km$^2$ (Vigerstol and Aukema, 2011). The spatial scale of ecosystem service models varies and is partly driven by the resolution of data available. RIOS and Eco-Serv-GIS focus on regional scales (Lüke and Hack, 2018; Vorstius and Spray, 2015). InVEST and ARIES have the potential to model down to 30m cell size (Vigerstol and Aukema, 2011) but can also be used to map at local, regional and even global scales (Lüke and Hack, 2018). Even finer, LUCI maps at 5m cell size and is only suitable for modelling fine scale landscape elements (Sharps et al., 2017). Among ecosystem service practitioners there is a preference for tools that model at multiple scales as it is efficient to learn one tool well (Bagstad et al., 2013).
User requirements vary between models. Some ecosystem service models including EcoServ-GIS, InVEST and LUCI can be used by those with basic GIS knowledge (Vorstius and Spray, 2015; Sharps et al., 2017). InVEST is noted to be particularly user friendly by Sharps et al. (2017) as it has a comprehensive manual. In comparison ARIES requires proficient GIS skills (Sharps et al., 2017). Some models like RIOS require users to have catchment knowledge (Lüke and Hack, 2018). As hydrological models focus on the processes which contribute to ecosystem service provision outputs require post-processing to produce service values, this requires extensive user knowledge (Francesconi et al., 2016; Lüke and Hack, 2018). To ensure users can interpret outputs correctly, models should provide uncertainty estimates, only reporting single values can create false confidence of result certainty (Bagstad et al., 2013). As model complexity increases uncertainty also increases, complex models should only be selected when including more biophysical processes is necessary (Hallouin et al., 2018). If complexity is required then a model such as ARIES in which the artificial element acts to reduce uncertainty may be advisable (Vigerstol and Aukema, 2011).

When modelling is proposed time and cost need to be considered. Indeed, Vigerstol and Aukema (2011) recommend pre-evaluation to determine if modelling is worth the investment. Time required to model can vary significantly. Bagstad et al. (2013) compare the potential of ARIES and InVEST to model carbon sequestration, carbon storage and water supply in the San Pedro catchment, it took experienced analysts 275 hours to run InVEST and 800 hours for ARIES. Running SWAT is also time consuming (Lüke and Hack, 2018). With the exception of LUCI, the models discussed above are free to access in some form. However, models which run over longer timescales or require extensive expertise may be expensive to undertake in terms of researcher costs.
While individual models have strengths and weaknesses, there are some overarching limitations of computer modelling ecosystem services. Despite the ability of ecosystem service models to capture multiple services, no model can yet capture the full suite of provisioning, regulating and cultural services deemed to be provided by rivers. Indeed, there is an agreement that models need to better integrate cultural services (Bagstad et al., 2013). The field of modelling is also considered to be limited by a lack of interest in modelling demand (Sharps et al., 2017). All models are limited by the quality and nature of input data. In their research in Patagonia, Pessacg et al. (2015) find variation in precipitation data sets leads to InVEST modelling different water yields. Pessacg et al. (2015) suggest that their results highlight the critical importance of considering uncertainties in the data which is input into models. There have also been calls for greater collaboration between ecosystem service modellers and researchers to allow better integration of data into models (Bagstad et al., 2013).

(ii) Ecosystem Service Capacity Matrices

The most popular non-computerised model for capturing ecosystem services appears to be the ecosystem service ‘capacity matrix’ originally designed by Burkhard et al. (2009) (Jacobs et al., 2015). Burkhard et al. (2009) developed the matrix in recognition of a lack of data appropriate for the quantification and spatial representation of ecosystem services at the landscape scale. The capacity matrix linked different land cover classes to expert judgement of their potentials to provide different ecosystem services (figure 8). Expert scores in boxes ranged from 0-5 with 0 referring to ‘no relevant capacity’ and 5 ‘very high relevant capacity’. Burkhard et al. (2009) describe that expert judgments within their matrix can be seen as hypotheses which require testing. Testing can occur through empirical case-studies which allow ‘maturing’ of the matrix.
Figure 8: Part of the ecosystem service ‘capacity matrix’ designed by Burkhard et al. (2009). On the y-axis Burkhard et al. (2009) place CORNIE land cover classes and on the x-axis ecosystem services

The design of capacity matrices facilitates several benefits which are responsible for their popularity (Campagne et al., 2020). Capacity matrices were originally designed to work in areas with low data creating one of their greatest advantages. Expert-matrices produce semi-quantitative data based on the best available knowledge without requiring the substantive amounts of data needed by biophysical and socio-economic assessments (Jacobs et al., 2015). As matrices do not require extensive data collection, assessments are rapid and efficient (Jacobs et al., 2015). Capacity matrices are adaptable and flexible. Matrices can be frequently updated with the addition of data from field studies and modelling. Land cover types and ecosystem services within matrices can also be updated, since publication Burkhard et al. (2009) has been updated with the addition of geobiophysical data into land cover types and the inclusion of the CICES classification (Jacobs et al., 2015). The approach is flexible as land cover classes and ecosystem services can be selected depending on where research is being conducted (e.g. Campagne et al., 2017). Additionally, the matrix is flexible in terms of spatial and temporal scales of
application (Campagne et al., 2017). Another advantage of capacity matrices is that they focus on multiple services and can include cultural services (e.g. Campagne et al., 2017). The use of standardised scoring means that multiple services including cultural can be compared and synergies/trade-offs identified (Jacobs et al., 2015; Burkhard et al., 2014).

Matrices are attractive for decision makers as they are easy to understand, good communication tools and can bring experts together (Jacobs et al., 2015; Campagne et al., 2017; Harrison et al., 2018).

Capacity matrices are not without criticisms. Indeed, Burkhard et al. (2009) described their matrix as both innovative and vulnerable. There are questions over the scientific credibility, reproducibility and incorporation of uncertainty (Jacobs et al., 2015). In particular uncertainty associated with expert judgement is frequently cited (Hou et al., 2013; Jacobs et al., 2015; Vihervaara et al., 2012; Campagne et al., 2017). Campagne et al. (2017) consider two sources of uncertainty arise from expert-judgement; variability between experts and variability of each expert (confidence in their scores). Variability occurs as scores represent ‘opinions’ which are related to experience, lifestyle and upbringing (Hou et al., 2013; Jacobs et al., 2015). Uncertainty associated with expert judgement reduces confidence in results. Confidence in results is also hampered by a lack of validation of matrix models (Schägner et al., 2013; Jacobs et al., 2015). Capacity matrices have also been marred by practical limitations. Burkhard et al. (2009) recognise that the resolution of CORNIE data at over 100m+ limited map usefulness and potential to investigate local scales. However, recent matrices have focused on the ecosystem service provision of smaller scale landscape features and even genus (Potts et al., 2014; Nordlund et al., 2016). While matrices can include cultural services they do not incorporate all the services considered by the UK NEA. Burkhard et al. (2009) only
included ‘recreation and aesthetic value’ and ‘intrinsic value of biodiversity’ because they considered cultural services to be difficult to grasp.

Several actions have been suggested to improve the robustness and repeatability of matrix assessments. To address the uncertainty Jacobs et al. (2015) recommend providing descriptions of expert backgrounds. Increasing the number of experts increases confidence in results, Campagne et al. (2017) found variation in scores to stabilise when 15 or more experts were involved. Confidence scores are recommended to allow experts to express uncertainties of their own knowledge and are welcomed by experts (Campagne et al., 2017). For example, Campagne et al. asked experts for confidence scores on a three-point scale from 1 (‘I don’t feel comfortable on my score’) to 3 (‘I feel comfortable on my score’). Confidence could also be improved by ensuring matrices can be repeated, to allow repetition researchers should note exact questions, time and place of survey among other details (Jacobs et al., 2015). Over time matrices can be validated through population with quantitative data (Jacobs et al., 2015).

Since the publication of Burkhard et al. (2009) the field of matrix-based ecosystem service quantification has expanded with several variations of matrices being created. In the marine realm Potts et al. (2014) use a capacity matrix to investigate protected area designation and ecosystem service potential. Their technique differs from Burkhard et al. (2009) as scientific literature is combined with expert-based scoring to determine linkages between features and services. Scores in the matrix boxes are then related to level of confidence in evidence supporting the linkage and not perceived potential (see figure 9). The matrix is developed through workshops with drafts posted online allowing peer review throughout the project. This lengthy development helps increase confidence and acceptance of the matrix. Comparatively Potts et al. (2014) operates at a higher
spatial resolution than the above terrestrial research as scores are linked to habitat types. Eastwood et al. (2016) also use the availability of scientific literature to determine confidence scores in their research investigating the impacts of nature conservation on the delivery of ecosystem services in the UK. Of the expert-scoring approaches considered here Eastwood et al. (2016) include the most cultural services (aesthetics, artistic inspiration, cultural heritage, education, religious experience, stewardship and tourism/recreation).

Large and Gilvear (2015) also use a matrix-based approach to investigate river ecosystem services. Here a matrix is created linking river corridor features to ecosystem service provision (figure 10). Unlike Burkhard et al. (2009) this matrix does not rate potential, instead experts simply decide if a feature does or does not contribute to service provision. Large and Gilvear (2015) develop their approach in recognition that there is limited quantitative evidence linking river corridor features to ecosystem service provision. Uniquely, Large and Gilvear (2015) base their assessment on features which can be
identified on Google Earth. Assessment is undertaken at the reach scale with a score of 0-3 given to river corridor features depending on their nature and presence. ‘Individual ecosystem service score’ is the sum of feature scores which the matrix consider contribute to service provision and ‘total ecosystem service score’ is the sum of ‘individual ecosystem service scores’. Scores are produced for consecutive reaches meaning ‘long-profiles’ of potential can be created (figure 11).

Figure 10: The river corridor feature - ecosystem service matrix created by Large and Gilvear (2015)

Figure 11: An ‘ecosystem service long-profile’ for the Yana River, created by plotting ecosystem service scores with distance downstream.
The method of Large and Gilvear (2015) has distinct advantages. The use of Google Earth means the approach is high resolution as small-scale features can be identified. Google Earth is free to download and does not require extensive training to use making the approach inexpensive. Furthermore, Google Earth is considered a good communication tool (Guralnick et al., 2007). The approach is not without limitations. Large and Gilvear (2015) fail to include any cultural services. Assessments are dependent on the quality of imagery; however it is expected that satellite image quality will increase in the future and therefore it makes sense to incorporate such imagery into ecosystem service science. The approach presents no consideration of certainty in relationships underpinning the matrix. Indeed, Large and Gilvear (2015) recognise the need for the matrix to be supported by scientific data focusing on how river corridor features contribute to ecosystem service potential. Large and Gilvear (2015) also consider that the impacts that upstream and downstream features may have on ecosystem service provision need to be incorporated.

3.3 Cultural ecosystem service methodologies

3.3.1 Introducing cultural services

Cultural services seem side-lined in both economic valuation and ecosystem service modelling, acknowledging this and the diversity of cultural services, a detailed review of cultural methodologies is regarded paramount. A brief history of cultural services within the ecosystem service sphere can be seen within section 2.2.3 titled ‘provisioning, regulating and cultural services’.
3.3.2 What cultural services do rivers provide?

Before methods used to capture river cultural services can be reviewed it is necessary to understand what cultural services rivers supply. Cultural services appear the most diverse. To ensure that all possible river cultural services are included in this research, lists presented by other river-based research considering multiple services were synthesised. These are; Straton and Zander (2009), Harrison et al. (2010), UK NEA (Watson et al., 2011), Gutiérrez and Alonso (2013) and Everard and Quinn (2015). To identify similarities between lists colour coding is undertaken (table four). Where a term was only mentioned once it was explored in more detail to see if it was synonymous with another.

All papers consider river environments to provide education, sense of place, recreation, while four of the papers consider rivers to provide aesthetics, spirituality, religious value, tourism. Gutiérrez and Alonso (2013) do not use the term ‘sense of place’ instead list ‘cultural identity and sense of belonging’, however according to literature these are elements of sense of place (Jorgensen and Stedman, 2006; UK NEA, 2011). The term ‘heritage’ is mentioned explicitly three times, however other terms appear synonymous. The UK NEA (2011) mentions ‘history’ and Gutiérrez and Alonso (2013) ‘local ecological knowledge’, on closer examination authors are referring to elements of heritage.
Table 4: Table containing lists of cultural services presented in existing research. A final list is deduced from analysis of these papers. Colour coding is used to determine when services are synonymous.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>• Aesthetic</td>
<td>• Aesthetic values</td>
<td>• History</td>
<td>• Cultural identity and sense of belonging</td>
<td>• Artistic inspiration</td>
<td>1. Aesthetics</td>
<td></td>
</tr>
<tr>
<td>• Educational</td>
<td>• Cultural heritage*</td>
<td>• Religion</td>
<td>• Cultural diversity, cultural heritage and geoheritage values</td>
<td>• Artistic inspiration</td>
<td>2. Artistic inspiration</td>
<td></td>
</tr>
<tr>
<td>• Heritage and sense of place</td>
<td>• Education and inspiration</td>
<td>• Science and education</td>
<td>• Environmental education</td>
<td>• Cultural meanings</td>
<td>3. Cultural heritage</td>
<td></td>
</tr>
<tr>
<td>• Recreational</td>
<td>• Recreation and tourism</td>
<td>• Sense of place</td>
<td>• Landscape-aesthetic values</td>
<td>• Educational values</td>
<td>4. Education</td>
<td></td>
</tr>
<tr>
<td>• Spiritual and inspirational</td>
<td>• Sense of place</td>
<td>• Tourism and recreation</td>
<td>• Local ecological knowledge</td>
<td>• Knowledge systems/knowledge capital</td>
<td>5. Recreation and Tourism</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Spiritual and religious values*</td>
<td></td>
<td>• Recreation and tourism</td>
<td>• Recreation and tourism</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Scientific knowledge</td>
<td>• Sense of place and aesthetic values</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Spiritual and religious values</td>
<td>• Sense of place</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>• Social relations</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>• Spiritual and religious values</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total: 5</td>
<td>Total: 6</td>
<td>Total: 5</td>
<td>Total: 7</td>
<td>Total: 9</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

¹ ME (2005)
² ME (2005)
3.3.3 Explanations and examples of cultural services

Drawing together these papers a final list of cultural ecosystem services potentially provided by river corridors was produced. Some of these ecosystem services appear obscure so the next step in this research is to investigate what the different services are and find examples of them being provided by river environments. Defining cultural services is considered to be a key pre-requisite of assessments (Hernández-Morcillo et al., 2013). Where the service is more obscure more detail on definition is given. When looking for evidence of the service being provided by rivers focus is initially on Scottish rivers, however as mentioned above cultural service literature is lacking so this may not be possible for all services. The outcome of this analysis is lengthy, and therefore presented as table five within appendix one.

3.3.4 Investigating the methodologies used to capture cultural services

After identifying the cultural services provided by river environments the next step is to identify and review the different methods used in their quantification. Initially, research began to look for papers focusing on the above list of cultural services within river environments however it quickly became clear that papers were not abundant. In response the review was expanded to look at the methods used to capture the listed cultural service in any environment. Papers were retrieved by searching the ecosystem service of interest followed by ‘ecosystem service’ e.g. ‘sense of place ecosystem service’ in Web of Science. Papers were retrieved between March and June 2017. For each ecosystem service the aim was to record the method used in the 15 most recent and 15 most cited publications. A maximum of 30 papers was decided due to time constraints, therefore, it is acknowledged that this a not an exhaustive review but a snapshot. Papers were screened to ensure they actually quantified ecosystem service potential, flow or
demand. Methodology categories were not pre-determined but instead an emergent approach was taken, this approach led to 8 methodologies which were used 5 times or more being identified and two other approaches that were used just twice each.

Table 6: Results of WOS literature retrieval. Literature retrieved by searching the ecosystem service of interest and ‘ecosystem service’. Aim was to find 15 most cited and 15 most recent papers for each ecosystem service. Methodologies were categorised using an emergent approach.

<table>
<thead>
<tr>
<th>Ecosystem Service</th>
<th>Rating survey</th>
<th>PPM*</th>
<th>Economic valuation</th>
<th>Frequency of use/feature</th>
<th>Content Analysis</th>
<th>Photo-preference survey</th>
<th>Cartographic data set as proxy</th>
<th>Expert based scoring</th>
<th>Other</th>
<th>Total</th>
<th>Actual Papers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aesthetic value</td>
<td>5</td>
<td>3</td>
<td>7</td>
<td>5</td>
<td>2</td>
<td>8</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>34</td>
<td>30</td>
</tr>
<tr>
<td>Artistic Inspiration</td>
<td>2</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>3</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>7</td>
<td>6</td>
</tr>
<tr>
<td>Heritage</td>
<td>4</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>5</td>
<td>2</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>21</td>
<td>20</td>
</tr>
<tr>
<td>Education</td>
<td>4</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>2</td>
<td>0</td>
<td>17</td>
<td>15</td>
</tr>
<tr>
<td>Scientific Knowledge</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>5</td>
<td>4</td>
</tr>
<tr>
<td>Recreation and Tourism</td>
<td>5</td>
<td>4</td>
<td>9</td>
<td>7</td>
<td>1</td>
<td>2</td>
<td>7</td>
<td>0</td>
<td>1</td>
<td>36</td>
<td>30</td>
</tr>
<tr>
<td>Sense of place</td>
<td>8</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>11</td>
<td>11</td>
</tr>
<tr>
<td>Social relations</td>
<td>4</td>
<td>5</td>
<td>0</td>
<td>2</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>13</td>
<td>10</td>
</tr>
<tr>
<td>Spiritual and Religious</td>
<td>7</td>
<td>3</td>
<td>0</td>
<td>2</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>15</td>
<td>13</td>
</tr>
<tr>
<td>No. of Services</td>
<td>9</td>
<td>8</td>
<td>5</td>
<td>6</td>
<td>8</td>
<td>6</td>
<td>3</td>
<td>3</td>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>40</td>
<td>24</td>
<td>23</td>
<td>21</td>
<td>18</td>
<td>15</td>
<td>9</td>
<td>5</td>
<td>4</td>
<td>159</td>
<td>139</td>
</tr>
</tbody>
</table>

*PPM is an abbreviation for Participative Perception Mapping

The results of the WOS searches are presented in Table six. The most obvious trend discernible from table six is that some ecosystem services have clearly been subject to more frequent capture than others. Looking at the actual number of papers retrieved the
full 30 papers sought were only attained for two of the nine ecosystem services; aesthetic value and recreation. The abundant quantification of recreation is concurrent with the river-based research of Hanna et al., (2017). In contrast to the above findings, Hanna et al. (2017) find aesthetic value to be infrequently captured for river environments with frequency of quantification similar to heritage and education. Of all the services, artistic inspiration and scientific knowledge were the least frequently quantified with just seven and five papers being retrieved respectively. For the rest of the services; heritage, education, sense of place, and spiritual and religious values between 10 and 20 papers were retrieved. In river cultural service research Hanna et al. (2017) find that spiritual and religious values are one of the most poorly quantified services. Although Hanna et al. did not consider the same 9 ecosystem services as this research it could be suggested, based on table six, that the trend in river cultural service quantification differs from that of general literature where environments were pooled.

The following sub-headings explore the different methodologies identified with focus on which services they are used to capture and their merits and weaknesses. Note that when summing the frequency methodologies were used the number is greater than number of actual papers retrieved, this reflects the fact that some papers use a combination of different methods to capture ecosystem services.

(i) Rating surveys

Rating surveys are identified as the most popular method for quantifying cultural services and are the only method found to capture all nine ecosystem services.

Surveys can seek opinions of service provision, preferences for visiting locations and perceived level of service provision. Some surveys are designed to ask multiple questions relating to a single service while others investigate multiple services. Sang et al. (2016)
focus only on aesthetic value and ask people to use a seven-point scale to agree or disagree to a set of statements relating to greenspaces in Gothenburg. In their research developing a tool for capturing cultural services Smith and Ram (2016) also use a seven-point agree-disagree scale but consider multiple services. Statements refer to the reasons people have for visiting certain locations and how they feel when there, for example ‘I came to this landscape for spiritual reasons’ and ‘I feel a strong sense of place in this landscape’. An alternative to agree-disagree statements is to ask respondents the extent they consider an area to provide ecosystem services. Oteros-Rozas et al. (2014) use a four-point scale of nothing – little – some-much in their research on the Conquense Drove Road in Spain. Zagarola et al. (2014) also use this approach but ask people to value perceived service delivery on a numerical 0-10 scale. Rating surveys can also investigate perceived importance of cultural services (e.g. Knez and Eliasson, 2017)

Rating surveys appear suitable for research at multiple scales. In terms of design the number of scale points varies. Soy-Massoni et al. (2016) use a four-point scale while Rall et al. (2017) investigate greenspaces using a 0-100 scale. Here seven-point scales are identified as the most popular (e.g Sang et al., 2016; Smith and Ram, 2016; Knez and Eliasson, 2017). Study area examined by rating surveys also varies in scale. In a relatively large-scale study Smith and Ram (2016) examine different landscape types including desert, seaside and mountains. In contrast Lindenmann-Matthies et al. (2010) asked people to rate the attractiveness of plant pots containing different species composition and richness. Additionally, number of participants varies. McCunn and Gifford (2014) investigate sense of place in neighbourhood communities with 84 participants while Biedenweg et al. (2017) obtain 4418 surveys when looking at sense of place and recreation in the 12,000km² Puget Sound area.
There are several benefits of rating surveys. Rating surveys allow the comparison of multiple cultural services in equitable terms (e.g. Smith and Ram, 2016). Furthermore, rating surveys have been used to compare cultural services with provisioning and regulating. Soy-Massoni et al. (2016) compare cultural, provisioning and regulating services using rating surveys and economic valuation. Using rating Soy-Massoni et al. find aesthetic value to be the second highest valued service after agriculture however economic methods value agriculture highly and aesthetic value lowly. In research on wetlands and rice fields Aiwang’Ondiek et al. (2016) value cultural services with a rating survey and provisioning services with economic valuation, comparison focuses on if values are relatively high or low. Through the inclusion of local communities rating surveys can reveal extensive local knowledge of the use and value of areas (Zagarola et al., 2014). When based on physical attributes there is potential for scaling up and benefits transfer meaning assessments can be conducted in other locations (van Zanten et al., 2016), however often studies focus on locally specific landscape attributes preventing this. Rating surveys also collect socio-demographic data which can highlight potential differences in preferences, for example Sang et al. (2016) found women gave greater aesthetic values to Gothenburg greenspaces.

(ii) Participative perception mapping (PPM)

Participation perception mapping (PPM) is identified here as the second most popular method. With the exception of scientific knowledge PPM is used to capture all cultural services. PPM involves asking individuals to mark on a map locations they consider important for service provision.

A particular benefit of PPM is that its spatial nature allows the identification of synergies, trade-offs and cold spots (Plieninger et al., 2013). For example, Rall et al. (2017) identify
strong correlations between services, for example between spirituality and inspiration. To capitalise on the spatial nature of PPM researchers must choose appropriate scale maps. Maps should not be too high resolution as PPM can be limited by the accuracy of participants marking locations (Hausner et al., 2015) however confining respondents to specific areas may mean places important for services are not identified (e.g. Plieninger et al., 2013). Another great strength of PPM is that it can be used to engage with different groups including land managers, residents and visitors (Brown and Fagerholm, 2015; Ribeiro and Ribeiro, 2016). However, there are questions about the extent PPM can understand tourist values as they are often unfamiliar with locations (van Berkel and Verburg, 2014). Another advantage of PPM is that it can collect other information alongside preferences, for example Hausner et al. (2015) asked people how areas should be managed.

PPM can occur on paper or on screen. Plieninger et al. (2013) pick between three paper methods. Allowing respondents to draw areas onto maps was rejected due to the expensive of digitalising. Using colour-coded dots was also rejected because maps field maps would become messy and complicated. Plieninger et al. (2013) decide to pre-define sites based on land cover type, respondents were asked where on the map they considered each service to be provided, interviewers noted down the land cover type. Ribeiro and Ribeiro (2016) used magnetised maps corresponding to park regions and asked people to place five counters where they felt each ecosystem service was provided. This method of placing dots and markers yields similar results to mapping frequencies of use (Nielsen-Pincus, 2011 in Brown and Fagerholm, 2015).

Specific software programmes are available for on screen PPM. Rall et al. (2017) opt for Maptionnaire in their cultural service research of Berlin. Using Maptionnaire participants
were asked to drop markers onto up to 10 green spaces they consider to be important to them, following placement a pop-up box opened asking users which cultural ecosystem services they consider to be delivered there. On-screen maps have some advantages over paper-based, the interactive nature means people can move around maps, and if zoom is an option high resolution data with good accuracy can be produced. Additionally, because physical dots are not required users can mark unlimited locations (Hausner et al., 2015; Fagerholm et al., 2016). However, on-screen PPM can have software issues which may reduce response rates (Hausner et al., 2015). Indeed, online PPM is reported to have low response rates (Hausner et al., 2015; Brown and Fagerholm, 2015).

(iii) Economic valuation

In agreement with others such as Hanna et al. (2017) this research indicates that economic valuation is not the most popular method for quantifying cultural services. Further in line with other studies (e.g Milcu et al., 2013) it is found that economic valuation is particularly popular in capturing recreation and tourism (9) and aesthetic value (7). However, this research finds that economic methods are adopted to capture other services. In the case of heritage Barrena et al. (2014) use WTP however both Gandarillas et al. (2016) and Vasquez et al. (2013) use Willingness-to-Work. Gandarillas et al. (2016) use willingness-to-work to reduce the high number of zero values that may have been given due to the study area of Sajama National Park being subject to poverty. In Spain Soy-Massoni et al. (2016) assess multiple ecosystem services including environmental education using a combination of a rating survey and WTP. In contrast with other research (e.g. Langemeyer et al., 2015) environmental education was valued greater using monetary valuation than non-monetary. Soy-Massoni et al. (2016) suggest this may be due to an increase in people finding it acceptable to pay for activities linked
to environmental education such as entrance to Natural Parks. Martin-López et al. (2014) also use a two-pronged methodology in the research of the Doñana socio-ecological system of South West Spain. For scientific knowledge the number of published papers is used as an indicator for biophysical assessment while the economic value is estimated from public investments.

Issues with the economic valuation of cultural services have already been touched upon in section 2.2.3, to reiterate, these include difficulties in undertaking valuation and moral objections. Economic valuation of cultural services is blighted by the same practical limitations of conducting economic valuation for provisioning and regulating services including being expensive, time consuming, data demanding and non-transferable (Hanley et al., 2006; Spash et al., 2009; Vermatt et al., 2016). The economic valuation of cultural services is morally rejected because services are viewed incommensurable (Chan et al., 2011; Gómez-Baggethun and Ruiz-Pérez, 2011) and fears of motivational corruption exist (Neuteleers, and Engelen, 2015).

(iv) Frequency of use/feature

To reduce the number of categories frequency of use and feature are grouped together. Frequency of use refers to a metric where the number of visitors or times someone visits an area is counted. Frequency of feature is when certain built or natural features are counted.

This research identified three methods for determining frequency of use. Observation and counting, surveys and geotagged images. Observation and counting has been used for recreation, social relations and education (Hein et al., 2006; Campbell et al., 2016). Observational counting is suited to small study areas where researchers can count effectively. This method is relatively cheap as aside from a surveyor/surveyors few
resources are required. Counting is however time consuming, and based on research objectives may need to take place under different weather conditions, during different times of the day and over different seasons.

Surveys capture social relations, recreation and spiritual/religious values (Knez and Eliasson, 2017; Branclion et al., year). Surveys require extensive pre-planning, questions must suit survey purpose and effort is required to reach target populations. However, surveys may be quicker to obtain results in comparison to observations, additionally surveys may be better when study areas are larger.

Using geotagged photographs appears the most popular frequency of use method (Caselegno et al., 2013; Figueroa-Alfaro and Tang, 2017; Yoshimura and Hiura, 2017; Sonter et al., 2016). Similar to the other frequency of use approaches geotagged images offer a free data source with processing being comparatively inexpensive and fast (Richards and Friess, 2015). Geotagged images offer the potential to investigate temporal patterns as photos are constantly uploaded and dated (Figueroa-Alfaro and Tang, 2017). Geotagged images can also be used to reveal public preferences allowing incorporation into management (Figueroa-Alfaro and Tang, 2017; Pastur et al., 2016). However, there are limitations. Currently geo-tagged images can only quantify some of the cultural services provided by rivers. Researchers must be aware that there is a bias in the group of people who upload photographs (Tenerelli et al., 2016). There is also a question of representativeness as photos uploaded only represent a small amount of those which are taken (Figueroa-Alfaro and Tang, 2017). Additionally, the use of geo-tagged images is limited where there is low photo availability (Pastur et al., 2016; Oteros-Rozas et al., 2018).
Frequency of feature is a measure of potential and is used to determine cultural heritage, tourism, educational value and religious/spiritual value (Felepné et al., 2014; Bieling and Plieninger, 2012; Rova et al., 2015; Eliff and Kikuchi, 2017; Felipe-Lucia and Comin, 2015). Different features are counted for different services, for example Felipe-Lucia and Comin (2015) count educational panels for education while a Bieling and Plieninger (2012) count a Christmas tree plantation for religious/spiritual services. Frequency of feature is also best conducted at the small scale and is inexpensive. This approach is unsuitable for landscapes with dense vegetation which may obscure features (Bieling and Plieninger, 2012). A fundamental flaw of this approach is that just because a feature is present it does not mean people engage with it and experience services.

(v) **Content analysis**

Content analysis is used to quantify aesthetic value, inspiration, cultural heritage, recreation and tourism, sense of place, social relations and spiritual/religious values. Content analysis can be performed on different types of information including photographs, surveys and interview outputs, short stories and historical achieves. Ecosystem services are quantified based on the number of times a service is identified within content.

The most popular type of content analysis is conducted on photographs (Pastur et al., 2016; Yoshimura and Hiura, 2017; Thiagarajah et al., 2015; Oteros-Rozas et al., 2018; Khakzad and Griffith, 2016). In particular the analysis of geotagged images is prevalent. Analysis of geotagged photos can involve categorising photo content (e.g. Pastur et al., 2016) or categorising based on hashtags (e.g Thiagarajah et al., 2015). Undertaking content analysis of geotagged images allows the mapping of multiple ecosystem services (Pastur et al., 2016). In an alternative approach Khakzad and Griffith (2016) give cameras
to residents in their research looking at sense of place, this approach is suitable for sense of place research as respondents require a pre-existing connection to the place. An advantage of photo-based content analysis is that it can be performed on historical images allowing comparisons of past and present (e.g. Thiagarajah et al., 2015).

Another popular method is content analysis of surveys and interviews (Gould et al., 2014; Fletcher et al., 2014; Thiagarajah et al., 2015 Campbell et al., 2016; Khakzad and Griffith, 2016). Interviews and surveys can either be conducted specifically for the research project or historical oral interviews can be used (Thiagarajah et al., 2015). Content analysis of interviews and surveys is similar to using photo hashtags, researchers code phrases relating to ecosystem services and note their frequency. An advantage of using surveys and interviews over geotagged photos is that researchers have greater control over survey population (e.g Fletcher et al., 2014). However, content analysis of interviews and surveys can be more time consuming as surveys need to be designed and interviews conducted which take time. Additionally, compared to geotagged photos data collected from interviews and questionnaires is likely to be limited to a snapshot in time unless repeats are conducted or decent historical archives are present (e.g. Thiagarajah et al., 2015).

A novel method worth mentioning is the content analysis of short stories undertaken by Bieling (2014). In the Swabian Alb biosphere service of Germany a short story competition was run, people were asked to submit stories focusing on: what is special about the area, which places are special, what are residents of the area like and how will life in the Swabian Alb be in 2020. Coding is undertaken to quantify the number of times each ecosystem services is mentioned but this approach also reveals much more. Responses are not pre-structured meaning people are allowed to openly express their
connections and feelings eluding to why services are valued. While this approach is interesting results have limited meaning as writing stories as a way to express their views is likely to appeal only to a certain group of people.

**(vi) Photo-preference survey**

Photo-preference surveys are rating surveys that use photographs as visual stimuli. Photo-preference surveys share the characteristics of rating surveys including the use of different size scales, varying study extents and different target populations. As a method photo-preference surveys are one of the less popular methods. Photo-preference surveys are most commonly used to capture aesthetic value but are also used to capture artistic inspiration, cultural heritage, education, scientific knowledge, and recreation/tourism.

There are benefits associated with conducting photo-based preference surveys but also potential limitations and sources of error. Using photographs can help people understand the multiple benefits that ecosystems provide (López-Santiago et al., 2014). Photographs are engaging as they trigger emotional responses, in their study in The Netherlands van Berkel and Verburg (2014) participants commented on how they enjoyed the experience of comparing and ranking images. Photo-elicitation can create support restoration actions, though their photo-preference work Southon et al. (2017) find that there is great support for planting meadows in urban green spaces. Similar to rating surveys socio-demographic data can be collected alongside to help understand preferences, for example Southon et al. (2017) find that meadows were preferred by those who frequently visited the countryside. Photo-preference surveys have been found to yield similar results to field-based assessments (e.g. Stamps, 1999; Palmer and Hoffman, 2001 both cited in Zoderer et al., 2016b) making them attractive to researchers such as Zoderer et al. (2016b) because they can be conducted in less time, additionally distributing surveys
online may save money. If preferences are collected at the landscape scale then there is potential for cultural services to be mapped by superimposing scores onto landscape maps (van Berkel and Verburg, 2014; Zoderer et al., 2016b).

One of the biggest potential limitations of photo-based preference surveys is that users can be influenced by the photographs chosen and bias potentially introduced (Gosal et al., 2018). Bias can be reduced though a number of means. Research has found there to be a ‘clear sky’ effect where participants prefer photographs with sunny clear skies. To avoid the ‘clear sky’ effect Zoderer et al. (2016b) ensure that all photographs used were taken in the summer under the same weather and light. In their research of alpine landscapes Schirpke et al. (2016) also ensured all photographs were taken on sunny days and preformed exposure correction if necessary but acknowledge there was some variation in cloud pattern and this may have hampered their research. Another method use to ensure consistency is to take one photograph and manipulate it using software. For agricultural landscapes van Zanten et al. (2016) manipulate single photographs for each study location using Adobe Photoshop by altering the presence of livestock, diversity of agricultural land cover, prevalence of green linear elements and of point elements. To ensure that photographs are representative multiple photographs of the same landscape features can be used (e.g. van Berkel and Verburg, 2014). Selecting the number of photographs to be use can be challenging, on one hand researchers want to ensure representativeness and that small scale features are included but must also be cautious not to use too many photographs as this may lead to fatigue (Schirpke et al., 2016). Landscape detail may be sacrificed in order to improve survey usability and completion, for example Zoderer et al. (2016b) keep their survey short by dropping landscapes that occupy a small percentage area.
(vii) Cartographic data as proxies

One of the less popular methods identified in this research is the use of existing spatial cartographic data sets to map ecosystem service potential. In this approach values for ecosystem service provision are linked to the properties of existing data sets. Here this method is found to capture aesthetics, heritage and most frequently tourism and recreation.

A range of different cartographic data have been used to map cultural services with the number of attributes selected varying between research projects. García-Nieto et al. (2013) only use the one proxy of ‘number of prey’ in their mapping of recreational hunting potential in the Sierra Nevada Mountains of Spain. In their mapping of recreation in California Chan et al. (2006) only select two attributes; amount of natural and semi-natural habitat and accessibility. Other researchers choose multiple proxies. In Southern Chile Nahuelhual et al. (2013) select five attributes to map tourism; presence/absence of natural resources, accessibility, scenic beauty, tourism use aptitude and tourism attraction potential. Casado-Arzuaga et al. (2014) use even more attributes to map aesthetic and recreation potential in Spain, 10 different GIS data sets including land cover, naturalness, bathing water quality, recreational sites and diversity of landscapes.

Key to the success of mapping using cartographic proxies is ensuring they are appropriate. An example of where poor proxies are selected is Casalengo et al. (2014). Casalengo et al. (2014) map recreation in Cornwall using data on the number of parks, gardens and golf courses in 1x1km$^2$ grid cells. One must question how representative the proxies are, does recreation in Cornwall just occur in parks, gardens and golf courses, what about the sea, rivers, estuaries and walking trails? Different methods have been used to improve the appropriateness of proxies selected. Both Nahuelhual et al. (2013)
and Van der Zanden et al. (2017) involve experts in the selection of cartographic data to ensure proxies are appropriate. Casado-Arzuaga (2014) validate their maps by collecting public participation data in the form of frequency of visitation and a photo-preference survey. Validation finds correlation of $r = 0.71$ between recreation provision from GIS map and frequency of visitation and $r = 0.77$ between GIS map and photo-questionnaire data for aesthetic value.

Using existing data sets to map cultural services with GIS enables patterns of cultural services to be compared with regulating and provisioning (e.g. Chan et al., 2006; Nahuelhual et al., 2013; Casalengo et al., 2014). For example, in Cornwall Casalegno et al. (2014) map tourism, recreation and aesthetic value alongside agriculture, soil carbon, aboveground carbon, flood mitigation and plant production at the 1x1km$^2$ scale. Mapping multiple services allows the identification of hotspots and trade-offs. For example Casalengo et al. find areas important for recreation to also deliver high levels of natural flood mitigation and carbon storage.

As with all methodologies there are some limitations. The approach can be constrained by data availability (Casado-Arzuaga, 2014). When suitable data sets are available their usefulness can be impeded by how frequently they are updated and how up to date they are (Nahuelhual et al., 2013). Indeed, the limited availability of data means some research produces maps with data relating to a combination of actual and potential service provision. For three of seven ecosystem services including cultural heritage Willemen et al. (2010) map actual provision based on land cover data and policy documents while four other services are mapped using landscape function data. Such maps may be confusing to understand. Another potential caveat of this approach is that it requires users which are proficient in GIS (Casado-Arzuaga, 2014). Perhaps the greatest limitation
of this approach is that currently it appears it cannot be used to capture the full range of cultural services considered to be provided by river environments.

(viii) Expert-based scoring

Expert-based scoring is one of the least popular methods identified to capture cultural services. The method is found here to capture aesthetics, education, recreation and spirituality/religious values. Expert-based scoring refers to the assigning of scores to perceived ecosystem service potential.

This approach has been undertaken using a variety of techniques and at a range of scales. At the landscape scale Vigl et al. (2017) ask experts from three backgrounds (ecological, social and geophysical science) to rank the aesthetic potential of different landscapes on a scale of 0 (no capacity) to 5 (very high capacity). Vigl et al. (2017) find that forest, grassland and pasture landscapes have high aesthetic potential as determined by experts while landscapes with high levels of anthropogenic land use were assigned low aesthetic potential. In their assessment of provisioning, regulating and cultural services in the Lake Biwa Region of Japan Chen et al. (2017) use expert judgement in their combination of indicators. Expert judgement is undertaken to capture environmental education values, judgement is based on the importance and influence of past events including publication of educational material and founding of environmental museums and organisations.

On the more local scale expert-based scoring is undertaken by More and Hunt (2010) and Radford and James (2013). More and Hunt (2010) use expert-based scoring to assess the potential for recreation and education from stormwater wetlands and ponds in North Carolina. More and Hunt first identify features which are important for ES provisioning. For recreation these are accessibility and recreation infrastructure and for education proximity to schools/education centres, historical education use and presence of
education infrastructure. Based on the nature and quality of these features ecosystem service scores are assigned, scores range from 0 (poor provision) to 4 (high service provision). Radford and James (2013) investigate ecosystem services including aesthetics and spiritual/religious values along a rural-urban gradient in Greater Manchester. Assessment is based on the Residential Environment Assessment Tool (REAT) (Dunstan et al., 2005). REAT bases the quality of the urban environment on five components (physical incivilities, territorial function/personal investment, defensible space, natural environment and miscellaneous), within these components are a number of indicators which Radford and James (2013) assign to relevant ecosystem services. Scores are then produced during a field survey where the observer rates indicators on a scale of 0-10 with 0 represent lowest quality and 10 highest quality. Using the approach Radford and James (2013) find both spiritual and aesthetic services are recorded to decline from rural – urban.

The significant advantage of this approach is that is allows ecosystem services for which there are no obvious proxies to be included in assessments. For example, Radford and James (2013) use expert-based scoring because they find economic methods are unsuitable for investigation of the urban environment and most alternative methods focus on more natural areas such as national parks. Using expert-based scoring means there is the option to compare intangible cultural services with tangible provisioning and regulating as demonstrated by Chen et al. (2017). Authors seem to regard expert-based scoring as a relatively simple and rapid approach to undertake (Radford and James, 2013; Vigl et al., 2017). However, both large- and small-scale assessments can be subject to limitations. Vigl et al. (2017) consider that the landscape scale approach they performed is limited because it does not account for landscape seasonality; seasonality significantly alters Italian mountain landscapes which are snowy in the winter and meadows in the
summer. Meanwhile the small-scale infield approach of Radford and James (2013) is limited to areas which can be accessed.

(ix) Other Approaches: Modelling and Academic Outputs

The two least frequently used methods are ecosystem service modelling and the quantification based on number of scientific publications. Ecosystem service modelling is used to capture aesthetics and tourism while the number of scientific publications is only appropriate for capturing scientific knowledge.

Bagstad et al. (2016) use modelling to compare maps of perceived and biophysically modelled ecosystem services including aesthetics in the Pike-San Isabel National Forest of the Rocky Mountains. To map perceived ecosystem services values Bagstad et al. (2016) use the Social Value for Ecosystem Services (SoLVES) 2.0 tool which utilises data collected from mail surveys. In the case of aesthetics the survey first used a rating question asking people ‘I value these forests because I enjoy the scenery, sights, sounds, smells etc’, respondents were then asked to map on a map where they considered aesthetic value to be high. Biophysical modelling is conducted using the Artificial Intelligence for Ecosystem Services (ARIES) model. To model aesthetic value a Bayesian model of viewshed quality was used. Chen and Wang (2009) model ecosystem services in the Tiantai County of China. In their attempt to model ecosystem service demand Chen and Wang (2009) attempt to create a model for mapping the direct economic value of ecosystem services in the Tiantai County of China. Modelling for tourism is based on entrance fees, a scenic spot map and a digital elevation model. Chen and Wang (2009) use entrance fees despite the fact they recognise it’s a controversial indicator because they are only interested in testing the technique and not producing exact and reliable data.
Modelling can be extremely useful as it spatially represents patterns of ecosystem service provision allowing ecosystem service hotspots to be identified (Chen and Wang, 2009; Bagstad et al., 2016). However, in the case of cultural services it seems modelling is not currently an available option for most services. An additional limitation of modelling is that output quality and usefulness depend on the availability of high resolution data (Bagstad et al., 2016).

A niche approach only used to capture scientific knowledge is quantification based on number of academic publications and or important conferences (Chen et al., 2017; Matrín-López et al., 2014). Scientific knowledge is difficult to capture, quantification of papers and conferences appears to be one of the only way of measuring research output. However, conferences and papers may be more prevalent in areas close to universities and with relatively easy access.

3.4 Deciding on a methodology

So far this chapter has focused on reviewing the methodologies used to capture river ecosystem services, now attention turns to selecting an approach suitable for achieving the overarching research aim. Indeed, to assist in the selection of methodologies it makes sense to think back to the research question and how it may be answered. The aim is to determine if ecosystem service provision differs between Scottish river corridors with and without nature designations. A logical approach to addressing this question is using a paired approach. The paired approach is demonstrated by Eastwood et al. (2016) and is a common approach taken for river studies (e.g. Merritt and Cooper, 2000; Brooks et al., 2003; Lara et al., 2009; Ebabu et al., 2018; Schenk, 2020). This approach overcomes the issue of having no pre-protection baseline data by comparing a protected area to a similar unprotected area (Ferraro et al., 2015). Using this approach designated and
undesignated rivers with similar characteristics including climate, location and catchment size will be compared. To select a methodology, first the methods used to capture provisioning and regulating services were pitted against each other. Cultural methodologies were then examined to see which would be the most suitable for the research aim and integrate best into the chosen provisioning and regulating methodology.

### 3.4.1 Provisioning and regulating methodology

Economic valuation is the original method used for quantifying ecosystem services but has many limitations which make it unfavourable for this research. The approach is poor at capturing multiple services which is incompatible with the research aim of determining if ecosystem service provision differs between Scottish river corridors with and without nature designations. Of more concern, however, is the opposition to using the approach arising from questions of its moral appropriateness. Monetary valuation is seen as morally wrong for several reasons; it leads to the commodification of nature, can cause motivational corruption and is deeply anthropocentric. Within ecosystem service research there have been calls to move away from the economic approach (Chan et al., 2012). Furthermore, in terms of practical application, the expense and time-consuming nature of the approach make it unattractive for a PhD project.

Unlike economic valuation there are no moral objections to modelling of ecosystem services. Those considering modelling freshwater services are faced with a plethora of models, key to the success of modelling appears to be the selection of an appropriate model. The question therefore is, which model, if any, would be suitable for this research project? Computer models used for freshwater services have been developed through two branches of science; hydrological and ecosystem service. Hydrological models have
a longer history of development and peer review but appear less suitable for this research project. Hydrological models such as SWAT and VIC require large data inputs, data post-processing, only model a few services and operate at comparably high spatial resolutions. Comparatively ecosystem service models are more diverse, but is there an ecosystem service model suitable for this research? Of all the ecosystem service models discussed InVEST is the most attractive. InVEST uses commonly available data, does not require extensive GIS knowledge, provides a user manual, models down to 30m cell size and provides user friendly outputs. Additionally, compared to the other more popular ecosystem service model of ARIES InVEST takes less time to undertake. However, despite the strengths of InVEST it can currently only model some of the ecosystem services texts including the UK NEA and Harrison et al. (2010) consider river environments to provide.

Of the provisioning and regulating methods considered, capacity matrix models capture the most ecosystem services. Burkhard et al. (2009) capture 22 services in their capacity matrix while the matrices developed by Campagne et al. (2017) between 17 and 25. As matrices use standardised scoring multiple services including cultural can be spatially compared allowing the identification of synergies and trade-offs. Another benefit of matrices is that they are designed to be used in areas with poor data availability which may be the case for remote areas of Scotland. A further positive of capacity matrices is that they can bring together experts from different fields of ecosystem service research. However, there are some serious questions about the uncertainty and reliability of expert judgement. The approach of Potts et al. (2014) who base scores on availability of supporting empirical evidence offers a way of reducing some of the uncertainty and improving robustness associated with capacity matrices. This research could adopt a similar approach where matrix boxes are populated with empirical evidence supporting
linkages between river features and service provision. Large and Gilvear (2015) present a river ecosystem service matrix which could be a starting point for this research.

The matrix of Large and Gilvear (2015) is based on river corridor features which can be identified on Google Earth. Google Earth seems a sensible platform for this research too. Firstly, Google Earth is free to download and does not require extensive training to operate. Large and Gilvear (2015) consider their approach could be undertaken by undergraduates with experience of fine scale landscape interpretation and aerial imagery. Comparatively Google Earth offers the potential for high resolution studies. ARIES and InVEST can map down to 30m cells, but Google Earth can identify river features at the meter scale (figure 12). Large and Gilvear (2015) remark that assessment may be challenging in some locations as currently Google Earth image quality varies spatially. However, it is expected that new images will be uploaded making an approach based on Google Earth suitable for use in the future alongside the present. Another benefit of using Google Earth worth mentioning is its ability to act as a communication tool, this will be useful when disseminating results.

Figure 12: Google Earth Image of the River Forth north of Stirling, image clearly shows small scale river corridor features including gravel bars, adjacent woodland, agriculture and wetland.
3.4.2 Cultural Methodology

Adapting the approach of Large and Gilvear (2015) seems appropriate for capturing provisioning and regulating services. The challenge then is to integrate multiple cultural services. Other matrices have included cultural services using expert judgment, however if the plan is to use scientific literature to support linkages between features and ecosystem services then to improve robustness, cultural services linkages should also be based on more than expert judgement.

The first logical step in selecting a cultural methodology is to rule out those niche approaches which are designed only to capture specific services. Niche approaches identified include; quantification based on number of scientific publications, computer based ecosystem service modelling and the use of cartographic data. Ruling out the niche approaches turns the focus to those methodologies used in the capture of many, but not all services. These methods are; economic valuation, frequency of use/feature, content analysis, participative perception mapping, rating surveys and photo-preference surveys.

Immediately economic valuation can be ruled out as it is deemed morally wrong for some cultural services. Additional limitations of economic valuation have been highlighted above.

Frequency of use/feature is used to capture 6 of the 9 ecosystems services including some often cited as challenging including social relations and education. Counting features seems incompatible with the intended matrix approach which is seeking to support feature- ecosystem service relationships. Frequency of use data is obtained through quantification of geo-tagged photographs, observations and surveys. Using a metric of photo frequency or density from geo-tagged photographs is unsuitable as the method is bias towards the quantification of aesthetic value and tourism and recreation. To fill a
feature-matrix with observation data seems challenging. Visible manifestations of the services must be identified, for services such as recreation this might be easy, while services like inspiration and spirituality would be difficult to identify without engaging with individuals. Additionally, observations are time consuming. Surveys can ask people how frequently they experience services from study locations, this approach is also incompatible with a matrix which focuses on land cover features and not specific locations.

Content analysis is identified to capture eight of nine cultural services. Content analysis can be undertaken on photographs, interviews, short stories and historical archives. Content analysis of geo-tagged photographs appears the most popular, services can be quantified based on the frequency they appear in photographs or hashtags. As photographs can be uploaded onto Google Earth this method was given consideration. However, unfortunately in Scotland this option seems unviable as there are few river orientated photographs uploaded onto Google Earth. It is difficult to envisage how the content analysis of interviews would capture information relating to multiple river corridor features. Typically, content analysis gathers information from a few open questions whereas for this research a question for each river corridor feature would be required creating lengthy surveys. Asking for short stories would be time consuming for participants. Trawling through historical archives would present a picture of the past, not present. Although content analysis seems unsuitable for this research it clearly has value in the ecosystem service paradigm as it reveals how people experience cultural services.

Participative perception mapping is also used to capture eight services. PPM involves asking people to mark on a map areas they consider important for the provision of ecosystem services. PPM certainly has properties which make it viable and attractive to
use. The spatial nature makes it complementary to the use of Google Earth and allows for the identification of potential trade-offs and synergies. The approach is described as inclusive and engaging. Also, PPM can be repeated allowing the identification of temporal trends. PPM could be conducted for each study river however it would be an ‘add on’, every time an assessment is undertaken PPM must also be. This is because the approach is river specific, findings would not be transferable. Depending on how many study pairs are chosen PPM could be time consuming and require lots of participants.

Rating surveys are the most popular methodology identified. Rating surveys seek information on people’s preferences and opinions. Surveys focus on perceived level of service provision or preferences for visiting locations. Using a rating survey to fill in a cultural matrix sounds attractive as it is the only method identified to capture all cultural ecosystem services. As rating surveys capture all nine services it means they can be compared in equitable terms. Additionally, some research has used rating surveys in the comparison of provisioning, regulating and cultural services, the only other approach to attempt this is capacity matrices. Another benefit is that rating approaches can also elicit local knowledge and feelings. Furthermore, rating surveys can collect socio-demographic information which can assist in analysis.

The focus of rating surveys determines if results can be transferable. Those focusing on generic landscape features can be ported elsewhere and potentially applied to different scales. In contrast, some seek preferences for specific locations or locally specific landscape attributes meaning results cannot be easily applied to other areas. If a rating survey is used here, it would make sense to base it on river corridor features that can be identified on Google Earth, this would enable results to be incorporated into a capacity matrix for Scottish rivers. In particular a photo-rating survey seems preferable for this
research. Photo-based surveys yield similar results to field assessments but can be more efficient as they are sent via post or conducted online. Additionally, respondents have reported to enjoy photo-surveys. To capture cultural service potential this research could use a photo-survey where participants are asked to rate their perceived service provision of river corridor features represented by photographs. Where people indicate a feature contributes to a service, matrix boxes could be filled in.

3.5 Conclusion

This chapter has reviewed the methods available for capturing river ecosystem services in order to decide on a method suitable for determining the service potential of Scottish rivers with conservation designations. Initially methods used to capture provisioning and regulating services were explored. Of those methods, a capacity matrix approach based on Google Earth seems to be most suitable for this PhD research project. Cultural services have been excluded in many past ecosystem service projects, determined not to do that, an extensive review of the methods used to capture cultural services was conducted. Although it appears there are more cultural methods available, this does not equate to more choice of methodology as many of these techniques are niche. Of all the cultural approaches considered it seems that a photo-based rating survey is the best method to integrate into the capacity matrix for cultural services.
4.1 Introduction: The creation of GE RES

Following the preceding extensive review of the methods available to capture river corridor ecosystem services, the matrix model approach is regarded as most suitable for determining if ecosystem service potential differs between protected and unprotected rivers. Over the next two chapters, a new tool called the Google Earth River Ecosystem Service Tool (GE RES) is created. GE RES is created in two parts, which will be integrated together. This chapter details the development of the first element, the creation of a robust matrix suitable for investigating provisioning and regulating ecosystem service potential.

It is worth mentioning that the matrix being developed here is focusing on ecosystem service potential, it is important to make this clear as early matrices (e.g. Burkhard et al., 2009; Burkhard et al., 2012) did not differentiate between potential/capacity and flow (Burkhard et al., 2014).

Before the framework of the matrix is tackled, the desired properties of the matrix are considered. These properties include vertical and lateral assessment scale, incorporation of trade-off relationships, and acknowledgement of uncertainty. Following consideration of how the matrix should operate, focus is shifted to developing a matrix for provisioning and regulating services. Logically, this initially involved deciding which services and features should be included for assessment of Scottish river corridors.

On establishment of the framework the next step and big challenge was to populate the capacity matrix. As outlined previously, for provisioning and regulating services,
empirical studies published in academic literature will populate the capacity matrix. Supporting matrix linkages with empirical studies is key to providing a robust methodology, by relying on more than expert-opinion the validity of the matrix is improved (Jacobs et al., 2015; Maebe et al., 2019; Campagne et al., 2020).

The populated matrix will then be integrated with a cultural service matrix to create the Excel-based GE RES tool where information on the presence of river corridor features is input, and measures of ecosystem service potential are output. The creation of the Excel-based GE RES tool is outlined at the end of chapter five, section 5.6 titled ‘Creating an Excel tool from the matrices.

### 4.2 Creating GE RES – decisions and desired properties

#### 4.2.1 Determining assessment scale

One of the first steps in developing a Google Earth based tool for capturing river ecosystem services is to decide the scale at which it should operate. Decisions need to be made in terms of both vertical and lateral scale.

**(i) Longitudinal scale**

Selecting vertical scale of assessment is a balance. If assessment scale is too coarse then areas of potential hotspots and trade-offs may go undetected while a too fine scale may make assessment lengthy and undesirable to conduct. In their research Large and Gilvear (2015) assess individual reaches with reach size depending on river length, a minimum reach length of 500m is suggested and a largest length of 10km is used on the 872km Yana River. Clearly using reaches of 10km would produce a low-resolution assessment of Scottish river corridors. Using the approach of Eastwood et al. (2016) which had a similar research aim to this project would also produce a low-detail assessments as the authors conducted the paired assessment on whole river lengths.
Outside of ecosystem service literature, a popular method for determining reach length is to normalise reach lengths as a function of channel-width, functions of channel width are chosen because channel width is the lowest limiting scale unit of river channel pattern (Nikora, 1991; Church, 2007 both in Egozi and Ashmore, 2008). Functions of river width have been used to determine reach length for both geomorphic and biological studies. Studies focusing on appropriate reach length for biological sampling report large variation in recommended river-width functions to be necessary for successfully capturing assemblages present. In aquatic fish monitoring Paller (1995) find sampling reach lengths of between 35-158 stream widths to be required to collect all species present, while Angermeier and Smogor (1995) find between 22-67 stream widths necessary, and Lyons (1992) found an average of 35 times to be required.

Within fluvial geomorphology a common channel-width function used to define reach lengths is 20 times the channel width, however the origin of this ‘20’ times seems unclear. Researchers use 20 times channel width to define study reaches but do not justify their choice (e.g. May et al., 2013). Some papers including Brardinoni and Hassan (2007) and Nitsche et al. (2012) cite Montgomery and Buffington (1997) as their source for using 20 times channel width. On reading Montgomery and Buffington (1997) it becomes apparent that their justification for reach length is based on expert opinion and not a wealth of quantitative data:

“…channel reaches of at least 10 to 20 times channel widths in length define a useful scale over which to relate stream morphology to channel processes, response potential, and habitat characteristics” –Montgomery and Buffington (1997, p. 596)

Other papers that have been cited to justify the choice of reach lengths 20 times the channel width include Harrelson et al. (1994) and Montgomery et al. (1995) (both cited by Levell and Chang, 2008). However, on closer inspection it becomes clear that as with
Montgomery and Buffington (1997) these references also do not contain quantitative evidence to explain their choice of channel width multiplier. Indeed, Egozi and Ashmore (2008) highlight that in many studies there is limited justification for the selection of reach length used for analysis.

Alongside significant diversity in reach-length proposed for biological studies and the lack of justification for different functions of channel width in fluvial geomorphology there are other limitations and practicalities of using a channel-width based approach. Ideally bankfull width should be used to calculate reach length (Bunte et al., 2009), however collecting bankfull field data is incompatible with the remote design of this tool. Using wetted width is advised against as changes in flow would lead to changes in reach length size hampering potential comparisons (Bunte et al., 2009). Additionally basing reach length on channel width is found to be inappropriate in geomorphologically altered reaches (Flotemersch et al., 2006) which are present in Scotland (Gilvear and Winterbottom, 1992).

Pizzuto et al. (2000) demonstrate the impact that human-induced geomorphic alteration can have on river width, in their comparison of paired gravel-bed channels in urban and rural areas of Pennsylvania, median channel width is found to be 26% greater in urban channels. Critically for this research the idea of using channel width to determine reach length is not favoured because if reach lengths are different across rivers this hampers comparisons between protected and unprotected rivers. Indeed, Large and Gilvear (2015) advised against basing reach length on a ratio of channel width to river length as this would lead to challenges in comparing rivers. Basing reach length on homogenous hydromorphic units such as the research of Van Looy et al. (2017) would also lead to comparison challenges. In their research investigating riparian ecosystem services and
potential management in the Brasse region of France, homogenous hydromorphic reaches are defined based on landuse and hydrological data and range in size from 0.8 to 8km.

It therefore seemed more appropriate for the Google Earth based tool developed for this research to operate using fixed length reaches. Using fixed length reaches will allow relatively easy comparison between rivers with and without designations.

The next decision involves deciding what length reaches should be. In their original research Large and Gilvear (2015) set minimum reach length to 500m to allow data to pair with other indices available such as the River Habitat Survey (RHS). Developing the tool to work with 500m reaches seems a good idea. Working at a scale of 500m seems sufficient to capture the features of small headwater streams and larger order rivers without being too time exhaustive. The longest river in Scotland is the Tay at 188km, using a 500m reach length would mean 376 total reaches which seems achievable. Using the same reach length as the RHS seems advisable in Scotland since there is a wealth of RHS data available (see http://www.riverhabitatsurvey.org/map-open-os/) which could be included or compared with. Fixed length reaches have been used in other research. In their paper looking at sampling protocols for the bioassessment of macroinvertebrate assemblage, Blocksom and Flotemersch (2008) advocate using fixed-length 500m reaches because longer reaches may mute stressor signals preventing their detection.

(ii) Lateral Scale

Large and Gilvear (2015) recognise that river environments consist of landscape patch mosaics which have longitudinal, lateral, and vertical connectivity with river channels (Poole et al., 2002; Newson and Large, 2006; Vaughan et al., 2009). Connectivity through fluxes of water, sediment, and nutrients shapes both adjacent landscape patches and river
channels (Thorpe et al., 2006). Thus, river ecosystem services are provided by river channels and the adjacent patches they connect with (Thorpe et al., 2010). In recognition of the connectivity between adjacent landscapes and river channels, Large and Gilvear (2015) develop their methodology to focus on the river corridor. The river corridor is a unit encompassing the features and processes associated with landscape-river connectivity. Harvey and Gooseff (2015) write:

“Typical two-dimensional velocity-area-based measurements of river discharge do not capture the complex, three-dimensional flows of a river interacting with undulating banks, side cavities, low-lying riparian areas, and permeable sediments and floodplains lying far outside of the river’s wetted width. Together, these features (river channels, fluvial deposits, riparian zones, and floodplains) form an inseparable unit—the river corridor” - Harvey and Gooseff (2015, p. 6893)

Our need and desire to understand river connectivity and dynamism means that in general river research the river corridor is regarded to be becoming a more common unit of study rather than the often previously studied wetted width (Harvey and Gooseff, 2015). As landscape units riparian corridors are considered to provide high levels of ecosystem services due to abundant fluxes and their arterial landscape position (Capon et al., 2013; Van Looy et al., 2017). Using the river corridor as the lateral unit for assessment therefore makes clear sense. But what is the spatial extent of the river corridor? In literature the river corridor is reported share vertical extent with the floodplain. In their paper looking at connectivity in rivers Wohl (2017) define the river corridor to include the active channel(s), floodplain and hyporheic zone. In modified areas the corridor may be constrained by human alterations;

“Linear features of the landscape bordering the river channel. The defining width of the corridor depends upon the topic under consideration and may encompass the full extent of the genetic floodplain, but is more likely to be constrained by human activities” – Downs and Gregory (2004, p. 5)
Within river ecosystem service assessments researchers have defined the river corridor using several methods. Large and Gilvear (2015) define the lateral extent of the river corridor by the floodplain margin. However Large and Gilvear describe that practically delineating the floodplain from Google Earth was challenging. In some instances, floodplain delineation was simple where valley floors and hillsides could be seen on satellite imagery, however in other instances additional data including elevation and oblique angle views were necessary to define floodplains. Vermatt et al. (2016) also take the extent of the floodplain to correspond with the river corridor, however, define the floodplain using historical flood maps. Van Looy et al. (2017) take an alternate approach using fixed distances from the river channel, river corridor elements are identified within 10, 30 and 100m from the river’s edge. Of these three approaches the use of flood data may offer the best method to define the river corridor. Attempting to manually define the floodplain on Google Earth was found to be challenging while using fixed widths seems at odds with the river corridor concept which is one of dynamism. Using flood data will define the extent to which flood water has, or could, exert influence on the surrounding landscape.

4.2.2 Inclusion of ecosystem disservices

Ecosystem disservices result from ecosystem processes, functions and attributes which reduce ecosystem service potential and have negative impacts on human wellbeing (Shackleton et al., 2016). The inclusion of ecosystem disservices within the ecosystem service research field is advocated for several reasons. Understanding patterns of disservices alongside synergies is critical to managing landscapes for ecosystem services (Turkelbloom et al., 2015; Shackleton et al., 2016; Blanco et al., 2019). Secondly, the inclusion of disservices allows the positive and negative impacts of ecosystems on
wellbeing to be assessed in balance and net contributions determined (Dunn, 2010; Schaubroeck, 2017). Furthermore, the study of disservices is crucial to their minimisation whilst maintaining ecosystem resilience (Lyytimäki, 2015). Crucially, ecosystem disservices should not be synonymised with ecosystem service trade-offs (Turkelbloom et al., 2015; Shackleton et al., 2016; Blanco et al., 2019). An ecosystem service trade-off is defined as a situation in which one ecosystem service is reduced as a consequence of increasing or desiring another (Rodríguez et al., 2006; Liu et al., 2018).

In their original matrix Large and Gilvear (2015) did not include disservice relationships where features act negatively to reduce service provision. However, within river environments disservices are commonly reported. For example, through altering water quality dynamics and physical habitat attributes, hydropower stations can reduce several services including fish for sustenance (Ziv et al., 2012), water quality (Brismar, 2002) and water for irrigation (Zeng et al., 2017). While agricultural practices can decrease water quality (Carpenter et al., 1998; Matthaei et al., 2010) and release greenhouse gases (Firbank et al., 2013).

Combining the arguments for understanding disservices with the knowledge that they occur within river environments presents a compelling argument for the inclusion of disservices within the matrix being developed here. To determine how disservice relationships should be included other matrix-based research is consulted. The original ecosystem service capacity matrix of Burkhard et al. (2009) recognises that some land cover types such as urban areas provide no ecosystem service potential but does not account for situations where potential may be reduced, scores are only given to positive potential relationships. Indeed, it seems many capacity matrices including Burkhard et
al. (2012), Hermann et al. (2014), Potts et al. (2014), Vigl et al. (2017) only focus on positive relationships.

However, there is some recognition amongst matrix researchers of the need to include disservices through the inclusion of negative relationships. Indeed, in their research focusing on ecosystem integrity and ecosystem services in Europe Stoll et al. (2015) remark that their matrix-based approach could be improved in the future by the inclusion of disservices. A few capacity matrixes have accounted for negative potential relationships indicating potential disservices. In their research looking at ecosystem services and landscape planning in northern Finland Vihervaara et al. (2010b) create a matrix scored from -2 to +2. Scores of -2 indicate a highly negative impact of land use on ecosystem service potential and +2 a highly positive impact. Kopperoinen et al. (2014) also use negative scores in their matrix investigating the role green infrastructure plays in providing ecosystem services. Experts are given a 7-point scale on which to give scores relating to land features and ecosystem service provision, the scale ranges from -3 (very harmful) to 3 (very favourable).

Progressing from the matrix of Large and Gilvear (2015), this methodology will seek to include disservices through the presence of negative relationships between river corridor features and ecosystem services, these will be supported by empirical evidence derived from academic literature. However, trade-off relationships cannot be explicitly included within the matrix as they require place specific knowledge of where one ecosystem service has been reduced as a result of another increasing another (Rodríguez et al., 2006; Liu et al., 2018).

4.2.3 Inclusion of uncertainty
Another feature lacking from the matrix of Large and Gilvear (2015) is the inclusion of a measure of uncertainty. Uncertainty will always be present in our understanding of ecosystems and human-ecosystem relations (Nicholson et al., 2009; Hou et al., 2013). Acknowledging and conveying uncertainty is therefore important for ecosystem service assessments. If uncertainty is not considered then assessment outcomes may lead to ineffective management choices, poor understanding of risks involved in management and false confidence in results (Grêt-Regamey et al., 2013; Cabral et al., 2017). Ignorance of uncertainty can ultimately lead to public loss of trust and confidence (Ascough et al., 2008). Nicholson et al. (2009) argue that the inclusion of uncertainty may slow progress but leads to the production of more robust assessments. Jacobs et al. (2015) remark that matrices which do not present measures of uncertainty are limited in usefulness. Despite the importance of including uncertainty estimates it is reported that many ecosystem service assessments fail to do so (Seppelt et al., 2011; Boerema et al., 2016).

In those few matrix papers that do include measures of uncertainty, they appear in the form of confidence scores. The nature of confidence scores built into ecosystem services matrices varies depending on how scores are decided. Campagne et al. (2017) base scores on expert judgement and thus scores reflect the confidence an expert has in their scores. Experts are asked to rate confidence in their score on a scale of 1 (‘I don’t feel comfortable on my score’) to 3 (‘I feel comfortable on my score’). With confidence scores based on expert judgement Campagne et al. find increasing the number of experts involved increases mean confidence. Additionally, confidence scores are welcomed by participating experts as they allow them to express uncertainty in their knowledge (Campagne et al., 2017). Potts et al. (2014) use scientific literature to develop their matrix and thus confidence scores are based on the availability and type of literature supporting linkages. A score of 3 represents UK peer-reviewed literature, 2 indicates support from
UK grey literature or overseas literature and 1 means linkage was based solely on expert opinion. This research seeks to evolve the work of Large and Gilvear (2015) through the creation of a matrix supported by scientific literature, therefore, for provisioning and regulating services, it makes sense to capture uncertainty through confidence scores similar to those used by Potts et al (2014).

4.2.4 Inclusion of Geomorphology

In 2015, Everard and Quinn wrote a paper titled ‘Realizing the value of fluvial geomorphology’. Everard and Quinn (2015) highlighted that there was a significant lack of scientific research examining the role fluvial geomorphology plays in facilitating the provision of ecosystem services. Understanding how fluvial forms and processes propagate to facilitate ecosystem service provision is deemed key to the sustainable management of fluvial ecosystem services (Everard and Quinn, 2015). The intentional or accidental degradation of fluvial processes can lead to reduced ecosystem service provision, disservices or trade-offs (Elosegi et al., 2010; Elosegi and Sabater, 2013; Everard and Quinn, 2015).

In an attempt to progress understanding of the interactions between river geomorphology and ecosystem service provision, the GE RES model will be built to capture reach geomorphology. In the context of this research, the inclusion of river reach geomorphology within GE RES assessments will allow an investigation into the extent to which geomorphology may influence ecosystem service potential. In particular, this investigation will seek to examine if geomorphology has a greater association with determining ecosystem service potential than nature designation.

Within geomorphological assessments, river geomorphology is captured using a geomorphological classification system. In response to the need to geomorphically
classify rivers for research, management, and rehabilitation purposes, two distinct types of classification emerged; classification could either be descriptive or process based. (Buffington and Montgomery, 2013). Process-based classification systems are regarded superior as they better appreciate dynamism and connectivity within river systems (Buffington and Montgomery, 2013).

Owing to this research focusing on Scotland, it seems logical to utilise the SEPA River Typology for classification. The SEPA typology is an adaptation of the Montgomery and Buffington process-based typology developed for North American mountain streams (Montgomery and Buffington, 1997; SEPA, 2012). The typology has been adapted to include low gradient rivers found within the UK (SEPA, 2012). Within the SEPA river typology there are six different river types, within some of these types are ‘sub-types’ (table seven).

In order to input geomorphological data into GE RES assessments, each 500m river reach will be classified as one of the six SEPA reach types. Reach classification will be based on the visual examination of Google Earth imagery guided by the classification guide presented within pages 43 – 68 of SEPA (2012). This guide is presented as appendix two. For each SEPA reach sub-type, the guide presents verbal descriptions of geomorphological features and physical processes which would lead to classification along with photographic examples (appendix two, pages viii – xxi). Additionally, the document includes a ‘River type summary sheet’, this one-page document is designed to be taken into the field, it also presents a photograph and verbal description of each sub-reach type (presented in appendix two on pages xxvi).

The results of analysis seeking to examine if river reach geomorphology is significant in determining river ecosystem service potential are presented within section 6.4.
Specifically, this research questions if geomorphology is more influential than protected status in determining ecosystem service potential from Scottish rivers. A discussion focusing on the results produced from the inclusion of reach type geomorphology within this comparison of ecosystem service provision from Scottish rivers with and without designations is presented in section 7.2.4.

Table 7: Table taken from SEPA (2012). The table shows the six different SEPA river reach types and their associated sub-types.

<table>
<thead>
<tr>
<th>SEPA River Type</th>
<th>Sub-types</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Bedrock, Cascade</td>
</tr>
<tr>
<td>B</td>
<td>Step-pool, Plane Bed</td>
</tr>
<tr>
<td>C</td>
<td>Plane-riffle, Braided, Wandering</td>
</tr>
<tr>
<td>D</td>
<td>Actively Meandering</td>
</tr>
<tr>
<td>E</td>
<td>Groundwater Dominated</td>
</tr>
<tr>
<td>F</td>
<td>Low Gradient Passively Meandering</td>
</tr>
</tbody>
</table>

4.3 GREAT to GE RES – Developing a provisioning and regulating capacity matrix

4.3.1 Selection of Services

After considering the properties the matrix should have, the next step in development was creating the framework, this involved deciding which ecosystem services and river corridor features should be included. Large and Gilvear (2015) select ecosystem services which are widely recognised to be provided by aquatic ecosystems. Eight services were selected and considered to represent provisioning, regulating and supported categories. In the original matrix, Burkhard et al. (2009) use a more rigorous approach and derive their set of ecosystem services from lists published in prominent ecosystem service research including Costanza et al. (1997), the MA (2005) and de Groot (2006). Other research has based ecosystem services solely on the MA (e.g. Eastwood et al., 2016), however, since publication the ecosystem service concept has progressed with the place of supporting services being reconsidered, sole use of this list seems out of date.
Campagne et al. (2017) also derive their provisioning and regulating services from only one source, but use the more up-to-date 2013 CICES classification. In an alternative approach, Nordlund et al. (2016) determine their list of matrix services from an open floor discussion with the experts chosen to fill the matrix, experts were encouraged to add, remove, or change services before deciding on a final list.

In an attempt to make GE RES as robust as possible, the process of deciding which ecosystem services should be included involved several steps. For all three service categories, in a similar manner to Burkhard et al. (2009), the determination of services to include began with a review of existing published lists (see table eight for lists). Two separate series of lists were scrutinized, one for cultural services, and one for provisioning and regulating (table four for cultural services, table eight for provisioning and regulating services).

Table 8: Table listing the academic papers which were used to determine which ecosystem services were included within the final matrix.

<table>
<thead>
<tr>
<th>List of academic papers used to determine ecosystem services included within the matrix</th>
<th>Provisioning and Regulating</th>
<th>Cultural</th>
</tr>
</thead>
<tbody>
<tr>
<td>The UK NEA (Watson et al., 2011)</td>
<td>• Harrison et al. (2010)</td>
<td></td>
</tr>
<tr>
<td>Gutiérrez and Alonso (2013)</td>
<td>• The UK NEA (Watson et al., 2011)</td>
<td></td>
</tr>
<tr>
<td>Vermaat et al. (2016)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The first stage of list scrutiny was consolidation, this involved determining the scenarios in which authors have used different terminology to refer to the same service. For cultural services, list consolidation occurred as part of Chapter Three to facilitate the review of cultural service methodologies (Section 3.3.2 and Appendix one). Consolidation of
provisioning and regulating lists is presented below (table 12). Drawing from the approach of Nordlund et al. (2016), list consolidation was supported by discussion during supervisory meetings. Following discussion within the supervisory team, it became evident that many of the provisioning and regulating services listed should not be included within the GE RES tool. The exclusion of ecosystem services can be attributed to two reasons: 1) the ecosystem service is not considered to be a ‘final’ ecosystem service but instead a supporting process (table nine, presented as appendix three) and 2) the ecosystem service is not considered to be delivered by rivers in Scotland (table ten, presented as appendix four).

Finally, lists of potential services were validated by exploring the service within the context of published riverine literature. For all service categories, this validation involved finding explanations and examples of the service being supplied. The validation of cultural services is presented as appendix one, whilst validation of provisioning and regulating services occurs below. For provisioning and regulating services, validation seeks to find evidence of the service being supplied by Scottish rivers. In contrast, due to a more limited research field, validation of cultural services only seeks to find evidence of the service being supplied by a river.

Following validation, nine cultural, four provisioning and three regulating services were to be included within the matrix framework (table 11).
Table 11: Lists of ecosystem services which are to be included within GE RES following a review of published literature (table 12), supervisory discussion, and literature validation.

<table>
<thead>
<tr>
<th>Provisioning</th>
<th>Regulating</th>
<th>Cultural</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water Supply</td>
<td>Natural Flood Mitigation</td>
<td>Aesthetic value</td>
</tr>
<tr>
<td>Agriculture</td>
<td>Climate Regulation</td>
<td>Artistic Inspiration</td>
</tr>
<tr>
<td>Timber Production</td>
<td>Water Quality</td>
<td>Cultural Heritage</td>
</tr>
<tr>
<td>HEP Production</td>
<td></td>
<td>Education</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Recreation and Tourism</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Scientific Knowledge</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Sense of place</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Social relations</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Spirituality and religion</td>
</tr>
</tbody>
</table>
Table 12: Lists of fluvial ecosystem services taken from papers considering multiple fluvial ecosystem services.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Provisioning</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Food and Fibre</td>
<td>Fish</td>
<td>Commercial fish catch</td>
<td></td>
<td>Fisheries</td>
<td></td>
</tr>
<tr>
<td>Freshwater</td>
<td>Freshwater</td>
<td>Drinking water</td>
<td></td>
<td>Water Supply</td>
<td></td>
</tr>
<tr>
<td>Timber/fuel/energy</td>
<td>Renewable energy</td>
<td>Hydropower</td>
<td></td>
<td>Timber</td>
<td></td>
</tr>
<tr>
<td>Genetic resources</td>
<td>Genetic resources</td>
<td></td>
<td></td>
<td>Genetic resources</td>
<td></td>
</tr>
<tr>
<td>Health products</td>
<td>Natural medicines</td>
<td></td>
<td></td>
<td>Biochemicals and medicines</td>
<td></td>
</tr>
<tr>
<td>Reeds, osiers and watercress</td>
<td></td>
<td>Reed crop for thatching</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ornamental resources</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Regulating</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Natural Hazard Regulation</td>
<td>Flood regulation</td>
<td>Natural hazard mitigation</td>
<td>Flood mitigation</td>
<td>Natural Hazard regulation</td>
<td>Flood mitigation</td>
</tr>
<tr>
<td>Water Flow Regulation</td>
<td>Flow regulation</td>
<td>Water and water quality regulation</td>
<td>Water Regulation</td>
<td>Water quality and waste treatment</td>
<td>Water quality</td>
</tr>
<tr>
<td>Water quality regulation</td>
<td>Water and water quality regulation</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Climate regulation</td>
<td>Local climate regulation</td>
<td>Climate Regulation</td>
<td>Carbon sequestration</td>
<td>Air quality and climate</td>
<td>Carbon sequestration</td>
</tr>
<tr>
<td>Erosion regulation</td>
<td>Erosion regulation</td>
<td>Sediment retention</td>
<td>Erosion regulation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Seed dispersal</td>
<td>Biological control</td>
<td>Pollination, disease and pest regulation</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Human health regulation</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Soil formation and fertility</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Nutrient retention</td>
</tr>
</tbody>
</table>
4.3.1.1 Validation of provisioning and regulating services

(i) Agriculture

Werritty and Chatterton (no date) highlight that around 6,259km$^2$ of Scotland’s prime agricultural land is located upon floodplains. According to information on the Scottish Governments website (gov.scot, 2018) 5.6 million hectares of land in Scotland consists of agricultural land use meaning that around 11.2% of prime agricultural land is located on floodplains. Scottish floodplains are clearly important for the provision of food.

(ii) Water Supply

Whilst lochs and reservoirs supply the majority of drinking water in Scotland (around 46%) rivers and burns also provide a significant proportion (38%) especially compared to that sourced from boreholes and springs (16%) (The Scottish Government, 2013). River water is also very important for industry in Scotland. SEPA (No Date) list the water used by industry in the Scotland river basin district connected with abstraction and flow regulation, the two highest uses of water are hydroelectricity generation at 23,755 million m$^3$year$^{-1}$ and Aquaculture at 1.582 million m$^3$year$^{-1}$.

(iii) Timber

Parrott and Holbrook (2006) highlight that substantial areas of floodplains in Scotland are occupied by plantation forestry. Since 1988 riparian buffer zones have been cleared of conifers, however minimum buffer widths are considered to be very narrow (Parrott and Holbrook, 2006). In SEPA's Natural Flood Management Handbook (2015) it is highlighted that native species planted on the floodplain for flood mitigation may be coppiced as a good management technique with coppice wood being used for fuel by the landowner.

(iv) Hydroelectricity
In Scotland there are 145 hydroelectric power stations which produce around 12% of Scotland’s electricity (Hi-energy, 2016). Hydroelectricity is an important ecosystem service provided by Scottish rivers.

(v) **Flood mitigation**

Flood mitigation in Scotland is considered crucial by SEPA as their fluvial flood maps indicate that around 49,000 homes and 13,000 non-residential properties are at risk during a 1 in 200-year event (Natural Flood Management Handbook, 2015). In Scotland SEPA consider that natural flood mitigation is going to become more important as local authority budgets shrink, population and demand for housing increases and the climate changes, hence the publication of the Natural Flood Management Handbook. Natural Flood Management techniques are also desirable because they can lead to improvements in water quality, biodiversity and carbon sequestration. Despite the growing popularity of natural flood mitigation measures they tend to concentrate on upland areas and for now it appears that in urban areas more traditional structural flood management options may still be required.

(vi) **Water Quality Regulation**

Across the world rivers and their corridors naturally regulate water quality (e.g. Chatzinikolaou and Lazaridou, 2007; Cukrov et al., 2008; Tian et al., 2011). In Scotland water quality is generally good, however there is evidence that some land uses including arable and urban are degrading water quality (Ferrier et al., 2001). Good water quality supports biological processes, biota and is also important for cultural services. Scotland is renowned for salmon fishing (Butler et al., 2009) and river water must be high quality to support salmon (Thorstad et al., 2008). Other recreational activities in Scotland that rely on good water quality include rafting, kayaking and wild swimming.
(vii) Climate Regulation

Depending on land cover river corridors can act as sinks for greenhouse gases thus assisting in climate regulation (Rieger et al., 2015; Fortier et al., 2010; Cierjacks et al., 2010). While climate regulation is required on a global scale it is in the interest of Scotland to concentrate on altering climate change as changes are projected to alter a range of ecosystem services. Scotland is tackling climate change through a combination of mitigation and adaptation strategies, mitigation techniques focus on dealing with the causes of climate change such as greenhouse gas emissions while adaptation strategies focus on responding to projected changes in climate (Moss et al., 2010). Mitigation techniques which are undertaken in Scotland include reducing greenhouse gas emissions through altering rural land use (Felicianio et al., 2013a) and focusing on renewable low-carbon energy (Kelly, 2006). Examples of potential adaptation strategies include introducing other species to planted forests (Meason and Mason, 2014) and the introduction of more natural flood management (Johnson et al., 2008).

4.3.2 Selecting river corridor features

Compared to the original matrix of Burkhard et al. (2009), the matrix being designed for this research is focusing on much finer scale landscape features. Indeed, the Google Earth approach is chosen because of the ability to recognise small scale features which allows a detailed comparison of designated and undesignated river corridors. This approach of using small-scale landscape features is unique with most authors focusing on land cover classes (e.g. Vihervaara et al., 2010b; Potts et al., 2014; Li et al., 2016). In their research Large and Gilvear (2015) determine features using expert judgement and attempt to keep the number to a viable minimum with 18 selected. In an attempt to make GE RES more robust, the selection of features was based on a discussion of the original GREAT methodology with six river experts and environmental stakeholders attending a meeting
focusing on this research in May 2017. Alongside the original GREAT model, this
discussion was guided by both the River Habitat Survey and examination of Google Earth
to determine which features could be recognised. Discussion focused on questioning if
specific river corridor features could link to ecosystem service potential.

Before developing a list of river corridor features that underpin ecosystem service
provision, it is important to be clear on how ecosystem services are produced. As
highlighted previously in section 2.2, Lovell and Johnston (2009) highlight that early
ecosystem service research concentrated on ‘natural’ environments, however more
recent research provides evidence that human altered and dominated landscapes
provide ecosystem services. For example, Moore and Hunt (2012) highlight the
ecosystem services provided by constructed wetlands and storm water ponds while
Santos et al. (2018) focus on the potential climate change mitigation potential of artificial
lakes. In this research it is thus considered that ecosystem services are not only provided
by natural ecosystems but also by ecosystems that have been subject to management. The
updated matrix recognises variation within river corridor features including different
types of woodland and wetland. There is therefore a total of 19 river corridor features in
the provisioning and regulating matrix. Table 13 presents features, their descriptions for
identification on Google Earth and how they should be measured for assessment.
Table 13: Table listing the river corridor features which will be included in the revised matrix, the evidence to look for on Google Earth and how to measure features for input into the GE RES Tool

<table>
<thead>
<tr>
<th>Feature/Attribute</th>
<th>Observable Evidence</th>
<th>How to measure</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>River Width</strong></td>
<td>Wetted width</td>
<td>Average of three measurements. Measure top, middle and bottom.</td>
</tr>
<tr>
<td><strong>River Morphology</strong></td>
<td>Morphological features identifiable include boulders, pools, riffles, bars and meanders</td>
<td>Classify using SEPA reach typology</td>
</tr>
<tr>
<td><strong>Weirs</strong></td>
<td>Structure that spans the width or partial width of the channel with water pooling behind it</td>
<td>Note number and if span full channel</td>
</tr>
<tr>
<td><strong>Channelization (including embankments)</strong></td>
<td>Including straightened reaches and reaches with concrete beds and banks, also look for raised parallel features of earth or constructed materials.</td>
<td>Estimate the percentage of the channel that appears to channelized or embanked</td>
</tr>
<tr>
<td><strong>Woodland</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>-Broadleaf/Mixed</td>
<td>Mixed colour woodland with green-brown species present, trees have wide canopies and/or a combination of mixed colour woodland with green-brown species present and dark green trees with narrower canopies</td>
<td>Estimate the percentage cover within the defined river corridor</td>
</tr>
<tr>
<td>-Conifer</td>
<td>Dark green forest, trees have narrow canopies and often appear in linear patterns, shadows often pointy</td>
<td>Estimate the percentage cover within the defined river corridor</td>
</tr>
<tr>
<td>-Young woodland</td>
<td>Evidence of tree planting – tree widths will seem smaller, trees may be planted in a linear fashion, likely to be gaps between all trees.</td>
<td>Estimate the percentage cover within the defined river corridor</td>
</tr>
<tr>
<td>-Felled Ground/ prepared for planting</td>
<td>Ground which appears bare or with stumps present, may to be surrounded by mature trees</td>
<td>Estimate the percentage cover within the defined river corridor</td>
</tr>
<tr>
<td><strong>Floodplain forest</strong></td>
<td>A patch of forest broadleaf forest in close proximity to the river channel that looks like it might flood frequently. Will not extent beyond corridor.</td>
<td>Estimate the percentage cover within the defined river corridor</td>
</tr>
<tr>
<td><strong>Riparian Buffer Strips</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Woodland Buffer</td>
<td>A linear strip of trees located parallel to the channel, not extensive in width</td>
<td>Estimate percentage of river bank with buffer adjacent</td>
</tr>
<tr>
<td><strong>Herbaceous Buffer</strong></td>
<td>A linear strip of light green or mottled green located parallel to the channel, not extensive in width</td>
<td>Estimate percentage of river bank with buffer adjacent</td>
</tr>
<tr>
<td>-----------------------</td>
<td>------------------------------------------------------------------------------------------------</td>
<td>--------------------------------------------------</td>
</tr>
</tbody>
</table>

**Wetlands**

<table>
<thead>
<tr>
<th><strong>-Upland wetlands</strong></th>
<th>Located in upland areas, dark or rough looking patches of vegetation away from the channel (upland over around 250m - <a href="http://jncc.defra.gov.uk/page-1436">http://jncc.defra.gov.uk/page-1436</a>)</th>
<th>Estimate the percentage cover within the defined river corridor</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>-Lowland wetlands</strong></td>
<td>Located in lowland areas, dark or rough looking patches of vegetation located proximal to the channel</td>
<td>Estimate the percentage cover within the defined river corridor</td>
</tr>
</tbody>
</table>

**Agricultural land**

| **Arable** | Fields with boundaries containing evidence of crops including plough lines and linear lines of vegetation separated by tractor wheel tracks Livestock: In the uplands may be rough grassland with evidence of livestock while in the lowlands likely to be grass fields also with evidence of livestock | Estimate the percentage cover within the defined river corridor |
| Livestock: In the uplands may be rough grassland with evidence of livestock while in the lowlands likely to be grass fields also with evidence of livestock | |

| **Amenity land** | Grassland adjacent to the channel that looks managed, may contain evidence of mowing lines or recreational features such as sports pitch markings/posts or picnic benches | Estimate the percentage cover within the defined river corridor |

<table>
<thead>
<tr>
<th><strong>Floodplain lake</strong></th>
<th>A body of water located on the floodplain</th>
<th>Estimate percentage cover within the defined river corridor</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th><strong>Natural lake</strong></th>
<th>A large body of water located along the river course that is not held behind a dam</th>
<th>Estimate percentage of river corridor area that contains the lake</th>
</tr>
</thead>
</table>

| **Dam-Reservoir unit** | A large concrete structure holding back water with a lower elevation below the structure | Estimate the percentage of river corridor area that contains the dam feature |

| **Urban areas** | Areas of dense settlement | Estimate the percentage cover within the defined river corridor |
4.3.3 Matrix Population

After creating the matrix framework, the next step in development was to establish linkages between services and features using scientific literature. Most matrix approaches including Burkhard et al. (2009) and Large and Gilvear (2015) base relationships solely on expert judgment, the inclusion of supporting scientific literature is seen as a progressive step improving the scientific credibility and robustness of the approach (Potts et al., 2014; Campagne et al., 2020). Indeed, Jacobs et al. (2015) highlight that the inclusion of quantitative empirical evidence within matrices boosts their validity.

Population started with a blank matrix with river ecosystem services on the x-axis and river corridor features on the y-axis. With 7 ecosystem services and 19 features the matrix had 133 boxes. Clearly not all of these boxes represent linkages so the next step in development involved recognising potential relationships. Through individual knowledge and discussion within the supervisory team, the initial matrix was colour coded with three colours (table 14). Boxes where features were not considered to underpin ecosystem service potential were left blank. Some features directly and obviously contribute to service provision (e.g. agricultural land to agriculture), in these cases boxes were shaded green. Where features were suspected to underpin ecosystem service provision but evidence to support relationships was required boxes were shaded orange. To account for ecosystem disservices, both positive and negative relationships are considered. In total 55 boxes were shaded orange. It is important to note that the initial decisions on where possible relationships exist were based on expert discussion and therefore as our understanding progresses, to ensure robustness and validity, matrix linkages will need to be periodically reviewed.
**Table 14:** First draft river corridor-ecosystem service matrix created following expert discussion. Colour-coding (see legend) indicates status of perceived relationship.

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<th>Provisioning</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Water Supply</td>
<td>Agriculture</td>
<td>Timber production</td>
<td>HEP production</td>
<td>Natural Flood Mitigation</td>
<td>Climate regulation</td>
<td>Water Quality</td>
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<tr>
<td>River Width</td>
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<tr>
<td>Morphology</td>
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<tr>
<td>Weirs</td>
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<tr>
<td>Channelization (including embankments)</td>
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<td><strong>Land Cover Type</strong></td>
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<tr>
<td>Woodland</td>
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<tr>
<td>-Broadleaf/Mixed</td>
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<tr>
<td>-Conifer</td>
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<tr>
<td>-Young woodland</td>
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<td>-Felled</td>
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<tr>
<td>-Floodplain forest</td>
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<tr>
<td>Riparian Buffer</td>
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<td>-Woodland Buffer</td>
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<tr>
<td>-Herbaceous buffer</td>
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<td>Wetlands</td>
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<tr>
<td>-Upland wetland</td>
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<tr>
<td>-Lowland wetland</td>
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<tr>
<td>Agricultural land</td>
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<tr>
<td>Amenity land</td>
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<tr>
<td>Floodplain lake</td>
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<tr>
<td>Natural lake</td>
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<tr>
<td>Dam and reservoir unit</td>
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<tr>
<td>Urban Areas</td>
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</tr>
</tbody>
</table>

**Legend**

- Blank boxes represented no link considered between feature and service
- Green box indicates direct obvious relationship with feature supporting ecosystem service provision
- Boxes shaded orange if feature is considered to support ecosystem service provision but empirical evidence is required to prove linkage
To determine if features do contribute to ecosystem service potential, three main academic search engines were used; Web of Science, SCOPUS and Google Scholar. Initially searches involved the river corridor feature, the specific ecosystem service and the term ‘ecosystem service’. When no supporting literature could be retrieved, or literature was exhausted the term ‘ecosystem service’ was dropped from searches. Additionally, synonyms and literature snowballing (Greenhalg and Peacock, 2005) were used. Initially two days of research was assigned to each box, however if the relationship was well documented then research would end early, but if the relationship was complex additional days would be assigned. Within appendix five, tables containing the outcomes of literature exploration are presented (tables 15, 16, 17 & 18). Tables contain relevant retrieved papers alongside explanations of the processes which contribute to service provision. Based on the availability of evidence confidence scores of 1-3 are assigned to linkages. The direction and confidence of relationships populates the ‘final-matrix’ which will be used in this research. Four different scenarios are identified:

1. The feature positively contributes to ecosystem service provision
2. The feature acts to reduce ecosystem service provision (ecosystem disservice)
3. Empirical studies contrast, some indicate feature supports provision and others indicate feature reduces provision
4. A linkage is likely but more detailed, specific research is required

The final matrix developed here is presented below as table 19. It is important to emphasise that the matrix is being termed ‘final’ only in the case of this research project. After spending a significant amount of time creating the matrix and synthesising papers it was necessary to draw a line under development and move forward with the research project in order to evaluate Scottish rivers with conservation status. It is acknowledged this a first attempt at the matrix and thus it is expected to evolve with the input of other
researchers and future empirical studies. Confidence scores of 1-3 are assigned to linkages. Scores are guided by the number and quality of available empirical evidence. If one or two papers were retrieved a score of 1 was considered. A score of two advised if 3-4 papers were identified and a score of 3 was recommended when 5 or more papers were identified. Strength and relevance of empirical research was also considered, and thus some confidence scores differ from this guide.
Table 19: The final matrix resulting from extensive searching through scientific literature and empirical research. Key is presented below. Note: although the matrix is termed final, that is in the context of this research, further researchers may modify the matrix.

<table>
<thead>
<tr>
<th></th>
<th>Provisioning</th>
<th>Regulating</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Water Supply</td>
<td>Agriculture</td>
</tr>
<tr>
<td><strong>River Width</strong></td>
<td>3</td>
<td>-</td>
</tr>
<tr>
<td><strong>Morphology</strong></td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td><strong>Weirs</strong></td>
<td>3</td>
<td>-</td>
</tr>
<tr>
<td><strong>Channelization (including embankments)</strong></td>
<td>-</td>
<td>2</td>
</tr>
<tr>
<td><strong>Land Cover Type</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Woodland</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>-Broadleaf/Mixed</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>-Conifer</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>-Young woodland</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>-Felled</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>-Floodplain forest</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td><strong>Riparian Buffer</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>-Woodland Buffer</td>
<td>2</td>
<td>-</td>
</tr>
<tr>
<td>-Herbaceous buffer</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td><strong>Wetlands</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>-Upland wetland</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>-Lowland wetland</td>
<td>-</td>
<td>3</td>
</tr>
<tr>
<td><strong>Agricultural land</strong></td>
<td></td>
<td>3</td>
</tr>
<tr>
<td><strong>Amenity land</strong></td>
<td></td>
<td>-</td>
</tr>
<tr>
<td><strong>Floodplain lake</strong></td>
<td></td>
<td>-</td>
</tr>
<tr>
<td><strong>Natural lake</strong></td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td><strong>Dam and reservoir unit</strong></td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td><strong>Urban Areas</strong></td>
<td>3</td>
<td>3</td>
</tr>
</tbody>
</table>

**Key**
- **River corridor feature positively contributes** to ecosystem service potential
- **River corridor feature negatively contributes** to ecosystem service potential
- **Very little** relevant academic literature supporting linkage
- **Moderate** relevant academic literature supporting linkage
- **Abundant strong** relevant academic literature supporting linkage
- **More research required**: Insufficient evidence currently available but a linkage is suspected to be present
- **Conflicting evidence**: Evidence is available but contradicting and/or a range of other variables must be known to more accurately determine linkage
Chapter Five: Methodology Development: Part Two

Cultural Services Methodology Development, Results and Evaluation

5.1 Outline of Chapter

The neglect of cultural services from many ecosystem service assessments drives this research to build a robust and repeatable assessment tool which can capture multiple river corridor cultural services. Unlike past research, this research will not ignore or neglect cultural services because of the complexity of capturing them. Similar research conducted around the same time as this by Thiele et al. (2020) also focuses on capturing multiple riverine cultural services for the same reason.

Chapter four outlined the creation of the capacity matrix for provisioning and regulating services, this current chapter details the final step in GE RES creation, the development of a matrix for cultural services. On review of methods used to capture cultural services within chapter in sections 3.3 and 3.4, it seems a photo-rating survey offers a suitable way of populating a river corridor – cultural ecosystem service matrix. Rating surveys were identified as the only method used to capture all cultural ecosystem services, basing surveys on photographs enables preferences to be attached to river corridor features identifiable on Google Earth, thus a cultural matrix can be created. Subsequently, within this chapter, a pilot survey is developed, conducted and evaluated. Of note, because the survey developed here is somewhat pioneering, the survey should be treated as pilot in nature, with results reviewed as somewhat preliminary.

To provide foundations for an approach which is robust and repeatable, careful consideration to survey development and design is required. Survey design started with discussion on the type of information the survey could gather. Alongside preference
information it was identified that the survey could, and should, attempt to understand why people value river corridor features differently, in light of this open questions were added. Additionally, the decision was made to capture socio-demographic information from respondents. Next method of survey distribution was determined. Focus then shifted to survey design. As with the matrix developed for provisioning and regulating services decisions were made regarding which services and features should be included. Before questions were written, survey usability and nature of photographs were considered. Subsequently preference, open and socio-demographic questions and answer options were decided. The final design of the cultural service survey is presented as appendix six. The survey design is included as in their research on ecosystem service matrices, Jacobs et al. (2015) note that researchers should record the exact questions they ask in order to allow repeatability of methods and improve confidence in scores. Finally, the survey population for this research was decided.

Attention then turns to exploring the outcomes, including results and evaluation of conducting the survey. Results presented in this chapter include a cultural service preference matrix and socio-demographics. Crucially, as the survey is developed here, it is necessary to reemphasise that its completion is pilot in nature with results regarded as preliminary. However, as alluded to in the literature review, methodology review and methodology development, this research adds to a very slim body of literature examining the role different riverine features have in providing multiple cultural ecosystems services. Such research is vital as consideration of riverine cultural services is important in river management (Schindler et al., 2014; Vollmer et al., 2015; Gerner et al., 2018). It is therefore incredibly meaningful, despite the pilot nature of this approach, to explore some reasoning for these perceived relationships. Subsequently, appendix seven utilises the open questions to delve into perceived relationships between river corridor features
and cultural service provision. Appendix eight then proposes options for river corridor management based on survey outcomes. Appendix nine contains the analyses of open question answers which supports appendix seven and eight.

Because the survey developed here is of a pilot nature, this means that evaluation of the approach is equally as important as the results produced. Survey evaluation is necessary to secure robustness and repeatability (Ball et al., 2019). Evaluation begins with weaknesses and areas for improvement before attention turns to methodological strengths. Finally, this chapter ends with suggestions for the future use of the developed methodology. This chapter complements chapter four to achieve the secondary research aim of developing a suitable methodology for capturing Scottish riverine cultural services.

5.2 Cultural Service Photo Preference Survey Development

5.2.1 Collecting more than rating information

The main aim of the survey is to populate a river corridor feature – cultural service matrix. Yet, this survey offers a fantastic opportunity to learn about more river cultural services. In acknowledgment of the information deficit relating to river cultural services (see section 3.3), early survey discussion focused on what other information the survey could elicit. During these discussions the suggestion was made to include open questions in an attempt to understand more about how people experience and connect with river corridors. Additionally, echoing other cultural service rating survey projects, this survey will integrate socio-demographic questions.

(i) Open Questions

Research that seeks only preference scores is limited in its application and usefulness because there is no information on the reasons why people attach different value to
different places or ecosystem services. Open questions are therefore used in cultural service research to allow people to express their feelings and attachments. In their investigation of the cultural ecosystem services of the Black Sea, Fletcher et al. (2014) ask the open question “What do you think of when you hear the word sea?” because they consider using an open question gains a more emotional perspective from survey respondents. Meanwhile, Gould et al. (2015) find open questions allow people to articulate values which can be difficult to express using methods of quantification. Additionally, the information gathered from open questions is useful for policy makers. Fletcher et al. (2014) recognise that revealing why people value ecosystems can give policy makers information which can be used to motivate people to participate in discussions and environmental actions.

Although they will not be used for this purpose here, open questions can be used to reveal ecosystem services. In their research investigating biophysical landscape features in Austria and Germany, Bieling et al. (2014) ask the question “How does the landscape here contribute to your wellbeing? Please briefly report anything that comes to your mind”. From this question seven cultural services are identified; aesthetic values, sense of place, recreation and tourism, cultural heritage, inspiration, spiritual/religious values and education.

(ii) Socio-demographic questions

When eliciting ecosystem service preferences, surveys often also collect socio-demographic data from respondents. Socio-demographic data is collected because it can help to explain variance in preference data. For example, in their research in Tyrolean landscapes, Zoderer et al. (2016a,b) found gender and environmental support to be important in the perception of all the cultural services they considered. Meanwhile,
tourist age, education level and place of residence significantly influenced the perception of single ecosystem services. However, socio-demographic data does not always explain variance in preference scores (e.g. Williams et al., 2017).

In terms of river cultural services, at the time of writing, no research papers linking socio-demographics to multiple services could be identified. Smith and Moore (2011) research socio-demographic variables and preferences for aesthetics, recreation and education on two rivers in the eastern United States but do not investigate relationships. Papers that focus on examining relationships between single cultural river ecosystem services and socio-demographic variables do exist. In particular, the relationship between socio-demographic variables and river aesthetic preferences has been examined (Van den Berg and Koole, 2006; Chin et al., 2008; Eder and Arnberger, 2016). Preferences for river-based recreation have also been linked to socio-demographics (Lee et al., 2007; Tangeland et al., 2013). One paper was retrieved focusing on sense of place, it found the service to be positively correlated with residence distance from location (Todd and Anderson, 2006). For six of the nine river cultural services nothing could be found exploring relationships between preferences and socio-demographics.

5.2.2 Survey Distribution
To encourage robustness and repeatability, before beginning to design individual elements of the survey, it seems important to determine if the survey should be online or paper-based. Method of distribution influences response rate, cost, return time and missing values.

Generally, it seems than online surveys are associated with lower response rates. In their review of travel-related surveys Pan et al. (2009) found many studies published online between 1999 and 2004 reported low response rates. Lower online response rates
compared to paper surveys have also been reported in research on teaching evaluation (Nulty, 2008). Additional research identifying lower response rates for online surveys includes Yetter and Capaccioli (2010), Hohwü et al. (2013) and Shin et al. (2011). In contrast Lonsdale et al. (2006) collected information from Athletes in New Zealand and had a 57.07% response rate from their online group and a lower 46.63% from the postal group.

While response rates may not be great for online surveys there are some significant advantages to using them. Perhaps the greatest advantage is that they are cheap because they do not require postage and data entry (Watt et al., 2002; Pan, 2009). Low response rates therefore may not be so much of an issue if the survey can be administered to more people because it is cheaper. Online surveys are also advantageous because they are returned faster, often instantaneously (Lonsdale et al., 2006; Pan, 2009). Online distribution may be preferable and more robust when surveys are going to be lengthy because they can contain less ‘missing values’. Wood et al. (2006) compared online and paper surveys finding less ‘missing values’ at the end of online survey suggesting paper surveys may be associated with greater boredom or fatigue. Indeed, some research including Salgado and Moscoso (2003) suggests that respondents find online surveys to be more enjoyable, this may be because online surveys can be made interactive and can include various types of multimedia (Pan, 2009). On review of the literature and taking into consideration the purpose of the survey the decision is to use an online survey. This decision is made because online surveys are cheaper, do not require data entry and are better for lengthy surveys. Furthermore, online surveys seem limited in the ecosystem service research field so this will act as a good opportunity to test their usage. For this research the online Survey Monkey tool was chosen. This decision was made because a
premium account was available to use and collected data can be downloaded in a file compatible with Microsoft Excel.

5.2.3 Survey design

After considering the type of information the survey should focus on capturing, the next logical step in development is to decide on the features and services which should be included.

(i) Services

Chapter three revealed river corridors provide nine cultural ecosystem services. Unfortunately, after some consideration, it has been decided that this research will have to omit the cultural service of ‘sense of place’. That does not mean ‘sense of place’ is not recognised as an ecosystem service provided by river corridors. It is that unlike other ecosystem services, research has found that ‘sense of place’ is largely not linked to physical landscape attributes but to place history, culture and experiences shared with friends and family (Kyle and Chick, 2007). It would therefore be impossible for people to attach ‘sense of place’ values to photographs of places that they do not know and have no memories of shared experiences with friends and family.

Excluding sense of place leaves eight services remaining. Techniques to improve survey usability are discussed below, but early on in survey development it seemed logical to merge the services education and scientific knowledge. It is felt this will make the survey easier to understand as people will not be confused by if they use environments for educating or acquiring knowledge. This approach of creating easier to understand surveys through the merging of service categories is undertaken by other cultural service researchers and may act to improve survey robustness (e.g. Tengberg et al., 2012; Bogdan et al., 2019). Additionally, having seven instead of eight services will also make the survey
slightly quicker to complete. The cultural services to be included in the survey and subsequent matrix are:

1. Aesthetic value
2. Inspiration
3. Cultural Heritage
4. Knowledge gain and sharing of knowledge
5. Recreation
6. Social relations
7. Spiritual and religious values

(ii) River Corridor Features

Next, the river corridor features must be determined. As this is pioneering research, the selection and exclusion of features was based on discussion within the supervisory team and environmental stakeholders attending a meeting focusing on this research in May 2017. Which river corridor features to include involves a compromise between making the survey as user friendly as possible and comprehensive enough to produce good meaningful results. Following consideration, the following 10 river corridor features have been selected:

1. Agricultural land
2. Amenity land
3. Felled woodland
4. Floodplain lake and lowland wetland
5. Built Heritage
6. Reservoirs and lakes
7. Upland wetland
8. Urban rivers
9. Waterfalls
10. Woodland (broadleaf/mixed/conifer/young)

The features chosen were felt to be those people mostly likely had cultural connections with. Omitted features include channel width, channelization and riparian buffers. As floodplain lakes and lowland wetlands are often both found in lowland environments the two were listed together to reduce survey length. Types of woodland were placed
together for two reasons; it was felt different types of woodland might be difficult to represent using photographs and showing multiple types of woodland may make the survey unnecessarily repetitive. Natural lakes and reservoirs were also placed together for the purpose of reducing survey length and repetitiveness. Two features not considered for provisioning and regulating services were added. Built heritage was added because it supports cultural heritage. Waterfalls were added as past research seems to have neglected their cultural importance and because they have historical importance for tourism in Scotland (Cole, 2015).

(iii) Photographs

Photo-based preference surveys can yield results very similar to field surveys (Stamps, 1999; Palmer and Hoffman, 2001 both cited in Zoderer et al., 2016b), however, to ensure robustness photo content and representativeness need to be considered. Weather conditions need to be accounted for. While some photo-based surveys appear to take no consideration of weather conditions (e.g. Le Lay et al., 2013, Reimann et al., 2014) other surveys ensure photographs are taken under similar, usually sunny conditions to reduce potential bias (e.g. Sahraoui et al., 2016, Tveit, 2009). It has been found that sunny weather can influence people’s preferences for landscapes (Beute and de Kort, 2013). In some research, where taking photographs with sunny conditions is difficult perhaps due to time constraints, photographs are edited to minimise differences in sky colour (e.g. Surová and Pinto-Correia, 2008).

When conducting photo-based surveys it is important that photographs are representative of the landscape or feature being investigated. Some researchers such as Cordingley et al. (2015) take multiple photographs and then select the most representative. Other researchers like van Berkel and Verburg (2014) choose to use
several different photos of the same landscape element. Using multiple photographs means that it is possible to demonstrate diversity in feature form.

To minimise potential weather bias and ensure landscape diversity is represented respondents will be presented with a collage of four photographs for each corridor feature. For consistency the brightness of dull images will be edited. The four photographs will capture form diversity, hopefully respondents will relate to at least one of the images.

(iv) Usability

Before questions are designed it seems sensible to consider survey usability, focusing on usability seems key for creating surveys that are robust and repeatable. To ensure surveys are easy to understand and complete, questions need to be worded carefully. Dolnicar et al. (2013) draw on the research of Cantril (1940), Payne (1980) and Converse and Presser (1986) to highlight a number of practical recommendations for the wording of survey questions:

- Use plain, everyday language – *It is important to use simple language so that questions can be understood by everyone*
- Use short questions – *Shorter questions are easier to understand, also minimise the amount of ‘difficult to understand’ words in each question*
- Avoid using technical terms – *Technical terms complicate questions and may require effort to understand which can put people off answering questions*
- Make questions specific – *Specific questions should mean that clarification is not required*
- Avoid double-negatives – *Such questions can confuse potential respondents*
- Avoid double-barrelled questions – *Each question should only focus on one object or attribute or responses can be invalid because you do not know what exactly people are responding to*
- Do no use ‘strongly agree’ to ‘strongly disagree’ scales because scales can be bias

This research shall aim to follow these recommendations as they should help the survey to be answered by everyone and help to increase responses (Dolnicar *et al.*, 2013) Dolnicar *et al.* (2013) also recommend that pre-testing of surveys occurs as this allows
feedback which can be used to improve survey design. Unfortunately, because there was a time constraint on this research, specific pre-testing of the survey could not occur, therefore completion of the survey needs to be viewed as somewhat of a pilot project with results seen as preliminary and subsequent post-survey evaluation occurring.

5.2.4 Questions

After deciding on the design of the survey questions can now be written.

(i) Preference Questions

The rating survey is being designed to elicit preferences for ecosystem services from river corridor features, to achieve this it is necessary to select an appropriate rating scale. Firstly, a decision should be made between using a unipolar or bipolar scale. Unipolar scales have answer options that go in one direction (usually positive) whereas bipolar scales have positive and negative responses (Dolnicar, 2013). Because in this research the focus is on potential, a unipolar scale seems sensible as there is no need for values below zero as zero is the lowest potential can be.

How many answer options should be on the unipolar scale? A range of size scales have been used to capture perceived values in ecosystem service research. Williams et al. (2017) use a three-point scale to ask people how they value 26 ecosystem services with one being ‘not important’ and three being ‘extremely important’. In their study looking at the social perceptions of ecosystem services provided by the Conquense Drove Road landscape in Spain, López-Santiago et al. (2014) go one further and use a one - four scale. Meanwhile Zoderer et al. (2016b) use a larger scale with seven options to assess the degree of ecosystem services tourists associate with different landscapes. Although a range of size scales have been used in ecosystem service research, authors provide little
or no justification for their choice of rating scale size which is unhelpful when trying to decide on a robust rating scale size for this study.

It is confusing that ecosystem service papers provide little or no justification for scale size because there is literature available which looks at the reliability of different size rating scales. Preston and Coleman (2000) examine the optimal number of categories in rating scales by administering surveys with different rating scales to people who visited stores and restaurants. Results find that while scales with two, three or four response options are considered quick to use, scales with five or more responses are preferable because they are more reliable and allow respondents to better express their feelings. Overall, Preston and Coleman (2000) consider that that seven, nine or ten point rating scales are best although 5 point scales may be preferable when time constraints are in place because they are perceived by respondents to be quick and easy. Based on the recommendations of Preston and Coleman (2000) this research will use a five-point scale. A five-point scale is a good compromise between allowing respondents to express their feelings and keeping the survey fairly quick.

After deciding on a five-point scale, the next step is to select response options. Firstly, it was questioned whether a ‘do not know’ option was necessary. Including a ‘do not know’ option can lead to satisficing and respondents seeing it as an ‘easy way out’ (Krosnick et al., 2002). Additionally, de Leeuw et al. (2016) find that including a ‘do not know’ option in online surveys increases the amount of missing data and often results in a decrease in reliability and robustness of results. Dolnicar (2013) conclude that researchers should only include a ‘do not know’ option if they believe some respondents will genuinely be unable to provide answers to questions. It is felt that everyone should be able to answer
questions relating to whether or not they would visit river corridor features, especially when four different photographs are presented.

Responses can be either verbally or numerically labelled. In their review Dolnicar (2013) find most papers in agreement that answer options should be verbally labelled. It is considered that verbally labelling makes answer options easier to interpret and therefore leads to better reliability and robustness of results (e.g. Peters and McCormick, 1966; Krosnick, 1999 both in Dolnicar, 2013). Moreover Rossiter (2010) argue that verbal labels should be used when measuring beliefs because beliefs are mentally stored in the verbal format. It is also recommended that all responses are labelled. Comparing end labelling and each category labelling Menold et al. (2014) find that labelling all categories leads to higher reliability of results.

Finally, the actual survey question can be decided. To elicit a measure of potential the survey question relates to potential visitation. To keep wording simple the question starts with ‘I would go here...’ followed by activities relating to the varying ecosystem services (table 20). Acknowledging response recommendations and after discussion the five response options selected were: never, rarely, sometimes, frequently and very frequently. Numerical values are attached to these response options as follows; never (0), rarely (1), sometimes (2), frequently (3) and very frequently (4). Linkages will be established in the matrix if the average responded score is above 2, representing a score above sometimes.
Table 20: Wording for the cultural service elicitation questions and respective ecosystem service

<table>
<thead>
<tr>
<th>Question</th>
<th>Ecosystem Service</th>
</tr>
</thead>
<tbody>
<tr>
<td>I would go here...</td>
<td></td>
</tr>
<tr>
<td>...because I find it beautiful/pleasing to look at</td>
<td>Aesthetic value</td>
</tr>
<tr>
<td>...to meet with friends and/or to partake in social activities</td>
<td>Social relations</td>
</tr>
<tr>
<td>...for inspiration to create something (such as a painting, poem, song</td>
<td>Inspiration</td>
</tr>
<tr>
<td>or photograph)</td>
<td></td>
</tr>
<tr>
<td>...to learn or teach about the environment</td>
<td>Education/scientific knowledge</td>
</tr>
<tr>
<td>...to experience cultural heritage</td>
<td>Cultural heritage</td>
</tr>
<tr>
<td>...to experience spirituality/religion</td>
<td>Spirituality and religion</td>
</tr>
<tr>
<td>...to partake in recreation (e.g. walking, kayaking, fishing)</td>
<td>Recreation</td>
</tr>
</tbody>
</table>

(ii) Open Questions

The purpose of the open questions are to understand how people connect with river corridor features. For each river corridor feature respondents are asked to 'Please use a few words or sentences to describe what this environment means to you’. Content analysis can then be undertaken to unravel respondents’ connections with river corridor features.

(iii) Sociodemographic questions

Above it is highlighted that socio-demographic questions may help explain variance in preferences. Socio-demographic questions will seek information which past research has found to potentially explain variance (Zoderer et al., 2016b). Questions will therefore be on: gender, age, education level, place of residence, membership of environmental organisations, and participation in environmental activities.

5.3 Survey population for this research

Above a survey has been designed which can be used to populate an ecosystem service capacity matrix linking Scottish river corridor features to cultural ecosystem service provision. The next step in this research is to test and evaluate the potential of the
methodology by conducting a survey. This requires consideration of survey population. Ideally the survey would be administered to a sample of both the Scottish population and outside travellers who may visit river corridors. For example, in their photo-based cultural services research in Spain, López-Santiago et al. (2014) surveyed local (191) and nonlocals (123). To replicate this with an online survey, hyperlinks to the survey could be posted on websites designed for locals and tourists, however in doing this, how do you ensure those you sample are representative of locals and tourists who visit river corridors? You would need to target many local groups and varying tourist pages, unfortunately finding these groups, contacting them to post the survey and ensuring a representative sample is beyond the scope of this research due to time constraints. Instead, the survey will be conducted on a smaller sub-population with a known bias, subsequently the survey undertaken should be regarded as a pilot project with results viewed as "preliminary knowledge" in nature.

After discussion with those at SNH it was decided the sample population for this research would be those people receiving the monthly Scottish Natural Heritage Newsletter. This choice was made for two main reasons. Through SNH it was possible to access the sub-population, email addresses did not need to be obtained as an article linking to the survey could be placed in the established newsletter. Secondly some assumptions about many of those receiving the SNH newsletter can be agreed. Assumptions made about the majority of the population are; they live or work in Scotland and have some involvement in environmental management. However, within this population there is still expected to be some diversity. Due to the restricted sample population, the survey conducted here needs to be viewed as a pilot project creating “preliminary knowledge”. It is thus recommended that a more extensive survey targeting a more representative sample of those visiting Scottish river corridors is conducted in the future. Of note, despite the survey being
conducted with a restricted population, there should still be significant scope to evaluate the survey as a novel way for capturing river cultural service potential.

5.4 Results

5.4.1 Cultural Service Matrix

As outlined in section 5.3, due to the challenging nature of capturing a representative population and the “preliminary knowledge” nature of this survey, a sub-population was selected for cultural service matrix population. To distribute this pilot survey, a blog post describing the nature of this PhD research and asking for people to help by completing the survey was published on Scotland’s Nature on the 20th of March 2018. A link to the blog post was included in the March edition of the Scottish Natural Heritage E-newsletter. After just under three months, on the 13th of June 2018 results were harvested. Due to the dispersion method chosen, it is not possible to gauge response rate, however completion rate can be identified, a total of 105 people started the survey and 62 finished giving a completion rate of 59%. As this survey is distinctly a pilot project, a small sample population compared to other ecosystem service research (e.g. van Berken and Verburg, 2014; Dou et al., 2017; Bullock et al., 2018) is not viewed as significantly detrimental. Indeed, several cultural service surveys have drawn conclusions from similar size or smaller populations (e.g. Brown et al., 2012; Mukherjee et al., 2014; Thiagarajah et al., 2015). Results were downloaded from Survey Monkey and analysed in Microsoft Excel.

To create a preliminary cultural service matrix the Likert options were assigned numerical values. The option ‘never’ was assigned the value of zero, values progress one integer place up to four for ‘very frequently’. Average scores were then produced for every feature-service combination included in the survey. If the average score exceeds 2 (‘sometimes’) then the feature is considered to provide the service and the matrix box
filled in. Although technically any score above 0 indicates that someone values the riverine feature for an ecosystem service, the objective here is to fill a matrix with strong positive relationships indicating potential ecosystem service provision. Subsequently, this matrix will allow cultural ecosystem services to be included equitably in the comparison of ecosystem service provision from Scottish rivers with and without nature designations.

The preliminary matrix produced from the results of this pilot survey clearly shows that perceptions of ecosystem service potential vary between riverine features (Table 21). Waterfalls facilitate the greatest number of potential services (5 out of 7) therefore appearing to be cultural service hotspots. Next comes heritage features, woodland and upland wetlands which support four of the seven services. Agricultural and amenity land both support three services. While lowland wetlands/floodplain lakes and natural lakes/reservoirs support two services. Not all river corridor features are identified to supply cultural services. Respondents find neither felled woodland nor urban areas to be areas they would visit to experience cultural services.
Table 21: The preliminary cultural service matrix. Preferences from the pilot survey were assigned numerical values, these values were then averaged. A feature is considered to provide the service if average score exceeds 2. Positive relationships are coloured green.

<table>
<thead>
<tr>
<th>Feature</th>
<th>Ecosystem Service</th>
<th>Aesthetic value</th>
<th>Social relations</th>
<th>Inspiration</th>
<th>Education/Knowledge</th>
<th>Heritage</th>
<th>Spirituality/religion</th>
<th>Recreation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Waterfalls</td>
<td>3.2</td>
<td>2.3</td>
<td>2.2</td>
<td>2.2</td>
<td>1.7</td>
<td>1.4</td>
<td>3.0</td>
<td></td>
</tr>
<tr>
<td>Heritage feature</td>
<td>2.5</td>
<td>2.1</td>
<td>1.5</td>
<td>1.7</td>
<td>2.5</td>
<td>0.6</td>
<td>2.3</td>
<td></td>
</tr>
<tr>
<td>Woodland</td>
<td>3.0</td>
<td>2.3</td>
<td>1.9</td>
<td>2.1</td>
<td>1.6</td>
<td>1.1</td>
<td>2.9</td>
<td></td>
</tr>
<tr>
<td>Upland wetlands</td>
<td>3.0</td>
<td>2.0</td>
<td>1.8</td>
<td>2.0</td>
<td>1.7</td>
<td>1.2</td>
<td>2.9</td>
<td></td>
</tr>
<tr>
<td>Agricultural land</td>
<td>3.0</td>
<td>1.8</td>
<td>1.6</td>
<td>2.1</td>
<td>1.8</td>
<td>1.0</td>
<td>3.1</td>
<td></td>
</tr>
<tr>
<td>Amenity land</td>
<td>2.6</td>
<td>2.2</td>
<td>1.3</td>
<td>1.7</td>
<td>1.7</td>
<td>0.8</td>
<td>2.6</td>
<td></td>
</tr>
<tr>
<td>Lowland wetlands/Floodplain lake</td>
<td>2.2</td>
<td>1.7</td>
<td>1.3</td>
<td>1.8</td>
<td>1.5</td>
<td>0.8</td>
<td>2.4</td>
<td></td>
</tr>
<tr>
<td>Natural lake/Reservoir</td>
<td>2.4</td>
<td>1.8</td>
<td>1.4</td>
<td>1.8</td>
<td>1.7</td>
<td>0.8</td>
<td>2.5</td>
<td></td>
</tr>
<tr>
<td>Felled Woodland</td>
<td>1.6</td>
<td>1.0</td>
<td>0.9</td>
<td>1.7</td>
<td>1.2</td>
<td>0.5</td>
<td>1.8</td>
<td></td>
</tr>
<tr>
<td>Urban areas</td>
<td>1.3</td>
<td>1.6</td>
<td>0.8</td>
<td>1.2</td>
<td>1.4</td>
<td>0.4</td>
<td>1.6</td>
<td></td>
</tr>
</tbody>
</table>

5.4.2 Socio-demographic questions

As outlined in section 5.2.1 (ii), the survey methodology has been designed to incorporate socio-demographic questions, by building these questions into the survey it is possible to better understand the dynamics of the pilot survey population. Knowing the survey population can unravel potential explanations for individuals’ preferences (Van den Berg and Koole, 2006; Lee et al., 2007; Chin et al., 2008; Tangeland et al., 2013; Eder and Arnberger, 2016; Zoderer et al., 2016a,b). In the case of this pilot survey, the majority of respondents were female (65%). The age categories 35-44, 45-54 and 55-64, had similar numbers of respondents (table 22), with respondents then tapering off towards the extremes. The majority of respondents held postgraduate qualifications (56%), although a large proportion held undergraduate qualifications as their highest qualification (36%). Few participants held college qualifications (8%) and no respondents had secondary school qualifications as their highest level of education. Most participants reside in rural...
areas (52%) with rural-urban areas the second most popular (27%), fewer live in urban areas (21%). Finally, the majority of respondents were part of an environmental organisation (79%).

Table 22: Table showing the age distribution of cultural service survey respondents

<table>
<thead>
<tr>
<th>Age</th>
<th>18-24</th>
<th>25-34</th>
<th>35-44</th>
<th>45-54</th>
<th>55-64</th>
<th>65-74</th>
<th>74+</th>
</tr>
</thead>
<tbody>
<tr>
<td>Percentage</td>
<td>3</td>
<td>8</td>
<td>25</td>
<td>29</td>
<td>25</td>
<td>8</td>
<td>2</td>
</tr>
</tbody>
</table>

5.5 Discussion: Evaluation of cultural service methodology

The completion and analysis of the survey results facilitates the evaluation of the proposed pilot methodology for capturing riverine cultural ecosystem services. Evaluation is a necessary step for reflecting on the contribution of this pilot survey to developing robust and repeatable approaches for the capture of river cultural services. This evaluation is divided broadly into weaknesses with suggestions for improvement and strengths of the pilot methodology.

5.5.1 Weaknesses and areas for future improvement

Unsurprisingly, considering the pilot nature of the survey, several flaws are identified during evaluation. These weaknesses are discussed in the following section along with recommendations to address them in future research, subsequently, the robustness and repeatability of the approach could be improved.

(i) Survey population and associated bias

Foreseeably, the most expected, yet significant weaknesses of the survey are associated with the survey population. As outlined in section 5.3 of chapter five, obtaining a true representative sample of locals and visitors who are likely to experience cultural river ecosystem services within Scotland was deemed beyond the scope of this research due to
time constraints. Subsequently, the decision was made to reach a sub-population with a known bias. Individuals were reached through the monthly Scottish Natural Heritage Newsletter, and it is therefore assumed that most respondents live or work in Scotland and have some involvement in environmental management. The analysis of results finds these biases to be somewhat identifiable, however, of importance, other additional biases not previously acknowledged appear emergent and somewhat dominant.

Notably, the most significant bias identified pertains to the education level of participants. Respondents were well educated, 92% had been awarded a minimum of a degree level qualification. This percentage of university graduates is high compared to other cultural ecosystem service research where a range of 58 – 84 % is identified (Brown et al., 2012; Dou et al., 2017; Rall et al., 2017; Ridding et al., 2018). Of significance, the extremely high percentage of participants holding a degree level qualification is unrepresentative of the Scottish population. The 2011 Census for Scotland found that 26% of adults held a minimum of an undergraduate degree (Scotland’s Census, 2011). This bias of highly educated participants needs to be addressed as it can influence preference scores. It is possible that the high percentage of respondents being graduates may have decreased recreational value (Zoderer et al., 2016a). Similarly, it could be hypothesised that the prevalence of degrees may have boosted perceived educational value. Additionally, it is possible that the educational bias may have led to a greater number of services being perceived (Bogdan et al., 2019).

It is hypothesised that the high education level of participants is a result of several factors arising from survey distribution method. Firstly, it is likely that the online method of distribution led to the preferential recruitment of respondents who are well educated (Li et al., 2013a). Secondly, it can be hypothesised that the method of distribution through
the Scottish Natural Heritage Newsletter tapped into the strong geo-science community present in Scotland (Gordon, 2012).

The second socio-demographic variable which may also be of influence is the high percentage of respondents who are part of an environmental organisation (79%). This variable may also have inflated the educational value assigned to features. This can be hypothesised because environmental organisations often seek to highlight and promote the educational value of ecosystems (Haigh, 2006; Schmidt et al., 2010).

Another significant bias in survey population discovered during results analysis is the gender division of respondents. 65% of survey respondents identified as female, this is 12.5% higher than the 52.5% reported in the 2011 Census for Scotland (Scotland’s Census, 2011). This is a greater bias than reported in ecosystem service mapping by Rall et al. (2017), in their survey 54.6% of respondents were female. It is highly possible that this gender inequality may have skewed preferences. Extrapolating the results of Chen et al. (2020), it could be hypothesised that the higher proportion of female respondents (65%) in this survey has inflated aesthetic value and deflated educational and inspirational value. Previous research by Plieninger et al. (2013) and Zoderer et al. (2016a) both find women to have higher appreciation of the non-material benefits of landscapes compared to men. It is thought that this may be a result of women having a greater sense of care towards the environment and greater appreciation of the intrinsic value of nature (Dietz et al., 2002; Calvet-Mir et al., 2016; Zoderer et al., 2016a). However, contrarily, Bogdan et al. (2019) identified that men were more likely to perceive more cultural services than women. Unsurprisingly, there are calls for more research to be conducted examining the gender difference of cultural ecosystem service perception (Calvet-Mir et al., 2016). If gender does influence cultural service perception, then for
results to be truly meaningful it is important that survey populations are representative of general populations.

The final bias which requires discussion concerns the residence of respondents. As outlined in section 5.3 it was assumed that because the survey was distributed via a SNH newsletter, respondents were very likely to live in Scotland. The strong geo-science community (Gordon, 2012) and progressive approach to the ecosystem service concept in Scotland (outlined section 2.5.1) could potentially have led to higher perceived values than might be given in other UK countries. In literature, Hossu et al. (2019) identified that residents and visitors held different views about the importance of urban lakes for different forms of recreation, inspiration and scientific/educational value. Incorporating the different views held by varying user groups within matrices is important for management, results can highlight areas where conflict and harmony may occur thus allowing local needs and economic benefits to be carefully balanced.

To progress from the pilot nature of this research and address the biases discussed above to make the results of the cultural service matrix more robust, it is crucial that the survey is repeated using a representative sample population. Representative sample populations are crucial in cultural ecosystem service research, since relationships are based on individual preferences participants need to represent general society (Howley et al., 2010). It seems likely that some researcher survey administration and supervision is required to achieve more representative sample populations. To address the proportional issue of education and gender amongst participants researchers could use a range of alternate mediums to promote the survey. For example, Ridding et al. (2018) advertise their survey through parish councils, local newspapers, and local community groups to diversify respondents. In-person surveys are also incredibly valuable for
obtaining representative samples, for example Hossu et al. (2019) undertake in-person targeted surveys within their study locations to ensure that the age distribution of the local area is represented. Importantly, to gain true representation of the population, researchers may need to be willing to conduct surveys when and where respondents feel most comfortable (Vollmer et al., 2015). In particular there needs to be an effort to reach those who are often under-represented by online surveys (Oteros-Rozas et al., 2018). Although such supervised surveys can be time-consuming, with careful planning, they can prove to be cost-effective (Willcock et al., 2017).

On a final note, there is clearly a need to investigate individual relationships between socio-demographic variables and multiple riverine cultural services alongside improving survey representativeness. It would be also meaningful to expand the socio-demographic questions to include a measure of visitation frequency, this is because research suggests that high visitation correlates with higher perceived cultural value (Bieling, 2014; Krasny et al., 2014; Rall et al., 2017).

(ii) Survey usability and design

Reflecting on survey usability and design is crucial for determining how repeatable the survey may be. Identifying strengths and weaknesses within design highlights where improvements can be made, subsequently, these improvements can contribute to increased repeatability and robustness of results.

The survey completion rate of 59% may be regarded by some to be a weakness of the methodology. Within literature the completion rate of cultural ecosystem service surveys is infrequently reported, those papers that do report indicate that 59% is relatively low (Bryce et al., 2016; Darvill and Lindo, 2016).
It is likely that survey completion rate is partly related to survey usability and design. Careful consideration of survey usability occurred in section 5.2.3. The survey was designed to be as short as possible, easy to understand and worded carefully. However, a completion rate of 59% suggests there is scope for improvement in design. Darvill and Lindo (2016) undertook a survey with only two open questions and reported a completion rate of 67%, it can therefore be hypothesised that seven open questions where respondents required to relay their thoughts and feelings may have caused fatigue. Yet, it is felt, and subsequently argued, that the value of responses to open questions is far greater than a 10% increase completion rate. The value of open questions is outlined in detail below in section 5.5.2 (ii). If it were felt that completion rate needed to be higher to improve robustness, entry to a prize draw could be added as an effective incentive (Helgeson et al., 2002; Ziegenfuss et al., 2013) as demonstrated by Martin et al. (2020).

Of relevance to survey design and repeatability, open questions are valuable because they facilitate the evaluation of survey design. Of importance, comments suggest that when the survey is repeated, there is a need to re-consider the amalgamation of river corridor features. Intentionally, to make the survey more user friendly (shorter) and to address single photograph bias, this research used four photographs for each feature, however this may have caused confusion. Participants noticed the amalgamation of different types of woodland with several indicating type influenced their preferences, therefore, moving forward it would be beneficial to separate broadleaf and coniferous woodland allowing differences in preferences to be captured. Similarly, comments reveal that the amalgamation of natural lakes and reservoirs might not be best practice as respondents tended to express views about reservoirs as opposed to natural lakes.
Open question comments also suggest that when the survey is repeated, robustness could be improved through the sub-division of recreation. Analysis of the open question for lakes and reservoirs revealed potential for six distinct recreational activities (Table ii, appendix seven). The identification and sub-division of multiple types of recreation is a practice advocated in other research examining river and lake environments (Allan et al., 2015, Reynaud and Lanzanova, 2017, Vierikko and Yli-Pelkonen, 2019, Thiele et al., 2020). In repeat surveys, this sub-division of recreation could be crucial for understanding and mitigating conflicts between individual types of recreation and between recreation and other cultural services (Meyerhoff et al., 2019).

On reflection, one of the biggest flaws of this pilot approach which could have improved future robustness and repeatability was not directly asking respondents for feedback on survey design. As outlined above, completion rate seems comparably low, therefore, if repeated, it would be valuable to capture how engaging respondents find the survey. Furthermore, design could be discussed and improved through workshops with experts and stakeholders (Baulcomb et al., 2015).

(iii) Spatial explicitness and actual use

Although this cultural service methodology was designed to be spatially inexplicit to allow for a matrix that can be transferred between rivers, the benefits of which are outlined below (section 5.5.2 iii), on reflection, the spatially inexplicit nature does have weaknesses. After deliberation (section 5.2.3 i) the decision was made to exclude ‘sense of place’, this occurred because ‘sense of place’ is predominately linked to place experiences (Kyle and Chick, 2007) and the survey needed to capture values for non-spatially specific river corridor features to fill the matrix. However, research shows rivers to be crucially important for ‘sense of place’ (e.g. Bricker and Kerstetter, 2002;
there therefore remains a significant need to explore the ‘sense of place’ associated with Scottish rivers. Furthermore, through comparison with other studies it is hypothesised that the spatially implicit nature of this approach may have contributed to the scarceness of cultural heritage, inspiration and spirituality within the matrix (Zoderer et al., 2016a; Assandri et al., 2018; Dou et al., 2019; Othman and Majid, 2018; Nagpal and Sinha, 2009; Badiali et al., 2018). Furthermore, the spatially inexplicit nature prevents the revelation of local knowledge regarding use and value (Zagarola et al., 2014).

Another distinct benefit of spatially explicit approaches is that they can capture actual use values as opposed to the potential use values generated from this survey. Future research should also focus on assessing how ecosystem service potential differs from actual ecosystem use. In their cultural service survey Rall et al. (2017) suggest there may be variance between potential and actual. In urban environments Kremer et al. (2016) suggest that the perceived value of urban green space may be greater than actual use value due to marketing focusing on ecosystem services and knowledge of the ecosystem services the spaces provide.

It is subsequently recommended that to improve robustness, it would be beneficial to incorporate into the matrix preferences obtained from spatially explicit studies. Approaches which enable the spatial specific capture of multiple cultural services and are consequently recommended include place-specific rating surveys (Smith and Ram, 2017; Zagarola et al., 2014) and participative perception mapping (PPM) (Plieninger et al., 2013). PPM may be particularly useful as it allows the identification of hotspots, synergies, trade-offs and cold-spots (Hauck et al., 2013; Rall et al., 2017), and can engage a range of different groups including stakeholders, residents and visitors (Brown and
Fagerholm, 2015; Ribeiro and Ribeiro, 2016). Equally, one approach which could reap significant rewards in terms of actual use data could be the content analysis of geo-tagged photographs. For example, Oteros-Rozas et al. (2018) undertake content analysis of geo-tagged images from Panoramio and Flickr to gauge cultural service use value from five European sites. While Chen et al. (2020) demonstrate how the Netlytic API-based tool, Arc-GIS, filtering and content analysis allowed mapping of cultural service use in the dykelands and marshes of the Cornwallis River in Nova Scotia.

(iv) Determining robustness

The above evaluation of the pilot survey has led to many recommendations for improving survey robustness, logically, to improve repeatability, the next step of survey development would be to capture how robust results actually are.

A photo-preference survey was selected based on existing research which has shown such surveys to yield similar results to field-based assessments (Stamps, 1999; Palmer and Hoffman, 2001 both cited in Zoderer et al., 2016b) with reduced time and monetary costs (Zoderer et al., 2016b). Therefore, field surveys located at specific river corridor features should be conducted in Scotland to evaluate and validate findings. Equally, the robustness of design could be evaluated through comparison with equivalent surveys with minor revisions including no labelling of each category and the use of numbers instead of words. Menold et al. (2014) suggest the labelling of categories conducted here should produce higher reliability. While in their review Dolnicar (2013) considered that verbally labelling makes answer options easier to interpret and therefore leads to better reliability of results (e.g. Peters and McCormick, 1966; Krosnick, 1999 both in Dolnicar, 2013). Conducting revised surveys would test the truth of the above researcher findings, and would therefore help to establish robustness.
It has been identified that there can be discrepancy between individuals stated preferences and actual behaviour, subsequently, this can damage the robustness of results (Godin et al., 2005; Johnston et al., 2017). To address this issue and test robustness, future surveys could integrate observations of human behaviour. For example, Gosal et al. (2018) conduct GPS tracking to identify which habitats individuals visit for recreation and aesthetic value. However, passive GPS tracking does not directly translate to value and is influenced by accessibility (Gosal et al., 2013). GPS tracking could be improved by asking respondents to answer a series of questions relating to habitats once they remain stationary for a period of time.

5.5.2 Strengths of riverine cultural service survey methodology

(i) Creation of a river corridor cultural service matrix

On evaluation, it appears that the pilot survey methodology has been successful in meeting the primary purpose of its design; the survey facilitated the creation of a matrix linking Scottish river corridor features to potential cultural service provision. Crucially, for the river cultural ecosystem service field, the success of the survey in creating a cultural service matrix which can be used to inform decision making demonstrates the power of non-monetary approaches. This approach therefore adds to the argument advocating the transition towards non-monetary quantification techniques (Daily et al., 2009; Hølleland et al., 2017; Hanna et al., 2017). The economic valuation of cultural services is deemed unfavourable due to moral dilemmas and the potential for the commodification of nature (Sandel, 2012 in Neuteleers and Engelen, 2015; Satz et al., 2013; Chan et al., 2012; Gómez-Baggethun and Ruiz-Pérez, 2011).

Of remark, the deviance away from economic valuation towards a preference survey has allowed the successful capture of multiple riverine cultural services, this is a significant
advancement within the research field. As discussed previously within the literature review, historically cultural service quantification has focused on recreation and tourism and aesthetic value because they are amiable to economic valuation, those services which are more intangible have been neglected due to the challenge of their capture (Feld et al., 2009; Schaich et al., 2010; Daily et al., 2009; Chan et al., 2011; Hernández-Morcillo et al., 2013; Milcu et al., 2013). In particular, the inclusion and exploration of cultural heritage within this ecosystem service assessment is somewhat progressive. In their review of cultural heritage as an ecosystem service Hølleland et al. (2017) found that 40% of reviewed papers only mention cultural heritage and did not explore the service.

Although there is a need to test robustness, it is positive that this method potentially adds to the bank of techniques which can be repeated to capture a range of services including social relations, inspiration, cultural heritage and education/knowledge in equitable terms facilitating more wholesome management decisions. However, as outlined above, there is a need to develop an approach which can include ‘sense of place’.

(ii) Open Questions

Perhaps the most unexpected strength of the methodology is revealed to be the use of open questions. Appendix seven demonstrates that comments arising from the open questions have been immensely valuable for unpicking matrix scores, unravelling thoughts and feelings and evaluating the survey methodology. Findings very much concur with Fletcher et al. (2014) who suggest using open questions gains a more emotional perspective from survey respondents. Furthermore, Watson et al. (2011) considers that the non-material wellbeing benefits of cultural services occur through a range of experiences, identities, capacities and activities, the open questions have been invaluable in beginning to unravel these mediums through which cultural services are generated
and experienced. Moving forward, the information gathered from open questions revealing why people value ecosystems can be incredibly useful for motivating individuals to participate in discussions and environmental actions (Fletcher et al., 2014).

Another benefit of open questions which became apparent during this research but could not be explored due to time constraints is the ability of open questions to reveal emergent cultural services. For example, of the 44 comments given for waterfalls, 17 seem to reveal respondents appreciate waterfalls for purposes other than the seven defined cultural services considered here. Analysing the comments shows that some respondents appreciate waterfalls because they are acoustically pleasant (5 of 17, e.g. Q1, 2) and exciting (4 of 17, e.g. Q3,4).

“peaceful, calm, associate images with the sound of moving water - a positive experience, natural and wild, a place I would like to spend time” Q1

“This is completely away from everything. The kind of habitat you can get lost in and forget about daily troubles and stresses of life. Hear and surround yourself with nature, including the running of the water and bird song” Q2

“invigorating, active, exciting environment” Q3

“There is something special about waterfalls, their dynamism entertains and excites.” Q4

This value of open questions for the revelation of emergent ecosystem services is consistent with other research. Using open questions Rall et al. (2017) identified urban green spaces in Berlin to be important for a variety of sports and relaxation. 41.5% of respondents viewed the urban spaces they mapped as important for relaxation (Rall et al., 2017). Combining the results presented here and Rall et al. (2017) provides some strong evidence for the consideration of relaxation as a cultural service. Future investigation into relaxation as a final cultural ecosystem service appears necessary.
Furthermore, concurring with Bogdan et al. (2019) it is suggested that moving forward researchers should be cautious of using fixed sets of services.

In summary of open questions, it is demonstrated here that their benefits significantly outweigh the negative of potential lower survey completion rate. It is certainly recommended that future research seeking to robustly quantify or explore cultural services provision integrates some form of open questions.

(iii) Further methodological strengths

Alongside the ability to capture multiple cultural services and elicit thoughts and feelings from respondents, this survey methodology has several other strengths which should be communicated. Firstly, by intentional design, the results of this survey can be transferred between Scottish river corridors. A criticism of many previous cultural service assessments is that they have focused on single sites, making it challenging to transfer results (Rall et al., 2017). Furthermore, this approach avoids the spatial patchiness associated with approaches that use geo-tagged social media photographs (Oteros-Rozas et al., 2018). The methodology developed enables assessments to be carried out without the need for data collection at individual rivers, however as mentioned above, spatially explicit studies are recommended to deepen understanding.

Another premediated practical strength of this approach is the time and cost efficiency. Compared to Zoderer et al. (2016b), the online method of data collection used here allowed for faster responses, less researcher time requirement, and no travel costs. Similarly, in contrast to frequency of use surveys such as Hein et al. (2009) and Campbell et al. (2016) this methodology required very little researcher time to be spent on data collection. Furthermore, this research considers the use of a photo-elicitation approach
easy to undertake, concurring with the findings of a similar study by Zoderer et al. (2016b).

It may sound obvious, but the inclusion of members of the public as participants is a significant methodological asset and contributes towards robustness. Acknowledging and appreciating subjectivity is crucial considering cultural values are fundamentally dependent on personal and cultural perceptions (Chan et al., 2012; Brown, 2013; Milcu et al., 2013; Small et al., 2017). Therefore, although the method of distribution created bias, the involvement of respondents means less potential bias and therefore a more robust outcome than if expert judgement had been used to infill the matrix (Dick et al., 2016). Similarly, using participants produced a matrix which is likely more robust than if proxies had been used. As highlighted in the literature review, finding proxies to represent cultural services is difficult and often, they can be inaccurate or unrepresentative of the service which is being mapped (García-Nieto et al., 2013; Casalengo et al., 2014). Indeed, in similar research conducted around the same time as this, Thiele et al. (2020) describe the struggles of selecting existing proxies and the need to combine multiple proxies to value one service. Combining proxies may increase the room for statistical error.

This research contributes to the development of cultural services methodologies which are suitable at the reach scale. In their research focusing on valuing and mapping cultural services of the Romanian Carpathians, Bogdan et al. (2019) highlight a need for cultural service methodologies that operate at small and local scales. Subsequently Bogdan et al. (2019) map cultural services in the at the kilometre squared scale, their findings show reveal the most valued places to be the river valleys. The GE RES tool developed here
therefore offers the potential for investigation of these hotspots at a higher resolution of meters and would be of use to stakeholders.

5.5.3 Potential for future use

Although evaluation of the pilot survey reveals some adjudgments to improve robustness and repeatability may be necessary, the successes of the tool indicate that it could be used in research focusing on temporal change and proposed management. Within lake environments, the pattern of cultural service provision has been identified to change seasonally (e.g Vierkko and Yli-Pelkonen, 2019), such research within the river realm appears necessary. Adapting photographs to represent river corridor features at different times of the year, this method could be utilised to examine seasonal patterns in river cultural service provision. The approach could also be used to examine temporal change over longer timeframes. Gilvear et al. (2013) suggested that as a result of degradation, rivers today are likely to provide less cultural services. Using before and after photographs, this approach provides a method for assessing changes in potential provision. Furthermore, using photographs of now and proposed management schemes, planners can gauge how different management scenarios will alter cultural service potential. Existing research such as Polizzi et al. (2015) and Vermaat et al. (2015) has focused on how management might alter those services which are easy to economically value, this method will allow a much broader range of services to be included in decision making. This could lead to river management which is more beneficial to wellbeing.

5.6 Creating an excel tool from the matrices

So far, this chapter has detailed the development, results and evaluation of a novel survey approach for capturing river cultural ecosystem services. Whilst the above evaluation reveals there is scope to improve the robustness and repeatability of the approach,
through the undertaking of a pilot survey the technique is sufficient to allow creation of a preliminary cultural service matrix. This can then be integrated with the literature-based provisioning and regulating service matrix to form the basis of GE RES, a novel new methodology which can be used to assess river ecosystem service provision.

To progress with methodology development, the provisioning and regulating matrix alongside the created cultural matrix must be integrated into a tool which can be used to investigate ecosystem service potential from rivers with nature designations. Information relating to the presence of river corridor features will be input into the tool with outputs then relating to ecosystem service potential. The tool will be built in Microsoft Excel. Programmed Excel Spreadsheets have been used in other research to output scores relating to ecosystem service potential (Bowd et al., 2012; Nordlund et al., 2016) and to estimate the contribution of habitats to ecosystem service provision (Christie and Rayment, 2012). Excel is favourable to use as an ecosystem service assessment tool because it is easily accessible and can be operated without extensive expert knowledge (Scholz and Uzomah, 2013).

The first step in creating the excel-based GE RES tool is deciding how river corridor data should be input. In their research Large and Gilvear (2015) input scores of 1-3 for river corridor features depending on their presence. Similarly, Brill et al. (2017) assign ecosystem service scores to the degree of presence of river corridor features. During the early stages of this research project, a pilot study was conducted using the Large and Gilvear methodology on three Scottish rivers, this pilot found a scoring system of 1-3 to be insensitive. Google Earth allows researchers to see river corridor features in relatively high detail so a more sensitive scale of 1-10 is introduced. This is consistent with the
recommendations of Kroll et al. (2011) who suggest studies using this approach should reach a good precision compromise.

Below table 2 highlights how scores of 0-10 are to be assigned based on the presence of river corridor features within 500m reaches. 13 of the 18 features are measured based on their percentage area of river corridor. Channelization and the two types of buffers are measured based on the percentage of channel length they are present. Width is a measure of wetted width while weirs are counted.

Before programming the excel tool it seemed logical to decide the desirable nature and form of outputs. After deliberation it was felt two sets of scores are necessary for each reach, one relating purely to ecosystem service potential and another adjusted for the area of river corridor. Using potential scores reaches can be compared in terms of the services which are present and the level of service provision. Area weighted scores are introduced in acknowledgment of the fact that river corridor width is variable along river courses, where river corridors are larger potential may technically be greater. Having area weighted scores therefore allows for a comparison which recognises potential is also a function of river corridor size.

The next stage in tool development was to programme excel to produce ecosystem service potential scores and area-weighted potential scores from input feature information. For the potential scores it was decided that the maximum score for each service should be 100, representing 100% potential. To area weight these scores they are to be multiplied by the river corridor area which can be measured on Google Earth using the polygon feature. The decision on which unit to measure river corridor in can be left up to the user, but to avoid working with extremely large area-weighted scores this research uses hectares.
For each ecosystem service, individual formulas will be written to reflect the unique combination of supporting features. In the original matrix of Large and Gilvear (2015), feature scores were summed to create ecosystem services, however this meant that for ecosystem services where there were more contributing features final ecosystem service scores could be higher. For example, only woodland plantation contributed to timber production, therefore the maximum score for timber production could be three, in contrast 11 different features contributed to biodiversity therefore creating potential for a much higher score. Here an alternate approach will be taken with 100% potential the maximum score which can be achieved for all ecosystem services. However, while multiple features contribute to service provision not all of these features can co-exist. For example, broadleaf woodlands and wetlands both contribute to water quality but saying they must both be present at maximum value (>80% river corridor) to create 100% potential would make no sense. 100% potential must therefore reflect the possible combinations of features that can exist within one reach. The possible combinations of river corridor features which could produce 100% potential will therefore be acknowledged in the formulas through the use of weightings. It is recognised that some river corridor features may exert a greater influence on potential than others, this will also be written into formulas through weightings. As the matrix used for GE RES is pioneering, these weightings will be based on discussion within the supervisory team, however, within the tool there will be the option to modify weightings to improve robustness. Each feature score will be multiplied by its corresponding weighting and then all weighted feature scores summed to provide potential scores. Crucially, formulas will be written to include disservice relationships. Alongside calculating ecosystem service scores the Excel tool will also be designed to calculate confidence scores for each
reach. Reach confidence scores are the sum of the matrix confidence scores given for all feature-service relationships identified within the reach.

On creation of the Excel GE RES tool, the substantial secondary research aim of selecting and developing an appropriate methodology for capturing river ecosystem service provision at a relatively small scale is achieved. Subsequently, this research can progress towards achieving the primary overarching aim of determining if ecosystem service provision differs between Scottish river corridors with and without nature designations
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<td>90-%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Floodplain lake</td>
<td>&gt;5%</td>
<td>1-5%</td>
<td>5-10%</td>
<td>10-15%</td>
<td>15-20%</td>
<td>20-25%</td>
<td>25-30%</td>
<td>30-35%</td>
<td>35-40%</td>
<td>40-45%</td>
<td>&gt;45%</td>
<td></td>
</tr>
<tr>
<td>Natural lake</td>
<td>&gt;5%</td>
<td>5-10%</td>
<td>10-20%</td>
<td>20-30%</td>
<td>30-40%</td>
<td>40-50%</td>
<td>50-60%</td>
<td>60-70%</td>
<td>70-80%</td>
<td>80-90%</td>
<td>Just lake</td>
<td></td>
</tr>
<tr>
<td>Dam-reservoir</td>
<td>&gt;5%</td>
<td>5-10%</td>
<td>10-20%</td>
<td>20-30%</td>
<td>30-40%</td>
<td>40-50%</td>
<td>50-60%</td>
<td>60-70%</td>
<td>70-80%</td>
<td>80-90%</td>
<td>Just reservoir</td>
<td></td>
</tr>
<tr>
<td>Urban area</td>
<td>&gt;5%</td>
<td>5-10%</td>
<td>10-20%</td>
<td>20-30%</td>
<td>30-40%</td>
<td>40-50%</td>
<td>50-60%</td>
<td>70-80%</td>
<td>90-%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Heritage feature (number)</td>
<td></td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>6</td>
<td>7</td>
<td>8</td>
<td>9</td>
<td>10</td>
</tr>
<tr>
<td>Waterfall (number)</td>
<td></td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>6</td>
<td>7</td>
<td>8</td>
<td>9</td>
<td>10</td>
</tr>
</tbody>
</table>
Chapter Six: Results of a paired river comparison

6.1 Introduction

This chapter presents and initiates discussion of the results of GE RES assessments undertaken in accordance with the overarching research aim of determining if ecosystem service provision differs between Scottish river corridors with and without nature designations. However, prior to delving into results this chapter outlines the nature and determination of study locations. The first results presented are an attempt to directly answer the overarching research question. Statistical analysis is conducted through two lenses, one set of results is non-area weighted and the other weighted according to river corridor area. Statistical tests are undertaken to compare ecosystem service metrics between the rivers in each pair, the outcomes of these tests are then combined and compared to determine if general patterns or trends can be distinguished. Conclusions from analyses are then presented to answer the overarching research question.

The second set of results presented is an attempt to investigate the role river reach geomorphology plays a role in determining river ecosystem service potential. Specifically, this set of results seek to answer the question; is river reach geomorphology more significant in determining river ecosystem service potential than nature designation? To answer this question river reaches were first classified according to the SEPA reach typology. Subsequently, owing to some rivers having very low numbers of certain reach types the decision was made to pool then compare data from protected and unprotected reaches. As with the first set of analyses, non-weighted and weighted comparisons were undertaken. The two sets of results are then examined before a conclusion on the sub-research question is tentatively reached.
The final set of results produced are somewhat different in nature taking the form of a case-study. The GE RES method produces continuous downstream spatial data for each 500m reach, thus, data allows the creation of ‘ecosystem service long-profiles’. This section of results outlines the characteristics and potential benefits of these long-profiles through the presentation of case study comparison between long-profiles for the Dee and Don. The case study begins by contrasting downstream trends in the various ecosystem service metrics. Subsequently, the longitudinal nature of these long-profiles opens the gateway for the examination and comparison of ecosystem service hotspots. Although a case study, with only one pair being examined, the investigation of hotspots somewhat contributes towards answering the overarching research aim.

6.2 Nature and determination of study locations.

In accordance with the research aim of determining if ecosystem service provision differs between Scottish river corridors with and without nature designations, a paired approach will be undertaken. Paired approaches are frequently used in river studies, two rivers with similar hydrological and climatological conditions are compared to determine the influence of external variables (e.g. Brooks et al., 2003; Ricker et al., 2008; Eastwood et al., 2016). Of significance, this assessment focuses on the designation of Special Areas of Conservation (SACs), this decision is made because SAC is the only designation given to the entire length of Scottish rivers. SACs are designated to protect one or more species listed within the EU Habitats Directive.

In an attempt to produce a robust assessment, four Scottish river pairs were selected. The specific rivers selected arose following discussion within the supervisory team, spatial location of rivers was somewhat confined by the need to have a pair of rivers. The pairs selected are the protected Almond & unprotected Earn, protected Teith & unprotected
Forth, protected Dee & unprotected Don and the protected Thurso & unprotected Forss Water. Figure 13 shows the locations of the eight chosen rivers. Fact sheets providing detail of each river are presented below (tables 24, 25, 26, 27, 28, 29, 30 & 31). Specifically, fact sheets contain information relating to geographical descriptions, nature and purpose of designation, status of protected habitats/species and management actions.

*Figure 13: Map showing the location of the eight study rivers within Scotland*
Table 24: Fact sheet for the protected river Almond

<table>
<thead>
<tr>
<th>River Almond</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Description</strong> – The River Almond is located in the Perth and Kinross region and is a tributary of the River Tay. The headwaters of the Almond are located at 900m a.s.l around Creag Uchdag, from here the river flows east for around 48km through Glen Almond and Almondbank before joining the Tay just above Perth.</td>
</tr>
<tr>
<td><strong>Designation and Purpose of designation</strong> - The primary reason for the designation of the Tay as an SAC is because the river supports a high-quality population of Atlantic salmon. Aside from Atlantic salmon the Tay also contains Sea lamprey, Brook lamprey, River lamprey and Otter which are qualifying features for designation but not the primary reason for designation.</td>
</tr>
<tr>
<td>Gravel beds are an important habitat</td>
</tr>
<tr>
<td><strong>Status of key habitats/species (last assessed condition in brackets)</strong> - Atlantic salmon (2011), Sea lamprey (2007), Brook lamprey (2007), River lamprey (2007) and Otter (2012) all considered in favourable condition (although data is for whole Tay SAC)</td>
</tr>
<tr>
<td><strong>Past and current management:</strong> To ensure the Tay remains favourable for the species for which the site was designated as an SAC there are several conservation objectives. The following require to be maintained in the long term: Population of the species, including range of genetic types for salmon, as a viable component of the site, distribution of species within site, distribution and extent of habitats supporting the species, structure, function and supporting processes of habitats supporting the species and no significant disturbance of species (obtained from a document on: <a href="https://gateway.snh.gov.uk/sitelink/siteinfo.jsp?pa_code=8366">https://gateway.snh.gov.uk/sitelink/siteinfo.jsp?pa_code=8366</a>)</td>
</tr>
</tbody>
</table>

Table 25: Factsheet for the unprotected river Earn

<table>
<thead>
<tr>
<th>River Earn</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Description</strong> - The River Earn flows out of Loch Earn and travels past Comrie, Crieff and Bridge of Earn for 74km before joining the River Tay near its tidal limit just before Newburgh.</td>
</tr>
<tr>
<td><strong>Past and current management</strong> – through the Tay and Earn Trust public and private sector funding has been used for a range of projects focusing on regeneration, education and research and environmental management. Projects delivered include: The Inner Tay Masterplan 2012-2022, phase 1 od the Perth City Activity Centre, back brases footpath Newburgh, harbour wall repair and construction of slipway Newburgh, bio-fuels feasibility study using Tay reed beds, willow and drift wood and interpretation boards for west oaks orchard and footpath to Rodney Pavilion Perth. However does not appear that any of these projects have focused on the Earn (to date)</td>
</tr>
</tbody>
</table>
| **River Earn Improvement Association** – conservation work of the association falls into two categories: 1) habitat improvement (lots of clearance activity, predominately on burns) and 2) hatchery/stocking work.
Table 2: Factsheet for the protected river Teith

<table>
<thead>
<tr>
<th>River Teith (Only concerned with Teith above confluence with Forth)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Description</strong> - The Teith is formed at the confluence of the Garbh Uisge and Eas Gobhain at Callander in Stirlingshire, the river flows for around 113km before joining with the river Forth at Stirling.</td>
</tr>
<tr>
<td><strong>Designation and Purpose of designation?</strong> Designated as an SAC. The primary reasons for the designation of the Teith is the presence of Sea lamprey, brook lamprey and river lamprey. Atlantic salmon are present as a qualifying features but are not the primary reason for designation. The conservation importance of the Teith is high because it supports all three lamprey species.</td>
</tr>
<tr>
<td>The river Teith provides excellent habitat for lamprey it contains extensive gravel bars and marginal silt beds which are important in the lamprey life cycle. Additionally, the majority of the river is has pristine water quality, banks are mostly well vegetated and the river has few barriers that can impinge migration.</td>
</tr>
<tr>
<td><strong>Past and current management</strong> - Habitat improvement works conducted by Forth and Tieth Management Group includes clearance of trees from watercourses, management of bank erosion. Management group consider that survey their survey findings and actions are important for management decisions. Management group also aid in the control of invasive species. Of note – The Deanston Distillery near Doune takes water from the Teith for the production of Whisky. River Forth Fisheries Trust – aim to conserve, maintain and restore freshwater habitats. Trust also focus on advancing public awareness. Conservation projects focus on pollution, catchment species, salmon identification, sea trout identification and designated sites (Teith). Past projects/ongoing projects include: Forth invasive species programme, scientific research, barrier easement and education.</td>
</tr>
</tbody>
</table>

Table 2: Factsheet for the unprotected river Forth

<table>
<thead>
<tr>
<th>River Forth</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Description</strong> (including region, length, source and confluence/mouth). The River Forth rises from Loch Ard in the Trossachs National Park, from here it flows through Aberfoyle before joining the Teith just above Stirling where shortly after the river becomes tidal. The river is around 30km long.</td>
</tr>
<tr>
<td><strong>Past and current management</strong>: Habitat improvement works conducted by Forth and Tieth Management Group includes clearance of trees from watercourses, management of bank erosion. Management group consider that survey their survey findings and actions are important for management decisions. Management group also aid in the control of invasive species. River Forth Fisheries Trust – aim to conserve, maintain and restore freshwater habitats. Trust also focus on advancing public awareness. Conservation projects focus on pollution, catchment species, salmon</td>
</tr>
</tbody>
</table>
identification, sea trout identification and designated sites (Teith). Past/ongoing projects include: Forth invasive species programme, scientific research, barrier easement and education.


Table 28: Factsheet for the protected river Dee

<table>
<thead>
<tr>
<th>River Dee</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Description (including region, length, source and confluence/mouth)</strong> The River Dee rises in the Cairngorm mountains and flows from 140km before reaching the North Sea at Aberdeen. During its course the River Dee flows through Braemar, Ballater and Banchory.</td>
</tr>
<tr>
<td><strong>Designation and Purpose of designation?</strong> The River Dee is designated an SAC because of the presence of freshwater pearl mussel, Atlantic salmon and otter (<a href="https://gateway.snh.gov.uk/sitelink/siteinfo.jsp?pa_code=8357">https://gateway.snh.gov.uk/sitelink/siteinfo.jsp?pa_code=8357</a>).</td>
</tr>
<tr>
<td><strong>Past and current management: Dee Catchment Partnership</strong> provide guidance and information on septic tanks, drain care, development guidelines (buffer strips), ponding and angling. Current projects include agricultural buffer strip creation, buffer strips for development, diffuse pollution priority catchments, drain campaign, easing obstructions to fish migration, Logie Burn restoration, managing recreation hotspot areas, natural flood management, partnership seminars, pearls in peril, pilot catchment initiative (morphology), raising awareness, Scottish Mink initiative, Tarland demonstration catchment, Think Tank, Upper Dee morphological improvements and Upper Dee Riparian woodland restoration. Fish Stocks and Habitat work conducted by the Dee District Salmon and Fishery Board and River Dee Trust includes: fish stocks (restoring access, reducing exploitation, improving habitat and stocking), habitat (improving habitat, restoring access and biosecurity) and smolt tagging and tracking project (<a href="http://www.riverdeetracking.com/">http://www.riverdeetracking.com/</a>). Improvements conducted on the Dee as part of a £3.5 million UK project to improve habitat for salmon and freshwater pearl muscles, planned work is the removal of gravel embankments along a 500m of the Allt an t-Slugain burn near Braemar. The embankments were originally built to contain flood waters but are considered to potentially increase flood risk downstream, they also accelerate flow which destroys habitat for fish and mussels.</td>
</tr>
<tr>
<td><strong>Past Project - Conservation of Atlantic Salmon in Scotland project (2004 – 2008)</strong> – Survey work taken to monitor population of Salmon in Dee, instillation of fish pass at Coy dam at Crathes castle, land entered into riparian land management agreements, fencing installed, new silt traps, riparian woodland coppicing and talks given to 32 classes of School children.</td>
</tr>
<tr>
<td><a href="http://www.snh.org.uk/salmonlifeproject/project_progress.asp">http://www.snh.org.uk/salmonlifeproject/project_progress.asp</a> Destruction of fishing platforms built in the 1990s on the Dee at Banchory to create habitat for freshwater pearl mussels and salmon – Part of the Pearls in Peril Project - <a href="http://www.deadlinenews.co.uk/2015/08/14/pearl-mussel-habitat-set-to-be-restored/">http://www.deadlinenews.co.uk/2015/08/14/pearl-mussel-habitat-set-to-be-restored/</a> Riparian woodland being installed along the Gairn, one of the largest tributaries of the Dee – also linked to the Peals in Peril project -</td>
</tr>
</tbody>
</table>

http://www.snh.org.uk/salmonlifeproject/project_progress.asp - four years worth of projects on the Dee

Table 29: Factsheet for the unprotected river Don

<table>
<thead>
<tr>
<th>River Don</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Description (including region, length, source and confluence/mouth)</strong> – The Don rises in the Cairngorms mountains and flows east for 132km before reaching the North Sea at Aberdeen. The Don passes Alford, Kemnay and Inverurie on its way to the sea.</td>
</tr>
<tr>
<td><strong>Past and current management – The River Don Trust</strong> – Projects include: genetic studies of salmon, biosecurity plan to prevent the spread of non-native invasive species, protection of key habitat and management of target species. Additionally, annual electro-fishing survey, trust have conducted a catchment wide walk-over habitat survey (including habitat types, obstacles, pollution and invasive species), Salmon in the Classroom and obstacle removal. The three groups concerned with the Don all have same common goals in regard to river habitat. Important for all organisations to work together (saving money and resources).</td>
</tr>
</tbody>
</table>

Table 30: Factsheet for the protected river Thurso

<table>
<thead>
<tr>
<th>River Thurso</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Description (including region, length, source and confluence/mouth)</strong> – The River Thurso is located in the Scottish Highlands in the North of Scotland. The Thurso begins at Dalagnachan in the Highlands where the Rumsdale Water meets to Glutt Water, from here the river flows 52km North East to Thurso on the North Coast of Scotland.</td>
</tr>
<tr>
<td><strong>Designation and Purpose of designation?</strong> The entire length of the Thurso is designated as an SAC for Atlantic salmon.</td>
</tr>
<tr>
<td><strong>Status of key habitats/species</strong> – The Thurso SAC was last assessed in 2011 with the Atlantic salmon population recorded as being unfavourable recovering.</td>
</tr>
<tr>
<td><strong>Past and current management: River Thurso Conservation Strategy 2016</strong> – Information about catch and release that is implemented on the river – 11th January – 19th June – prior to 1st of April all Salmon must be returned, 1st of April to 19th of June – fish must be handed over to a manager if they are incapable of being returned. 20th of June – 5th October – visitors may retain 1 or 2 fish depending on their length of stay. Treble hook use not permitted and all hooks should be barbless for final five weeks from September 1st.</td>
</tr>
</tbody>
</table>

http://www.thursorsriver.co.uk/docs/THURSO%20RIVER%20Conservation%20Strategy%202016.pdf
Table 31: Factsheet for the unprotected Forss Water

<table>
<thead>
<tr>
<th>Forss Water</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Description (including region, length, source and confluence/mouth):</strong> The Forss river itself flows for 22 km from Loch Shurrery to Crosskirk. In order to make the Forss comparable to the Thurso the Torran water and then the Cnocglas water upstream of Loch Shurrery are also included in this assessment. Total assessment length is 41 km. The Forss and associated rivers are located in Caithness in the Northern Highlands of Scotland.</td>
</tr>
<tr>
<td><strong>Past and current management</strong> - Could not find anything</td>
</tr>
</tbody>
</table>

Once river pairs were selected, river corridor area needed to be determined. As outlined above, flood extent data will be used to define the river corridor. For the purpose of GE RES assessments, data from the IH130 Digital Flood Risk Maps, produced by the UK Centre of Ecology and Hydrology will be used. This data is selected for three reasons. Firstly, at the time, a license for data could be obtained for free, this aligns with the cost-effective use of Google Earth. Secondly, the data set is available in a format which can be imported into Google Earth. Finally, this data set was chosen because it is relatively high resolution at a 50m gridded data set.

Once the appropriate licenses for the use of IH130 data were obtained the data was input into Google Earth. Once in Google Earth the pencil feature was used to delineate the 2-meter flood extent. Flood extent delineation required some expert determined extrapolation as data existed in 50m raster format, but assessment would be more accurate in the vector format. In layman’s terms, this essentially involved smoothing the edges of 50m block data into flood extent lines more likely to be present within nature. Using expert-judgement to delineate flood-extends is common practice within hydrological studies (Noman *et al.*, 2003; Chignell *et al.*, 2015; Montello *et al.*, 2022).

Once the flood extents had been marked out, each river was divided into 500-meter reaches. Reach length was based on channel length which was determined using the
pencil feature of Google Earth. When all reaches were defined, GE RES assessments could commence. The assessments themselves are a simple process, they require the user to input data into the excel spreadsheet using the categories assigned to the presence of river corridor features outlined in table 23. The output of the excel spreadsheet were two sets of ecosystem service scores, these are presented in the following section.

6.3 Ecosystem service scores: Mann-Whitney Statistical comparisons

The overarching aim of this research is to determine if ecosystem service potential differs between rivers with and without nature designations. Using the GE RES model it is possible to obtain a range of ecosystem service potential metrics for the eight study rivers. Logically, the next step in achieving the research aim is to compare ecosystem service potential between the pairs of protected and unprotected rivers. To make comparisons robust the use of statistical tests is deemed necessary. Following deliberation of the different statistical tests available, the decision to use the Mann-Whitney U Test is reached. The Mann-Whitney test is considered most appropriate because it can test for statistical difference without the need for a data to have a normal distribution. Data input into GE RES model is categorical because the presence or absence of features is scored on a scale of 0-10, subsequently, this leads to non-parametric data ruling out the possibility for tests which rely on normally distributed data. Additionally, the use of the Mann-Whitney U Test is deemed appropriate due to its application in other ecosystem service research. The Mann-Whitney U test has been preformed in a variety of different ecosystem service studies including those comparing provision from different land types (e.g. García-Nieto et al., 2013; Hou et al., 2017; Zaehringer et al., 2017) including pairwise studies (e.g. Gosal et al., 2018), research comparing perceptions (e.g. Quintas-Soriano et al., 2018; Cornell et al., 2019), investigating beneficiaries (e.g.
Zorrilla-Miras et al., 2013), attempting ecosystem service measurement (e.g. Marques et al., 2011, Chamberlain et al., 2017) and studies examining the influence of restoration on services (Odgaard et al., 2017).

The statistical pairwise comparison of ecosystem service metrics from rivers with and without nature designations occurs through two lenses. First focus will be on non-weighted scores. These scores represent maximum potential provision which is independent of river corridor area; regardless of size all river corridor reaches could achieve a maximum ecosystem service potential score of 100 for any given service. Next attention turns to area-weighted scores. These scores are also important, by accounting for area it is possible to compare and understand patterns of ecosystem service potential in the landscape.

Overall, 136 Mann-Whitney tests were conducted. For both the non-weighted and area-weighted scenarios, statistical tests were conducted for all 17 ecosystem service metrics. Accounting for the use of four pairs, for each scenario a total of 68 tests were undertaken. Of the 68 tests undertaken on the non-weighted ecosystem service metrics 43 are recorded to be statistically different while the remaining 25 are identified to be statistically similar. For the area-weighted statistical tests, 46 are recorded to be statistically different leaving 22 as statistically similar.

6.3.1 Ecosystem Service Scores: Comparison tables
### Dee vs Don Comparison Table

*Table 32: Results of Mann-Whitney U tests seeking to determine if ecosystem service metrics are different for the protected river Dee or unprotected river Don. Mann-Whitney tests conducted in Minitab to a p value of 0.05.*

<table>
<thead>
<tr>
<th>River Dee vs River Don</th>
<th>Protected</th>
<th>Unprotected</th>
<th>Statistically Different?</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Total ecosystem service scores</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Area Weighted</td>
<td>Mean 5089.9</td>
<td>4517.5</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Median 4712.5</td>
<td>3715</td>
<td>Protected Greater</td>
</tr>
<tr>
<td>Non-weighted</td>
<td>Mean 381</td>
<td>385.3</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Median 352.5</td>
<td>368</td>
<td>No</td>
</tr>
<tr>
<td><strong>Total provisioning service score</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Area Weighted</td>
<td>Mean 1390.1</td>
<td>1164.6</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Median 1255.5</td>
<td>982</td>
<td>Protected Greater</td>
</tr>
<tr>
<td>Non-weighted</td>
<td>Mean 94.6</td>
<td>92.5</td>
<td>Protected Greater</td>
</tr>
<tr>
<td></td>
<td>Median 108</td>
<td>102</td>
<td></td>
</tr>
<tr>
<td><strong>Individual Provisioning Services</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Water supply</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Area Weighted</td>
<td>Mean 344.1</td>
<td>166.4</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Median 333.7</td>
<td>131.9</td>
<td>Protected Greater</td>
</tr>
<tr>
<td>Non-weighted</td>
<td>Mean 24.8</td>
<td>14.5</td>
<td>Protected Greater</td>
</tr>
<tr>
<td></td>
<td>Median 24</td>
<td>12</td>
<td></td>
</tr>
<tr>
<td>2. Agriculture</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Area weighted</td>
<td>Mean 699</td>
<td>843.1</td>
<td>Unprotected Greater</td>
</tr>
<tr>
<td></td>
<td>Median 543.3</td>
<td>614.6</td>
<td></td>
</tr>
<tr>
<td>Non-weighted</td>
<td>Mean 42</td>
<td>60.7</td>
<td>Unprotected Greater</td>
</tr>
<tr>
<td></td>
<td>Median 50</td>
<td>70</td>
<td></td>
</tr>
<tr>
<td>3. Timber</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Area weighted</td>
<td>Mean 336.4</td>
<td>154</td>
<td>Protected Greater</td>
</tr>
<tr>
<td></td>
<td>Median 282.5</td>
<td>97.9</td>
<td></td>
</tr>
<tr>
<td>Non-weighted</td>
<td>Mean 27.5</td>
<td>16.9</td>
<td>Protected Greater</td>
</tr>
<tr>
<td></td>
<td>Median 20</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>4. HEP</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Area weighted</td>
<td>Mean 10.7</td>
<td>1.1</td>
<td>No</td>
</tr>
<tr>
<td></td>
<td>Median 0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Non-weighted</td>
<td>Mean 0.4</td>
<td>0.4</td>
<td>No</td>
</tr>
<tr>
<td></td>
<td>Median 0</td>
<td>0</td>
<td>No</td>
</tr>
<tr>
<td><strong>Total regulating service scores</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Area Weighted</td>
<td>Mean 1066.2</td>
<td>534.2</td>
<td>Protected Greater</td>
</tr>
<tr>
<td></td>
<td>Median 920.9</td>
<td>430.3</td>
<td></td>
</tr>
<tr>
<td>Non-weighted</td>
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(ii) Teith vs Forth Comparison Table

Table 33: Results of Mann-Whitney U tests seeking to determine if ecosystem service metrics are different for the protected river Teith or unprotected river Forth. Mann-Whitney tests conducted in Minitab to a p value of 0.05.

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<th>Unprotected</th>
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Protected Greater | Non-weighted | Protected Greater | Non-weighted | No | Protected Greater | Non-weighted | No | Protected Greater | Non-weighted | No
### (iii) Almond vs Earn Comparison Table

Table 34: Results of Mann-Whitney U tests seeking to determine if ecosystem service metrics are different for the protected river Almond or unprotected river Earn. Mann-Whitney tests conducted in Minitab to a p value of 0.05.

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### Individual Cultural Service Scores

1. **Aesthetic value**
   - Area weighted: Mean 406.8, Median 316.5
   - Non-weighted: Mean 64.5, Median 70
2. **Social relations**
   - Area weighted: Mean 172.1, Median 169.8
   - Non-weighted: Mean 36, Median 30
3. **Inspiration**
   - Area weighted: Mean 1.6, Median 0
   - Non-weighted: Mean 0.5, Median 0
4. **Education/knowledge**
   - Area weighted: Mean 380.4, Median 304
   - Non-weighted: Mean 62.3, Median 75
5. **Heritage**
   - Area weighted: Mean 9.23, Median 0
   - Non-weighted: Mean 1.6, Median 0
6. **Recreation**
   - Area weighted: Mean 406.8, Median 316.5
   - Non-weighted: Mean 64.5, Median 70
(iv) Thurso vs Forss Water Comparison Table

Table 3: Results of Mann-Whitney U tests seeking to determine if ecosystem service metrics are different for the protected river Thurso or unprotected Forss Water. Mann-Whitney tests conducted in Minitab to a p value of 0.05.

<table>
<thead>
<tr>
<th>Thurso and Forss Water</th>
<th>Protected</th>
<th>Unprotected</th>
<th>Statistically Different?</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Total ecosystem service scores</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Area Weighted</td>
<td>Mean 5433.5</td>
<td>3716.8</td>
<td></td>
</tr>
<tr>
<td>Median 4063.1</td>
<td>2372.4</td>
<td>Protected Greater</td>
<td></td>
</tr>
<tr>
<td>Non-weighted</td>
<td>Mean 346.5</td>
<td>351.3</td>
<td></td>
</tr>
<tr>
<td>Median 350.3</td>
<td>354</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td><strong>Total provisioning service score</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Area Weighted</td>
<td>Mean 1174.3</td>
<td>483.8</td>
<td></td>
</tr>
<tr>
<td>Median 611.6</td>
<td>62.4</td>
<td>Protected Greater</td>
<td></td>
</tr>
<tr>
<td>Non-weighted</td>
<td>Mean 57.9</td>
<td>32</td>
<td></td>
</tr>
<tr>
<td>Median 43</td>
<td>4</td>
<td>Protected Greater</td>
<td></td>
</tr>
<tr>
<td><strong>Individual Provisioning Services</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Water supply</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Area Weighted</td>
<td>Mean 416.4</td>
<td>199.4</td>
<td></td>
</tr>
<tr>
<td>Median 153.2</td>
<td>28.7</td>
<td>Protected Greater</td>
<td></td>
</tr>
<tr>
<td>Non-weighted</td>
<td>Mean 18.8</td>
<td>11.3</td>
<td></td>
</tr>
<tr>
<td>Median 8</td>
<td>4</td>
<td>Protected Greater</td>
<td></td>
</tr>
<tr>
<td>2. Agriculture</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Area weighted</td>
<td>Mean 104.4</td>
<td>482.5</td>
<td></td>
</tr>
<tr>
<td>Median 0</td>
<td>203.2</td>
<td>Unprotected Greater</td>
<td></td>
</tr>
<tr>
<td>Non-weighted</td>
<td>Mean 11.3</td>
<td>31.9</td>
<td></td>
</tr>
<tr>
<td>Median 0</td>
<td>20</td>
<td>Unprotected Greater</td>
<td></td>
</tr>
<tr>
<td>3. Timber</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Area weighted</td>
<td>Mean 26.2</td>
<td>38.1</td>
<td></td>
</tr>
<tr>
<td>Median 0</td>
<td>0</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td>Non-weighted</td>
<td>Mean 2.1</td>
<td>1.4</td>
<td></td>
</tr>
<tr>
<td>Median 0</td>
<td>0</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td>4. HEP</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Area weighted</td>
<td>Mean 153.9</td>
<td>237.2</td>
<td></td>
</tr>
<tr>
<td>Median 0</td>
<td>0</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td>Non-weighted</td>
<td>Mean 7.3</td>
<td>5.8</td>
<td></td>
</tr>
<tr>
<td>Median 0</td>
<td>0</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td><strong>Total regulating service scores</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Area Weighted</td>
<td>Mean 1404.3</td>
<td>1450.7</td>
<td></td>
</tr>
<tr>
<td>Median 1005.6</td>
<td>1093.4</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td>Non-weighted</td>
<td>Mean 104.5</td>
<td>152.5</td>
<td></td>
</tr>
<tr>
<td>Median 100.5</td>
<td>187</td>
<td>Unprotected Greater</td>
<td></td>
</tr>
<tr>
<td><strong>Individual Regulating Services</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Natural Flood Mitigation</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Area weighted</td>
<td>Mean 863.2</td>
<td>757</td>
<td></td>
</tr>
<tr>
<td>Median 718.9</td>
<td>574.2</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td>2. Climate regulation</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>----------------------</td>
<td>--</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Area weighted</strong></td>
<td>Mean</td>
<td>7</td>
<td>23.6</td>
</tr>
<tr>
<td></td>
<td>Median</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td><strong>Non-weighted</strong></td>
<td>Mean</td>
<td>.2</td>
<td>1.5</td>
</tr>
<tr>
<td></td>
<td>Median</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>3. Water Quality Regulation</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Area weighted</strong></td>
<td>Mean</td>
</tr>
<tr>
<td></td>
<td>Median</td>
</tr>
<tr>
<td><strong>Non-weighted</strong></td>
<td>Mean</td>
</tr>
<tr>
<td></td>
<td>Median</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Total cultural service scores</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Area Weighted</strong></td>
<td>Mean</td>
</tr>
<tr>
<td></td>
<td>Median</td>
</tr>
<tr>
<td><strong>Non-weighted</strong></td>
<td>Mean</td>
</tr>
<tr>
<td></td>
<td>Median</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Individual Cultural Service Scores</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>1. Aesthetic value</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Area weighted</strong></td>
<td>Mean</td>
</tr>
<tr>
<td></td>
<td>Median</td>
</tr>
<tr>
<td><strong>Non-weighted</strong></td>
<td>Mean</td>
</tr>
<tr>
<td></td>
<td>Median</td>
</tr>
</tbody>
</table>

| **2. Social relations**           |  |
| **Area weighted**                 | Mean | 44.4  | 24.6  |
|                                   | Median | 0    | 0     |
| **Non-weighted**                  | Mean | 2.9   | 2.3   |
|                                   | Median | 0    | 0     |

| **3. Inspiration**                |  |
| **Area weighted**                 | Mean | 3.6   | 0     |
|                                   | Median | 0    | 0     |
| **Non-weighted**                  | Mean | 1     | 0     |
|                                   | Median | 0    | 0     |

| **4. Education/knowledge**        |  |
| **Area weighted**                 | Mean | 390.8 | 98    |
|                                   | Median | 226.2 | 0     |
| **Non-weighted**                  | Mean | 25    | 10.1  |
|                                   | Median | 18.8 | 0     |

| **5. Heritage**                   |  |
| **Area weighted**                 | Mean | 91.6  | 34.9  |
|                                   | Median | 0    | 0     |
| **Non-weighted**                  | Mean | 5.8   | 3.7   |
|                                   | Median | 0    | 0     |

| **6. Recreation**                 |  |
| **Area weighted**                 | Mean | 1162.3 | 812.4 |
|                                   | Median | 876.8 | 513.1 |
| **Non-weighted**                  | Mean | 74.6  | 75.4  |
|                                   | Median | 75   | 75    |
### 6.3.2 Non-weighted Comparison

*Table 36: Summary of the Mann-Whitney U tests undertaken to identify statistical difference within the non-weighted ecosystem service metrics for protected and unprotected rivers. Mann-Whitney tests conducted in Minitab to a p value of 0.05.*

<table>
<thead>
<tr>
<th>Score for Mann-Whitney</th>
<th>Not Weighted</th>
<th>Protected Greater</th>
<th>Unprotected Greater</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Ecosystem Service Score</td>
<td>Teith</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Total Provisioning Scores</td>
<td>Dee, Teith, Earn, Forss</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>1. Water Supply</td>
<td>Dee, Teith, Thurso</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>2. Agriculture</td>
<td>Don, Forth, Earn, Forss</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>3. Timber</td>
<td>Dee, Teith, Almond</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>4. HEP</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total Regulating Scores</td>
<td>Dee, Teith, Almond, Forss</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>1. Natural Flood Mitigation</td>
<td>Dee, Teith, Almond, Forss</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>2. Climate regulation</td>
<td>Dee, Almond</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>3. Water Quality Regulation</td>
<td>Dee, Teith, Almond, Forss</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>Total Cultural Service Scores</td>
<td>Don, Thurso</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>1. Aesthetic value</td>
<td>Don, Teith, Earn</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>2. Social relations</td>
<td>Dee, Almond</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>3. Inspiration</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4. Education/knowledge</td>
<td>Dee, Forth, Earn, Thurso</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>5. Heritage</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6. Recreation</td>
<td>Don, Teith, Earn</td>
<td>1</td>
<td>2</td>
</tr>
</tbody>
</table>

**Legend**

- Red text indicates Mann-Whitney test identified unprotected river to have greater potential
- Green text indicates Mann-Whitney test identified protected river to have greater potential

Table 36 summarises the information presented in tables 32-35 to capture the patterns of statistical test outcomes for the non-weighted data set. In the case of the non-weighted potential scores there is no statistical difference in ‘Total Ecosystem Service Score’ for three of the four pairs. The question is then, are they providing the same services or different? The picture is split for total provisioning score with two protected rivers (Dee, Teith) and two unprotected (Earn, Forss) statistically greater. However, delving into individual services reveals some identifiable differences. All four unprotected rivers are recorded to supply statistically greater agricultural potential. While for both water
supply and timber three of four protected rivers are recorded to supply greater potential. The Dee and Teith both have greater potential for water supply and Timber. The Thurso has greater potential for water supply while the Almond appears to supply more timber. As highlighted above HEP does not seem to have been successfully integrated into this approach.

Three of the four protected rivers (Dee, Teith, Almond) and one unprotected river (Forss) have statistically greater total regulating scores. For both natural flood mitigation and water quality regulation the picture is the same, the protected Dee, Teith and Almond and unprotected Forss have statistically greater potential. The protected Dee and Almond are also recorded to supply greater climate regulation potential.

In comparison to provisioning and regulating services a pattern for cultural services seems less discernible. One protected (Thurso) and one unprotected river (Don) have greater total cultural service scores. Two unprotected rivers (Don, Earn) and one protected (Teith) have greater potential for aesthetic value and recreation. Statistically greater potential for education/knowledge is split with two protected (Dee, Thurso) and two unprotected (Forth, Earn) rivers having greater potential. Social relations are statistically greater for only two protected rivers (Dee, Almond).

It is also meaningful to examine results from an individual pair angle. Of the four pairs the Dee & Don appear the most statistically different, having statistical difference in 13 of the 17 metrics. Of those differences in 9 instances, it is the protected Dee which provides greater ecosystem service potential. Of the 4 instances when the Don provides greater service potential three of these are cultural services. Both the Teith & Forth and the Almond & Earn are statistically different in 11 of the 17 metrics. However paired relationships are quite different. The Teith & Forth pair is similar to the Dee & Don with
the protected Teith having greater potential for 9 metrics and the unprotected Forth suppling greater potential for only two metrics. The metrics supplied in greater quantity by the Forth are agriculture and education/knowledge. The Almond & Earn pair is split with the protected Almond statistically greater for 6 metrics and the unprotected Earn 5 metrics. Of the 6 scenarios where the Almond supplies greater potential 4 are metrics relating to regulating services. Contrary, of the 5 scenarios where the Earn has greater ecosystem service potential three relate to cultural service provision. The Thurso & Forss are the most similar being different in only 8 of the 17 metrics, furthermore this is the only pair where the unprotected river (Forss) has statistically greater potential for more services than the protected (5 unprotected, 3 protected). Two of the three occurrences of protected area potential being greater occur in cultural service matrix. In contrast none of the 5 times the unprotected Forss has greater potential occur for cultural services, these are split between provisioning and regulating services.
### 6.3.3 Area-weighted Comparison

*Table 37: Summary of the Mann-Whitney U tests undertaken to identify statistical difference within the weighted ecosystem service metrics for protected and unprotected rivers. Mann-Whitney tests conducted in Minitab to a p value of 0.05.*

<table>
<thead>
<tr>
<th>Score for Mann-Whitney</th>
<th>Area Weighted</th>
<th>Protected Greater</th>
<th>Unprotected Greater</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Ecosystem Service Score</td>
<td>Dee, Teith, Earn, Thurso</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>Total Provisioning Scores</td>
<td>Dee, Earn, Thurso</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>1. Water Supply</td>
<td>Dee, Teith, Earn, Thurso</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>2. Agriculture</td>
<td>Don, Forth, Earn, Forss</td>
<td></td>
<td>4</td>
</tr>
<tr>
<td>3. Timber</td>
<td>Dee, Teith</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>4. HEP</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total Regulating Scores</td>
<td>Dee, Teith, Earn</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>1. Natural Flood Mitigation</td>
<td>Dee, Teith, Earn</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>2. Climate regulation</td>
<td>Dee, Almond</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>3. Water Quality Regulation</td>
<td>Dee, Teith, Almond, Forss</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>Total Cultural Service Scores</td>
<td>Teith, Earn, Thurso</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Aesthetic value</td>
<td>Don, Teith, Earn, Thurso</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>2. Social relations</td>
<td>Dee, Almond</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>3. Inspiration</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4. Education/knowledge</td>
<td>Dee, Forth, Earn, Thurso</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>5. Heritage</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6. Recreation</td>
<td>Don, Teith, Earn, Thurso</td>
<td>2</td>
<td>2</td>
</tr>
</tbody>
</table>

**Legend**

Red text indicates Mann-Whitney test identified unprotected river to have greater potential

Green text indicates Mann-Whitney test identified protected river to have greater potential

Similar to table 36, table 37 summarises the outcomes of statistical tests for the area-weighted data presented in tables 32-35. Examining the area-weighted scores from an ecosystem service angle reveals some differences in potential between protected and unprotected Scottish rivers. Total ecosystem service scores are statistically different for all four pairs. For three pairs (Dee & Don, Teith & Forth, Thurso & Forss) it is the protected river which has the greater score while for one pair it is the unprotected river (Almond & Earn). Total provisioning scores are statistically different for three of the four pairs. The protected Dee and Thurso and unprotected Earn are recorded to provide statistically...
greater provisioning service potential. The provisioning services agriculture and water supply are both statistically different for all four pairs. In every pair it is the unprotected river identified to have greater agricultural potential. In contrast results suggest water supply is provided mostly by protected rivers. Water supply is greater from the protected Dee, Teith and Thurso as well as the unprotected Earn. Potential for timber is statistically different for two pairs, in both pairs it is the protected river with greater timber potential (Dee and Teith).

Total regulating service scores are statistically different for three pairs. Regulating service potential is greater for the protected Dee and Teith and the unprotected Earn. Water quality regulation is the only regulating service found to be different for all four pairs. Potential for water quality regulation is higher in three protected rivers (Dee, Teith, Almond) and the unprotected Forss Water. Natural flood mitigation scores share the same differences as the total regulating score, at a ratio of 2:1 there is an indication that protected rivers have greater potential for natural flood mitigation. Climate regulation is also identified to be statistically greater for two protected rivers (Dee, Almond) but is not identified greater in any unprotected river.

Similar to total provisioning and total regulating scores total cultural service scores are statistically different for three of the four pairs. However, the three pairs are different from the other total scores. For total cultural service score the protected Teith and Thurso and the unprotected Earn have the higher supply. Of the cultural service metrics, three are identified to be statistically different for each of the four pairs, interestingly, for each service two protected and two unprotected rivers have greater potential. For aesthetic value and recreation the protected Teith and Thurso and unprotected Don and Earn have greater potential. While for Education/knowledge value it is the protected Dee and
Thurso and unprotected Forth and Earn. Difference in social relations is also identified but is only present for two pairs, in both instances it is the protected river with greater potential (Dee and Almond).

As with the non-weighted scores investigating the dynamics of individual river pairs is important. Two pairs share the ‘most statistically different’ title here, the Dee & Don and Almond & Earn are statistically different in 13 of the 17 metrics. However, the relationships between protected and unprotected rivers is quite contrasting. For the Dee & Don, 10 of the 13 differences occur as a result of the protected river having greater potential. The inverse appears apparent for the Almond & Earn with the unprotected Earn holding statistically greater potential for 10 of the 13 service metrics. Of the instances where the unprotected Don provides greater ecosystem service potential two of these occur for cultural services and the remaining is for the provisioning service of agriculture. Meanwhile the Dee supplies greater potential for the three remaining provisioning metrics and all regulating metrics. In some contrast the unprotected Earn provides statistically greater potential for four cultural metrics, three provisioning metrics and two regulating. Two of the regulating metrics are greater for the Almond as is the cultural metric of social relations.

The Teith & Forth and Thurso & Forss pairs appear to share greater similarity with the Dee & Don with protected rivers supplying greater service potential for most metrics. For the Teith & Forth 10 of the 17 metrics show statistical difference, in eight instances it is the protected Teith where provision is higher. Of those eight instances four relate to regulating service metrics and three to cultural services (the remaining is TES). The Forth is identified to provide greater potential for agriculture and education/knowledge. For the Thurso & Forss Water nine of 17 metrics prove statistically different. Of the seven
times the protected Thurso provides greater service provision four are associated with
cultural service metrics and two for provisioning services. Interestingly the unprotected
Forss provides greater agriculture and water quality regulation.

6.3.4 Area makes a difference!

Table 38: Table showing the mean area and standard deviation for each river alongside whether
areas for river pairs are statistically different. Statistical difference was determined by utilising
Mann-Whitney T-Tests in Minitab, tests conducted to a p value of 0.05.

<table>
<thead>
<tr>
<th>River</th>
<th>Mean Area</th>
<th>Standard Dev.</th>
<th>Statistically different? (T-Test)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dee</td>
<td>14.40</td>
<td>8.26</td>
<td></td>
</tr>
<tr>
<td>Don</td>
<td>12.09</td>
<td>7.29</td>
<td>Yes</td>
</tr>
<tr>
<td>Teith</td>
<td>17.71</td>
<td>12.71</td>
<td></td>
</tr>
<tr>
<td>Forth</td>
<td>17.91</td>
<td>16.45</td>
<td>No</td>
</tr>
<tr>
<td>Almond</td>
<td>7.05</td>
<td>8</td>
<td></td>
</tr>
<tr>
<td>Earn</td>
<td>17.9</td>
<td>11.43</td>
<td>Yes</td>
</tr>
<tr>
<td>Thurso</td>
<td>15.50</td>
<td>11.21</td>
<td></td>
</tr>
<tr>
<td>Forss Water</td>
<td>10.76</td>
<td>12.14</td>
<td>Yes</td>
</tr>
</tbody>
</table>

One of the first trends revealed during inspection of tables 36 and 37 is that the Mann-
Whitney results are different for non-weighted and area-weighted comparisons. Of the
68 Mann-Whitney tests 35 outcomes are the same for non-weighted and area-weighted
scores but a further 16 differ. Two scenarios are identified for the contrasting trends
between non-weighted and area-weighted scores. In 13 of the 16 instances there is
statistical difference between either the paired non-weighted or area-weighted scores
but not both. The remaining three differences occur due to contrasting Mann-Whitney
outcomes. In terms of river pairs difference between area-weighted and non-weighted
scores seems to be more prevalent for the Almond & Earn and Thurso & Forss (6 times
each) compared to the Dee & Don and Teith & Forth (twice each). Predictably, this
difference pairs well with river corridor areas (Table 38). Of the four pairs the Teith &
Forth have the most similar average area (17.71ha and 17.91ha respectively), the Dee &
Don follow next (14.40ha and 12.09ha respectively). There is a larger difference in average area of 4.74 ha between the Thurso & Forss Water (15.50 and 10.76 ha), but the difference is much greater for the Almond & Earn at 10.85 ha (7.05 and 17.9 ha).

Area weighting alters the pair dynamics for three of the four provisioning metrics (HEP is excluded due to null results). Agricultural potential is the only metric to remain exactly the same following area adjustment with all protected rivers providing statistically more potential. In terms of total provisioning service score accounting for area changes the dynamics of two pairs. Surprisingly considering the two rivers have very similar average corridor size area-weighting removes the statistically difference between the Teith & Forth. In addition, weighting reverses the relationship in the Thurso & Forss, total provisioning score becomes greater for the protected Thurso, however this is not surprising given the larger average area of the Thurso corridor. Following weighting, the general trend for total provisioning score becomes one of protected rivers being greater. Three statistical relationships are present, the protected Dee and Thurso and unprotected Earn are greater. Area weighting scores for water supply creates statistical difference between the Earn & Almond. Landscape supply for the Earn is identified to be statistically greater, this is predictable considering the average river corridor area is over double that of the Almond. For the remaining three pairs it is the protected river that provides greater water supply potential in terms of both potential and potential in the landscape. In contrast to water supply area-weighting removes the statistical difference between the Almond & Earn for timber supply. However, the trend for timber supply potential remains a feature of protected rivers, under the weighted scenario only two pairs have statistical difference, the Dee and Teith. In general, with the exception of agriculture, which is greater for unprotected rivers, it appears that area-weighting of scores creates a picture of provisioning service metrics being greater for protected rivers.
Relationships for two of the four regulating service metrics change on area-weighting. For both total regulating score and natural flood mitigation potential area adjustment inverses the relationship between the Almond & Earn. The unprotected Earn being identified to have greater potential for these two services is likely a function of the Earn having greater average river corridor area. Total regulating score and natural flood mitigation potential are also different following weighting for the Thurso & Forss, similar to total provisioning score the Forss is no longer identified to have significantly greater potential. As with changes in the Almond & Earn this is probably a reflection of differences in area. Despite the changes in statistical outcomes occurring as a result of area-weighting, the trend remains for total regulating score and natural flood mitigation potential to be greater for the protected river. These scores are greater for the protected Dee and Teith and the unprotected Earn. Mann-Whitney finds area weighting to have no impact climate regulation and water quality regulation potential. For both scores’ climate regulation is greater for the protected Dee and Almond. Meanwhile for water quality regulation the protected Dee, Teith and Almond and unprotected Forss provide greater potential. In summary, evidence indicates that regulating metrics are greater for protected rivers.

Of the five cultural service metrics for which statistical testing is valid, area weighting changes outcomes for three metrics. For total cultural service score only the Thurso & Forss dynamics stay the same, the protected Thurso continues to have greater potential. Weighting removes the relationship between the Dee & Don whilst simultaneously creates relationships between the Teith & Forth and Almond & Earn. These relationships are polar with the protected Teith and unprotected Earn providing statistically greater total cultural potential. Amalgamating outcomes for all statistical tests, it appears that protected rivers have greater total cultural service scores. The protected Teith and
Thurso and unprotected Earn are statistically greater. Aesthetic value and recreation share the same pattern as each other with only the Thurso & Forss pair changing following area weighting. Here it is the protected Thurso with its larger average river corridor area which is subsequently identified to provide greater potential for aesthetic value and recreation. This transition is akin to that identified for total regulating score, natural flood mitigation and total provisioning score. Following weighting the picture for aesthetic value and recreation becomes unclear with two protected and two unprotected rivers having greater potential. There is no difference in Mann-Whitney outcomes for social relations and education/knowledge. In terms of numbers, the weighted outcome for education/knowledge shares the split pattern between protected and unprotected rivers also identified for aesthetic value and recreation, although the dynamics of pairs is different. Education/knowledge is greater for the protected Dee and unprotected Forth. Finally, social relations remains statistically greater for the Dee and Almond with only tests for these two pairs being statistically different. In summary, the picture for all cultural metrics is one not significantly favouring protected or unprotected rivers. For two metrics provision is greater from protected rivers while for three there is distinct division.

6.4 River reach morphology, protected status, and potential ecosystem service provision

The first logical step to investigate the influence of river geomorphology on the provision of ecosystem services was to run statistical tests to determine if ecosystem service potential was statistically different or similar between the same reach types for each protected-unprotected pair. This involved running tests for all 17 service metrics for each of the five SEPA reach types, for both the unweighted and weighted data sets.
tests were required, this produced a total of 680 tests. To maintain consistency and owing to the non-parametric nature of data the decision was made to use the Mann-Whitney statistical test. However, unfortunately, this test cannot be run if the data set is smaller than ten (Zhao et al., 2007), accounting for scenarios where one data set was less than ten and where a river did not have a specific reach type present significantly reduced the number of valid tests. This process revealed just 153 out of a possible 340 could be conducted for each set of results. Table 39 outlines where and why some statistical tests were not possible.

Due to the limited number of tests which could be conducted, the decision was made to pool all the data for each service metric from each reach type and then compare protected and unprotected pooled reach data. This meant that some of the previously potentially invalid tests because of a sample number below ten could be conducted. Despite the pooling of data, only two reach A types were present for the unprotected rivers, as a result Mann-Whitney tests were conducted for each of the 17 metrics for reach types B, C, D and F. Subsequently, for the non-weighted and weighted data sets 68 statistical tests were undertaken each. Four outcomes of statistical tests were recognised:

1. The pooled protected reaches provide a statistically greater service potential.
2. The pooled unprotected reaches provide a statistically greater service potential.
3. There is no statistical difference in pooled data.
4. The statistical test could not produce a valid result.

Analysis begins with the general patterns identified within the non-weighted and weighted data sets. (table 40). For the non-weighted data set, 61 of the 68 statistical tests had a valid outcome. Of these tests, 14 (21%) identified the protected reaches to be statistically greater. 16 (24%) identified the unprotected reaches to be statistically
greater. Finally, 31 (46%) tests identified no statistical difference, that is, results are statistically similar. For the weighted data, the same 7 statistical tests produced invalid results leading also to a total of 61 tests with a valid statistical outcome. In comparison to the non-weighted data set, with 22 (32%) test outcomes, the weighted data set identified protected reaches to more frequently provide statistically greater ecosystem service provision. In conjunction, the weighted data set shows a fewer number of 11 (16%) unprotected metrics to be statistically greater. 28 (41%) tests identified no statistical difference. Concluding, the general trend for both sets of data appears to be a close division between statistical difference and non-statistically difference.
Table 39: Table outlining where statistical tests were and were not possible for geomorphological reach analysis along with the reasons why.

<table>
<thead>
<tr>
<th>SEPA Geomorphological Reach Type</th>
<th>River Pair</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>F</th>
<th>Number of tests possible</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dee &amp; Don</td>
<td>No. Only one reach A for the Don</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>68</td>
</tr>
<tr>
<td>Teith &amp; Forth</td>
<td>No. No reach A type for the Forth</td>
<td>No. Neither river has enough Type B</td>
<td>No. Forth does not have enough Type C</td>
<td>No. Neither river has enough Type D</td>
<td>Yes</td>
<td>17</td>
<td></td>
</tr>
<tr>
<td>Almond &amp; Earn</td>
<td>No. No reach A for Earn</td>
<td>No. Only four reach B for Earn</td>
<td>Yes.</td>
<td>No. Only four reach D for Almond</td>
<td>No. No reach F for Almond</td>
<td>17</td>
<td></td>
</tr>
<tr>
<td>Thurso &amp; Forss Water</td>
<td>No. Neither river has enough Type A</td>
<td>Yes</td>
<td>Yes</td>
<td>No. Neither river has enough Type D</td>
<td>Yes</td>
<td>51</td>
<td></td>
</tr>
</tbody>
</table>

**Total**: 153

**Legend**

<table>
<thead>
<tr>
<th>SEPA Reach type description</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
</tr>
<tr>
<td>B</td>
</tr>
<tr>
<td>C</td>
</tr>
<tr>
<td>D</td>
</tr>
<tr>
<td>F</td>
</tr>
</tbody>
</table>

Detailed descriptions of SEPA reach types are presented in Appendix two

Table 40: Table showing the statistical outcomes of the 68 tests performed for each set of pairwise ecosystem service score results. Four types of outcome were identified. Mann-Whitney statistical tests were conducted in Minitab to a p-value of 0.05.

<table>
<thead>
<tr>
<th>Statistical test outcome</th>
<th>Non-Weighted</th>
<th>Weighted</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Protected Statistically Greater</td>
<td>14</td>
<td>22</td>
</tr>
<tr>
<td>2. Unprotected Statistically Greater</td>
<td>16</td>
<td>11</td>
</tr>
<tr>
<td>3. No statistical Difference</td>
<td>31</td>
<td>28</td>
</tr>
<tr>
<td>4. Invalid Test</td>
<td>7</td>
<td>7</td>
</tr>
</tbody>
</table>
6.4.1 Non-Weighted Results
Table 41: Outcomes of reach type analysis for the non-weighted set of results. The reach type columns contain the outcomes of statistical tests, these are either no statistical difference, protected greater, unprotected greater or invalid, the percentage column then sums up the outcomes of the reach tests. The table also highlights if reach test outcomes fit the general trend of pairwise analysis along with a description of why they do or do not. Statistical tests were conducted using the Mann-Whitney test within Mini-tab (p-values of 0.05).

<table>
<thead>
<tr>
<th>Metric</th>
<th>Reach Type</th>
<th>Percentage</th>
<th>Fits the general trend?</th>
<th>Description (of paired comparison)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total ES Score</td>
<td>B</td>
<td>C</td>
<td>D</td>
<td>F</td>
</tr>
<tr>
<td>Total Provisioning Score</td>
<td>NSD</td>
<td>PG</td>
<td>NSD</td>
<td>UPG</td>
</tr>
<tr>
<td>Total Regulating Score</td>
<td>PG</td>
<td>NSD</td>
<td>PG</td>
<td>PG</td>
</tr>
<tr>
<td>Total C ES Score</td>
<td>NSD</td>
<td>UPG</td>
<td>UPG</td>
<td>UPG</td>
</tr>
<tr>
<td>Water Supply</td>
<td>PG</td>
<td>PG</td>
<td>NSD</td>
<td>PG</td>
</tr>
<tr>
<td>Agriculture total</td>
<td>UPG</td>
<td>NSD</td>
<td>UPG</td>
<td>UPG</td>
</tr>
<tr>
<td>Timber Production</td>
<td>NSD</td>
<td>PG</td>
<td>NSD</td>
<td>NSD</td>
</tr>
<tr>
<td>HEP Production</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>NFM</td>
<td>NSD</td>
<td>NSD</td>
<td>PG</td>
<td>PG</td>
</tr>
<tr>
<td>Climate regulation</td>
<td>NSD</td>
<td>NSD</td>
<td>NSD</td>
<td>NSD</td>
</tr>
<tr>
<td>Water Quality</td>
<td>NSD</td>
<td>NSD</td>
<td>NSD</td>
<td>PG</td>
</tr>
<tr>
<td>Aesthetic Value</td>
<td>UPG</td>
<td>UPG</td>
<td>UPG</td>
<td>NSD</td>
</tr>
<tr>
<td>Social relations</td>
<td>PG</td>
<td>PG</td>
<td>PG</td>
<td>NSD</td>
</tr>
<tr>
<td>Inspiration</td>
<td>N/A</td>
<td>NSD</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Education/knowledge</td>
<td>NSD</td>
<td>NSD</td>
<td>UPG</td>
<td>UPG</td>
</tr>
<tr>
<td>Cultural Heritage</td>
<td>NSD</td>
<td>NSD</td>
<td>NSD</td>
<td>NSD</td>
</tr>
<tr>
<td>Recreation</td>
<td>UPG</td>
<td>UPG</td>
<td>UPG</td>
<td>NSD</td>
</tr>
<tr>
<td>Total protected</td>
<td>3</td>
<td>4</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>statistically greater</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total unprotected</td>
<td>3</td>
<td>3</td>
<td>6</td>
<td>4</td>
</tr>
<tr>
<td>statistically greater</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total statistically</td>
<td>9</td>
<td>9</td>
<td>6</td>
<td>7</td>
</tr>
<tr>
<td>different</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>SEPA reach types</th>
<th>Key</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>B</td>
<td>Step-pool, Plane</td>
<td>C</td>
</tr>
<tr>
<td>D</td>
<td>Actively Meandering</td>
<td>F</td>
</tr>
</tbody>
</table>

Reach Type Key: NSD - No statistical difference, PG - Protected Statistically Greater, UPG - Unprotected Statistically Greater.
The question which requires investigating is: to what extent do the results of the pooled reach comparison correspond with the trends presented in the above protected unprotected comparison? Answering this question is key to determining if it is geomorphology or protected status which exerts a more dominant influence on ecosystem service potential.

For the non-weighted data set, of the 16 metrics, eight show clear concurrence with the patterns identified in the above pair-wise comparisons (table 41). Of these, two similarities occur due to no statistical difference being identified in either comparison (inspiration and cultural heritage). Of the five similarities which are present in both comparisons, four pertain to a metric being statistically greater in protected rivers. In both comparisons, the general trend is for the total regulating service score, water supply, timber potential, and social relations to be greater in protected rivers. Agriculture is the only metric which is identified to be consistently greater in unprotected reaches and rivers. The final similarity identified occurs for total provisioning score, in both sets of analysis an even split between provision being statistically greater in protected and unprotected is identified.

Two distinct divergences are identifiable. In the reach comparison, total ecosystem service score is only identified to be statistically different for reach type D. In this scenario, it is the unprotected reaches which are found to provide statistically greater potential, this contrasts the protected-unprotected pairwise analysis within which one protected river is identified to provide statistically greater provision. Reach based tests find no statistical differences in climate regulation, this contradicts the pair-based analysis within which climate regulation was identified to be statistically greater from two unprotected rivers.
For the six remaining metrics, the comparison between the two sets of data appears to produce a mirky picture. The reach type comparison produces results which somewhat similar to the protected non-protected analysis but do not follow the exact trend. In reach-based analysis total cultural service score is identified to be greater for unprotected reach types C, D and F, in contrast, the paired analysis identified the score to be statistically greater for one protected and one unprotected river. The picture for natural flood mitigation is confusing, in two of the reach analysis tests (D＆F) potential is identified to be statistically greater from the protected reaches whilst the paired analysis found provision to be greater from three protected and one unprotected river. The picture is near identical for water quality except for only reach type F being statistically greater for protected rivers. For both aesthetic value and recreation the same scenario is present. Unprotected reach types B, C and D are identified to have statistically greater provision whilst the pairwise comparison found two protected and one unprotected river to hold greater provision. The remaining cultural service of educational value presents a similar picture to aesthetic value and recreation. For educational value, reach types D and F are identified to have greater potential whilst paired analysis found two unprotected and one protected to be greater.

Although a confusing picture to digest, once considered from the ecosystem service perspective it seems, that for the weighted scenario, the trend identified in the pair-wise analysis of protected-unprotected seems somewhat present when data are examined through the lens of reach type. In particular, similarity is arises from total regulating score, water supply, timber production and social relations being statistically greater in protected rivers and reaches alongside agriculture being greater in unprotected. Of note, drawing together these results it could be argued that reach type B, for which four of
these similarities occur, is significant in driving differences between protected and unprotected rivers.

6.4.2 Weighted Results
Table 42: Outcomes of reach type analysis for the weighted set of results. The reach type columns contain the outcomes of statistical tests, these are either no statistical difference, protected greater, unprotected greater or invalid, the percentage column then sums up the outcomes of the reach tests. The table also highlights if reach test outcomes fit the general trend of pairwise analysis along with a description of why they do or do not. Statistical tests were conducted using the Mann-Whitney test within Mini-tab (p-values of 0.05).

<table>
<thead>
<tr>
<th>Metric</th>
<th>Reach Type</th>
<th>Percentage</th>
<th>Fits the general trend?</th>
<th>Description (of paired comparison)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>B</td>
<td>C</td>
<td>D</td>
<td>F</td>
</tr>
<tr>
<td>Total ES Score</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total Provisioning Score</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total Regulating Score</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total C ES Score</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Agriculture total</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Timber Production</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HEP Production</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NFM</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Climate regulation</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Water Quality</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Aesthetic Value</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Social relations</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Inspiration</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Education/knowledge</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cultural Heritage</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Recreation</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total protected statistically greater</td>
<td>5</td>
<td>8</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Total unprotected statistically greater</td>
<td>3</td>
<td>2</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Total statistically not different</td>
<td>7</td>
<td>6</td>
<td>8</td>
<td>7</td>
</tr>
</tbody>
</table>

Reach Type Key

<table>
<thead>
<tr>
<th>Reach Type</th>
<th>General Trend Key</th>
</tr>
</thead>
<tbody>
<tr>
<td>NSD</td>
<td>No statistical difference</td>
</tr>
<tr>
<td>PG</td>
<td>Protected Statistically Greater</td>
</tr>
<tr>
<td>UPG</td>
<td>Unprotected Statistically Greater</td>
</tr>
</tbody>
</table>

General Trend Key

<table>
<thead>
<tr>
<th>General Trend</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Y</td>
<td>Fits the general trend of pairwise comparison</td>
</tr>
<tr>
<td>Y&amp;N</td>
<td>Somewhat fits the trend of pairwise comparison</td>
</tr>
<tr>
<td>N</td>
<td>Does not fit trend of pairwise comparison</td>
</tr>
</tbody>
</table>

SEPA reach type

<table>
<thead>
<tr>
<th>Reach Type</th>
<th>General Trend</th>
</tr>
</thead>
<tbody>
<tr>
<td>B</td>
<td>Step-pool, plane</td>
</tr>
<tr>
<td>C</td>
<td>Plane-riffle, Brained, Meandering</td>
</tr>
<tr>
<td>D</td>
<td>Actively Meandering</td>
</tr>
<tr>
<td>F</td>
<td>Low-gradient passively meandering</td>
</tr>
</tbody>
</table>

219
Within this set of data, it appears that there is no clear disparity or congruence between the reach investigations and paired analysis results. Of the 16 metrics, six are found to have contrasting outcomes between the reach analysis and paired comparison (table 42). These metrics are total provisioning score, total cultural service score, climate regulation, water quality, aesthetic value and recreation. A further six metrics are identified to be somewhat similar to the protected non-protected analysis but do not follow the exact trend. This is the case for total ecosystem service score, total regulating score, agriculture, potential timber production, natural flood mitigation and education. Although there is no clear disparity or congruence between the investigations, the identification of only four metrics showing similarity between data sets indicates that divergence is the dominating pattern. The metrics which show clear congruence between the sets of results are water supply, social relations, inspiration and cultural heritage.

Six metrics show obvious divergence between data sets. In the case of total provisioning score the reach type analysis finds potential to not be overall greater for either protected (type C) or unprotected reaches (type F), this contrasts the pairwise analysis within which protected rivers most frequently have greater potential. Similarly, the pairwise comparison identified cultural ecosystem service score to be greater for protected rivers, however within the reach analysis only one relationship for reach type D is statistically significant, and it sways in the unprotected direction. Climate regulation shows no concurrence as in the reach analysis no statistical difference is present whereas in the pairwise comparison two protected rivers are revealed to have greater potential. Finally, for both aesthetic value and recreation the reach analysis dominates towards protected reaches being statistically greater (types B, C & D) whereas the pairwise data shows an equal division between protected and unprotected being statistically greater.
Almost paradoxically, examining those metrics which demonstrate congruence between data sets adds weight to the suggestion that the overarching trend is one of divergence. Inspiration and cultural heritage are found to be similar because in both data sets no statistical difference is identified. Arguably, the only two true similarities present occur for water supply and social relations. Reach analysis finds water supply potential to be greater for all four reach types, this corresponds with the pairwise analysis within which water supply is predominantly greater for protected rivers. Similarly, social relations are identified to be greater for three of the four reach types, this corresponds with paired analysis within which two protected rivers are found to have greater potential for social relations.

Determining the overarching relationship between the two data sets is made challenging by the presence of metrics which show some, but not exact, similarity. In the cases of total ecosystem service score and water quality the dominant trend in the pairwise comparison is for protected rivers to supply greater potential whereas in the reach-based analysis the trend is divided between protected greater (types C & F) and no statistical difference (types B & D). For both total regulating score and natural flood mitigation potential is greater for all four reach types, this somewhat contrasts with the pairwise comparison within which one unprotected river is greater. For agricultural potential reach-based analysis finds that for two of the four scenarios there is no statistical difference (types B & F), in contrast pairwise analysis finds agricultural potential to be greater in all four unprotected rivers. From the research perspective, potential timber production is found mostly statistically similar between reach types (B, D & F) whereas in paired analysis there is an even division between protected rivers having greater potential and statistical similarity. Finally, potential for education is identified to be greater for one reach type for both protected (C) and unprotected (F) and statistically
similar for the remaining two types (B & D), in the paired analysis all relationships are identified to be statistically different.

As with the non-weighted scenario, comparing reach and pairwise analysis is challenging. Acknowledging the nature of similarities, differences and conflicting scenarios presented above it appears that in the case of the weighted results, the trends present in pairwise comparisons do not overwhelmingly exist within reach investigations. The trend for only the two metrics of water supply and social relations is identified to be consistent between the two data sets. In contrast, difference identified through statistical test outcome is clear for five services (total provisioning score, total cultural score, climate regulation, aesthetic value and recreation).

6.4.3 Comparison and summary of geomorphic analysis

Following analysis, it appears that the non-weighted and weighted comparisons produced different outcomes. In the non-weighted comparison, some similarity between reach investigations and pairwise analysis was discernible. Obvious similarity is present for five service metrics. Total regulating score, water supply, timber potential and social relations are consistently statistically greater for protected reaches and rivers while agriculture is greater for unprotected. Furthermore, some similarity between analyses is present for total provisioning score, total cultural service score, natural flood mitigation, water quality, aesthetic value, recreation and education value. In contrast, within the weighted set of results, little similarity between reach and pairwise data is evident.
6.5 Case study: Using river ecosystem service long-profiles to compare potential from rivers with and without nature designations (Dee Vs Don)

A significant benefit of the GE RES approach is the ability to create downstream ‘river ecosystem service long-profiles’. River ecosystem service long-profiles are constructed by presenting the ecosystem service scores produced for each reach in the form of stacked area line graphs for each river. These profiles facilitate the exploration of longitudinal patterns of river ecosystem service potential. Significantly, long-profiles also enable the identification of ecosystem service hotspots and coldspots. The following section seeks to demonstrate the information that can be gleaned from river ecosystem service long-profiles. To achieve this aim, the context of a comparison between the protected river Dee and unprotected river Don is utilised. The Dee & Don are chosen as a case study because they are similar in length and have previously been used in comparative protected area ecosystem service research (Eastwood et al., 2016).

Prior to the creation of long-profiles for the comparison of ecosystem service potential between the Dee & Don it was necessary to consider whether graphing the non-weighted or weighted data set would be more appropriate. Following deliberation, the decision to use the weighted data set was reached. The decision to use the area weighted scores was made because it is felt these scores more accurately represent likely actual supply of ecosystem services. However, using the weighted score comes with the caveat that hotspots and coldspots may be functions of reach area as opposed to river corridor features. To help determine how significant reach area is for each coldspot or hotspot, reach area is also plotted on the long-profiles.

To begin examination of river ecosystem service potential long-profiles, it seems logical to start with a broader picture, subsequently long-profiles detailing total provisioning,
total regulating and total cultural service potential for the Dee and Don will be compared and unpicked. Comparing the long-profiles presented in figure 14 reveals both similarities and differences along the two rivers.
Figure 14: Ecosystem service long-profiles for the protected river Dee (above) and unprotected river Don (below). Profiles are stacked line graphs showing Total Regulating Score, Total Provisioning Score and Total Cultural Score for each 500m reach. Yellow circles represent ecosystem service hotspots with total scores over 10,000 while red circles represent ecosystem service coldspots. Reach area is plotted on the secondary y-axis in a dashed line.
The most obvious similarity evident from visual inspection is that both long-profiles have peaky-trough natures. In further similarity, for both long-profiles, the first approximate 20km of rivers appears less peaky in terms of ecosystem service score compared to the downstream sections. Another similarity between the two long-profiles also appears evident within the headwater sections. For around the first 15km of each river the supply of provisioning services is comparatively negligible.

One further evident similarity discernible is that for both long-profiles total cultural service score seems to constitute the greatest proportion to the stacked line graph. It is important to highlight that the apparent dominance of total cultural score reflects the use of a stacked line graph. Seven different cultural service scores are added to create the total cultural service score whilst four service constitute the total provisioning score and three add together to create the total regulating score.

Predictably, along with similarities, visually examining the river ecosystem service long-profiles also reveals differences between the Dee & Don. In regard to the three scores graphed, it appears that for the River Don, total regulating service score is continually lower than for the protected Dee. This is consistent with the Mann-Whitney statistical tests undertaken above in section 6.3 which find the protected Dee to have statistically greater total regulating score potential.

Although both long-profiles show peaky-trough natures, the River Dee appears to have slightly more ecosystem service hotspots and coldspots (figure 14). The Dee long-profile has 17 reaches over an ecosystem service score of 10,000 compared to 14 on the unprotected Don (table 43). Interestingly the distribution and nature of peaks is different.
Of those peaks over 10,000 they are more spread across the long-profile for the Dee, whereas for the Don there is only one peak above 10,000 within the first 55km.

Table 4.1: Table outlining properties of hotspots with total ecosystem service scores exceeding 10,000 along the Dee and Don. Table shows the reach number, location, total ecosystem service score and ranking for hotspots.

<table>
<thead>
<tr>
<th>Reach Number</th>
<th>Distance Downstream (km)</th>
<th>TES* Score</th>
<th>Ranking</th>
<th>Reach Number</th>
<th>Distance Downstream (km)</th>
<th>TES* Score</th>
<th>Ranking</th>
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</table>

*TES Abbreviation of Total Ecosystem Service Score (which is the sum of individual scores for all ecosystem services included within GE RES assessments)

Examining the hotspots and coldspots along the two rivers leads to the final significant difference observable difference between the two long-profiles. Visually comparing the area line with the stacked ecosystem service scores suggests that the ecosystem service long-profile for the River Don has a closer relationship with area than the River Dee. Subsequently, this relationship can be tested through producing correlation coefficients. Using scatter graphs to calculate the R² values of correlation between total ecosystem
service score and area reveals the Don long-profile does more closely correlate with area than the Dee (figure 15). The $R^2$ value for the River Don is calculated to be 0.8829 compared to 0.5856 for the River Dee. It could be hypothesised that the weaker relationship between river corridor area and total ecosystem service score but higher prevalence of hotspots along the river Dee indicates that protection may be responsible for boosting ecosystem service scores.

Figure 15: Scatter graphs plotting total ecosystem service score and area for river reaches for the unprotected river Don (left) and protected river Dee (right). Regression analysis is undertaken with $R^2$ values presented. The red dashed lines represent lines of best fit.

6.5.1 Investigating individual hotspots: are ecosystem service bundles present?

The identification of ecosystem service hotspots along the Dee and Don leads to the question of whether ‘ecosystem service bundles’ are present. The recognition of ecosystem service bundles is widely credited to the 2010 paper produced by Raudsepp-Hearne et al. titled “ecosystem service bundles for analyzing tradeoffs in diverse landscapes”. Within this paper, ecosystem service bundles are defined as “a set of ecosystem services that repeatedly appear together across space or time”. Crucially, this
definition of ecosystem service bundles is now widely accepted within the ecosystem service community (Berry et al., 2016; Saidi and Spray, 2018). It is believed that the identification of ecosystem service bundles can inform management and policy decisions (Saidi and Spray, 2018; Meacham et al., 2022). Regarding management, several benefits of utilising ecosystem service bundles are perceived. In a time of budget constraints, management focused toward bundles may be favoured due to lower costs (Maes et al., 2012b; Crouzat et al., 2015; Meacham et al., 2022). It is considered that bundle focused management approaches may act to discourage the enhancement of specific services which can often induce negative consequences (Queiroz et al., 2015; Saidi and Spray, 2018). Furthermore, it believed that centring management on ecosystem service bundles can help stakeholders to understand relationships between services and varying priorities (Martín-López et al., 2012; Hamann et al., 2015; Meacham et al., 2022). Determining if ecosystem service bundles exist along either the Dee and Don may therefore have positive outcomes for ecosystem service management.

To determine if ecosystem service hotspots along the Dee and Don represent ecosystem service bundles it is necessary to determine if they constitute recurring sets of services or if they are individually unique in characteristics (Saidi and Spray, 2018; Meacham et al., 2022). Within ecosystem service research typically ecosystem service bundles are identified using statistical analyses, of the papers included within their review, Saidi and Spray (2018) identified that the two statistical techniques of cluster analyses (k-means or hierarchical) and graphical/tabular detection were used in 90% of papers. In accordance with other spatial studies and due to the ease of methodology (Saidi and Spray, 2018), hierarchical cluster analyses will be undertaken to investigate if ecosystem service hotspots along the Dee & Don constitute ecosystem service bundles. Cluster
analyses is undertaken within the Minitab software package, for each river a dendrogram colour coding hotspots with a total ecosystem service score of 10,000 to a level of 60% similarity is produced (figures 16 and 17). Ecosystem services with zero values required removal from Minitab analyses, resultantly, scores for twelve services were included, a similarity level of 60% therefore represents similarity between seven of the twelve services. The interpretation of cluster dendrogram is supported by tables 44 and 45 which contain ecosystem service scores for each hotspot included within analyses. Tables 44 and 45 were produced in excel using conditional formatting, the darker green a cell is shaded, the higher ecosystem service score is.
Figure 16: Graphical dendrogram showing the outcome of hierarchical cluster analysis for the 17 hotspots along the protected river Dee with total ecosystem service scores exceeding 10,000. The dendrogram is undertaken at a level of 60% similarity. Zero value ecosystem services could not be included within cluster analyses, therefore a total of 13 ecosystem service scores are included (water supply, agriculture, timber production, HEP, NFM, climate regulation, water quality, aesthetic value, social relations, inspiration, education/knowledge value, cultural heritage and recreation).

Figure 17: Graphical dendrogram showing the outcome of hierarchical cluster analysis for the 14 hotspots along the protected river Don with total ecosystem service scores exceeding 10,000. The dendrogram is undertaken at a level of 60% similarity. Zero value ecosystem services could not be included within cluster analyses, therefore a total of 13 ecosystem service scores are included (water supply, agriculture, timber production, HEP, NFM, climate regulation, water quality, aesthetic value, social relations, inspiration, education/knowledge value, cultural heritage and recreation).
(i) River Don

Comparing the dendrograms for the two rivers instantly reveals distinct natures. At the 60% similarity level, noticeable clustering is present along the River Don. In particular, one large cluster with over 60% similarity is present. This large cluster, coloured in burgundy on figure 17, contains nine reaches (120, 135, 126, 171, 172, 204, 205, 211 and 237). The other noticeable cluster is coloured blue, and contains three reaches (49, 127 and 131) with over 66% similarity. Two reaches are not clustered, one of these is reach 255, which is appears most distinct from all other reaches with no similarity recorded. The second distinct reach, with around 40% similarity is reach 170. Utilising table 45 allows the characteristics of these potential bundles and discrete hotspots to be examined.

The large group of ecosystem services appears to be characterised by comparatively high scores for agriculture, aesthetic value, education/knowledge potential and recreation. In conjunction all hotspots have no climate regulation and cultural heritage potential. Despite these reaches being grouped together at the 60% similarity level, table 45 reveals differences within the cluster. Reaches 120, 126 and 135 have potential for timber production potential and social relations but the remaining reaches do not. Furthermore, only reach 120 has water quality potential. Additionally reach 135 is distinct from the rest of the cluster owing to low water supply potential.

The second most noticeable cluster of hotspots consists of reaches 49, 127 and 131. This cluster shares many similarities with the larger cluster, these include high presence of recreation, education/knowledge value and recreation alongside an absence of climate regulation. Distinguishing between the two is difficult but arise due to slightly higher
potential for water supply and natural flood mitigation, slightly lower agricultural potential, and consistent presence of timber production and social relations potential. Of interest, reach 49 is clustered within this group despite being one of only two reaches with cultural heritage present.

The dendrogram shows reach 255 to be the least similar to the other hotspots, examining table 45 shows that this results from several phenomena. The most distinct characteristic of reach 255 is that no agriculture is present. This absence of agriculture is combined with greater potential for climate regulation, water quality, social relations and cultural heritage that other reaches. Of note scores for aesthetic value, education/knowledge and recreation appear lower than other hotspots along the Don.

Reach 170 is also identified to be distinct at the similarity level. Examining table 45 reveals that this research the highest potential for agriculture, aesthetic value, education/knowledge and recreation. This is combined with one of the lowest scores for water supply.

(ii) River Dee

The dendrogram for the protected river Dee presents a contrasting picture to that of the Don. Visually inspecting the two dendrograms alludes to less clustering along the Dee. The lower degree of clustering means that there are more smaller clusters present (figure 16). Indeed, utilising the colour scheme generated by Minitab reveals at the 60% similarity level there are ten clusters for the Dee and only four for the Don. Furthermore, at the mark of 50% similarity, the dendrogram for the river Dee has five branches compared to just two the Don. At the 60% level of similarity for the Dee there are five reaches clustered on their own, whilst only two for the Don. Notably, the largest cluster
at 60% similarity along the river Dee is three reaches, compared to nine for the Don. The higher number of clusters and lower degree of clustering along the river Dee indicates that hotspot reaches are more heterogenous in regard to high ecosystem service potentials.

Owing to the higher number of clusters, the differences between them are more subtle than those identified for the Don. Subsequently, to unpick the nature of hotspots along the river Dee it makes sense to begin higher within the dendrogram. At 11% similarity, the first separation of clusters occurs. The larger cluster with x reaches contains numbers 46, 118, 117, 258, 160, 230, 173, 260, 54 and 262 whilst the smaller cluster consists of 41, 113, 82, 229, 231, 190 and 232. Examining table 44 reveals the larger cluster to be separated out based on cultural services. Within this larger cluster, scores for aesthetic value, social relations and recreation all appear higher.

The first reach to be clustered on its own within the larger cluster is reach 262, this occurs because only this reach has potential for HEP. The second reach to cluster on its own within this group is number 54. Studying table 44 indicates this reach clusters out due to its low potentials for water supply and natural flood mitigation, additionally potential for timber production and education/knowledge gain is notably high. One branch down, reach 260 is also clustered on its own, this reach is unique owing to its higher potential for social relations.

The remainder of this larger cluster consists of one cluster of three services and two clusters of two. Reaches 160, 230 and 173 are all clustered together. This clustering can be attributed to higher scores for natural flood mitigation and water supply alongside similar moderate scores for education/knowledge gain. Reach 117 and 258 form a
cluster. This cluster is characterised by high aesthetic and recreation values in conjunction with low values for education/knowledge gain and agricultural potential. However, despite clustering, variance is prominent within scores for agriculture, timber production, natural flood mitigation and water quality. The remaining two reaches, which are clustered together, are 46 and 118. These two reaches have low values for water supply, natural flood mitigation, social relations but relatively high agricultural potential. Of note, and as with the previous cluster discussed, some divergences within scores are present. Variance within scores for timber production and education/knowledge gain is evident.

The smaller cluster contains two clusters of only one reach. The first of these reaches to branch out is number 232. Examining table 44 reveals this reach to be characterised by very high agricultural potential, high potential for natural flood mitigation and education/knowledge gain. Additionally, potentials for timber production, aesthetic value, social relations and recreation are notably low. One branch down, reach 190 is then clustered on its own. Reach 190 seems to be distinct owing to high potentials for climate regulation and water quality, in conjunction with low potentials for timber production, aesthetic value social relations and recreation.

Alongside the clusters of singular reaches, the smaller cluster contains one cluster of three reaches and one of two. The larger cluster consisting of three reaches contains hotspots 41, 113 and 82. Of note, examining table 44 reveals that for many services, these three reaches have dissimilar scores. Values for water supply, potential timber production, natural flood mitigation, climate regulation, social relations and education/knowledge gain vary significantly between reaches. Acknowledging these
differences, it is recognised that clustering is based on comparatively low scores for agricultural potential and high scores for both aesthetic potential and recreation. The last cluster to be outlined contains reaches 229 and 231. Like the cluster of three service, there is some disparity between scores, this occurs for water supply, agricultural potential, timber production, aesthetic value, social relations and recreation. It therefore appears that these reaches are defined by similarly high values for natural flood mitigation and education/knowledge value.

(iii) Summary of cluster analyses

Above, hierarchical cluster analyses has been undertaken and reviewed to determine if ecosystem service hotspots along the protected Dee and unprotected Don constitute ecosystem service bundles. Synthesising the above descriptions of hierarchical analysis, the picture for the protected river Dee seems clear, despite some clustering, ecosystem service hotspots are not ecosystem service bundles. Whilst interpreting the dendrogram reveals some clusters of services at the 60% similarity, on closer inspection, despite sharing similar values for some services, reaches clustered together are also divergent in levels of ecosystem service potential. The clustering of five single reaches as clusters also suggests that along the Dee hotspots are heterogenous and not recurring sets of services.

The picture for the river Don is somewhat different. At the 60% similarity there are less clusters, this indicates greater homogeny amongst hotspots. However, two of these clusters are single reaches, this demonstrates that there are hotspots present along the Don which cannot be deemed repeated units. All other reaches fall into one of two clusters. Clearly in order to be clustered, these reaches share similarities, yet, within both these clusters reaches are found to have individual characteristics. Synthesising cluster
analyses indicates that hotspots do more closely resemble bundles along the Don than for the Dee. However, owing to the presence of some distinct hotspots like reaches 170 and 255, and the heterogeneity of clusters, it is likely hotspots are more individually unique than recurring sets of services.

Although fixed ecosystem service bundles are unlikely to be present along each river, it is the case that the dynamics of hotspots differ between the two rivers. Hotspots along the unprotected Don are consistently characterised by a more similar suite of services (agriculture, aesthetic value, education/knowledge gain, recreation, and natural flood mitigation) while those along the protected Dee appear more heterogenous (may be characterised by water supply, natural flood mitigation, aesthetic value, social relations, education/knowledge, recreation, agriculture, and timber production). Alongside these similarities, it is also worth noting that there are some slight similarities between the general nature of hotspots. Cultural services, in particular aesthetic value and recreation appear to dominant hotspots whilst the services of HEP, climate regulation, water quality, inspiration and cultural heritage appear sporadically. Drawing on the above hierarchical analyses it seems these sporadic services may be crucial in influencing hotspot heterogeneity.
Table 44: Table showing ecosystem service scores for each of the 17 hotspots along the protected river Dee identified to have total ecosystem service scores exceeding 10,000. Ecosystem service scores are conditionally formatted in Microsoft Excel, the two ends of this gradient are white (zero score) and dark green (higher score).

<table>
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<th>Reach Number</th>
<th>Total Ecosystem Service</th>
<th>Watershed</th>
<th>Agriculture</th>
<th>Potential Timber Production</th>
<th>HEP Production</th>
<th>Natural Flood Mitigation</th>
<th>Climate regulation</th>
<th>Water Quality</th>
<th>Aesthetic Value</th>
<th>Social relations</th>
<th>Inspiration</th>
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<td>1838</td>
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</table>
Table 45: Table showing ecosystem service scores for each of the 14 hotspots along the unprotected river Don identified to have total ecosystem service scores exceeding 10,000. Ecosystem service scores are conditionally formatted in Microsoft Excel, the two ends of this gradient are white (zero score) and dark green (higher score).

<table>
<thead>
<tr>
<th>Reach Number</th>
<th>Total Ecosystem Service</th>
<th>Water Supply</th>
<th>Agriculture</th>
<th>Potential Timber</th>
<th>HEP Production</th>
<th>Natural Flood Mitigation</th>
<th>Climate Regulation</th>
<th>Water Quality</th>
<th>Aesthetic Value</th>
<th>Social Relations</th>
<th>Inspiration</th>
<th>Education / Knowledge</th>
<th>Cultural Heritage</th>
<th>Recreation</th>
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<tr>
<td>49</td>
<td>13095</td>
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<td>1815</td>
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<td>0</td>
<td>0</td>
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<td>713</td>
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<tr>
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<td>485</td>
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<td>1334</td>
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<td>2426</td>
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</table>
6.6 Summary of all results

The objective of this chapter has been to present and examine results from GE RES assessments in accordance with the overarching research aim of determining if ecosystem service potential differs between rivers with and without nature designations. This summary draws together key findings from results and presents discussion points which will form the backbone of the proceeding discussion chapter.

Statistical pairwise comparisons of ecosystem service metrics from rivers with and without nature designations are the first set of results to be presented. Analysis is a direct attempt to answer the overarching research aim and is conducted with non-weighted and area-weighted metrics.

Comparing non-weighted and weighted results, there is a consistent trend for water supply, total regulating score, natural flood mitigation and water quality regulation to be greater for protected rivers. In contrast, there is less diversity in services identified to be consistently greater for unprotected rivers, agricultural potential is the only one. Differences in trends for timber production, total ecosystem service score and total cultural service score demonstrate the influence of area on ecosystem service potential from river corridors. The influence of area-weighting can be identified through investigation from an individual pair perspective. The Almond & Earn and Thurso & Forss Water have the greatest discrepancies in average areas and are also the two pairs to have the greatest number of test outcomes change following weighting.

Referring back to the overarching research question, it seems that ecosystem service potential does differ between rivers with and without nature designations. Specifically, it appears that protected rivers provide higher potential for a greater, more diverse range
of ecosystem services. However, in contrast, there is a clear trend for potential for agriculture to be greater for unprotected rivers.

From the findings of the pairwise comparison arise several important questions which require exploration. Protected rivers are identified to supply a greater number and higher diversity of river ecosystem services; does this correspond with existing research and what are implications for management? A trade-off between ecosystem service diversity and agriculture is identified, is it necessary to mitigate this trade-off and if so, what approaches should be advised?

The second set of results produced sought to determine if river reach geomorphology exerted a greater influence on ecosystem service potential than nature designation. Geomorphic reach investigations were compared to ecosystem service score pairwise analysis, from this comparison it is tentatively concluded that in comparison to nature designation, reach geomorphology may only have a limited influence on ecosystem service potential. Subsequently a crucial question arises: is this consistent with existing research or is there evidence which indicates geomorphology does influence ecosystem service potential? Additionally, discrepancies between non-weighted and weighted reach type analysis indicates that reach area is more significant in determining ecosystem service potential than geomorphology, this adds gravitas to the importance of considering reach area in river corridor ecosystem service assessments.

The final set of results is slightly different, the GE RES model produced longitudinal ecosystem service potential data for rivers, consequently, a case study approach is undertaken to examine the value of ‘ecosystem service long-profiles’. The presentation and comparison of long-profiles for the Dee & Don revealed benefits which are two-fold.
Firstly, long-profiles are identified to be valuable data tools, they facilitate the identification of spatial patterns of ecosystem service metrics, reveal interactions between metrics and enable the investigation of hotspots and coldspots.

Secondly, comparison of the Dee & Don long-profiles yields information which provides another layer of detail for answering the overarching research aim. Analysing ecosystem service long-profiles depicting the three main service categories highlights similarities and differences between the rivers. Similarities identified include both rivers displaying peaky-trough natures, negligible provisioning service potential within the headwaters and the dominance of cultural services throughout river course. Differences between rivers are identified to be lower regulating scores for the Don and a higher number of ecosystem service hotspots and coldspots along the Dee.

The recognition of ecosystem service hotspots leads to the question of whether these areas of high ecosystem service potentials are discrete or repeatable bundles. Understanding if bundles are present, and their natures can become a logical guiding principle for river management. To determine if ecosystem service bundles are present along either river, hierarchical cluster analyses is undertaken with Minitab. Comparing dendrograms for the Dee and the Don reveals a greater degree of clustering for the Don. On syntheses, it is fairly evident from visual inspection of the dendrogram that ecosystem service bundles are not present along the Don, instead ecosystem service hotspots appear to be discrete heterogenous reaches. Despite a greater degree of clustering along the Don, analyses of individual clusters reveals heterogeneity within them, therefore it is also likely that for the Don, hotspots are not recurring bundles but heterogeneous discrete locations. Although ecosystem service bundles are not identified, notable differences in
hotspot dynamics exist between rivers. Hotspots along the unprotected Don are consistently characterised by a narrow range of services (agriculture, aesthetic value, education/knowledge gain, recreation, and natural flood mitigation), in contrast, those along the Dee seem more heterogenous (may be characterised by water supply, natural flood mitigation, aesthetic value, social relations, education/knowledge, recreation, agriculture, and timber production). Additionally, potential for HEP, climate regulation, water quality, inspiration and cultural heritage appears sporadically and potentially drives hotspot heterogeneity.

Expectedly, the information gleamed from the comparison of the Dee & Don long-profiles leads to many discussion points. Does existing research also find protected areas to have a greater number of hotspots? Protected hotspots appear to be more heterogenous in both ecosystem service dynamics and physical characteristics, does this correspond with other studies? Cultural services appear important in hotspot creation, does this align with other research or is dominance the result of methodology?

On a summative note, the analysis of three separate but related sets of results has answered the overarching research aim, it appears that, in comparison, designated Scottish river corridors supply higher levels of ecosystem service potential. From all three sets of results one key question arises; What do findings mean for the future of protected area river management and research? This question forms the basis of the proceeding chapter. Naturally, it is expected that through seeking answers to these questions, more questions will arise leading to fruitful opportunities for further research beyond this thesis.
Chapter Seven: Discussion of GE RES assessments along paired Scottish river corridors

7.1 Introduction

Following the literature review, it can be said, with some confidence, that the ecosystem service concept has changed attitudes towards environmental management. One aspect of change is that areas protected for biodiversity are now expected to deliver both conservation objectives and ecosystem services. Subsequently, this leads to the question of whether this is occurring in practice; are areas protected for conservation simultaneously delivering ecosystem services? Currently, it appears there has been little focus on answering this question in regard to protected rivers. It is deemed that Scotland makes an idea location to investigate this question. This is owing to the abundance of designated rivers, and a progressive approach towards the ecosystem service concept by the Scottish government and Scottish research groups. Consequently, the overarching research aim of this PhD is to determine if ecosystem service provision differs between Scottish river corridors with and without nature designations.

In order to answer this research question, a secondary research aim of developing a methodology suitable for capturing ecosystem potential for Scottish rivers was necessary. In order to capture ecosystem service potential at a fine scale from Scottish rivers the GE RES methodology was developed. One fundamental aspect of the GE RES method is the inclusion of cultural services, this is significant as cultural services have historically been comparatively neglected. A paired approach with four case-studies was then undertaken. The proceeding chapter presents the results of GE RES assessments. Analysis of GE RES results includes; statistical comparisons between unprotected and
protected rivers, the investigation of river reach morphology and comparison of river long-profiles.

This current chapter seeks to discuss the significance of results produced from the pairwise analysis conducted using GE RES. This chapter begins by exploring GE RES results in the context of other published research. This first involves comparing both the general pattern and trends for individual services identified through statistical tests with the findings of other studies. Next the characteristics of hotspots identified along paired rivers are compared to those outlined in other research studying ecosystem service hotspots. Finally, the role reach geomorphology plays in determining ecosystem service potential is examined.

Next this chapter moves to examining the interactions between designation, biodiversity and ecosystem service potential within Scottish riverine SACs. This starts by presenting the last reported conservation status for the species each river is protected for. Logically conservation status for each river is then discussed in the context of ecosystem service potential. Advancing further, discussion then moves to consider the influences that species pressures may have on ecosystem service potential.

Finally, this chapter explores the implications that GE RES results have for the future management of Scottish rivers. Recommendations for the management of Scottish rivers are viewed from four lenses. Firstly, potential future management for unprotected rivers is considered. Next focus shifts to the meaning results may have for the management of protected rivers. Attention is then given to how ecosystem service hotspots may be managed. The final lens then presents general recommendations for approaches to the
management of rivers for ecosystem services. Eventually, this chapter is drawn together with a conclusion.

### 7.2 Exploration of results in context of other research

The previous chapter presents the results of pairwise GE RES assessments undertaken in accordance with the overarching research aim of determining if ecosystem service provision differs between Scottish river corridors with and without nature designations. Summarising results, it is identified that ecosystem service potential does differ between Scottish river corridors with and without nature designations. The outcomes of pairwise analysis for both non-weighted and weighted results can be swept into three general statements. Firstly, it can be asserted that, although not without exception, there is a general trend for protected status to be associated with higher ecosystem service potential. Subsequently, and secondly, protected rivers also appear to be more diverse in the provision of ecosystem service potential. Thirdly, unprotected rivers seem to supply statistically higher potential for agriculture. Overall, results do therefore indicate that areas protected for biodiversity are important for the provision of ecosystem services.

The GE RES methodology also highlighted another significant phenomenon. River ecosystem service long-profiles created for the Dee and the Don highlight that both unprotected and protected rivers contain ecosystem service hotspots. On investigation, these ecosystem service hotspots do not appear to constitute ecosystem service bundles. Finally of note, GE RES identified geomorphology to be a negligible influence in the provision of ecosystem service potential.

Following the analysis of GE RES results, it is natural to question what these results mean for future river management in Scotland. However, before suggesting management
recommendations, it is useful to compare the results of GE RES to published research. Having a notion of whether results resemble, or contrast other studies can guide potential management practices. Comparison with other research will focus on ecosystem service diversity, trends for individual services including agricultural potential, ecosystem service hotspots and the influence of geomorphology.

7.2.1 Ecosystem Service Diversity
One of the clearest findings from GE RES pairwise assessments is that protected rivers are identified to supply statistically greater potential for a higher diversity of ecosystem services. Comparison between the results of this study and existing research begins with Eastwood et al. (2016), this paper makes a good starting point for exploration since the authors also used a paired approach and the Dee & Don are one of their nine multi-landscape case studies. Comparing the two Dee & Don case studies does reveal the same general trend for a greater number of ecosystem services to have greater potential along the protected river Dee. However, it could be inferred that this trend is stronger within the GE RES assessments. Of the 13 ecosystem services included within GE RES seven, are identified to be statistically greater for the protected Dee. Eastwood et al. (2016) also identify seven services to be higher for the protected Dee, however a total of 24 services were included in the assessment. Furthermore, in research examining the Spanish Doñana National Park, Palomo et al. (2013) also find the diversity of ecosystem services to be greater within the protected area in comparison to that without protection. Greater ecosystem service diversity within protected areas is attributed to the restriction and control of human activities within the boundaries, subsequently ecosystems can functional naturally thus facilitating the provision of ecosystem services (Dudley, 2008 IN: Willemen et al., 2013).
While there is some research aligning with the findings of GE RES, it is worth noting that not all studies agree regarding the diversity of ecosystem services supplied by protected areas. Research examining the ecosystem services of Canadian riparian ecosystems conducted by Hanna et al. (2020) found protected status to be associated with no significance difference in ecosystem service diversity; ecosystem service diversity appeared to be driven by catchment land cover and land use.

7.2.2 Trends for individual services

GE RES is able to produce results for individual services and therefore it makes sense to compare patterns for individual services identified in the pairwise comparison to other ecosystem service research. However, it is important to note that variety in the services included within assessments somewhat limits comparison. For example, Eastwood et al. (2016) identify environmental stewardship and genetic resources to be different between the rivers, but these are not equitable to any services included in GE RES. Inconsistency between ecosystem service assessments is a known issue which limits comparisons within the ecosystem service field, this research therefore echoes the calls of other such as Fisher et al. (2009), Seppelt et al. (2011) and Nahlik et al. (2012) for greater harmony to strengthen comparisons and improve potential management.

(i) Agricultural production

One of the most obvious trends present within the pairwise comparison is the greater statistical potential for agriculture from unprotected rivers. This is a pattern also captured in other protected area ecosystem service research. In their case study of the Dee & Don, Eastwood et al. (2016) identify food provision to be greater for the unprotected Don. Similarly, UK terrestrial based research conducted by Eigenbrod et al.
(2009) identified agricultural production to be comparatively low within protected areas. Eigenbrod et al. conclude that this finding is unsurprising as agricultural practices conflict with biodiversity conservation (Henle et al., 2008). Outside of the UK, in their research of the Spanish Doñana National Park, Palomo et al. (2013) also find agriculture to be significantly greater in the adjacent area outside of the studied protected area.

Significantly, GE RES results allude to a trade-off between agriculture and ecosystem service diversity occurring along unprotected rivers. It appears that high agricultural potential occurs to the detriment of water supply potential, natural flood mitigation, timber production potential and social relations. Within protected area research these findings echo that of Palmono et al. (2013) who reported that outside of the protected area all other ecosystem services studied were traded-off for food supply from agriculture.

The identification of this trade-off between ecosystem service diversity and agricultural potential along Scottish rivers should be of no surprise as it is perhaps the most common trade-off reported within ecosystem service research (MA, 2005; Rodriguez et al., 2006; Carpenter et al., 2009; Martín-López et al., 2011; Schripke et al., 2012). This discovery also appears consistent with the broad findings of the UK NEA (Watson et al., 2011). Specifically, the UK NEA found agricultural production to negatively relate to climate regulation and water quality. Similarly, research in Quebec by Raudsepp-Hearne et al. (2010) identified intensive agriculture to be negatively correlated with a high number of ecosystem services including the regulating services of climate regulation and water quality. Of concern, this trade-off may have lasting impacts on ecosystem service potential from Scottish rivers. Several studies have indicated that the practices associated
with the maximisation of agriculture can reduce the ability of landscapes to provide a
diverse range of ecosystem services over the long-term (De Fries et al., 2007; Gordon et al., 2010; Schneiders et al., 2011).

Logically, it seems necessary to attempt to understand why the maximisation of agricultural production has occurred in Scotland. In a broad paper examining the maximisation of provisioning services, Rodríguez et al. (2006) suggest several reasons which could provide foundations for understanding. Firstly, the maximisation of agriculture may occur due to the way human societies develop and the need to meet short-term needs (DeFries et al., 2004, Rodríguez et al., 2006). Secondly, the maximisation of agriculture may result from short-term policies and goals which are designed to achieve results within political terms (Rodríguez et al., 2006). Thirdly, maximisation of agricultural production may occur due to the considerable economic value of agricultural products (Rodríguez et al., 2006). Of those three potential reasons for agricultural maximisation, two seem likely. The first reason relating to the need to meet short-term human needs seems unlikely considering the advanced socio-economic status of Scotland.

(ii) Timber Production

GE RES identified potential for timber production to potentially be greater from protected areas, as a result GE RES indicates that timber production is in synergy with the provision of other ecosystem services. This trend appears somewhat to contrast other research findings. As part of the UK NEA (2011) the working group examining ecosystem service provision in Scotland identified that coniferous timber production occurred at the expense of other ecosystem services. Correspondingly, Caputo et al. (2016) report that
timber production for fuel creates trade-offs with climate regulation and water quality. Indeed, commercial forestry is widely reported to cause aquatic degradation (Swank et al., 2001; Forsyth et al., 2006; Neal et al., 2010). However, since 1988 riparian buffer zones in Scotland have been cleared of conifers (Parrott and Holbrook, 2006), from this it could be deduced that the timber production potential along protected rivers arises from deciduous species which are recorded to have a lower impact on water quality (Eisalou et al., 2013).

(iii) Recreation and aesthetic value

GE RES results indicate that potential for recreation may be greater along unprotected rivers. This result does concur somewhat with Eigenbrod et al. (2009) who identified recreational potential to be lower within protected areas. However, Eigenbrod et al. regard the low recreational value of protected areas to be a function of their location, many of the protected areas included within their research were upland in nature, these areas are located away from zone of high population therefore reducing the ease of visitation. Since GE RES links ecosystem service provision to land cover type, location in relation to areas of population cannot be the cause of difference, instead it must be linked to river corridor land cover. Of note, other papers contrast the finding of GE RES. In their comparison of the Dee & Don, Eastwood et al. (2016) find recreational potential to be greater for the protected Dee. Furthermore, research in the marine realm by Rees et al. (2015) also finds recreation to be greater within a protected area. It is recommended that additional research is conducted into the recreational value of protected and unprotected river zones. In particular, as highlighted in appendix seven (lxxviii), it would be beneficial to break recreation down into subcategories.
The pattern for aesthetic value is similar to that for recreation. Aesthetic value is identified to be greater for the protected River Dee by Eastwood et al. (2016) but for unprotected rivers within GE RES.

(iv) Other similarities and differences

The limited research conducted into the ecosystem service potential of protected areas makes exploring results for some services challenging. In this section an attempt is made to explore the remaining services in the context of limited published research, this could then provide a building block for future studies.

The most common outcome of comparison between GE RES and the general results of Eastwood et al. (2016) is for one to identify a trend not present within the other. Eastwood et al. identify educational potential and artistic inspiration to be greater for protected areas whilst no trend for either service is present within GE RES. Meanwhile GE RES assessments identify water supply, natural flood mitigation and climate regulation to be greater for protected areas whilst Eastwood et al. report no significant statistical difference. However, in regard to climate regulation, the outcome for protected areas to have greater potential corresponds with the UK based research of Eigenbrod et al. (2009) who attribute higher climate regulation potential to the upland location of protected areas included within their research.

Meanwhile water quality seems to be somewhat an exception as greater potential for protected areas is identified both within GE RES and the wider findings of Eastwood et al. (2016), additionally, research conducted outside of the UK by Sáenz et al. (2016) concludes that in Cambodia protected areas are important for providing water quality. Further similarity between Eastwood et al. (2016) and GE RES is that no statistical
difference between protected and unprotected areas is identified for cultural heritage, religious value and energy provision/HEP production. Finally, it is worth noting that social relations and timber production are identified by GE RES to be greater for protected rivers but not included within Eastwood et al. (2016).

(v) Summary of comparison to existing research

In summary, in comparison to existing research, the results of GE RES appear to allude to nothing significantly new. In terms of ecosystem service diversity, increased diversity within Scottish riverine protected areas appears consistent with other studies. The finding that agriculture occurs in greater quantities outside of protected areas and the presence of an apparent trade-off between agriculture and ecosystem service diversity is also aligned with other research. Inconsistencies regarding patterns of individual services are identified to be present, but due to the limited research field it is challenging to identify the extent to which GE RES results are anomalous or synonymous.

Hanna et al. (2020) conclude that IUCN (International Union for Conservation of Nature) category II protection is not necessary for the provision of ecosystem services and biodiversity conservation. The same conclusion cannot be made for the SACs investigated here, indeed, the results of GE RES and other research (e.g Eigenbrod et al., 2009; Palomo et al., 2013; Eastwood et al., 2016) indicate that it could be dangerous to downplay or underestimate the value of nature designation for the provision of ecosystem services and biodiversity.
7.2.3 Protected areas and ecosystem service hotspots

The creation of ecosystem service long-profiles allowed for the identification of ecosystem service hotspots. Subsequently, it is possible to compare the prevalence and nature of hotspots along the protected river Dee and unprotected river Don.

Within literature there is some debate as to whether ecosystem service hotspots are more prevalent inside or outside of protected areas. In the Doñana National Park, Palomo et al. (2013) identify service provision hotspots to be of highest value within the Natural Park, this represents a high diversity of ecosystem services. Of note, Palomo et al. (2013) find a strong association between ecosystem service diversity and species richness. Similarly in their mapping of forest ecosystem services within the Sierra Nevada Mountains, García-Nieto al. (2013) find the majority of ecosystem service hotspots to be located within the National Park area. In another continent, Willemen et al. (2013) find that protected areas within the Democratic Republic of Congo are real hotspots for ecosystem services.

On the other hand, Davids et al. (2016) identify protected areas to be unimportant for the provision of ecosystem service hotspots. Davids et al. (2016) investigate ecosystem service hotspots in South Africa, examining a total of 13 services it is found that there is no strong correlation between hotspots and conservation areas. Of interest, Davids et al. find the majority of ecosystem service hotspots to be within communally (41%) or privately (27%) owned lands. As a result of most hotspots being located outside of protected areas, Davids et al. consider that ecosystem service provision and therefore wellbeing is vulnerable to human destruction.
In response these contradictory outcomes, Spanò et al. (2017) conduct research in Southern Italy with the aim of determining the extent to which ecosystem service hotspots are located within and outside of protected areas. Spanò et al. (2017) find that 23.7% of hotspots are located within protected areas, owing to protected areas constituting 30.1% of the studied landscape it can be concluded that hotspots do not occur proportionally more frequently within protected areas. However, Spanò et al. (2017) acknowledge that their research was constrained by the rare occurrence of hotspots within their study location. This may result from the fact that only four ecosystem services were included within the assessment (carbon storage, soil erosion protection, biodiversity and recreation), it seems reasonable to suggest that the fewer services which are included, the less likelihood there is for the identification of hotspots?

GE RES included a total of 14 services, therefore increasing the potential for the identification of hotspots. In accordance with Palomo et al. (2013), García-Nieto al. (2013) and Willemen et al. (2013), GE RES, through the Dee & Don case study does identify protected areas to contain a greater number of ecosystem service hotspots. 17 hotspots with a total ecosystem service score exceeding 10,000 are identified for the protected river Dee compared to 14 for the unprotected Don.

The identification of ecosystem service hotspots led to the question of whether these areas of high ecosystem service potential constituted ‘ecosystem service bundles’. Ecosystem service bundles are viewed to be distinct sets of services which repeat over time or space (Raudsepp-Hearne et al., 2010; Berry et al., 2016; Saidi and Spray, 2018). Performing and analysing hierarchical cluster analyses within section 6.5 reveals that hotspots along both the Dee and Don are heterogenous and therefore specific bundles are
not present. Although discrete bundles are not identified, it is worth noting that hotspots along the unprotected Don consist of a narrower range of services than those along the Dee. Logically, the question following cluster analyses is: to what extent is the absence of ecosystem service bundles consistent with other protected area research?

On searching academic literature, it becomes evident that answering the above question is challenging due to limited research examining ecosystem service bundles within protected areas. Furthermore, the research which has been undertaken does not appear to provide a clear picture. PCA analyses on perceptions of ecosystem service within the Spanish Sierra de Guadarrama protected areas by Cebria’n-Piqueras et al. (2020) does reveal ecosystem service bundles. Research conducted within South African National Parks by Ament et al. (2017) also reveals bundles to be present, however the scope of this research is limited by the sole focus on cultural services. Similarly, in their research of cultural ecosystem services within the Portuguese udoeste Alentejano and Costa Vicentina Natural Park, Clemente et al. (2019) identify ‘bundles’ where three or more cultural services are present, however, the authors do not outline these bundles to be repeatable, and on examination is it possible the authors have used the term bundle to refer to ecosystem service hotspots. Further evidence of authors inadequately defining bundles within protected area research can be found in Eastwood et al. (2016). Here the authors remark on the bundling of cultural services but do not state the explicit bundles which were identified. Owing to the limited availability of research within the ecosystem service bundle-protected area field it is not possible to determine if the absence of bundles along the Dee and Don are consistent with a wider trend. Drawing together the findings of GE RES hotspot analyses and the above attempt to equate findings with
existing literature it is advocated that more research effort is given to understanding the natures of hotspots and bundles within protected areas.

The final question arising from the investigation of hotspots along the Dee and Don which requires investigation centres on the significance of cultural services. Cultural services are identified to be important for the generation of hotspots, is this consistent with other research? This significance of cultural services may parallel with the Canadian research of Raudsepp-Hearne et al. (2010) who identified cultural services to be key constituents of hotspots. In further similarity, especially for unprotected hotspots, Raudsepp-Hearne et al. identify some hotspots appear to be generated through a synergy between agriculture and cultural services. However, the dominance of cultural services may be driven by the GE RES methodology which captures three regulating, four provisioning and six cultural services, the greater number of cultural services could enhance their potential to dominate hotspots. To gain a better understanding of the role cultural services play in determining hotspot location, continued research into their presence and characteristics is recommended.

7.2.4 Geomorphology and ecosystem service potential

In an attempt to be as transparent as possible and to present a detailed picture of riverine ecosystem service potential from Scottish protected rivers, this research included reach geomorphology within the analysis of results. The inclusion of geomorphology produced a significant quantity of data, however, on synthesis, a conflicting and confusing story emerges. Data were pooled into reach types and then two lenses were used for examination. First results are viewed from solely the reach type perspective, ecosystem service potential metrics from specific reach types were compared between protected
and unprotected pooled data. The second lens then sought to compare data from the reach perspective to results of the GE RES comparisons. Overall, no clear or dominant trends are identified through either lens for both sets of results. Logically the question arises as to whether this finding is consistent with other research examining riverine ecosystem services and natural geomorphology?

Reviewing academic literature indicates that the findings of GE RES may contrast the present general consensus of research examining fluvial geomorphological processes and ecosystem service provision. Recent field-based research conducted along the Hungarian Tisza River by Sazbo et al. (2020,) identified that riverine and floodplain geomorphology influenced heavy metal sediment concentrations. Although these sediments are deposited, the threat of the remobilisation of heavy metals exists owing to the possibility of significant flood events, there is potential therefore that river geomorphology influences water quality. Similarly, Gucker and Boëchat (2004) reveal how the geomorphology of tropical headwater streams influences ammonium retention.

Although not explicitly linked to geomorphic reach types, Tomscha et al. (2017) research how ecosystem service provision varies along the longitudinal dimension of the Chiwawa River in Canada. From their aerial photograph-based research, Tomscha et al. (2017) find longitudinal position does correspond to potential for different ecosystem services. Upper reaches seemed to provide greater capacity for carbon storage and fish capacity, middle reaches for recreational paddle sports and lower reaches for agricultural production. Meanwhile, modelling conducted by Zhou and Endreny (2020) found that the straightening of meanders reduced hydraulic complexity which has the potential to alter
ecosystem service provision. However, unfortunately, the authors do not allude to which services may be changed and how they may be altered.

Evidence also suggests that river geomorphology can influence potential for cultural services. In a case study estimating the potential ecosystem service value of restoration for the Emscher River in Germany, Gerner et al. (2018) write that restoration towards a more natural appearance should enhance the provision of cultural services. Of note, papers examining geomorphic characteristics and restoration exist, with many discussing the physical and biological characteristics of rehabilitation measures, but they then fail to outline how these influence ecosystem service provision (e.g. Holtgrieve et al., 2010; Frainer et al., 2018).

The above attempt to relate GE RES results to scientific literature highlights that six years after the call for more research by Everard and Quinn (2015), a significant research gap is only just beginning to be stemmed. While it is shown above that research examining fluvial geomorphological processes and ecosystem service provision does exist, to date it appears that detailed studies explicitly linking geomorphological processes to the provision of multiple ecosystem services are absent. Therefore, to promote the sustainable management of fluvial ecosystem services, this research reiterates the recommendations of Everard and Quinn. To address the research gap three key challenges presented by Everard and Quinn (2015) need to be tackled. Firstly, there is a need for cross-disciplinary collaboration between those working within geomorphology, biodiversity, and the broader fluvial research field. Secondly, geomorphology needs to be appropriately factored into ecosystem service quantification. Thirdly, there needs to be a
bank of successful research projects demonstrating how investment within fluvial geomorphology can enhance ecosystem service potential and human wellbeing.

When a detailed research base examining the relationships between geomorphological processes and multiple ecosystem service provision is established, it might be useful to conduct another comparison with the GE RES results to determine if they still go against the prevailing trend by indicating geomorphology does not influence ecosystem service potential.

7.3 Designation, biodiversity status, and ecosystem service potential in Scottish riverine SACs.

7.3.1 Introduction

In section 2.3 of the literature review it is outlined that a recent paradigm shift in the role of protected areas has occurred. Historically, the main sole focus of protected areas was the conservation of species and habitats (Palomo et al., 2014). Yet today, pressure on land space owing to population increase and projected climate change means that protected areas should be designated and managed simultaneously for biodiversity and ecosystem service provision (Watson et al., 2014). Acknowledging this, the literature review presents a fundamental question: To what extent do protected areas currently deliver conservation objectives and ecosystem service provision?

Examining existing research, the literature review considers this question in the context of the terrestrial, freshwater and marine realms. In regard to the terrestrial realm, the literature review draws no strong conclusions on the effectiveness of protected areas for simultaneous biodiversity conservation and ecosystem service provision, this is a result of available studies reaching contrasting conclusions (e.g. Eastwood et al., 2016; Castro
et al., 2015; García-Márquez et al., 2017) or only examining a handful of ecosystem services (e.g. Eigenbrod et al., 2009). Meanwhile for both the marine and freshwater realms, limited available research makes drawing any conclusions relating to biodiversity conservation and ecosystem service potential impractical.

Owing to the limited research available for freshwater environments, and the confusing picture presented for the terrestrial realm it seems crucial that this research seeks to answer the above question in the context of Scottish Riverine Special Areas of Conservation and GE RES results. Of importance, the literature review highlighted that when examining the conservation objectives and ecosystem service potential of protected areas it is necessary to appreciate current conservation status. This following section seeks to take the GE RES analysis one step further through acknowledging and exploring the conservation status of protected rivers. Status is determined using last assessed condition. Furthermore, since the information is available, it seems useful to investigate the dynamics between species pressures and ecosystem service potentials. The outcomes of this analysis will then be integrated into management recommendations in the final section of discussion.

7.3.2 Special Area of Conservation Characteristics

As mentioned previously within the literature review, Special Areas of Conservation (SACs) are designated under the EC Habitats Directive and are designated to protected specific species and habitats listed in annexes of the Habitats Directive. Table 46 outlines the primary reasons for designation and qualifying features present for the four river SACs included within GE RES assessments. Although each river is designated for a unique set of primary and secondary purposes, some similarity is present. Atlantic salmon is
either a primary or secondary reason for designation for all rivers. Of note, freshwater pearl mussels are only a reason for designation for the River Dee, all other species feature for at least two rivers.

Table 46: Table showing the primary reasons for study river designation as a SAC alongside qualifying features.

<table>
<thead>
<tr>
<th>River</th>
<th>Primary Reason for Designation</th>
<th>Species present as qualifying feature but not primary reason for designation.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Almond (Tay SAC)</td>
<td>Atlantic salmon</td>
<td>Sea lamprey, Brook lamprey, River lamprey, Otter.</td>
</tr>
<tr>
<td>Dee</td>
<td>Freshwater pearl mussel, Atlantic salmon, Otter</td>
<td></td>
</tr>
<tr>
<td>Teith</td>
<td>Sea lamprey, Brook lamprey, River lamprey</td>
<td>Atlantic salmon</td>
</tr>
<tr>
<td>Thurso</td>
<td>Atlantic salmon</td>
<td></td>
</tr>
</tbody>
</table>

7.3.3 Conservation status

Examining the conservation status of the four SACs included within the study reveals that there is no distinct general trend, each river and species seems to have its own dynamics. In regard to last assessed condition, the river found to be best achieving conservation objectives is clearly the Almond (as part of the Tay SAC) (table 47). All five species (Atlantic salmon, River lamprey, Brook lamprey, Sea lamprey and Otter) were last recorded to be in favourable maintained condition. For both the Dee and Teith last assessed condition records a more mixed picture. Synthesising table 47, it could be stated that the Dee is in slightly better conservation condition that the Teith. For the Dee, two species are recorded to be in favourable condition, however whilst Atlantic salmon is recorded to be in favourable maintained status, Otter is last reported to be in favourable declining status. Meanwhile, freshwater pearl mussels are identified to be in
unfavourable no change status. In comparison, two species apiece are recorded to be in favourable and unfavourable status for the Teith (table 47). Brook lamprey and River lamprey are both recorded to be in favourable maintained status. Atlantic salmon is found to be in unfavourable recovering status whilst unfortunately Sea lamprey is identified to be in unfavourable declining status. Finally, the picture for the Thurso is clearer owing to protection being given for only one species. Atlantic salmon was last recorded to be in unfavourable recovering status (table 47).

The finding that SACs are not overwhelmingly delivering conservation objectives is divergent with reviews on the effectiveness of protected areas from the terrestrial (Geldmann et al., 2013, Watson et al., 2014) and marine realms (Halpern, 2003; Watson et al., 2014) which find that protection can and does often positively contribute to biodiversity conservation. However, results also do not correspond perfectly with the research of Hermoso et al. (2016) who reported that freshwater biodiversity was continuing to decline despite protection.

The mixed conservation status of the SACs included within this GE RES assessment may allude to limited success of past management. This finding would be consistent with the meta-review of Watson et al. (2014) who identified that up to 80% of protected areas were being managed ineffectively. Moving forward it is strongly recommended that a renewed effort is placed on the conservation of target species as research suggests maintaining areas of biodiversity is more attainable than attempting restoration (Mora and Sale, 2011).
Table 47: Table showing the last assessed condition and last assessed date for primary designated species for the four protected study rivers. Data obtained from: https://sitelink.nature.scot/home

<table>
<thead>
<tr>
<th>Species</th>
<th>Last Assessed Condition</th>
<th>Year of assessment</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>River Tay SAC (Almond)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Atlantic salmon</td>
<td>Favourable Maintained</td>
<td>2011</td>
</tr>
<tr>
<td>River lamprey</td>
<td>Favourable Maintained</td>
<td>2007</td>
</tr>
<tr>
<td>Brook lamprey</td>
<td>Favourable Maintained</td>
<td>2007</td>
</tr>
<tr>
<td>Sea lamprey</td>
<td>Favourable Maintained</td>
<td>2007</td>
</tr>
<tr>
<td>Otter</td>
<td>Favourable Maintained</td>
<td>2012</td>
</tr>
<tr>
<td><strong>River Dee SAC</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Freshwater pearl mussel</td>
<td>Unfavourable No change</td>
<td>2003</td>
</tr>
<tr>
<td>Atlantic salmon</td>
<td>Favourable Maintained</td>
<td>2011</td>
</tr>
<tr>
<td>Otter</td>
<td>Favourable Declining</td>
<td>2012</td>
</tr>
<tr>
<td><strong>River Teith</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sea lamprey</td>
<td>Unfavourable declining</td>
<td>2011</td>
</tr>
<tr>
<td>Brook lamprey</td>
<td>Favourable maintained</td>
<td>2011</td>
</tr>
<tr>
<td>River lamprey</td>
<td>Favourable maintained</td>
<td>2011</td>
</tr>
<tr>
<td>Atlantic salmon</td>
<td>Unfavourable recovering</td>
<td>2011</td>
</tr>
<tr>
<td><strong>River Thurso</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Atlantic salmon</td>
<td>Unfavourable recovering</td>
<td>2011</td>
</tr>
</tbody>
</table>

7.3.4 Conservation status linked to ecosystem service potential

The question of whether protected areas simultaneously achieve conservation objectives and provide ecosystem service potential is critical. To answer this question an investigation will be undertaken. The non-weighted data set will be used as it best reflects the influence that conservation and not river corridor area has on ecosystem service potential.

The Almond is the river identified to be in best ecological status in regard to conservation objectives, yet this is not the pair for which the protected river provides the greatest number of services. Indeed, for this pair, the protected Almond is identified to provide statistically greater potential for six metrics whilst the unprotected Earn five. Delving into the specific metrics reveals somewhat of a pattern in service provision. The protected
river Almond appears to provide greater potential for regulating services, all four of the regulating metrics are identified to be greater for the Almond. In contrast, the unprotected Earn seems to provide greater potential for provisioning and cultural services with total provisioning score, agriculture, aesthetic value, education/knowledge gain and recreation potential being statistically greater. Timber production and social relations potential are almost anomalies as they are identified to be greater for the protected Almond.

Interestingly, it is the two rivers with the mixed conservation status which are identified to provide a far greater number of ecosystem service metrics than their unprotected pair. Both the Dee and Teith are identified to provide statistically greater potential for nine ecosystem service metrics. Protected rivers are identified to provide statistically greater potential for at least two metrics from each service category. Of note, total provisioning score and total regulating score are statistically greater for the protected rivers. Indeed, the metrics of water supply, timber production, natural flood mitigation and water quality regulation are all statistically greater for the protected Dee and Teith. Differences between the two protected rivers present themselves as climate regulation, social relations and education/knowledge gain being statistically greater for the protected Dee, and total ecosystem service score, aesthetic value and recreation greater for the Teith. In regard to the unprotected rivers, both the Don and the Forth provide greater potential for agriculture but differences in cultural service potential are present. The Don provides greater potential for the metrics of total cultural score, aesthetic value and recreation whilst the Forth provides education/knowledge gain.
Summing up, it could be inferred, that for the Dee and Teith, designation is associated with higher ecosystem service potentials and ecosystem service diversity but not perfectly with conservation objectives. The mixed status of conservation objectives indicates neither obvious synergy or trade-offs between conservation objectives and ecosystem service provision occurs.

Regarding ecosystem service potential metrics, the Thurso and Forss Water pair buck the trend of the protected river by supplying a greater number of metrics. The protected Thurso is identified to supply statistically greater potential for water supply, total cultural service score and education/knowledge gain. Meanwhile the unprotected Forss Water provides greater potential for total provisioning score, agriculture, total regulating score, natural flood mitigation and water quality regulation. This pair differs from the other pairs in that potential for total regulating score, natural flood mitigation and water quality regulation are greater for the unprotected river.

The reverse trend for the Thurso is interesting due to two phenomena. Firstly, the Thurso is only protected for one species. This subsequently raises the question of whether protection measures undertaken for additional species along the other rivers contribute to enhanced ecosystem service potential. Secondly, the one species the Thurso is protected for, the Atlantic salmon, was last recorded to be in unfavourable recovering status. It is therefore questioned if unfavourable condition is responsible for, or relates to, the lower level of statistically greater ecosystem potential metrics.

7.3.5 Conclusion

This sub-section of discussion attempts to determine if protected areas simultaneously achieve conservation objectives and provide ecosystem service potential.
The Almond is in consistent favourable conservation status for all species yet only provides greater potential for one more service than the unprotected Earn. For both the Dee and Teith protection is associated with a high number of services, but conservation status is mixed. Finally, the Thurso, which is in unfavourable condition, bucks the general trend with a lower number of services being statistically greater than the unprotected Forss Water.

Drawing together all four pairs reveals an inconclusive picture. Whilst protection is associated with greater ecosystem service potential, this does not clearly pair with achieved conservation objectives. Overall findings affirm the conclusions of section 2.3.3 ‘Protected areas and ecosystem services’ within the literature review which identified no clear relationship between conservation status and ecosystem service potential for the freshwater realm (Eastwood et al., 2016; Sáenz et al., 2016).

It is therefore advocated that in the years to come significant research effort is given to examining the extent to which protected areas are achieving biodiversity goals and ecosystem service provision simultaneously. Understanding such dynamics is vital to successful protected area management in times of increased population and climate change (Palomo et al., 2014; Watson et al., 2014; Eastwood et al., 2016).

7.4 Species Pressures, Status and Ecosystem Service Potential

The monitoring of Special Areas of Conservation involves recording the pressures experienced by the species for which designation is given. In this examination of conservation status and ecosystem service potential it is therefore of significance to consider the dynamics between pressures and ecosystem service potential. Following the
above logic and for consistency, the non-weighted set of results will be used in this investigation.

Firstly, examining tables 48, 51, 52 & 51 reveals that, of significance, most species pressures can be classified as ecosystem services. This fact is a recurrent trend identified within protected area research (Maskell et al., 2013; Schirpke et al., 2017; Azevedo-Santos et al., 2019) and emphasises how challenging the management of protected areas for biodiversity and ecosystem services is (Anderson et al., 2009; Cordingley et al., 2016). Indeed, the fact pressures facing Scottish SACs are so synonymous with the ecosystem services may offer significant explanation as to why the previous 7.3.4 identified no clear relationship between ecosystem service potential and conserved species status.

Unfortunately examining the pressures, conservation status and ecosystem service provision of Scottish riverine SACs does not identify clear trends. Instead, several unique patterns emerge. For the Almond, all species were last recorded to be in favourable conservation status, this suggests that species pressures are being managed effectively (table 48). Hence it can be hypothesised that high potential for water regulation and water quality alongside low potential for agriculture and recreation may result from management activity conducted to protect designated species. Owing to differences in the last recorded status for protected species, the Dee presents a more complicated picture (table 49). The last recorded status of unfavourable no change for freshwater pearl mussels in 2003 would suggest that the from pressures agriculture and water regulation are poorly managed. However, the more recent assessment of favourable maintained for Atlantic salmon indicates the pressures of agriculture, water regulation and water quality are being somewhat effectively managed. Management may then be manifested through
higher ecosystem service potential for water regulation and water quality and lower potential for agriculture. All species along the Teith were last assessed in 2011, during this round of assessment a scenario of mixed conservation status was identified, owing to this it is difficult to determine if conservation actions are supporting biodiversity objectives (table 50). However, it could be tentatively hypothesised that the pressure of water management may have lessened owing to two of the three species for which it is a pressure last recorded as being favourable maintained. For the Teith, the limited available evidence indicates that any management actions undertaken have not been particularly successful for conservation status but have facilitated the higher potential of the pressures/services of timber production and water quality. Finally Atlantic salmon along the Thurso being recorded more recently as unfavourable recovering indicates that pressures of forestry operations and overgrazing are being reduced (table 51). Integrating GE RES results, it could be hypothesised that these management actions have caused timber production and agricultural potential to not be statistically greater for the protected Thurso.

In summary, available evidence suggests that for two of the four rivers (Almond and Dee), biodiversity pressures may be managed in a way conducive to both conservation status and ecosystem service potential. Meanwhile along the Teith it appears any management action favours ecosystem service potential as opposed to conservation status, in contrast actions along the Thurso appear to support conservation objectives but not necessarily ecosystem service potential. What a confusing picture! This confusing view corresponds with the findings of other researchers who call for greater clarity in understanding the success of protected areas for biodiversity and ecosystem service objectives (Geldmann et al., 2015; Jones et al., 2018; Geldmann et al., 2019).
Of significance, deducing a clear trend is hampered by the most recent conservation status assessments for rivers being at least 10 years old. It is evident that moving forward there is a need to untangle the interactions between conservation species pressures, conservation status, management actions and ecosystem service provision. Additionally, the following questions require investigation: which practices enhance conservation and ecosystem service potential and which practices reduce conservation objectives and ecosystem service potential?

Table 48: Table showing the species pressures experiences by primary designated species along the River Tay (Almond) SAC

<table>
<thead>
<tr>
<th>Species</th>
<th>Pressures</th>
</tr>
</thead>
<tbody>
<tr>
<td>Atlantic salmon</td>
<td>Extraction, Game/fisheries management, Invasive species, Water management, Water quality</td>
</tr>
<tr>
<td>River lamprey</td>
<td>Development, Water management, Water quality</td>
</tr>
<tr>
<td>Brook lamprey</td>
<td>Development, Water management, Water quality</td>
</tr>
<tr>
<td>Sea lamprey</td>
<td>Development, Water management, Water quality</td>
</tr>
<tr>
<td>Otter</td>
<td>Agricultural operations, Invasive species, Recreation/disturbance, Water management</td>
</tr>
</tbody>
</table>
Table 49: Table showing the species pressures experienced by primary designated species along the River Dee SAC

<table>
<thead>
<tr>
<th>Species</th>
<th>Pressures</th>
</tr>
</thead>
<tbody>
<tr>
<td>Freshwater pearl mussel</td>
<td>- Development</td>
</tr>
<tr>
<td></td>
<td>- Invasive species</td>
</tr>
<tr>
<td></td>
<td>- Over grazing</td>
</tr>
<tr>
<td></td>
<td>- Water management</td>
</tr>
<tr>
<td>Atlantic salmon</td>
<td>- Agricultural operations</td>
</tr>
<tr>
<td></td>
<td>- Invasive species</td>
</tr>
<tr>
<td></td>
<td>- Water management</td>
</tr>
<tr>
<td></td>
<td>- Water quality</td>
</tr>
<tr>
<td>Otter</td>
<td>- No negative pressures</td>
</tr>
</tbody>
</table>

Table 50: Table showing the species pressures experienced by primary designated species along the River Teith SAC

<table>
<thead>
<tr>
<th>Species</th>
<th>Pressures</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sea lamprey</td>
<td>- Forestry operations</td>
</tr>
<tr>
<td></td>
<td>- Water management</td>
</tr>
<tr>
<td></td>
<td>- Water quality</td>
</tr>
<tr>
<td>Brook lamprey</td>
<td>- Forestry operations</td>
</tr>
<tr>
<td></td>
<td>- Water management</td>
</tr>
<tr>
<td></td>
<td>- Water quality</td>
</tr>
<tr>
<td>River lamprey</td>
<td>- Forestry operations</td>
</tr>
<tr>
<td></td>
<td>- Water management</td>
</tr>
<tr>
<td></td>
<td>- Water quality</td>
</tr>
<tr>
<td>Atlantic Salmon</td>
<td>- Forestry operations</td>
</tr>
<tr>
<td></td>
<td>- Invasive species</td>
</tr>
<tr>
<td></td>
<td>- Water Quality</td>
</tr>
</tbody>
</table>

Table 51: Table showing the species pressures experienced by primary designated species along the River Thurso SAC

<table>
<thead>
<tr>
<th>Species</th>
<th>Pressures</th>
</tr>
</thead>
<tbody>
<tr>
<td>Atlantic salmon</td>
<td>- Forestry operations</td>
</tr>
<tr>
<td></td>
<td>- Over grazing</td>
</tr>
</tbody>
</table>
7.5 Introduction to management

Without question, the management of river ecosystem services is crucial for human survival. Referring back to the Millennium Ecosystem Assessment (2005), ecosystem degradation as a result of human actions is jeopardising current and future human wellbeing. The UK NEA (Watson et al., 2011) echoed this sentiment, the assessment considered that declining ecosystem services are the result of decreased habitat conditions, reduced habitat extents and changes in biodiversity. Therefore, the protection of biodiversity and ecosystem services is without doubt key to ensuring our resilience to the pressures of increasing populations and climate change (Biggs et al., 2012; Keppel et al., 2012; Heller et al., 2015). Indeed, in recent years there has been a paradigm shift within riverine management to approaches that focus on rehabilitating river processes and ecosystem services in order to provide benefits to human wellbeing (Dufour and Piégay, 2009; Gilvear et al., 2012; Gilvear et al., 2013). Subsequently, significant outputs of this research for riverine ecosystem service provision are recommendations for future management. Owing to the specific nature of this research, recommendations for management based on the results of GE RES assessments shall be considered from four perspectives; approaches suitable for unprotected rivers, protected rivers, potential hotspots, and more general recommendations. Finally, discussion turns to consider several deliberations which should be explored prior to the beginning of any management action.

Of note, it is important to highlight that to correspond with the GE RES methodology, management is discussed from the lens of the river corridor unit. The use of the river corridor as a study unit owes to the understanding that river ecosystem services are the
product of river channels and the adjacent patches they are connected too (Thorp \textit{et al.}, 2010; Large and Gilvear, 2015). This more holistic approach to river management is now widely adopted within the river science community (e.g. Mozzorana \textit{et al.}, 2018; Schiemer \textit{et al.}, 2018; Wohl, 2019).

7.5.1 Proposed Management for Unprotected Rivers

Regarding the future of Scottish unprotected river corridor management, two outcomes of GE RES paired assessments appear most significant. Firstly, unprotected areas are identified to supply lower levels of ecosystem service potential. Secondly, agricultural potential is identified to be statistically higher for all unprotected rivers.

Owing to simultaneous projected changes in climate and population increase it seems logical to focus management effort on increasing the provision of services from unprotected areas. However, this is complicated by the fact that within this research, and that of others (Bennett and Balvanera, 2007; Power, 2010; Raudsepp-Hearne \textit{et al.}, 2010), the dominance of agriculture is likely to have induced trade-offs with other ecosystem services. In particular, the results of GE RES identified potential for the services of water supply, natural flood mitigation, water quality regulation and climate regulation to be lower along agriculturally dominated rivers. Subsequently, this section shall present ideas for the management of agriculture in a way which may alleviate ecosystem service trade-offs and discuss how potential can be increased for those services which seem comparatively low. To provide recommendations for individual unprotected rivers, long-profiles produced from GE RES analysis will be utilised (presented as appendix ten).
(i)  **Agricultural Potential**

In regard to the management of agricultural land along unprotected Scottish rivers, it is necessary to recognise the socio-economic importance of agriculture. The high agricultural potential of the unprotected rivers included within this assessment contributes to Scotland's food security, economy, and employment (Palmono et al., 2013). As highlighted previously, historically, agricultural production has occurred at the expense of other ecosystem services, however, recently there has been a transition toward creating multi-functional landscapes and wildlife friendly farming that delivers agricultural production alongside many regulating and cultural services (Green et al., 2005; Bugalho et al., 2011). An approach of managing agricultural land for multiple ecosystem services is therefore advocated for the unprotected rivers of Scotland.

Progress in our understanding of the harm some agricultural practices can have on the environment and other ecosystem services means that a variety of different techniques now exist which support multi-functional landscapes and environmentally friendly farming.

With respect to river environments, riparian buffers are probably one of the most well-known techniques that contribute towards multi-functional landscapes and wildlife positive farming. Empirical evidence identifies that riparian buffers can mitigate potential water quality issues caused by agriculture whilst simultaneously providing natural flood mitigation and wildlife habitat (Stutter et al., 2012; Cole et al., 2020). Despite the advantages of riparian buffers, their installation can sometimes be met with resistance due to practicality and finances. For example, in Ireland, Buckley et al. (2012) found that 53% of the farmers sampled felt negatively about their installation, reasons
for negativity include reduced production, production interference and potential
nuisance. Logistically it may not be possible to install riparian buffers universally,
therefore catchment management plans should be drawn to identify the areas where
buffers would have the most impact (Cole et al., 2020).

In situations where riparian buffers are unfeasible, alternatives that have a lesser impact
on production may be more suitable. Diversifying cropping systems is identified to create
win-win scenarios. Reviews of empirical studies identify that diversification can enhance
diversity, pest control, water regulation, pollination, soil fertility and nutrient cycling
without compromising crop yields (Tamburini et al., 2020; Beillouin et al., 2021).
However, those pursuing an increase in crop-density need to be mindful that species
selected should not require intensive management because this can undo potential
ecological benefits (Hass et al., 2018).

Another option could be the planting of hedgerows and grass strips around arable land.
A synthesis conducted by Van Vooren et al. (2017) found that hedgerows and grass strips
both enhanced crop yield and improved water quality. Additionally, Asbjornsen et al.
(2014) suggest the strategic planting of small patches of perennial vegetation within
agricultural landscapes that are dominated by annual crops could enhance the services
of water quality, water flow regulation and fuel whilst maintaining agricultural
productivity.

One of the most significant findings of the GE RES paired comparisons for Scottish rivers
is identified to be the revelation that all four unprotected rivers appear to provide
statistically greater agricultural potential. In practice, this means that there is the
potential to create multi-functional landscapes along all four rivers. However, analysing
river ecosystem service long-profiles reveals that each river has unique spatial opportunities for multi-functional zones.

Along the unprotected River Don, agriculture is a dominant ecosystem service from approximately 15km downstream from the source, however, notably agriculture occurs without the significant presence of other services for two blocks, from around 35km to 50km and 98 to 120km downstream. Meanwhile, the headwaters of the unprotected Forth, to around 18km are characterised by the presence of multiple ecosystem services, including water quality regulation, climate regulation, natural flood mitigation, potential for timber production, climate regulation and agriculture. However, after around 18km agriculture is clearly the dominant service, with much less service synergy present, this suggests clear potential for the creation of multi-functional landscapes. In comparison, to the above rivers, agriculture along the unprotected Forss water appears less dominant, however, two noticeable stretches are present, these are between 22 – 25km and 28 – 34km downstream. Finally, the unprotected Earn hosts another pattern, the river does not appear to have discrete blocks of agricultural potential, instead agricultural potential is identified to present almost continually throughout the long-profile. Consequently, the Earn provides significant opportunity for the development of multi-functional landscapes.

(ii) Natural Flood Mitigation Potential

Referring back to the GE RES matrix enables suggestions of possible management options which could increase potential for natural flood mitigation along unprotected rivers. Features which are identified to positively contribute to natural flood mitigation are three types of woodland (broadleaf, conifer, floodplain forest; Calder et al., 2003; Lana-Renault
et al., 2012; Fu et al., 2013; Wenzel et al., 2014; Lunka and Patil, 2016), both types of buffer (woodland and herbaceous; Mclean et al., 2015; Gao et al., 2016), lowland wetlands (Bullock and Acreman, 2003; Acreman and Holden, 2013; Yao et al., 2014; Mirosław-Świątek et al., 2016) and natural lakes (Peng et al., 2005; Arp et al., 2006; Nakayama and Watanabe, 2008). These potential management options pair well with the Natural Flood Mitigation Handbook (SEPA, 2015), which advocates woodland creation, riparian buffers, land management, river and floodplain restoration.

In regard to improving natural flood mitigation along the unprotected rivers studied within this assessment, it seems logical to recommend specific approaches depending on the locality of low potential areas along the river corridor. Within the uplands, upland woodland creation is recommended, whilst further down the course riparian buffers, lowland wetlands and natural lakes are likely more suitable. Of note, drawing from river ecosystem service long-profiles in appendix ten (iv and viii) the Forss Water and Earn appear to have potential for Natural Flood Mitigation throughout their courses, therefore these rivers may need less attention, depending on demand, than those others included within this assessment.

Empirical evidence demonstrating the potential ability of upland woodlands to provide natural flood mitigation is abundant (Carroll et al., 2004; Ford et al., 2016; Murphy et al., 2020; Monger et al., 2022). It is hypothesised that flash flooding is mitigated due to increased soil hydraulic conductivity, reduced soil compaction and lower bulk density (Murphy et al., 2020). Examining ecosystem service long-profiles for each of the four rivers included within this assessment reveals that the opportunity for upland woodland creation to improve natural flood mitigation seems greatest for the River Don. The Forss
Water, Forth and Earn all have natural flood mitigation within their uplands, but woodland creation may be necessary with projected changes in climate and population increases.

If upland woodland is to be pursued for the potential for natural flood mitigation, then there are some deliberations which would need to be made before management can begin. Firstly, which type of woodland is most suitable for the Scottish riverscape? Modelling conducted within the Scottish Tarland catchment by Iacob et al. (2017) identified that coniferous afforestation provided the greatest peak flow attenuation, however, historically coniferous forests can be associated with river acidification which could potentially harm protected species (Dunford et al., 2012; Feeley and Kelly-Quinn, 2014; Harrison et al., 2014b). Secondly, the specific locality of upland woodland needs to be evaluated as success for natural flood mitigation may be enhanced by soil drainage and restriction of livestock grazing (Murphy et al., 2022). Finally, if woodland planting is pursued, it is vital to remember that natural flood mitigation benefits will be long-term as initially young woodland can have higher runoff, lower infiltration and consume less water before it matures (Deuchars et al., 1999; Iroumé et al., 2006; Tian et al., 2008; Choi et al., 2011; Archer et al., 2013; Marshall et al., 2014; Archer et al., 2015).

Further down course, examining the ecosystem service long-profiles for the four unprotected reveals several localities which may benefit from riparian buffers or lowland wetlands to increase natural flood mitigation potential (appendix ten, ii, iv, vi and viii). Along the Don there is a zone between 98-106km which seems to have comparable low potential for NFM. Meanwhile, along the river Forth the presence of NFM seems less
abundant after around 28km downstream, this downstream area seems to be dominated by agriculture.

Traditionally, riparian buffers have been introduced within agricultural land to mitigate the impact of agriculture on water quality (Osborne et al., 1993; Lyons et al., 2000; Anbumoxhi et al., 2005), however empirical evidence suggests that they may simultaneously mitigate downstream flooding (Mclean et al., 2015; Gao et al., 2016). Subsequently, their implementation may significantly reduce the economic impact of flood events (e.g. Rein, 1999). However, if riparian buffers are to be undertaken as a measure, then post-project monitoring would be beneficial to the geoscience community since matrix population identified quantitative evidence demonstrating the effectiveness of buffers to be somewhat limited.

Wetlands may also be created to provide flood mitigation potential. If wetland creation is undertaken then managers should carefully consider location, modelling conducted by Ameli and Creed (2019) suggests that wetlands closer to the main-stream network are more significant for attenuating peakflow. Of note, the creation of wetlands may help to provide future security against flooding as modelling conducted by Moor et al. (2015) in Sweden identified that due to changes in plant functional traits associated with projected climate change, wetland ability to attenuate floods may increase.

Within urban areas, where logistically the creation of upland woodland, riparian buffers or wetlands may not be possible, then stormwater ponds may be created to enhance natural flood mitigation. Green stormwater ponds can provide both flood attenuation and habitat for wildlife (Moore and Hunt, 2012; Hassall and Anderson, 2014). However, to maintain their effectiveness ponds require the frequent removal of sediment (Drake and
Guo, 2013), therefore their creation and design needs to be carefully considered in regard to continued maintenance and potential ecosystem disturbance within a designated area.

Finally, if funding permitted, it could also be valuable to set up pilot projects investigating the role riparian amenity land and agricultural land can play in providing flood mitigation. During the creation of the matrix, some evidence suggesting amenity land and agricultural land can mitigate flood events was retrieved (Förster et al., 2005; de Vleeschauwer et al., 2014), however, no conclusions could be made at the time due to a lack of strong empirical hydrological evidence. Unfortunately, research into the role agricultural land may play in mitigating flood events may be challenging due to resistance from farmers owing to potential loss of productivity (Posthumus et al., 2008). Similarly, there is limited evidence demonstrating the role floodplain lakes have in attenuating floods (Emmerton et al., 2007; Lininger and Latrubesse, 2016), however, none of this evidence focus on temperate environments, therefore pilot projects could be undertaken to dam this knowledge gap.

(iii) Water Quality Potential

Examining the ecosystem service long-profiles suggests that for several rivers, low water quality potential coincides with high agricultural potential. Along the river Don, there is good water quality along the headwaters until around 15km downstream, from here there appears to be patchy areas of high water quality potential, however generally potential is low with high agricultural potential (appendix ten, ii). Similarly, for the Forth, the headwaters are characterised by the presence of high water quality in a peaky pattern, however following 20km downstream water quality potential is reduced as agricultural potential dominates ecosystem service provision (appendix ten vi).
Additionally, along the river Earn water quality potential appears generally low compared to other ecosystem services, this coincides with higher agricultural potential (appendix ten, viii).

Logically, within agricultural areas, tackling water quality degradation depends upon the specific threat faced, this includes whether the source of pollution is point or diffuse (Ice, 2004; Kay et al., 2009; Smith et al., 2017). Depending on the nature of pollution, there are several common practices which can be undertaken to improve water quality within agricultural areas, approaches which may be deliberated include nutrient management, crop rotation, contour farming, agricultural fencing, reduced overgrazing, reduced livestock density, constructed wetlands and riparian buffers (Kay et al., 2009; Liu et al., 2017).

Of these measures, riparian buffers may be preferrable because they do not require extensive amounts of land and can allow other farming practices to remain unaltered (Sullivan et al., 2004; Kenwick et al., 2009). Riparian buffers can be broadly divided into woodland and herbaceous, evidence from infield studies and meta-analyses suggests the two to have similar abilities to assimilate nitrogen and trap fine sediment (Lyons et al., 2000; Mayer et al., 2007; Yuan et al., 2009). However, woodland buffers have one advantage over herbaceous buffers in that they are able to regulate water temperature via shading (Clinton, 2011; Wilkerson et al., 2006; Bowler et al., 2012). Ultimately, the decision upon which type of buffer should be installed depends on local characteristics including native flora and fauna, space available and pollution threat. Whichever type is chosen, managers should seek to make buffers as wide as feasible, this is because for both
types of buffer greater width increases effectiveness (Sweeney and Newbold, 2014; Miller et al., 2015; Yuan et al., 2009).

Water quality potential along the unprotected Forss water is comparably high, however around 16km downstream is Loch Shurrery, this loch is retained by a dam, subsequently, there is the potential that water quality is being degraded (appendix ten, iv). Addressing negative water quality impacts caused by reservoir-dam systems is challenging. There is a strong trend for the removal of dams across the world (Bellmore et al., 2016; Ding et al., 2019) with numerous studies reporting ecological benefits to occur following system recovery (Tullos et al., 2014; Carlson et al., 2018; Brenkman et al., 2019). However, the removal of dams is complex. In the short-term, dam removal can cause environmental damage (Bednarek, 2001; Tonitto and Riha, 2016; Rubin et al., 2017), and in the longer-term dam removal reduces the potential for water supply and hydroelectricity (Menzie et al., 2012; Reilly and Adamowski, 2017; Habel et al., 2020). Additionally, the removal of dams is incredibly costly (Baish et al., 2002; Lejon et al., 2009; Jeuland, 2020). Subsequently, owing to the complexity of dam removal it is recommended that along the Forss Water, focus should be given to introducing measures which can maintain water quality downstream of the dam.

Although agriculture and a dam are likely the major suppressors of water quality along the rivers considered here, the matrix highlights some other land uses which may require local management.

There are a number of potential management options which can successfully improve water quality within urban areas. Hard engineering options which are identified to be quantitively successful include; catch basin inserts (Morgan et al., 2005), aeration
systems (Cong et al., 2009) and water diversion (Wang et al., 2012). Soft engineering techniques are also found to be successful at mitigating water quality within urban areas. Indeed, depending upon individual locational characteristics, soft engineering can be preferable due to lower costs and less environmental disturbance (McGrane, 2016; Stefanakis, 2019). Soft engineering options commonly rely on the natural water purification ability of riparian and wetland plant communities. Successful techniques include stormwater ponds (Ivanovsky et al., 2018), bioretention systems (Davis et al., 2003), constructed wetlands (Wahlroos et al., 2015; Stefanakis, 2019), riparian buffers (Matteo et al., 2006; Valera et al., 2019) and land use conversion away from impervious surfaces to areas of herbaceous (Salerno et al., 2018) or woodland species (Dosskey et al., 2010; Sung, 2013; Livesley et al., 2016). Public campaigns designed to encourage environmentally sensitive practices such as better hygiene, reduced pesticide and fertiliser use can also contribute to improved water quality within urban areas (Pennington et al., 2003; Chan, 2012).

In comparison, tackling water quality pollution arising from channelisation will likely be far more challenging owing to the need for hard engineering to protect valuable Scottish infrastructure (SEPA, 2015) and cost (Guida et al., 2016; Logar et al., 2019). Research suggests that channelisation degrades water quality via the deposition and release of excess suspended sediment which can contain significant quantities of heavy metals and organic matter (Nakamura et al., 1997; Ciszewski and Czajka, 2015). Of significance to unprotected river management in Scotland, research seems to identify that although suspended sediment can be an issue in channelised reaches, its source is often agricultural, urban and forestry areas (Collins et al., 1997; Walling and Fang, 2003; Froger et al., 2018; Ferreira et al., 2020). If catchment studies reveal suspended sediment to be
a pollutant along unprotected rivers in Scotland, sediment tracing could be undertaken to identify the source and allow targeted management (Walling, 2005; Froger et al., 2018).

Conifer woodlands can be blighted by low pH episodes and high organic aluminium concentrations (Dunford et al., 2012; Feeley and Kelly-Quinn, 2014; Harrison et al., 2014b). While legislation focusing on reducing atmospheric emissions which induce stream acidification has been partly successful (Feeley and Kelly-Quinn, 2014), felling and re-planting with alternative trees is still seen as a necessary management action in some circumstances (Tetzlaff et al., 2007; Shah and Nisbet, 2019). If a long-term plan of conifer removal is to be considered, then it is vital felling is conducted as sensitively as possible due to potential negative impacts. Negative impacts caused by felling include acidification (Neal et al., 1992), increased nitrate concentrations (Neal et al., 2004), excessive sedimentation (Motha et al., 2003; Karwan et al., 2007) and increased water temperature (Wilkerson et al., 2006). Approaches such as phased felling and low impact harvesting (Shah and Nisbet, 2019) are advised.

Alongside managing the specific threats to water quality, the encouragement of land use types which positively contribute to good water quality should be adopted. GE RES identifies broadleaf/mixed woodland, young woodland, floodplain forest, woodland buffers, herbaceous buffers, upland wetlands and lowland wetlands to be such land uses. Broadleaf/mixed woodlands regulate water quality through several processes including the retention of nitrate and phosphate (Greathouse et al., 2014; Hervé-Fernandez et al., 2016), the trapping of sediment (Burylo et al., 2012) and moderation of stream temperature via shading (Quinn et al., 1997; Imholt et al., 2013a,b). Similarly, floodplain
forests are identified to improve water quality through the retention of nutrients (Bechtold *et al.*, 2003; Hogan *et al.*, 2004; Cuevas *et al.*, 2014). Wetland plant communities are identified to perform an incredibly diverse range of water quality improving functions including the removal of heavy metals, herbicides, and pesticides, the anaerobic decomposition of pollutants, nutrient removal for biomass production, nitrification, and water oxygenation (Kennedy and Mayer, 2002). Owing to these multiple functions, wetlands are frequently created specifically to improve water quality (Shutes *et al.*, 2001; Song *et al.*, 2006; Matamoros and Salvadó, 2012; Vymazal and Březinová, 2015). Therefore, if possible, the management of unprotected areas could include the construction of wetlands to provide the ecosystem service of water quality.

(iv) Water Supply Potential

Examining the river ecosystem service long-profiles for the four unprotected rivers reveals an identifiable pattern of water supply potential being comparably low (appendix ten, ii, iv, vi and viii). Along the River Don, virtually no water supply potential is present for the first 15km, after this water supply appears to be provided inconsistently and at comparably low volumes (appendix ten, ii). Throughout the course of the Earn small quantities of water supply potential are identifiable, however compared to other ecosystem services present, the level of potential is low (appendix ten, viii). Along the course of the Forss Water, generally water supply potential is absent or in very low volumes, however there is a sustainable zone of potential which can be attributed to Loch Shurrery around 16km downstream (appendix ten, iv). Similarly, along the River Forth, water quality potential is identified to be a dominant ecosystem service between 10-16km, this is attributed to Loch Ard, water supply potential is then identifiable until around 30km downstream from which potential becomes absent (appendix ten, vi).
Generally, it seems that all unprotected rivers could do with a boost to water supply potential.

Although, within the context of Europe, Scotland has historically been regarded as a relatively water rich country, dry periods have occurred, and, according to projections, drought risk is expected to increase (Brown et al., 2011; Gosling, 2014; Visser-Quinn et al., 2021). Concerningly, due to the interconnected nature of ecosystem services, drought in Scotland could potentially harm agricultural yields, aquaculture, and hydropower generation (Brown et al., 2011; Visser-Quinn et al., 2021). Subsequently, it is of national interest to focus on maintaining and increasing the potential water supply of Scottish rivers. There are several potential management options which could be undertaken to boost water supply potential.

Following the GE RES matrix, the most logical management options would be the planting of broadleaf, mixed and conifer woodland, all of which are identified to contribute positively to water supply regulation (Neary et al., 2009; Biao et al., 2010, Núñez et al., 2006; Roa-García et al., 2011). In particular, the conversion of grassland, including that used for agricultural purposes, to woodland has been demonstrated to increase streamflow (Wilcox and Huang, 2010). Indeed, in Scotland, modelling conducted by Iacob et al. (2017) found that the afforestation of farmland could reduce the risks of low-flow events. Although traditionally the afforestation of farmland has been viewed negatively due to decreases in agricultural output (Beckert et al., 2016), attitudes may change as it has been hypothesised that climate change may boost agricultural yields within Scotland (Butterworth et al., 2010; Werritty and Sugden, 2013; Yawson et al., 2016). As all four
rivers have high agricultural potential, conversion of land to woodland may be considered for all.

If woodland creation is to be seen as a feasible approach, it is crucial to stress that increases in potential water supply may not occur in the short term, this is because young woodland is identified to reduce water supply potential (Scott and Prinsloo, 2008; Webb and Kathuria, 2012; Birkinshaw et al., 2014). Reductions in baseflow are believed to occur as a result of higher evapotranspiration rates from younger trees (Perry and Jones, 2017). The planting of trees would therefore be seen as a long-term management approach.

Another potential approach, which could be considered along unprotected rivers is to evaluate and reduce impervious surfaces within urban areas since they are linked to reduced baseflow (Leopold, 1968; Finkenbine et al., 2000; Kauffman et al., 2009; Rose and Peters, 2001; Chang, 2007; Hardison et al., 2009).

In regard to water supply potential, in times of water scarcity, it will be tempting to increase water abstraction from rivers, however, to maintain supply it will be crucial to prevent, limit or carefully monitor any water abstraction. Water abstraction is already carefully regulated in Scotland (Dunn et al., 2003; SEPA, 2022), but policies and practices will need revisiting as the climate changes (Rio et al., 2018; Dallison et al., 2020). Fortunately, within Scotland, researchers have already begun to examine how water flows may alter in the near future (Fennell et al., 2020; Visser-Quinn et al., 2021).

Additionally, to successfully maintain or enhance levels of water supply it is necessary to understand groundwater dynamics within the catchments. Empirical studies such as Weber and Perry (2006), McCallum et al. (2012), and Mukherjee et al. (2018) have identified that reductions in groundwater can reduce river baseflow. Therefore, it is
necessary to monitor groundwater to prevent reduced river flow which could threaten
domestic water supply, agriculture, industry, and ecology (Mukherjee et al., 2018).

(v) Climate Regulation Potential

The river ecosystem service long-profiles indicate that climate regulation potential is
perhaps the most absent service along all unprotected rivers (appendix ten, ii, iv, vi and
viii). The Don and Forss Water only have one noticeable patch of climate regulation
potential each. For the Don a very small patch is located around 5km downstream
(appendix ten, ii) and for the Forss Water there is one noticeable patch at 25km
downstream (appendix ten, iv). The Forth and Earn both have several patches present.
For the Forth some noticeable patches are present within the headwaters, prior to 10km
downstream (appendix ten, vi). Similarly, for the Earn there are several small patches
also present before 10km, however after this there is only another small patch at
approximately 42km downstream (appendix ten, viii). It is clear that management actions
should focus on improving the climate regulation potential of all unprotected rivers
considered within this assessment.

River corridors can act as either sinks or sources of greenhouse gases depending on land
cover (Rieger et al., 2015; Fortier et al., 2010; Cierjacks et al., 2010). Through the scouring
of existing literature, the GE RES matrix identifies broadleaf woodland (Janssens et al.,
2003; Canadell and Raupach, 2008; Keith et al., 2009; Chiti et al., 2012), conifer forests
(Sharma et al., 2010; Wang et al., 2016; Dar et al., 2017) and young woodland (Bradform
and Kastendick, 2010; Coomes et al., 2011) to contribute towards positive climate
regulation so it could be advised that improvement of climate regulation potential begins
with woodland planting.
If woodland planting is pursued, then it would be useful to conduct several pilot projects to determine the most suitable approach. Firstly, it would be beneficial to determine if broadleaf or coniferous woodland sequestered the most carbon in Scotland, previous research indicates the two woodland types may sequester different carbon volumes (Chiti et al., 2012; Wiesmeier et al., 2013; Wang et al., 2016). Secondly, the climate regulation potential of floodplain woodland and woodland buffers could be investigated. On scouring research to fill the matrix it became apparent that floodplain forests can act as both sinks and sources for greenhouse gases depending on climate (Smith et al., 2000; Cierjacks et al., 2010; Ricker et al., 2014; Poblador et al., 2017). Similarly, literature also demonstrates that woodland riparian buffers can be sources and sinks of greenhouse gases (Hefting et al., 2003; Tufekcioglu et al., 2003; Dhondt et al., 2004; Mander et al., 2008; Fortier et al., 2010; Fisher et al., 2014; Fortier et al., 2015; Jacinthe et al., 2015). In a world facing a potential climate crisis it would therefore be incredibly useful to determine the climate regulation potential of temperate Scottish floodplain woodlands and riparian woodland buffers; do they act as net greenhouse gas sources or sinks?

Simultaneously, management should also focus on maintaining and not reducing climate regulation potential. In particular, this involves seeking to minimise the felling of woodland. Deforested and cleared woodland zones reduce potential for climate regulation due to the loss of carbon stored as above ground biomass (Nunery and Keeton, 2010; Grünzweig et al., 2015) and within soils (Thuille et al., 2000; Conti et al., 2014).

Agricultural land is also identified to potentially reduce climate regulation (Firbank et al., 2013). Potential management may seek to focus on practices of fertiliser use, nitrogen enrichment, livestock keeping, and the storage of slurry and manure as these processes
contribute to the release of N2O and CH4 (Husted, 1994; Thomas et al., 2011; Wang et al., 2011; Outram and Hiscock, 2012; Skiba et al., 2012; Feliciano et al., 2013a; Firbank et al., 2013).

Some research indicates that upland wetlands have potential for carbon storage (Craft and Casey, 2000; Worrall et al., 2003; Worral et al. 2009; Bernal and Mitsch, 2012; Craft et al. 2017), however some evidence also shows they can be sources of CO₂, CH₄ and N₂O (Worrall et al., 2003; Li et al., 2013b). In comparison to upland wetlands, lowland wetlands appear to have greater global warming potential storage (Craft and Casey, 2000, Bernal and Mitsch, 2012, Audet et al., 2013; Bernal and Mitsch, 2013, Craft et al., 2017, Fennessy et al., 2017). Yet, other research identifies lowland wetlands to be sources (Muñoz-Leoz et al., 2011; Sha et al., 2011; Morin et al., 2017; Nag et al., 2017). The conflicting evidence for woodland buffers, upland and lowland wetlands leads to the recommendation that the climate regulation effect of these river corridor features in Scotland is researched. Additionally, due to limited evidence it is suggested that the role temperate riverine amenity land and floodplain lakes play in providing climate regulation potential is explored.

Finally, on a note of any potential research projects, it is fundamental to recommend that long-term post project monitoring occurs as GHG fluxes change over time and gases remain in the atmosphere for varying time spans (Whiting and Chanton, 2001; Mitsch et al., 2013).

(vi) Additional notes for unprotected area management

It is clear that the management of unprotected Scottish rivers requires both an appreciation of the importance of agriculture, and an appreciation of each river's
characteristics and threats. Subsequently any management undertaken should be individual to each river, however, there are also some general guiding recommendations that apply. Firstly, in summary of their modelling research, Gilvear *et al.* (2013) suggest that rehabilitation seeking to improve connectivity, dynamism and heterogeneity will improve ecosystem functioning thus inducing greater ecosystem service provision. Secondly, the success of river rehabilitation is dependent on the scale of rehabilitation measures, location of rehabilitation within the catchment and any existing pressures constraining the network (Wohl *et al.*, 2005; Gilvear *et al.*, 2013). Indeed, as with protected rivers there needs to be an appreciation of landscape history, without such knowledge potential trade-offs may be induced (Tomscha and Gergel, 2017). Furthermore, when deliberating management options for unprotected Scottish rivers, potential to deliver multiple ecosystem services through one decision should be considered. For example, planting trees within urban areas could synergistically improve water quality (Livesley *et al.*, 2016), natural flood mitigation (Roy *et al.*, 2012; Baker *et al.*, 2021), climate regulation potential (Roy *et al.*, 2012) and cultural services (Roy *et al.*, 2012; Thompson *et al.*, 2013). Finally, a key to successful river rehabilitation is long-term post-project monitoring, this facilitates the evaluation of approaches producing understanding of what went well and what can be improved in the future (Gilvear *et al.*, 2013).

**7.5.2 Proposed Management for Protected Rivers**

The results of the GE RES assessment indicate that in general, Scottish riverine SACs are providing both greater potential for many services and a higher diversity of services than unprotected rivers. However, examining conservation status reveals that the protected
rivers included are not overwhelmingly achieving their conservation objectives. Therefore, arguably one of the most pressing targets for the management of protected rivers should be the improvement of conserved species status. The argument for this is twofold. Firstly, protected areas are supposed to do exactly that, protect species. Secondly protected rivers are comparably delivering higher levels of ecosystem service potential, so focusing on maximisation should not be the main priority. However, it would be negligent to not recognise that ecosystem service potential, in both volume of individual services and number of services, requires considered management. Once satisfactory progress has been made towards achieving good species conservation status, decision making should then focus on the dual objectives of protecting biodiversity and ecosystem service provision (Powers et al., 2020). It should be kept in mind that as population continues to grow and the climate changes, approaches to managing protected areas will need to develop to remain effective (Hanna et al., 2020).

(i) Management for specific conserved species

Of the protected rivers included within this research, examining their last assessed status indicates that some need more management focus than others. The river Tay may require less attention owing to all conserved species (Atlantic salmon, River lamprey, Brook lamprey, Sea lamprey and Otter), last assessed to be in favourable maintained conservation status. In contrast, two of three species are a concern along the river Dee, freshwater pearl mussels were last recorded to be unfavourable whilst Otters were in favourable decline. The Teith and Thurso also need some concentrated management. Whilst two species (Brook lamprey and River lamprey) were last assessed to be favourable maintained along the Teith, Sea lamprey were recorded to be unfavourable declining and Atlantic salmon unfavourable recovering. Atlantic salmon are also last
assessed to be in unfavourable recovering status for the Thurso. Acknowledging the species which are not assessed to be in favourable maintained status allows for some species-specific management options to be recommended. The following section outlines potential management focuses for individual species.

**Freshwater pearl mussels**

Protecting freshwater pearl mussels along the river Dee is of significant conservation importance owing to the estimation that approximately half of the known population of this endangered species are located within Scotland (Cosgrove *et al.*, 2000).

Research demonstrates that high water quality is crucial for the establishment and survival of pearl mussel populations, and therefore surrounding land use is a significant factor in the distribution of populations (Ma, 2016). Chemical water analysis conducted at 38 sites of varying land use along the Scottish River South Esk by Ma (2016) indicates that river water travelling through woodland areas may be most attractive to mussels, this is owing to high water quality and shading created by trees. Indeed, it is believed that most of the world's remaining pearl mussel population lives in catchments that are wholly or partially forested (Cosgrove *et al.*, 2017).

Ma (2016) also identify that livestock pasture does not exert a significant negative impact on water quality for pearl mussels, however livestock proximal to the river can disturb habitats and degrade water quality by increasing turbidity. Meanwhile, water quality within irrigated crop land and urban areas seems to be poor, and therefore does not support freshwater pearl mussel populations.
Additionally, specific research conducted along the river Dee by Cooksley et al. (2012) identified that artificial structures including bank protection and bridges were likely responsible for some decline in pearl mussel populations.

Assimilating these research outcomes leads to several management recommendations which may support pearl mussel populations along the river Dee. These recommendations should build on the work of the EU LIFE+ NATURE ‘Pearls in Peril’ (PIP) project which ran from 2012 – 2017 (Dee Partnership, 2022). As part of the PIP project over 75km of upland woodland were planted, logically, since woodlands are crucial for pearl mussels, additional woodland planting is advocated. In conjunction with woodland planting, forestry practices need to be sensitive. Conducting research in three Scottish catchments, Cosgrove et al. (2017) provide a series of cost-effective measures which can support pearl mussel populations. Measures include blocking forest drainage ditches to limit siltation and runoff from forestry activities, sensitive harvesting which limits soil erosion and the removal of instream trees which were shedding needle litter (Cosgrove et al., 2017). The PIP project involved the creation of over 45km of agricultural buffer strips, if possible, more buffers should be considered. However, if riparian buffers are not feasible then the fencing and management of livestock to prevent access to water courses is recommended (Kileen, 2012; Horton et al., 2015). Along the Dee some structures including croys have been removed, it is recommended that evaluation of any remaining structures is conducted to determine if any can be removed or altered, however if any changes are to occur, they must not risk damaging any freshwater pearl mussels present (Cooksley et al., 2012).
Otters

Alongside habitat improvement for pearl mussels, last assessed conservation status highlights that management along the river Dee also needs to focus on otters. Within the UK, four main causes of European Otter decline have been identified: habitat degradation, insufficient prey, water pollution and incidental mortality (Bedford, 2009).

In the UK, between 1950 – 1970, water pollution was believed to be the most significant threat to otter populations (Kruuk and Conroy, 1996; Bedford, 2009). Compounds including polychlorinated biphenyls (PCBs) and persistent organochlorine pesticides were identified to bioaccumulate within otters (Mason, 1998; Simpson et al., 2000). Fortunately, due to the introduction of stringent environmental regulations within the 1960’s, the input of pollution into water declined and populations were seen to increase (Andrews and Crawford, 1986; Strachan et al., 1990; Kruuk and Conroy, 1996).

Fish are estimated to constitute around 70 – 92% of the diet of otters (Tüzün, and Albayrak, 2005; Preston et al., 2006), therefore in areas where there are pressures on fish species, otter populations will subsequently also struggle (Strachan and Jefferies, 1996).

For otter populations to survive, specific habitat requirements are needed. Otters need resting-up sites such as sedges and reeds as well as mature vegetation for the establishment of holts (Kruuk et al., 1998; McCafferty, 2005). Furthermore, sufficient area of suitable otter habitat is required due to their territorial nature. Research indicates that otter density may be as low as one per 4-5km of river, with territories potentially extending to 20km (Erlinge, 1968; McCafferty, 2005). The loss of riparian vegetation to agricultural production and urbanisation is hypothesised to have contributed to otter population decline (Strachan and Jefferies, 1996; Bedford, 2009). Furthermore, the
alteration of flow regimes due to abstraction and flood schemes is thought to have altered fish habitat, therefore causing a decline in species population which has propagated to otter populations (Bedford, 2009).

In regard to the incident deaths of otters, at one point, it was believed that in the Southwest of England, the main cause of otter death was road accidents (Bedford, 2009). Additionally, it is regarded that the hunting of otters may have reduced populations to an unsustainable level (Chanin and Jefferies, 1978; Bedford, 2009).

The need to address otter populations along the river Dee has been recognised by the Scottish Government. In 2020 £90,000 was given to the Dee District Salmon Fishery Board to create better habitats for otters. Specific measures outlined include restoration along the Garbh Allt and Upper Muick. Along the Garbh Allt it was planned that embankments would be removed, and backwater channels reconnected to the mainstem in order to hopefully restore natural processes (Easton, 2020). Meanwhile within the upper reaches of the Muick woody structures were proposed in order to create habitat areas (Easton, 2020). These techniques will encourage the growth of otter populations via improvement of habitat for both otters and their food species, however, it may be necessary that as human population increases there is a focus on monitoring and reducing incident deaths.

**Sea Lamprey**

The river Teith is unique amongst designated rivers in Britain, it supports populations of all three lamprey species (JNCC, 2022). Whilst Brook and River lamprey were last assessed to be in favourable maintained status, sea lampreys were recorded to be in unfavourable declining status. Protecting sea lamprey within the Teith is crucial
considering within Scotland, populations appear small, and evidence collected by fisheries managers indicates that Scottish spawning populations are in decline (Hume, 2017). Additionally, encouraging populations of sea lamprey may bring other ecological benefits as research indicates that spawning results in nutrients being added to freshwater environments (Nislow and Kynard, 2009).

The lifecycle of sea lamprey involves spawning and larval rearing within fluvial habitats and juvenile foraging within the marine environment. Significantly, sea lampreys require very specific habitat conditions for spawning, research suggests that gravels must range from 9 to 60mm, beyond this range it is believed that the fish cannot move gravel particles (Maitland, 2003). The requirement of gravel of a specific size significantly reduces the availability of spawning sites, indeed within the American Fort River, 90% of spawning redds are located within 5% of the total river length (Nislow and Kynard, 2009). Resultantly, key to the protection of sea lamprey is ensuring access to spawning grounds (Hume, 2017; Davies et al., 2021).

Unfortunately, physical barriers within fluvial environments cause habitat fragmentation and therefore reduce populations (Hume, 2017). Research conducted on the River Severn by Davies et al. (2021) found that only 4% of migrating sea lamprey passed the fifth weir, furthermore, the upstream extent of 85% of migrants was recorded to be directly below a weir. Weirs also delay sea lamprey reaching spawning sites, this is also concerning because it can reduce spawning opportunities (Davies et al., 2021). Critically, sea lamprey struggle to utilise traditional fish passes (Rooney et al., 2015; Pereira et al., 2017), resultantly evidence strongly suggests that removing barriers to sea lamprey spawning grounds is crucial for recolonization (Hogg et al., 2013; Magilligan et al., 2016). It is
therefore advocated that, if possible, weirs and migration barriers should be removed along the course of the Teith. However, if barrier removal cannot occur, evidence collected by Davies et al. (2021) indicates that elevated discharges can assist sea lamprey in passing weirs, therefore elevating discharge during spawning season may be a possible management option along the Teith.

**Atlantic Salmon**

Atlantic salmon were last recorded to be in unfavourable recovering status for both the Teith and Thurso.

On a positive note, measures to restore Atlantic salmon along the river Teith are a strong conservation objective. In 2021 a £350,000 scheme to encourage population increase commenced (Dick, 2021). The work undertaken by the River Teith Catchment Project seeks to rehabilitate the headwaters of the river. Specific measures planned include the extensive planting of trees along the river corridor, the addition of woody debris within the channel and bank reinforcement.

Planting trees along the river corridor will create shade and cover which are required for salmon populations to thrive (Armstrong et al., 2003). Research conducted along the River Dee by Imholt et al. (2012) found that via shading effects riparian trees reduced maximum stream temperatures by up to 4 ºC. Similarly, research conducted within the Scottish Loch Ard forest park by Dugdale et al. (2018) identified that both commercial conifer plantations and semi-natural deciduous woodlands moderated stream temperatures in comparison to open grassland terrain.

The addition of woody debris to the channel should support salmon populations through the improvement of instream cover and increased habitat diversity. In Nova Scotia, Floyd
et al. (2009) find the addition of large woody debris induced the creation of pools which could be used for refuge and gravel accumulation for spawning and fry shelter. Research demonstrating the success of introducing large woody debris in increasing salmon includes Cederholm et al. (1997), Roni and Quinn (2001) and MacInnis et al. (2008). If following large woody debris addition, salmon populations do not appear to improve then the synthesis of research produced by Roni et al. (2015) indicates that other catchment processes such as hydrology, sedimentation, water quality and water quantity need to be examined. Additionally, woody debris acts as a food source for invertebrate species, consequently the food availability for salmon should be increased (Utz et al., 2012).

The final focus of the river Tieth restoration is on bank reinforcement. By utilising natural materials, it is hoped that excessive erosion into the channel will be reduced and subsequently populations will recover. It is crucial that excessive sedimentation is mitigated within salmon rivers as sediments can clog spawning sites, this can prevent fish from laying eggs or lead to eggs being laid superficially which may then be washed away (Crisp, 1990; Soulsby et al., 2001; Greig et al., 2005).

In contrast, it appears there is much less conservation action being undertaken for Atlantic salmon populations along the river Thurso. However, the river does have a conservation advice package put together by NatureScot (2022) which outlines three objectives for the management of Atlantic salmon.

The first objective is the restoration of the Atlantic salmon population. This objective focuses on increasing the number of salmon parr within the river. To do this, it is recommended that focus is on increasing the number of adult spawning salmon and
ensuring access to spawning grounds. Crucially, young salmon should not be introduced as they would be less adapted to the river and may compete with the wild native fish for food and resources, this would likely lead to an overall reduction in smolt numbers.

The second objective focuses on restoring the distribution of salmon throughout the Thurso. Achieving this objective involves ensuring that salmon have access to spawning sites, juvenile rearing sites and adult rest areas before spawning. The advice package highlights that in particular there needs to be a focus on a burn downstream of Loch Calder which has been impacted by abstraction from the loch. To ensure salmon can access the necessary sites a combination of barrier removals and compensation flows are recommended.

The final objective centres on restoring habitat sites and availability of food. Throughout their various life stages, Atlantic salmon require specific river geomorphology, and high-water quality to survive. Specific geomorphology which supports Atlantic salmon include gravel beds for spawning, riffles for young fry, deep water with coarse a rough bed for parr, and pools for adult fish. Water quality must be good for salmon to survive within spawning areas well oxygenated water is required for egg development. In addition, water quantity is also important within the salmon lifestyle, water levels need to be sufficient to allow access to, and from, spawning areas and high enough to provide adequate juvenile habitat.

It is clear that there is a deep understanding of the necessary objectives for salmon conservation along the river Thurso, however, this needs to be translated into action. Owing to the delicate life cycle of the salmon species, numerous instream and riparian management options are advocated for their conservation. Specific measures will
depend on the outcome of biological and geomorphological assessments. Papers focusing on the restoration of salmonid habitats which may be useful to stakeholders along the Thurso include Roni et al. (2008), Beechie et al. (2013), Foote et al. (2020) and Lennox et al. (2021).

(ii) General Recommendations for the management of protected rivers

Although specific conservation measures will depend upon target species, some general recommendations for the management of designated areas can be made. A primary step toward improving conservation is better monitoring, for most rivers the last assessed conservation status is in the region of ten years ago. This is concerning as Geldmann et al. (2013) describe that our true understanding of species populations within protected areas is limited by poor long-term monitoring, shortages of which are reported to occur due to cost and time. Monitoring protected area and protected species status is fundamental to identifying if conservation goals are being achieved and inferring the success or failure of specific management actions (Iojă et al., 2010). Indeed, conservation goals themselves are a critical technique for evaluating the effectiveness of protected area management (Halpern, 2003). Lundquist and Granek (2005) advocate that goals for protected area management need to be clear, achievable and measurable. Moving forward it is strongly advised that carefully considered conservation goals are set for Scottish riverine SACs and that monitoring programmes are funded to allow for the evaluation of progress towards goals. However, action to conserve species and deliver ecosystem services cannot be held until such a time as perfect data availability. In their research examining biodiversity conservation in Canada Buxton et al. (2021) outline how experts concluded that it is a lack of action and not a lack of data which threatening
biodiversity conservation. Buxton et al. consider that using available information to undertake biodiversity action can be more pressing than collecting new data.

The inclusion of species pressures within the above analysis draws out one of the most significant challenges to biodiversity conservation. In the cases of the Scottish SACs included within this assessment and other published research, many pressures exerted on protected species are ecosystem services (Maskell et al., 2013; Schirpke et al., 2017; Azevedo-Santos et al., 2019). Undoubtedly, this makes the management of protected areas for biodiversity and ecosystem service provision incredibly challenging (Anderson et al., 2009; Cordingley et al., 2016). In the case of this research, no general trend can be identified regarding species pressures, conservation status and ecosystem service provision, this highlights the unique natures of each river and the need for site specific research and management (Geldmann et al., 2015; Jones et al., 2018; Geldmann et al., 2019). Such site-specific approaches have been advocated by other researchers seeking to promote simultaneous biodiversity and ecosystem service objectives (e.g. Duru et al., 2015; Eyvidson et al., 2018).

To assist in selecting conservation actions we need to better understand interactions between biodiversity, ecosystem services and management practices. This in part will be assisted by appreciating how elements of biodiversity such as species abundance, species richness or habitat structure contribute to ecosystem service provision (Harrison et al., 2014a). A unique key to this may be understanding the presence and supporting nature of charismatic species (Mace et al., 2012; Cimon-Morin et al., 2013; Brambilla et al., 2013). However, management involving charismatic species must be cautious as spatial mismatches in conservation can occur when charismatic, threatened or endangered
species are protected at the detriment of ecosystem service provision (Cimon-Morin et al., 2013). It is necessary to improve our knowledge of species interactions, in particular it would be beneficial to know how conservation actions influence species and how this propagates to conservation status and ecosystem service potential (Montoya et al., 2012; Dee et al., 2017; Xiao et al., 2018). Of course, to assist in selecting conservation actions we also need to develop our understanding of the influences conservation practices have on creating trade-offs or win-win scenarios for biodiversity conservation and ecosystem service provision (Beaumont et al., 2017; Xiao et al., 2018).

The management of protected areas is unique owing to the need consider edges, acknowledging boarder practices is vital for both conservation and ecosystem service objectives. Hermoso et al. (2016) recommend that protected area management understands how practices within adjacent areas influence dynamics within designated areas. Appreciating connectivity is also necessary for protected areas, Chape et al. (2005) highlight that the isolation of protected areas is one of the most significant threats to their ability to conserve species. Ecosystem service modelling conducted by Palomo et al. (2013) found that ecosystem potential at the edges of protected areas was more vulnerable to decline than potential at the centre. In particular, water quality close to the upstream boundaries of protected areas can be vulnerable to edge effects as a result of hydrological connectivity and degrading land uses such as agriculture and mining (Serrano et al., 2006; Olías et al., 2008). Owing to potential downstream impacts of agriculture, Palomo et al. (2013) recommend that multi-functional landscapes and wildlife friendly farming should be located upstream of protected areas to limit water quality degradation therefore contributing towards the long-term achievement of conservation goals. Cogently, management seeking to maintain or improve the ecosystem
service potential of Scottish SACs needs to account for land use upstream and surrounding designated areas.

Although improving biodiversity conservation may be the more pressing need for Scottish SACs, the management of ecosystem services should not be neglected. One of the most significant findings of the GE RES assessment is that Scottish SACs appear to provide simultaneous high potential for a diverse number of services. When it comes to managing these protected areas, it is therefore recommended that land managers understand all services which are being supplied (Turkelboom et al., 2015), failure to acknowledge a service could lead to its decline which may disrupt synergistic relationships (Bennett et al., 2009). Indeed, future research should seek to focus on examining the relationships between those services identified to be supplied by Scottish riverine SACs, this is crucial to anticipating the impact of any potential management actions (Turkelboom et al., 2015). It is recommended that ecosystem service interactions are examined at different temporal scales, understanding both short term and long-term interactions is essential (Mouchet et al., 2014; Birkhofer et al., 2015). Of note, Tomscha and Gergel (2016) conclude that by exploring ecosystem services over the long-term it is possible to better understand their interactions inducing potential for more effective management.

A significant challenge within the management of protected areas for both biodiversity and ecosystem service potential is the financial cost involved (Armsworth et al., 2011; Jantke et al., 2018). However, protected areas should not be viewed as economic drains. Indeed, in their review of protected areas and ecosystem services, Dudley et al. (2011) found that in many scenarios economists recognised that investing in protected areas is more cost-effective than attempting to restore degraded ecosystems or attempting to
engineer alternatives. One potential strategy for the simultaneous management and financial support for protected areas which could secure the future of Scottish protected areas, is the marketing and sale of ecosystem services present. Return investment can then be used to achieve both conservation and ecosystem service objectives (Willemen et al., 2013). However, an incredibly cautious approach to this would need to be taken within protected areas so as not to compromise biodiversity objectives (Watson et al., 2014).

It is clear from the above discussion that the management of Scottish protected rivers for biodiversity and ecosystem service provision is incredibly challenging, this challenge is further complicated by the need to manage with respect to a changing climate. Research from across the world indicates that projected changes to the climate will alter biotic and abiotic conditions beyond the natural ranges many species tolerate, subsequently this could mean that many protected areas are no longer suitable for the conservation of the species they were designated to protect (Hannah et al., 2005; Kharouba and Kerr, 2010; Araújo et al., 2011; Feeley et al., 2016). Additionally, as the climate changes, protected areas may become subject to invasion by non-native species which are better adapted to new climate conditions, this could decimate those species for which protection occurred (Vicente et al., 2013). This means that management discussions and decisions relating to protected areas must have an appreciation of how, and where, climates may alter and the potential impact this could have on species and ecosystem service provisions.

The final recommendation for the management of riverine protected areas in Scotland is one of collaboration. Collaboration between all stakeholders and scientists with interests in biodiversity and ecosystem services is vital for holistic management which delivers
sustainable biodiversity and ecosystem service objectives (Balvanera et al., 2020; Buxton et al., 2021). Indeed, from their review, Dudley et al. (2011) conclude that to be effective at achieving long-term biodiversity and ecosystem service goals, the management of protected areas needs to involve all stakeholders with interests, as well as members of the public. Meanwhile, research conducted in European protected areas by Hirschnitz-Garbers and Stoll-Kleemann (2010) identified that the inclusion of local people within management schemes created positive attitudes and feelings towards protected areas, additionally local people bring with them local knowledge which can facilitate more locally sympathetic management. Furthermore, Rega and Baldizzzone (2015) outline that public involvement can meaningfully improve environmental action plans, but there may be a need to better structure such involvement through stricter requirements, legislation, and better guidance for participation.

7.5.3 Potential Management for Ecosystem Service Hotspots

Hotspots are identified along both protected and unprotected rivers, since these are areas of enhanced ecosystem service provision, it seems sensible to suggest that irrespective of designation such areas are given considered management. Such an assertion is supported by Palomo et al. (2013) and García-Nieto et al. (2013) who both advocate that hotspots with high ecosystem service diversity could be managed as priority areas which provide services vital to human wellbeing. Above in the discussion of protected areas, consideration has been given to the management of areas with high ecosystem service diversity, this following section refers more specifically to ecosystem service hotspots. These hotspots are areas of exceptionally high ecosystem service potential in relation to the surrounding river corridor.
Cluster analyses conducted within section 6.5 suggests the ecosystem service hotspots identified along both the Dee and Don are not set bundles of services but unique spatial combinations. For example, along the Don, at a 60% level of similarity hierarchical cluster analyses groups reaches 120, 135, 126, 171, 172, 204, 205, 211 and 237, however examination of individual reaches reveals disparity within scores for timber production, social relations, water quality and water supply potential. Furthermore, at the 60% level of similarity, seven reaches are clustered individually, this indicates that many reaches have particularly unique ecosystem service combinations. The recognition of hotspots as unique locations indicates that each should have their own management plan. This is consistent with the recommendations of other researchers. Rouget et al. (2016) find that hotspot areas can be incredibly vulnerable to human induced degradation and therefore they should have individual management and protection strategies. Egoh et al. (2008) suggest that focused management on hotspots could be potentially resource and effort efficient. Similarly, Bai et al. (2021), recognise understanding the spatial location of hotspots allows for prudent and targeted landscape management. Of significance for biodiversity conservation, Schmidt et al. (2019) denote that individually managing hotspots can also protect elements of biodiversity.

Unfortunately, it is beyond the scope of this research to provide recommendations for the management of all 31 hotspots identified along the Dee and Don. Subsequently, some guiding principles for tailored plans are proposed. Firstly, it is recommended that the management of ecosystem service hotspots recognises the landscape features which are key to service provision. Concerningly, in their research of the Scottish Pentland Regional Park Schmidt et al. (2019) identified that there is a clear mismatch between management strategies and the landscape features which support ecosystem service hotspots.
Secondly, as with all ecosystem service management, there is a need to understand how actions within hotspots will influence ecosystem service interactions leading to potential trade-offs or synergies (Powers et al., 2020).

Along with guiding principles for hotspot management, some recommendations for future research are advocated. Research within protected areas of East Africa by Wei et al. (2012) found that ecosystem service and species richness hotspots only overlapped for 14.4% of the study area, this suggests complex spatial interactions between ecosystem service potential and elements of biodiversity within hotspots. Subsequently it is recommended that future research focus on the spatial congruence between ecosystem service hotspots and biodiversity metrics within Scotland. GE RES hotspot analysis also indicates there is a need to investigate the role cultural services play in creating hotspots. Additionally, it is crucial that the management of hotspots is sustainable as these areas are going to be key for ecosystem service provision in the future (Spanò et al., 2017). On a final note, when researching recommendations for the management of ecosystem service hotspots, a relatively small volume of research could be identified, because these areas have substantial value to human wellbeing it is recommended that research into the evaluation of their management is paramount.

7.5.4 General Recommendations for Management

The investigation of ecosystem service hotspots along the Dee & Don revealed that both protected and unprotected Scottish rivers can provide high levels of cultural service potential (see section 6.5). The cultural value of Scottish rivers parallels with the broad trend for European rivers; throughout Europe demand for cultural services has increased and is predicted to increase further (Harrison et al., 2010; Gutiérrez and Alonso, 2013).
Tangible and intangible cultural services contribute significantly to human wellbeing (Kumar and Kumar, 2008; Hernández-Morcillo et al., 2013; Chan et al., 2012; Scholte et al., 2015; Raymond et al., 2014; Small et al., 2017). While an economic approach to cultural services cannot be used as the sole motivator for protection due to the intangibility of some services it would be naive to downplay the economic significance of Scottish rivers for some services such as recreation (Riddington et al., 2004; Butler et al., 2009) and cultural heritage (Courtney et al., 2006). Furthermore, it should be kept in mind that it is believed that cultural services cannot be replaced by technical means (Hernández-Morcillo et al., 2013). Consequently, the future management for all rivers in Scotland needs to appreciate their cultural significance.

If managed with consideration, the significance of rivers for cultural services can be an asset to riverine management. Research finds that cultural services connect people to nature, these connections can then be used to support potential management schemes (Chan et al., 2012; Daniel et al., 2012). These nature connections can also be used as avenues to communicate the need to protect ecosystems (Gobster et al., 2007; Orenstein, 2013).

On the individual service level, education may be particularly crucial for inducing positive connections to riverine ecosystems. Angiel and Angiel (2015) find a high level of river knowledge relates to positive attitudes regarding river environments. Tapsell et al. (2001) write that river-based education can persuade individuals to embrace more environmentally sensitive practices. Of importance, educating younger generations who are the future decision makers is deemed key to the sustainable management of river
environments (Angiel and Angiel, 2015). Additionally, potential enhancement of aesthetic value can induce support for restoration schemes (Buijis, 2009).

When it comes to the management of rivers for cultural services, it seems that the greatest challenge is to design management that allows wellbeing and economic benefits but not at the cost of environmental exploitation or degradation (Quine et al., 2013; Löf et al., 2016; Rall et al., 2017; Vierkko and Yli-Pelkonen, 2019; Ignatieve et al., 2020). Additionally in the interest of cultural service provision to not overly anthropomorphise environments, Vigil et al. (2017) find that landscapes with high human influence are less aesthetically appealing.

When deliberating management scenarios, it crucial to focus on riverine biotic factors alongside abiotic characteristics. Johnson et al. (2020) argue that if river rehabilitation is to be successful in reinstating river functions which have been in long-term decline then it is essential to reconsider what is meant by river rehabilitation. Key to this reimagining of river rehabilitation, is healthy riverine biology and a connectedness between biology and riverine processes (Johnson et al., 2020).

Throughout this thesis the concept of economically valuing ecosystem services is discouraged, however, there is likely a case for incorporating economic valuation into riverine corridor management. Droste and Meya (2017) outline how ecosystem service focused cost-benefit analysis of river restoration schemes can facilitate more efficient spending of public money. That being said, it is important to remember that motivational corruption, where a focus on money undermines an intrinsic desire to morally protect the environment can occur as a result of being strongly focused on economic value (Luck et al., 2012; Neuteleers, and Engelen, 2015).
In a time of restrained budgets, it is necessary to consider the place of charitable and volunteer roles within the management of both protected and unprotected areas. It seems obvious that the encouragement of voluntary and charitable river conservation is advocated. Activities undertaken through voluntary or charitable organisations reduce pressure on government finances and can have significant environmental benefits (e.g. Brightsmith et al., 2008; Cerrano et al., 2017; Li et al., 2019). Volunteer based schemes can also be used to monitor projects and have the potential to yield relatively unbiased reliable data (Schmeller et al., 2009; Valois et al., 2020). Furthermore, if activities take place in groups there is the potential for social relations to be induced which can connect people to each other, and to river environments (Everard and Quinn, 2015).

As management proceeds, a collaborative approach involving multiple stakeholders is advocated. SEPA (no date) outline that key to the success of using an ecosystem service approach in Scotland is working with multiple agencies since varying organisations hold different data sets which help to determine the service provision and health of ecosystems. Key to collaboration between stakeholders, including the public is strong communication (Luck et al., 2012; Buytaert et al., 2014).

Additionally, during the discussion of protected and unprotected Scottish river corridor management several recommendations have been made which are also worth re-emphasising in this ‘general recommendations’ section. Namely these are: research into ecosystem service interactions, post-project monitoring, public engagement and resilience to climate change.
The final general recommendation for the management of Scottish rivers is the inclusion of the recent ‘Green Recovery’ paradigm. Green Recovery is seen as a recovery pathway to the Covid-19 pandemic which involves the rehabilitation of the economy, environment and society through measures which are sustainable, inclusive and resilient (scdi, 2021). The forum for Scotland’s voluntary environment community Scottish Environment LINK regard the post-covid period as a unique and unmissable opportunity to revaluate environmental management (LINK, 2020). In part, this opportunity arises from individuals’ deeper connections to nature developed during periods of lockdown. It is hoped that these deeper connections to nature will help generate public support to push forward an agenda of Green Recovery. Crucially it needs to be understood that Green Recovery is not simply restoration to pre-pandemic status, prior to the pandemic Scotland faced a climate emergency and nature crisis, the future must look brighter (LINK, 2020).

Green Recovery is strongly advocated by the Scottish National Party who currently control spending within Scotland (SNP, 2020). In response the SNP have adapted their Climate Action Plan. The overarching aim of this climate action plan is to achieve net carbon zero by 2045, the government hope to achieve this simultaneously with the building of prosperity and tackling of inequalities for future generations through the creation of thousands of high-quality green jobs (SNP, 2020).

Specific measures outlined in the Climate Action Plan include the decarbonisation of the transport system, developing a low-carbon industry suitable for a green future, creating new jobs which are green and sustainable, and finally, and perhaps most relevant to this
research project; the restoration of Scotland’s natural environments including the improvement of biodiversity (SNP, 2020). The Green Recovery scheme recognises that the Scottish natural environment is a significant asset and must therefore be protected for future generations. In particular, Green Recovery focuses on woodland and peatland ecosystems, these ecosystems are important for carbon sequestration but also deliver other economic benefits including the creation of employment and sustainable tourism (SNP, 2020). Under the Green Recovery Plan the government have pledged £130 million to woodland creation, £250 million for the restoration of peatlands and £120 million to enhance biodiversity.

Intertwining the results of this research it seems logical to suggest that the government may wish to use Green Recovery funding to improve the conservation status of designated rivers. Furthermore, funding should be used to increase the provision of ecosystem services within unprotected river corridors because GE RES identified potential to be lower along unprotected corridors in comparison to protected rivers.

7.5.5 Deliberations prior to Management

Prior to any riverine management decisions, if possible, the modelling of different management options and their outcomes should be conducted. Gilvear et al. (2013) develop an approach for modelling the impacts that different management options will have on potential ecosystem service provision. Applying the model to the Eddleston water in Scotland, Gilvear et al. (2013) suggest that a long-term approach focusing on the adoption of less intensive land management, re-meandering and the reintroduction of floodplain forest would provide the most overall ecosystem service benefits. However, owing to the nature of this research, it seems logical to suggest that any model developed
or used needs to also include likely outcomes for different elements of biodiversity following rehabilitation techniques.

It should not be forgotten that due to the scope of this research, the GE RES assessment focuses on ecosystem service potential, the dimensions of demand and actual use are not yet incorporated. To make fully informed management decisions it is necessary to understand the dynamics between all three components (Villamanga et al., 2013; Geijzendorffer et al., 2015; Vigl et al., 2017). Crucially, knowing how the three elements are interacting allows for the sustainability of ecosystem service consumption to be determined (Villamanga et al., 2013; Baró et al., 2016). For example, comprehending how potential and flow relate can reveal either unsustainable use or potential underutilisation (Villamanga et al., 2013; Schröter et al., 2014; Geijzendorffer et al., 2015). However, it should be emphasised that understanding the dynamics between the three components will be challenging, particularly as dynamics are not static but change with society, demography, management and seasonality (Schröter et al., 2014; Burkhard et al., 2014; Villamanga et al., 2013). On a slight tangent, it is also advised that the seasonality of ecosystem service potential is considered during management discussions. Indeed Vigl et al. (2017) outline how producing management recommendations from their research in Italian mountain landscapes was hampered by failing to study seasonality, these landscapes produce vastly different services during the snow-covered winter and summer meadows.

7.6 Concluding remarks

This chapter presents a discussion of GE RES results in the context of published research, and their implications for future Scottish river corridor management.
Within this assessment, Scottish protected rivers are identified to supply a greater diversity of ecosystem services, this is somewhat consistent with existing evidence. Furthermore, GE RES results indicate that high agricultural potential along unprotected rivers occurs at the loss of other services, this trade-off is extensively reported within the ecosystem service research field and will require specific management attention.

Another key outcome of GE RES assessments was the revelation that ecosystem service hotspots are more prevalent along protected rivers. Currently, research examining the prevalence of hotspots within protected and unprotected areas is limited, the evidence that does exist seems to present a divided picture, this research therefore boosts the evidence that indicates designation may be associated with greater hotspot prevalence. Through cluster analysis, this research concludes that hotspots are unique sets of services and not bundles, it is not possible to determine if this is consistent with other studies as very limited research is available, it is therefore recommended that this research field is developed.

The final set of results to be explored in the context of published studies pertains to geomorphology. This research sought to investigate if geomorphology and not nature protection strongly influenced ecosystem service potential. Results indicate that geomorphology may be insignificant in determining ecosystem service potential, this somewhat contrasts existing research and indicates there is a need for more detailed studies to determine the role Scottish river geomorphology plays in ecosystem service potential.

This chapter approaches future river corridor management in Scotland from four perspectives: unprotected areas, protected areas, ecosystem service hotspots and
general recommendations. Ecosystem service long-profiles and conservation status data are utilised to detail specific localities which may require enhanced management.

GE RES indicates two characteristics which require management along unprotected rivers: the dominance of agriculture and low potential for several services. Firstly, it is likely that the dominance of agriculture is inducing trade-off relationships, but its significance for the Scottish economy calls for a careful management approach. Multi-functional landscapes that support agriculture, biodiversity and other ecosystem services are advocated. Secondly, to support multi-functional landscapes recommendations to improve the potential of natural flood mitigation, water quality, water supply and climate regulation seem logical. Owing to the creation of ecosystem service long-profiles, it has been possible to indicate spatial locations that may particularly require management, however, for many services, whole river corridors need consideration. Other overarching suggestions for the management of unprotected rivers include seeking to improve connectivity, dynamism, and heterogeneity, appreciating locality and landscape history, utilising synergies and long-term post-project monitoring.

When GE RES results are compared to conservation status for the four protected rivers it is identified that focus for protected rivers should initially be on boosting conservation. With the exception of the Tay, for which all services were last assessed to be in favourable maintained status, all rivers need management to conserve at least one protected species. Measures which could boost populations of freshwater pearl mussels, Otters, Sea lamprey and Atlantic salmon are proposed. Alongside these species-specific measures, the management of protected areas should be supported by better monitoring, well-constructed conservation goals, an understanding of edge effects and connectivity, cost-
effective plans, and collaboration between stakeholders. Additionally, one notable finding which impacts the future management of protected areas is that species pressures are often synonymous with ecosystem services, it is clear there is a need to investigate these interactions for successful future management.

Cluster analysis on ecosystem service hotspots located along the protected Dee and unprotected Don reveals that they are unique entities and not repeated bundles. Regarding management this indicates that each one requires a unique tailored management plan.

Alongside specific measures linked to designation status and hotspot presence, some more general recommendations for the management of Scottish river corridors are proposed. Firstly, Scottish rivers are identified to have significant cultural value, if managed sensibly, this cultural value could be harvested to encourage rehabilitation and protection. Secondly it is believed that any management actions need to appreciate both biotic and abiotic elements of river corridors. A significant number of management recommendations are proposed based on the results of GE RES assessments, conservation status and academic literature, resultantly it is crucial to remember that ultimately management actions should depend upon ecosystem service potential, localised conditions, ecosystem service demand and available resources.
Chapter Eight: Thesis Conclusion

8.1 Introduction and key research findings

The overarching aim of this PhD thesis has been to determine if ecosystem service provision differs between Scottish river corridors with and without nature designations. The research was commissioned by NatureScot (formerly Scottish Natural Heritage) – the government body in Scotland with nature conservation responsibilities. The field of enquiry is highly topical at a time where “green recovery” and “working with nature” is the emerging environmental management paradigm. To achieve the overarching aim, this thesis had the substantial secondary aim of developing a methodology suitable for capturing and assessing the relative value of multiple Scottish riverine ecosystem services. This final chapter seeks to summarise main research findings and consider their importance for future river and floodplain management both within Scotland and globally. In particular, the significance of results are considered in the context of future ecosystem service science and nature conservation practice.

In a nutshell, the research presented in this thesis provides substantial contributions to the science and application of the ecosystem services approach to rivers by:

- Building significantly upon previous knowledge on the subject of river ecosystem service research as synthesised by Hanna et al. (2017).
- Advancing the river ecosystem services assessment approach piloted by Large and Gilvear (2013). It does this in a number of ways including incorporation of uncertainty, addition of cultural ecosystem services, using scores weighted and non-weighted by river corridor area, and a more robust underlying approach to scoring.
• Being the first detailed attempt to examine the role of nature conservation designations on rivers in an ecosystem services context. This was undertaken on 4 paired rivers, with and without European Union Special Area of Conservation nature conservation designations, in Scotland

• A rare, possibly unique, attempt to simultaneously assess, at a reach scale, provisioning, regulating and cultural ecosystem services along multiple river corridors at a river system scale.

• Providing preliminary evidence that suggests areas with nature designations, established for biodiversity conservation, may also deliver a greater range and higher levels of river ecosystem services.

These scientific advances have been recognised by publication of an international journal paper that documents the basics of the methodology and a synthesis of findings (Keele et al. 2019). Given the infancy of the science and its application to rivers there is still the need for further research on the subject. This work is already a catalyst for follow up work (e.g. Ekka et al., 2020) on the effect of anthropogenic modification and river ecosystem services using the Keele et al. (2019) approach.

The following section synthesizes the content and key findings of each chapter, and highlights that each provides a unique and significant contribution to the fields of river ecosystem service assessment and nature conservation designation.

8.2 Synthesis of Chapter findings

8.2.1 Ecosystem Service Literature Review

The literature review presents a pathway to the overarching research aim. Unravelling the history of the ecosystem service concept begins with a definition of the term as simply
the benefits humans gain from nature. Examination of the history of the paradigm reveals that the monetary valuation of nature in the 1990s acted as a significant catalyst. The concept is advocated because it highlights the significant dependence of humans on functioning ecosystems and the negative impacts our actions have on our own wellbeing. The Millennium Ecosystem Assessment sought to categorise ecosystem services. Later clarification of categorisation within academic literature led to the development of the ‘ecosystem service cascade’. This cascade sees supporting services as underpinning final provisioning, regulating and cultural services. Historically it appears provisioning services have been maximised due to the order societies develop, their economic value and political policies. In contrast, cultural services had been neglected, this is related to their intangible natures and poor amenability to economic valuation. In recognition of the poor integration of cultural services, recently, an attempt was made by IPBES to adopt the term ‘Nature’s Contribution to People’ in place of ‘ecosystem services’. Significantly, it appears that the ecosystem service community rejected this attempt to paradigm shift because integration of cultural services into the concept is improving.

Within the ecosystem service cascade, it is now more widely accepted that biodiversity supports the provision of ecosystem services than it is itself a final service. Exploring the place of biodiversity within the ecosystem service concept leads to a question significant for landscape management; to what extent do areas protected for biodiversity simultaneously provide ecosystem services? Subsequently, evidence of protected areas achieving these goals was sought. Analysing literature, no strong conclusion as to the ability of protected areas to achieve the two simultaneous goals could be reached. Consequently, it appeared that there was a research gap in our understanding of the ability of freshwater protected areas to deliver ecosystem services. The history of river
management reveals several paradigm shifts in guiding principles with the emerging one being dominated by the ecosystem service concept (Hanna et al. 2017). The adoption of the ecosystem service paradigm within river management is identified to bring advantages including encouraging interdisciplinary science, more holistic rehabilitation schemes, generating public support for rehabilitation schemes, inducing connections between nature and people, and raising awareness of the threat’s river environments face.

8.2.2 Methodology Review

The secondary aim of this research was to select and develop a method suitable for the primary aim of determining if ecosystem service provision differed between Scottish river corridors with and without nature designations. As such, it was vital to review the current methodological approaches available for quantifying ecosystem services. Key points arising from the review and selection process are outlined below.

To initiate the review of ecosystem service quantification methods it was necessary to explore some underpinning aspects. Firstly, there needs to be an appreciation that different aspects of ecosystem service provision (potential, flow and demand) can be measured. Secondly, it is crucial to understand there is a difference between monetary and non-monetary valuation. Finally, it is highlighted that within the river ecosystem service field, many niche methods for the quantification of sole services have been developed. Understanding that many quantification approaches are niche enables focusing of the methodology review to those techniques which can capture multiple river ecosystem services in accordance with the overarching research aim. Owing to the
distinct nature of cultural services, provisioning and regulating methods are reviewed separately.

This chapter commences the review of methodologies used to capture provisioning and regulating services with monetary valuation. It is evident that historically monetary valuation was a dominant approach for the quantification of river ecosystem services (Chan et al., 2012). For the capture of provisioning and regulating services, limitations of economic valuation include; being expensive and time consuming, poor ability to represent individual preferences, high uncertainty caused by the need for multiple techniques, and questionable moral appropriateness (Chan et al., 2012; Gómez-Baggethun and Ruiz-Pérez, 2011; Hanley et al., 2006; Lehtoranta et al., 2017; Neuteleers, and Engelen, 2015; Spash et al., 2009; Vermatt et al., 2016).

Ecosystem service modelling was revealed to be the major alternative to economic valuation. Within the river research field two dominant branches of modelling emerged; numerical computer-based and capacity matrices. A notable advantage of both types over economic valuation is that they are designed to spatially represent and link ecosystem character and environmental quality to elements of ecosystem service provision. Computer-based models used to capture riverine ecosystem services come from two branches of science; hydrologic and ecosystem service science. At the time of writing, no computer-based models were able to capture the full suite of ecosystem services supplied by river environments. Furthermore, models are limited by the availability and quality of river character input data.

Capacity matrices produce ecosystem service scores by linking land cover features to ecosystem service potential (Burkhard et al., 2009; Campagne et al., 2017; Jacobs et al.,
Initially these linkages were based solely on expert opinion, but more recently they have been supported by empirical evidence. Capacity matrices are identified to have two significant advantages; they can be used in areas of low data availability, and they can compare multiple services equitably with ease. Unsurprisingly matrices are not without criticisms, there are questions regarding the level of uncertainty involved in expert judgement as acknowledged by Large and Gilvear (2013).

Cultural service quantification has been neglected in general and river ecosystem service research. The historic disregard of cultural services is significantly attributed to their poor amenability to economic valuation. Nine distinct cultural services are perceived to be supplied by river environments, these are; aesthetic value, artistic inspiration, cultural heritage, education, recreation and tourism, scientific knowledge, sense of place, social relations and spirituality and religion (Everard and Quinn, 2015; Gopal, 2012; Gutiérrez and Alonso 2013; Harrison et al., 2010; UK NEA, 2011). This is viewed as positive because cultural services can be mediums through which people connect to nature, resultantly people then desire to protect ecosystems. Eight distinct methodologies alongside the category of ‘other’ were identified. These methodological approaches were; rating surveys, participative perception mapping, economic valuation, frequency of use/feature, content analysis, photo-preference surveys, cartographic data as proxies and expert-based scoring. Logically chapter three next explores the strengths and weaknesses of each identified cultural service methodology.

Of the provisioning and regulating service methodologies the approach of a capacity-matrix is deemed most appropriate. A capacity matrix utilising the virtual globe Google Earth as the primary data source is selected. This decision is based on the free cost of
data, low user requirements and ability to detect small-scale river corridor land cover features. Chapter three ends by selecting a cultural methodology. A photo-based preference survey is deemed the most suitable. Selection of this technique is based on its ability to equitably capture all nine services listed above, capability to elicit feelings and potential for integration into a Google Earth-based provisioning and regulating matrix.

8.2.3 Methodology Development: Part One (Provisioning and Regulating Services)

Utilising the methodological decisions made in chapter three, the purpose of chapter four was to contribute towards the subsidiary aim of developing a model which can be used to answer the primary aim of determining if ecosystem service provision differs between Scottish river corridors with and without nature designations. This model is to be known as the Google Earth River Ecosystem Service Tool (GE RES). Specifically, chapter four sought to develop a capacity matrix which could capture provisioning and regulating potential. Prior to creating the matrix framework, it was necessary to deliberate the desired properties of GE RES. A key issue was spatial scale of analysis. A reach length that was required that was of high enough spatial resolution to detect ecosystem service hotspots and coldspots, but not too high resolution that assessment would become time exhausting. For a focus on Scottish rivers a 500-metre length was deemed appropriate. The approach also went “beyond the river channel” and adopted the modelled 2-meter flood inundation extent as the river corridor definition and focus of assessment (Harvey and Gooseff, 2015).

To improve the robustness of the GE RES tool, the decision was made to include additional properties over and above that of the Large and Gilvear approach (2015). Firstly, and significantly, to improve the robustness of the matrix, linkages were to be supported by
empirical studies. Secondly, GE RES is designed to account for ecosystem disservices. The inclusion of disservice relationships is deemed a prerequisite for appropriate ecosystem service management. The second additional property is the inclusion of an uncertainty measure. Uncertainty is a caveat inherent to ecosystem service assessments, therefore, presenting a measure of uncertainty is crucial for enabling considered management, preventing false confidence in results, and maintaining public trust. In terms of the actual final matrix the following services are included: agriculture, water supply, timber, hydroelectricity, floor mitigation, water quality regulation and climate regulation. Regarding river corridor features, 19 were included within the final provisioning and regulating matrix to cover all contributing features but without duplication of impacts on scores. In total the initial matrix created had 133 possible linkages, therefore, a pre-screening process involving discussion amongst experts sought to establish which linkages were credible. In total 55 linkages required investigation through the analysis of empirical research. Following a thorough review of empirical research, the final matrix was produced (table 19). Two types of information are presented in the provisioning and regulating matrix: the nature of relationship and a confidence score.

8.2.4 Methodology Development: Part Two

Cultural Services Methodology Development, Results and Evaluation

To integrate cultural services into the matrix, the creation of a photo-preference survey needed to be accomplished. In light of the potential magnitude of the survey, discussions were held to consider how the robustness, repeatability and usefulness of survey output could be maximised through survey design. In response, it was decided that alongside preferences the survey would seek to gain an understanding of individual feelings and
attachments with open questions. Additionally, socio-demographic questions were integrated because they may help to explain variance in preferences. Following question deliberation, an online survey was conducted using the software Survey Monkey as the best means of information capture. The investigation of literature revealed a number of practical recommendations for survey wording, these include; the use of everyday language, short questions, exclusion of technical terms, specific questions, avoidance of double negatives and double-barrelled questions and evasion of the term ‘strongly’ prefixed to agree or disagree. The seven included services were aesthetic value, inspiration, cultural heritage, knowledge gain and sharing of knowledge, recreation, social relations, and spiritual and religious value. A five-point unipolar scale was utilised as a compromise between allowing respondents to express their feelings and keeping survey completion efficient. For analysis, a numerical score was later attributed to each verbal answer, these ranged from 0-4. If the average response score for a feature-service relationship exceeded 2.0, above sometimes would visit, then a linkage would be established within the matrix.

Ideally, the survey would capture preferences from every individual who experiences cultural benefits from Scottish river corridors, however, within the scope of this PhD thesis that could not be achieved. Instead, a pilot-study approach, with a known population bias is undertaken. The decision was made to administer the survey to those in receipt of the monthly Scottish Natural Heritage Newsletter. Assumptions included that respondents probably lived or worked in Scotland, and had some involvement in environmental management. It is crucial to emphasise here that owing to the biased population, the conduct of the survey should be viewed as “preliminary knowledge” serving the purpose of illustrating the approach rather than a definitive finding. Logically,
it is recommended that moving forward the survey is repeated with a population more representative of all those who culturally benefit from Scottish river corridors.

Although the results of the survey need to be viewed as preliminary, because the field of research examining multiple cultural service potential from river corridors is limited, a detailed discussion of results obtained from preference and open questions is presented as appendix seven. Furthermore, also owing to a lack of previous exploration, appendix eight proposes management recommendations for river corridor features based on survey results.

Chapter five includes an evaluation of the survey methodology. Evaluating the survey is a crucial foundation block for developing a methodology which is robust and repeatable for capturing multiple riverine cultural ecosystem services. As alluded to above, one of the most significant areas for improvement is the representativeness of the sample population. Socio-demographic questions revealed participants were better educated than the general Scottish population, countering this imbalance is necessary because education level has been shown to skew cultural ecosystem service preferences. The gender bias of survey requires addressing because research has demonstrated that women have a greater appreciation of the non-material benefits, and men may perceive potential for a greater number of cultural services. Respondent residence also needs addressing, Scottish riverine cultural services are experienced by local people and visitors. To address issues of survey bias and improve robustness, researcher survey administration and supervision are advocated.

The first strength of the approach outlined is that the cultural service methodology appears to have been successful in achieving its purpose, cultural services have been
integrated into the GE RES matrix. Of significance, the use of a non-economic approach has facilitated the inclusion of many services which have been neglected due to perceived intangibility. It is hoped that the inclusion of intangible services here induces more comprehensive river corridor management and acts as a foundation for continued research into the lesser captured services. The incorporation of open questions is potentially the most unexpected strength of survey design. Open question comments were found to be instrumental in unpicking matrix scores, unravelling thoughts and feelings, and evaluating the survey design. It is concluded that the benefits of using open questions outweigh the potential negative of reduced survey completion rate, subsequently it is recommended that open questions are included within future river cultural service surveys.

Further methodological strengths which indicate the approach is repeatable include: transferability, time and cost efficiency, the inclusion of the public, and success at the small scale. In accordance with the wider objective of GE RES, the survey was intentionally designed to be transferable between river corridors, the strength of this approach means that costly site-specific surveys and issues of low data availability are avoided. Developing a methodology which is centred around public preferences is a significant strength, cultural values are ultimately driven by subjectivity and this approach can capture individual preferences. Chapter five next suggests future uses for the cultural service photo-preference tool. Temporal trends could be investigated by using seasonal photos or from photos taken decades apart. The tool could also guide management actions, respondents could be asked to assign preferences to different potential management scenarios, information gained could then be used to deliberate specific rehabilitation techniques.
Finally, chapter five ends by outlining how the provisioning, regulating and cultural matrices are developed into the Excel based tool which becomes GE RES. Microsoft Excel is chosen to facilitate GE RES because it is widely available and can be operated without expert knowledge, this pairs nicely with the logic of selecting Google Earth.

**8.2.5 GE RES Results**

The preceding chapters established the foundations for chapter six. Chapter six presents the results of GE RES assessments which were undertaken to pursue the overarching research aim of determining if ecosystem service provision differs between Scottish river corridors with and without nature designations. Four pairs, each with one protected (Special Area of Conservation, SAC) and one unprotected river were selected. The SAC designation was selected because it is the only statutory protection given to the entire length of Scottish rivers. Summarising results, it can be said that rivers with nature designations provide higher potential for a greater number of services and subsequently have a greater ecosystem service diversity. Of note, and unsurprisingly, agricultural potential is consistently greater for unprotected rivers. Following pairwise analyses, the influence of river corridor area is explored.

Chapter six also addresses another issue. It could be possible that river reach geomorphological character is more significant in driving differences in ecosystem service potential than nature designation. However, the picture, although complicated, suggests that nature designation exerts a greater influence over differences in ecosystem service potential than reach geomorphology. There is, however, still an identified need for future research to examine the influence river geomorphology has on river ecosystem service potential.
The final set of results explored within chapter six is an investigation of ecosystem service hotspots through a case study of the Dee & Don pair. The nature of GE RES allows for the creation of river ecosystem service long-profiles, these spatial graphs facilitate the exploration of longitudinal patterns of ecosystem service scores. Comparing long-profiles revealed that the protected River Dee has a greater number of 17 ecosystem service hotspots with a total ecosystem service score of over 10,000, compared to 14 along the unprotected Dee. Of note, the relationship between river corridor area and total ecosystem service score is much weaker for the protected river Dee, this indicates that higher prevalence of hotspots is more likely a function of protected status that river corridor area. Cluster analyses performed on hotspots along both rivers appears to indicate that hotspots do not constitute ecosystem service bundles, instead they are discrete locations with unique sets of services.

8.2.6 Discussion of GE RES Results

The overarching aim of this research has been to determine if ecosystem service provision differs between Scottish river corridors with and without nature designations. The answer to this question is yes, nature designation appears to be associated with higher potential for numerous ecosystem services and a higher ecosystem service diversity. Chapter seven focuses on the extent to which results of GE RES compare with existing research, and their implications for the management of Scottish river corridors.

The identification that ecosystem service diversity appears higher within protected areas is likely consistent with other research (Eastwood et al., 2016; Palomo et al., 2013). The trend for agricultural potential to be greater within unprotected areas is also consistent with other research (Palomo et al., 2013; Eigenbrod et al., 2009; Eastwood et al., 2016),
indeed within this research trade-offs between agriculture and ecosystem service diversity are identified, this too reflects a wider recognised trend (MA, 2005; Rodríguez et al., 2006; Carpenter et al., 2009; Martín-López et al., 2011; Schripke et al., 2012). In contradiction to existing research, the results of GE RES indicate that potential for timber production is in synergy with the provision of other services (Swank et al., 2001; Forsyth et al., 2006; Neal et al., 2010; Caputo et al., 2016), this may be a result of coniferous species being cleared from riparian buffers within Scotland. Trends for recreation and aesthetic value to be greater for unprotected areas appear to conflict with established studies (Rees et al., 2015; Eastwood et al., 2016), it is recommended that future research is conducted to shed more light on this pattern. In summary, despite some nuances, this research adds to the pool of studies which demonstrate protected areas to supply higher levels and greater diversity of ecosystem services. This conclusion indicates that nature designation may be crucial for the supply of ecosystem services.

Within literature there is some debate as to whether nature designation is associated with increased prevalence of ecosystem service hotspots (Nieto et al., 2013; Palomo et al., 2013; Willemen et al., 2013; Davids et al., 2016; Spanò et al., 2017). Analyses of the Dee & Don case study enhances the pool of literature which indicates designation is associated with higher ecosystem service hotspot abundance. Cluster analyses on hotspots along the Dee & Don appears to indicate that ecosystem service hotspots do not constitute ecosystem service bundles, due to a limited research field examining the dynamics of ecosystem service bundles within protected areas it is not possible to determine if this finding is consistent with a wider trend, subsequently, more research is advocated. Cultural services are found to be significant underpinning elements for the creation of
hotspots, looking to determine if this parallels an already known phenomenon leads to the conclusion that there is a need to better examine hotspot characteristics.

Utilising the SEPA reach typology, this research seeks to question if geomorphology and not designation may influence ecosystem service potential. It is tentatively concluded that geomorphology may have little influence on ecosystem service potential, on synthesis of existing literature it is discovered that this finding may be inconsistent with the work of others (Gücker and Boëchat, 2004; Tomscha et al., 2017; Sazbo et al., 2020; Zhou and Endreny, 2020). It is therefore recommended that further research is conducted to unpick the role of geomorphology in the provision of Scottish riverine ecosystem services.

Following the exploration of GE RES results in the context of published scientific research, this chapter shifts focus onto the investigating the extent to which the protected areas included within assessment are simultaneously achieving high ecosystem service and their conservation objectives. Examining ecosystem service potential and last recorded conservation status reveals a divergent picture for all four rivers, this seems to affirm the findings of the literature review which found no obvious relationship between conservation status and ecosystem service potential within the freshwater realm. Results somewhat indicate that protection is associated with greater ecosystem service potential but not always good conservation status. It is therefore recommended that, in a time of constrained budgets and ecosystem pressure, it is crucial to further research the extent to which designated areas are simultaneously achieving conservation objectives and providing ecosystem service potential.
This chapter next moves to discuss potential interactions between species pressures, species conservation status and ecosystem service potential. One of the most significant phenomena highlighted is that many species pressures are actually ecosystem services. This finding is concurrent with other protected area research (Maskell et al., 2013; Schirpke et al., 2017; Azevedo-Santos et al., 2019). Examining species pressures, conservation status and ecosystem service potential reveals no overarching trend, instead it is emphasised how complex interactions are. A need for a greater understanding of interactions between these elements is clear. To properly understand interactions, it is necessary to conduct frequent detailed monitoring of conserved species and areas.

After discussing the results of GE RES in the context of published research and species conservation status, chapter seven shifts focus to discussing the significance of results for Scottish riverine management. Recommendations for management are discussed from four perspectives: approaches for unprotected rivers, protected rivers, potential hotspots and general recommendations. Utilising ecosystem service long-profiles produced from GE RES (appendix ten), site specific management actions are proposed.

Two lenses are used to focus on the potential management of unprotected rivers. Unprotected rivers are crucial for the supply of agriculture; therefore, the first lens focuses on how agricultural landscapes may be managed to synergistically supply potential for other ecosystem services. The second lens concentrates on increasing potential for those services which GE RES identifies to be supplied in statistically lower quantities along unprotected rivers.
In a world challenged by food security, it is obvious that unprotected areas should be managed in such a way that agricultural yields are maintained. As such, it is recommended that agricultural lands within Scotland are managed with a view to creating multi-functional landscapes (Green et al., 2005; Bugalho et al., 2011). Specific measures which are advocated include riparian buffers, crop diversification, and hedgerow planting (Stutter et al., 2012; Asbjornsen et al., 2014; Van Vooren et al.; 2017; Cole et al., 2020; Tamburini et al., 2020; Beillouin et al., 2021). Since all unprotected rivers are dominated by agriculture, there is potential for multi-functional landscapes along each. However, specific locations which may benefit include two blocks along the Dee and Forss water, downstream after around 18km for the Forth, and the entire length of the Earn.

Discussion focusing on the services for which there may be scope to increase potential along unprotected rivers begins with natural flood mitigation. In the uplands, woodland planting is recommended (Carroll et al., 2004; Ford et al., 2016; Murphy et al., 2020; Monger et al., 2022), in particular the uplands of the Don may benefit from upland woodland creation. Within the lowlands, riparian buffer creation, lowland wetland, natural lake management and stormwater ponds are advocated (Moore and Hunt, 2012; Hassall and Anderson, 2014; Mclean et al., 2015; Moore et al., 2015; Gao et al., 2016; Ameli and Creed, 2019). Examining long-profiles indicates that the Forth and one zone of the Don may particularly benefit from lowland natural flood mitigation potential interventions. Of note, the long-profiles indicate that the Forss Water and Earn have comparably high natural flood mitigation potentials and therefore may not be a primary management focus. In regard to future research, it is recommended the role of amenity land in providing flood relief is studied, this could impact urban flood management plans.
Examining the river long-profiles reveals there is a general pattern for water quality potential to be lower within agricultural areas. Subsequently, a variety of agricultural pollutant mitigation techniques are recommended. Depending on the source of pollution, one, or a combination of, the following may be undertaken: nutrient management, crop rotation, contour farming, agricultural fencing, reduced overgrazing, reduced livestock density, constructed wetlands and riparian buffers (Kay et al., 2009; Liu et al., 2017). Of these measures, riparian buffers may be more desirable due to a lesser impact on farming activities (Sullivan et al., 2004; Kenwick et al., 2009). In comparison to the other rivers, water quality potential along the Forss water appears higher, however the dam located at Loch Shurrery has the potential to degrade water quality. In some scenarios, dam removal has been undertaken along rivers to improve water quality, however the complexity, financial and environmental cost of dam removal led to a recommendation for water quality management below the dam as opposed to removal.

To improve water quality along unprotected rivers it is recommended that management also focuses on water quality within urban areas, the impacts of channelisation and consequences of conifer plantations.

Within urban areas water quality may be improved through hard engineering such as catch basin inserts, aeration systems and water diversion (Morgan et al., 2005; Cong et al., 2009; Wang et al., 2012) and/or soft engineering like storm water pond Ivanovsky et al., 2018s, wetland creation and riparian buffers (Matteo et al., 2006; Wahlroos et al., 2015; Stefanakis, 2019; Valera et al., 2019). Acidification associated with conifer plantations can be mitigated through the removal of trees species (Tetzlaff et al., 2007; Shah and Nisbet, 2019), however in order to prevent water quality degradation during
removal phased felling and low impact harvesting are recommended (Shah and Nisbet, 2019). Finally, alongside these specific mitigation measures, it is advised that where possible, land use conversion towards woodland and wetlands which positively contribute to water quality potential should be considered.

Interpreting long-profiles, it appears that along unprotected rivers there are only small zones of high-water supply potential, therefore all unprotected rivers may require management to boost water supply potential. The main method advocated to improve water supply potential is the conversion of some agricultural grasslands to woodlands (Wilcox and Huang, 2010; Jacob et al., 2017). Whilst it may be thought that this approach would decrease agricultural yields, this may be counteracted by changes in the climate that could boost agricultural yields (Butterworth et al., 2010; Werritty and Sugden, 2013; Yawson et al., 2016). If woodland planting is to be undertaken, then managers need to be mindful that this is a long-term approach as within the short-term yields can be reduced (Scott and Prinsloo, 2008; Webb and Kathuria, 2012; Birkinshaw et al., 2014). Owing to the rapidly changing climate, the planting of woodlands may be deemed somewhat time critical. In conjunction with woodland planting, management should also focus on reducing impervious services within urban areas (Leopold, 1968; Finkenbine et al., 2000; Kauffman et al., 2009; Rose and Peters, 2001; Chang, 2007; Hardison et al., 2009), tightly regulating abstraction (Rio et al., 2018; Dallison et al., 2020) and monitoring groundwater supplies (Mukherjee et al., 2018).

River long-profiles show climate regulation potential present only in small discrete patches along all unprotected rivers. Woodland planting is recommended for all rivers to boost climate regulation potential (Janssens et al., 2003; Canadell and Raupach, 2008;
Keith et al., 2009; Bradform and Kastendick, 2010; Sharma et al., 2010; Coomes et al., 2011; Chiti et al., 2012; Wang et al., 2016; Dar et al., 2017). If woodland planting is to be undertaken then pilot projects are recommended to determine where planting should occur and with which species. Alongside woodland planting, to improve climate regulation potential there needs to be a focus on woodland harvesting regimes and agricultural practices. In conjunction, research should focus on determining the climate regulation potential of upland wetlands, lowland wetlands, amenity land and floodplain lakes, as these features could then be incorporated into management plans. Crucially, following management or research, for informed subsequent management, long-term post-project monitoring is recommended as GHG fluxes change over time (Whiting and Chanton, 2001; Mitsch et al., 2013).

Following the analyses of GE RES results, recommendations for the management of unprotected areas focus on improving ecosystem service potential, however this may not be the immediate focus for protected area management. Owing to the results of GE RES demonstrating that protected rivers supply greater volumes of ecosystem service potential and synthesising last conserved species status, an alternative theme for the management of protected areas is advocated. It is argued that one of the most pressing management objectives should be to focus on improving the status of species for which designation was given.

With the exception of the river Almond, for which all services were last assessed to be in favourable maintained status, all rivers need management to conserve at least one protected species. Along the Dee, freshwater pearl mussels were last recorded to be unfavourable whilst Otters were in favourable decline. Along the Teith, Sea lamprey were
recorded to be unfavourable declining and Atlantic salmon unfavourable recovering. Atlantic salmon are also last assessed to be in unfavourable recovering status for the Thurso. Each of these species require unique sets of living conditions, and therefore recommendations for management actions are tailored to each species and each river.

Along the Dee, recommendations to encourage pearl mussel populations build upon the work of the EU LIFE+ NATURE ‘Pearls in Peril’ (PIP) project. Specific measures include upland woodland planting, sensitive forestry practices, blocking forest drainage ditches, the removal of instream needle shedding trees, structure removal and riparian buffer creation (Cooksley et al., 2012; Kileen, 2012; Horton et al., 2015; Cosgrove et al., 2017; Dee Partnership, 2022).

Alongside management for freshwater pearl mussels, the Dee also needs to be managed to improve Otter populations. Measures which can support the growth of Otter populations include embankment removal, backwater channel reconnection and the introduction of woody structures (Easton, 2020).

Along the Teith, last assessed status reveals a need for management to focus on improving sea lamprey populations. Key to protecting this species, is ensuring they have access to spawning grounds (Hume, 2017; Davies et al., 2021), to achieve this, attention needs to be on removing weirs and other migration barriers (Hume, 2017; Davies et al., 2021). If it is not possible to remove barriers, then it may be necessary to create periods of elevated discharge which can assist lamprey to pass weirs (Davies et al., 2021).

Atlantic salmon were last recorded to be in unfavourable recovering status for both the Teith and Thurso. To support the recovery of Atlantic salmon, recommended measures include riparian woodland planting, the addition of woody debris, bank reinforcement,
barrier removals and compensation flows (Cederholm et al., 1997; Roni and Quinn, 2001; Armstrong et al., 2003; Maclnnis et al., 2008; Roni et al., 2008; Beechie et al., 2013; Foote et al., 2020; Lennox et al., 2021).

Alongside these species-specific recommendations, chapter seven also provides some more general recommendations for the management of protected areas following GE RES. Firstly, there is a need for better monitoring of conserved rivers and conserved species status (Geldmann et al., 2013).

Frequent monitoring is necessary for determining if conservation objectives are met and evaluating the successes and failures of conservation actions (Iojă et al., 2010). Secondly, conservation goals need to be clear, achievable and measurable (Lundquist and Granek, 2005). Thirdly, there is a need to understand how edge effects and connectivity with unprotected areas influences dynamics inside designated boundaries (Palomo et al., 2013; Hermoso et al., 2016). The management of protected areas is costly, and therefore it is necessary to question how management can be most cost effective, this could include financially marketing some services, focusing on hotspot locations or encouraging volunteer activities (Armsworth et al., 2011; Willemen et al., 2013; Jantke et al., 2018).

One significant outcome of comparing GE RES results to conservation status for protected rivers is that many species pressures are ecosystem services, this is consistent with the outcomes of other researchers (Maskell et al., 2013; Schirpke et al., 2017; Azevedo-Santos et al., 2019). This phenomenon raises considerable challenges for the management of protected areas in a time when they need to meet the dual objective of delivering ecosystem service potential and species conservation (Anderson et al., 2009; Cordingley et al., 2016). In order to successfully manage protected areas for multiple objectives there
is a need to improve our knowledge of the interactions between elements of biodiversity, ecosystem services and management practices. Crucially, it is recommended that research focusing on interactions also considers how climate may alter them, and the implications this may have for the future.

The final recommendation for the management of protected areas, is one of collaboration. Many stakeholders, scientists and local residents have different agendas for these precious designated areas, but in a time of extreme landscape pressure and restricted funding, there is a need to work together, for a common interest, their future success (Dudley et al., 2011; Balvanera et al., 2020; Buxton et al., 2021).

Through the creation of ecosystem service long-profiles, this research revealed the presence of ecosystem service hotspots. This recognition of ecosystem service hotspots along the Dee & Don case study led to the question of whether ecosystem service bundles were present. Following cluster analysis, it is determined that hotspots along these rivers are discrete sets of services and not repeated bundles. In terms of management, this leads to the conclusion that each hotspot should have its own individual management plan. To support these individual management plans it is advocated that there is good knowledge of the landscape features which induce hotspots and interactions between ecosystem services within hotspots. In regard to future research, it seems necessary to understand spatial congruence between riverine hotspots and biodiversity metrics.

Chapter seven finalises by outlining some general guiding principles for the future management of Scottish river corridors. Firstly, results have highlighted that Scottish river corridors supply high volumes of cultural service potential; therefore, it is crucial that management plans recognise their significance for the Scottish economy. The
cultural significance of Scottish rivers is advantageous from a river management perspective because cultural connections induce stewardship (Gobster et al., 2007; Chan et al., 2012; Daniel et al., 2012; Orenstein, 2013). Encouraging cultural services can therefore have positive impacts for management, however there is a need to carefully balance cultural activities with conservation measures to prevent environmental degradation (Quine et al., 2013; Löf et al., 2016; Rall et al., 2017; Vierkko and Yli-Pelkonen, 2019; Ignatieve et al., 2020). Secondly, in times of budget constraints, managers should seek to collaborate with charities and volunteers when possible. Within this section it is again emphasised that there is a need for collaboration between all potential river users, this is necessary both for practical data purposes and to mediate conflicts.

The final recommendation for the future management of Scottish river corridors is that it occurs under the ‘Green Recovery’ paradigm. The Green recovery paradigm is a pathway for recovery from the Covid-19 pandemic that centres on rehabilitating the economy, environment and society through measures which are sustainable, inclusive and resilient (scdi, 2021).

It is fully accepted that more research is required to support informed management decisions, however it is advocated that management actions should not be stalled until a time of perfect knowledge and data availability. Beginning river and catchment management now is vital to reducing further landscape degradation, therefore preventing decreases in human wellbeing and conservation losses from freshwater systems.
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Appendix One: Table Five

Table 5: presenting explanations and examples of cultural river services. Where available evidence of the river being provided by Scottish rivers is explored.

| 1. Aesthetics | Beautiful landscapes create pleasing or fulfilling sensory experiences (Pflüger et al., 2010) and therefore landscape beauty is valued and appreciated by humans. Rivers across the world including in Scotland have long been recognised to have aesthetic value (Knudson, 1976; Smith, 1977; Erickson and Steams, 1979; Harrison et al., 2010). It seems that the dynamism of river environments influences perceived aesthetic value. In New Zealand Pflüger et al. (2010) found higher flows and little bank exposure to be deemed more aesthetically pleasing in small rivers and intermediate flows and low turbidity in larger rivers. Meanwhile Le Lay et al. (2013) investigate perceptions of braided rivers and find that photographs of reaches with gravel bars were perceived to be less aesthetically attractive. Aesthetic value has a mixed relationship with river health. In England Gregory and Davis (1993) find research participants (geography and psychology undergraduates and research staff/students) to prefer woodland streams without woody debris. In contrast Cottet et al. (2013) find perceptions of wetland aesthetics and healthiness are well correlated with wetland ecological health. Desire for aesthetic value can induce support for river restoration schemes (Seidl and Stauffacher, 2013). Buijs (2009) report that the enhancement of scenic beauty is one the main reasons for support for floodplain restoration. Additionally increase in aesthetic value can offset loss of place attachment which may occur alongside restoration (Buijs, 2009). |
| 2. Artistic Inspiration | Inspiration is one of the least researched services (Hernández-Morcillo et al., 2013) which is surprisingly given how many artistic works are based on ecosystems. To be inspired humans require external stimuli (Thrash and Elliot, 2003) which river ecosystems seem to provide. Harrison et al. (2010) consider the numerous creative works focused on river ecosystems indicates high inspirational value. Early documented work inspired by rivers includes Samuel Coleridge’s Poem Sonnet: To the River Otter and John Constable’s 1821 The Hay Wain. Rivers have likely been inspiring people for longer but occurrences were not recorded or documents lost. Rivers |
continue to inspire a range of creative works. For example, Coscieme (2015) find rivers to be the third most popular ecosystem for inspiring popular music.

Evidence shows Scottish Rivers have been inspiring people for centuries. Recently the Scottish National gallery held an exhibition called ‘Rocks & Rivers’ which included 19th Century paintings from Scotland. Scottish rivers continue to inspire painting and drawing, a company called ‘Wild at Art’ organise painting holidays where people can paint Scottish rivers. Searching the Scottish Poetry website reveals Scottish rivers form the subject of many poems. A famous Scottish river poem is ‘Muckle Spate’ written in 1851 by David Grant following a flood which damaged Strathspey. Scottish rivers also inspired songs including Scottish Rivers, Silver Bridges Across the Clyde, and Banks of the Dee.

### 3. Cultural Heritage

Cultural heritage is another service which seems under researched with only brief mentions in articles (Høllelanda et al., 2017). In part research scarcity results from no consensus on the definition of cultural heritage as an ecosystem service (Hølleland et al., 2017). Heritage can be ‘derived from the landscape’ or ‘as tangible manmade remnants’ (Hølleland et al., 2017). While is easy to understand how heritage from landscapes is a function of ecosystem processes there is a question about manmade heritage. One argument suggests that built heritage is a supporting feature as it provides habitat for plants and animals (Hølleland et al., 2017). However built heritage may also be the product of ecosystems if natural construction materials are used (Gordon, 2012). Clarification is required to better understand cultural heritage (Hølleland et al., 2017).

Rivers provide cultural heritage value through their landscapes and manmade constructions. The Canadian Heritage Rivers System (CHRS) conserves river landscapes that have outstanding heritage values, for example the French River in Ontario played an important role in the fur trade and was a vital trade link to port of Montreal (Erickson, 2015). In Scotland waterfalls are important cultural heritage with some being associated with local myths (Cole, 2015). Manmade structures within river environments which contribute to cultural heritage include watermills (Fajer, 2014) and weirs (Loures, 2008). Despite a lack of research focusing on river based cultural
heritage in Scotland, heritage is important as it can facilitate local economic benefits (Courtney et al., 2006). The inclusion of cultural heritage within this assessment is important as a: 2015 SNH developed a working paper titled ‘Cultural Ecosystem Services – towards a common framework for developing policy and practice in Scotland’ (Rawcliffe, 2015) outlined that cultural heritage should be included in cultural service assessments.

| 4. Education | Education as an ecosystem service means that an ecosystem provides opportunities for people to learn about nature and natural environmental processes (Harrison et al., 2010). For river ecosystems Harrison et al. (2010) consider that education is often facilitated by conservation areas where nature trails, information centres and boards are available to inform people about the river processes they are witnessing. Outside of conservation areas education may be facilitated by river-based organisations. For example West Country Rivers Trust runs a citizen science scheme which involves training and a monitoring kit for participants to use (http://wrt.org.uk/project/become-a-citizen-scientist/).

Education is important in shaping the way people connect with rivers. A high level of river knowledge is linked with positive attitudes towards rivers (Angiel and Angiel, 2015). Education of river environments can lead people to feel compelled to adopt environmentally-sensitive lifestyles (Tapsell et al., 2001). In particular education of the younger generation is important as they are going to be making the future river and catchment management decisions (Angiel and Angiel, 2015). If possible, education should take place in the field as this gives studies the opportunity to be more immersed (Angiel and Angiel, 2015). Additionally, planned educational visits can change perceptions of rivers from marginal places to places where special activities and experiences can take place (Tapsell et al., 2001).

| 5. Recreation and Tourism | The UK NEA (2011) consider important river-based recreational and tourist activities to include fishing, kayaking, canoeing, swimming and nature viewing. Scotland has a history of attracting people to rivers and associated features. Cole (2015) indicate that waterfalls have been of interest to travellers and recreationists since at least 1769. Trip advisor indicates how important rivers and water are for tourism. The three highest rated ‘things to do’ for the Loch Lomond and Trossachs National Park are the Dochart
Falls, Loch Katrine and Bracklinn Falls Bridge and Callander Crags. Scottish residents also make use of rivers for recreation. In 2014 the Scottish Household Survey estimated that 48% of adults partook in outdoor recreation at least once a week. Only 6% of outdoor visits in 2013/2014 were estimated to be to rivers although 41% of visits were to local parks/open spaces where it is likely rivers are present and appreciated.

Recreation and tourism are important for the Scottish economy. Fishing brings in significant revenue. In 2004 it was estimated that game and course freshwater was worth £113 million per annum, Atlantic salmon anglers provided the greatest contribution (65%) followed by rainbow and brown trout anglers (30%) (SNH, 2016). In a case study Butler et al. (2009) estimate 2003 angler expenditure in the Spey Catchment was around £10.8 million. Additionally, Riddington et al. (2004) estimate sailing, rafting and canoeing in the Spey catchment to be worth £1.7 million in 2003. Fishing also provides employment, Butler et al. found fishing in the Spey catchment creates the equivalent of 366 fulltime jobs.

<table>
<thead>
<tr>
<th>6. Scientific Knowledge</th>
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| Under the ecosystem service paradigm there is little literature focusing on capturing the scientific value of river environments, this seems surprising considering the volume of research papers focusing on rivers across the world. Gutiérrez and Alonso (2013) highlight the scientific knowledge value of rivers in Spain by highlighting the number of articles that have been published in the Journal of the Iberian Association of Limnology between 1984 and 2009 relating to rivers and riparian areas and the number of maters and PhD theses relating to aquatic ecosystems and water. If literature and publications are an expression of the scientific value of rivers then it is clear than Scottish rivers facilitate significant opportunities for scientific knowledge.

The scientific knowledge value of Scottish rivers can be considered high owing to the fact that 5,865 scientific papers were retrieved following a Web of Science search using the terms ‘Scotland’ and ‘River’ on 01.12.2021.

The volume of academic research focusing on Scottish rivers may be higher than expected when considering geographic area owing to the fact that scientific enquiry is considered an important part of Scottish cultural heritage (Gordon, 2012).
### 7. Sense of place

Within ecosystem service research ‘sense of place’ is taken to be multidimensional. In their research looking at ‘sense of place’ in Cornish fishing communities Urquahart and Acott (2014) write:

“The term “sense of place” (Shamai, 1991) is a multidimensional construct often used to encompass the concepts of place identity, place attachment and place dependence, which are frequently understood as representing cognitive, affective and conative dimensions (Jorgensen and Stedman, 2006).”

**Place identity** is considered to refer to the role a distinctive place plays in cultural identity development and the promotion of a sense of belonging (Davenport and Anderson, 2005). **Place attachment** involves an emotional attachment between person and place and that this leads to the love of a place which has also been referred to as a ‘sense of belonging’ (Hidalgo and Hernandez, 2001 in Urquart and Acott, 2014). Place dependence refers to the extent to which a place can facilitate the attainment of behavioural goals (Jorgensen and Stedman, 2006), here a group or individual is attached to a place because of the functions a place provided (White *et al.*, 2008).

Rivers clearly induce strong sense of place as place attachment has been found to influence support for river restoration (Buijis, 2009; Alam, 2011). Rivers provide ‘sense of place’ at varying scales. Durie *et al.* (2005) consider that in Scotland rivers contribute ‘sense of place’ country scale. Most studies of ‘river sense of place’ are at the smaller scale with rivers contributing to ‘sense of place’ all over the world (e.g. Bricker and Kerstetter, 2002; Shamsuddin *et al.*, 2008; Nielson-Pincus, 2017; Ganzevoort and van den Born, 2018).

Currently there is very little research looking at the ‘sense of place’ associated with Scottish rivers however this does not mean people do not develop deep sense of place with Scottish rivers, it’s just that studies have yet to capture this service.

### 8. Social relations

In literature there appears to be little written about the service of ‘social relations’. This reflects the list synthesis above where social relations is only mentioned by Everard and Quinn (2015). While not well incorporated into the ecosystem service concept as an individual service research finds that social relationships driven by positive social interactions contribute to human wellbeing (Street *et al.*, 2007; Cattell *et al.*, 2008; Yan
Wellbeing arising from social relations is facilitated by a number of different social activities and events including volunteering (Musick et al., 1999; McMunn et al., 2009), paid work (McMunn et al., 2009) meeting family and friends (Mair and Thivierge-Rikard, 2010), group exercise (Adamsen et al., 2009; Malcolm et al., 2013) and group creative projects (Pearce and Lillyman, 2015). It is important to note that not all forms of social relations contribute to wellbeing, some forms of interaction such as online communication can negatively impact wellbeing (Hu et al., 2017). The lack of ecosystem service research focused on social relations is slightly baffling as across the world ecosystems facilitate social activities.

As landscape features rivers bring people together leading to the creation of river-based organisations which facilitate social relations. River orientated social groups include angling associations, river restoration organisations and hiking groups, the social interaction of these groups can increase individual and community wellbeing (Everard and Quinn, 2015). In Scotland there are national and local organisations based on river environments. At the national level there is the Scottish Anglers National Association (SANA) which organises among other things angling competitions, coaching and instruction and meetings which all provide opportunities for people to develop social relations based on their shared interests. On the more local scale there are 26 river trusts, trusts have volunteer networks and through volunteering people are able to share experiences and ideas. The potential for social relations has been found to be a motivation for people to partake in river-based activities. In Ohio Lepp and Herpy (2015) research motivations for paddling activities along the Cuyahoga river and find four distinctive motives; experiences and learning, intrinsic benefits and social relations.

**Spirituality and religion**

Similar to cultural heritage in some places the link between ecosystems and spiritual/religious values is more difficult to establish as human constructed elements often distinguish sites. Constructed features include religious buildings, statues and symbols. However, this is not the case for all spiritual/religious sites, values may also be attached to areas such as glaciers (Allison, 2015), forests (Gould et al., 2014), mountains (Zoderer et al., 2016) and rivers where it is easier to seen connection to ecosystems.
In their review Harrison et al. (2010) consider that European rivers do not have significant religious value. However, Gutiérrez and Alonso (2013) believe that some spiritual and religious practices do occur in river environments in small rural Spanish villages. Gutiérrez and Alonso (2013) highlight that some localised springs and small freshwater ecosystems were historically protected by traditional religious events, however these events now appear to be attended by more urban people who do not understand or appreciate traditions leading to less favourable status of these water bodies. Outside of Europe some rivers have significant religious and spiritual value. The Ganges river is connected to the Lord Shiva in the Hindu Faith. As part of their religious obligations Hindus must visit a place of pilgrimage near a river at least once in their life, Hindus believe if they bathe in scared waters they will be cleansed of sin (Agoramoorthy, 2015).

The spiritual and religious values associated with rivers leads to communities wanting to protect them. In New Zealand the Māori people have a deep spiritual connection with the Waitkato river that has lasted in excess of six centuries. The Māori feel an obligation to keep the river clear and flowing, because of their connection the Māori claimed ownership of the river when the New Zealand government attempted sell shares of the river to electricity companies (van Meijl, 2015). In Siberia the Altaian people believe rivers to have spirit owners which should be honoured. The connection between the Altaian people and sacred Katun River drove the Altaian people to take action against the proposed construction of a dam on the river by the Soviet Union which would have harmed both its sacred and ecological value (Klubnikin et al., 2000).
Appendix Two: Extract from SEPA (2012) which details how different reach geomorphologies can be classified into one of six reach types

PART 3: Annexes

Detailed information to help carry out individual procedures.

- Annex A: Description of River Types
- Annex B: SEPA River Type Database
- Annex C: River Type Field Survey Guidance
- Annex D: Using maps and photographs to identify morphological pressures

Annex A Description of River Types

Rivers are a complex and diverse continuum of channel patterns and forms. This results from complex processes of sediment erosion, transport and deposition operating within the constraints imposed by the geology and terrain of the surrounding landscape. River channel typologies provide a basis for ordering physical features and processes into groups based on common characteristics.

SEPA’s morphological river typology is based on the Montgomery & Buffington typology for mountain streams in North America. This has been modified to include the low gradient channels found in the UK. The typology is process based i.e. channel sub-types are grouped together according to the similar morphological processes present. As such the groupings have similar sensitivity to morphological pressures such as channel modifications. Other key features are that the types are natural, i.e. they assume the channel is unmodified, and that types exist at a reach scale, with individual reaches varying considerably in length.

Table 4 below shows a summary of the channel types and sub-types. The proceeding pages then give more details about each type/sub-type and the distinguishing characteristics of each. Type E has not been included in this guidance as it does not generally exist in Scotland.

Table 4  SEPA River Typology

<table>
<thead>
<tr>
<th>SEPA River Type</th>
<th>Sub-types</th>
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<tbody>
<tr>
<td>A</td>
<td>Bedrock, Cascade</td>
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<tr>
<td>B</td>
<td>Step-pool, Plane Bed</td>
</tr>
<tr>
<td>C</td>
<td>Plane-riffle, Braided, Wandering</td>
</tr>
</tbody>
</table>
## TYPE A: Bedrock & Cascade

Generally a very high energy environment but quite stable

Common in upland areas

Bedrock outcrops in lowland areas (e.g. gorges)

Generally very steep (particularly cascade reaches)

Very little, if any, sand and gravel bed material present

Bedrock channels are dominated by solid exposed rock on the channel bed and banks.

Cascade channels are dominated by large cobbles and boulders on the channel bed and banks.

Limited connection with the riparian zone.
Figure v Type A Cascade – Example 1

Figure vi Type A Cascade – Example 2
Figure vii Type A Cascade – Example 3

TYPE B: Step Pool

Discrete accumulations of large cobbles and boulders across the channel forming steps separated by pools.
Steps typically spaced 1-4 channel widths apart.
Steep gradient.
High energy environment but quite stable channel.
Generally confined by valley sides.
Figure viii Type B Step Pool – Example

Figure ix Type B Step Pool – Typical longitudinal profile
TYPE B: Plane Bed

- Featureless gravel/cobble bed often armoured (larger gravel and cobbles on surface protecting smaller gravels underneath from erosion).
- Moderate gradient.
- Generally stable banks resistant to erosion.
- Generally straight in confined or unconfined valleys.
- Can include glides, riffles or rapids.
- A transitional type between the higher energy cascade and step-pool channels to more dynamic/meandering channels (C, D and F).

Figure x Type B Plane Bed – Example

TYPE C: Plane Riffle

- Intermediate between plane bed (Type B) and meandering (Type D).
- Retain many features of meandering but less well defined pools, coarser bed and less extensive deposits.
- Often straight/gently curved planform.
- Banks generally stable and well vegetated.
- Bed substrate: cobbles and course gravel (may be armoured).
• Bars small and infrequent.

Figure 23 Type C Plane Riffle - Example

TYPE C: Braided

• Relatively high gradients but generally lower than Types A and B.
• Normally abundant bedload (input of sediment from upstream and/or bank erosion).
• Channel split into a number of threads around in-stream bars (gravel/cobble deposits).
• Bars often bare or with pioneer species.
• Poor bank strength.
• Unconfined.
• Highly dynamic: channels frequently change position.
Figure 24 Type C Braided - Example

TYPE C: Wandering

- Transition between braided and lowland meandering types.
- Exhibit characteristics of braided and meandering channels.
- Dynamic reaches.
- Extensive erosion at bends (typically >2m/year).
- Planform is mis-shaped/irregular meanders.
- Highly variable width (generally larger rivers).
- Susceptible to channel avulsion during high flows.
- Well developed floodplain with abandoned channels.
TYPE D: Active Meandering

- Distinct bed morphology: undulations in bed create a REPEATING SEQUENCE of pools separated by riffles
- Regular sequence of bars
- Alternating side bars in straighter channels
- Point bars on inside of bends in more sinuous channels
- Bed material typically sands and gravels
- Fine sediment accumulations
- Channel typically unconfined by valley sides
- Bank material = sands and gravels therefore generally erodible
- Channels migrate slowly across floodplain (typically < 2m/year)
- Extensive floodplains and riparian zones
Figure 26 Type D Active Meandering – Example 1

Figure 27 Type D Active Meandering – Planform View
Figure 28 Type D Active Meandering – Example 2

TYPE F: Low Gradient Passively Meandering

- Low gradient and sinuous.
- Bed material typically sands and silts.
- Some small gravel deposits might be present.
- Typically lowland (high order).
- Generally deep laminar flows (glides) with runs at bends.
- Channel typically unconfined by valley sides.
- Very fine bank material (clays and carse deposits) = stable and resistant to erosion.
- Typically fixed planform.
- Often incised into floodplain.
Channel Type Bed Profiles

The bed profile of a channel is often a good indicator of the channel type. The diagram below highlights the main differences between bed profiles for some of the channel sub-types noted above.

Bed profiles for Type C wandering and braided channels tend to be much more chaotic.
Annex B SEPA River Type Database

The SEPA River Type database, covering a total of 25,000 km of river length, was derived using remotely sensed data.

The literature review of channel types, which led to the selection of the typology described in Annex A, suggests that channel type at any point on a watercourse can be predicted by analysing four key driving variables:

- Drift geology
- Channel slope
- Valley confinement
- Sinuosity

These driving variables can be derived from GIS datasets held by SEPA using GIS data manipulation and extraction techniques. The method used for each variable is summarised below.
Drift geology was extracted directly from the British Geological Society Drift maps. These can be viewed on SEPA’s GIS Intranet under the “Groundwater” theme.

Channel slope was calculated using elevation data extracted from the NEXTMAP DTM and channel length derived from a channel centreline generated specifically for this project from OS Mastermap.

Valley confinement is measured as a ratio of channel width to valley width. To calculate channel width a new dataset was generated that contained left and right bank lines in order that the distance between them could be calculated. Valley width was derived from polygons in the 200 year flood outline maps held by SEPA, where the extent of the 200 year flood was assumed to be the valley edge. Ratios were then categorised as confined, semi-confined or unconfined.

Sinuosity is measured as the ratio of channel length between two points to the straight line distance along the valley centreline between the same two points. Channel length was derived from the channel centreline and valley centreline was derived using the flood outline maps.

Note: National coverage datasets for other variables such as stream power and bed sediment size are not currently available.

A GIS tool was designed to extract the chosen variables at 50m intervals along the entire SEPA Baseline Water Body network.

An algorithm was then constructed to use the extracted variables to predict channel type at each point. Adjacent sample points of the same type were then merged to show reaches of the same type within each water body. As expected, reaches are highly variable in length.

The algorithm (shown in the table below) was constructed using thresholds derived from a review of literature relating to the various river types, including some work on Scottish rivers. Allocation works from left to right and top to bottom i.e. start by assessing geology then slope, etc.
Table 5  River type algorithm

<table>
<thead>
<tr>
<th>Geology</th>
<th>Slope</th>
<th>Sinuosity</th>
<th>Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bedrock</td>
<td>any</td>
<td>any</td>
<td>A</td>
</tr>
<tr>
<td></td>
<td>&gt; 0.1</td>
<td>any</td>
<td>A</td>
</tr>
<tr>
<td></td>
<td>&gt; 0.03</td>
<td>≤ 0.1</td>
<td>B</td>
</tr>
<tr>
<td></td>
<td>&gt; 0.005</td>
<td>≤ 0.03</td>
<td>D</td>
</tr>
<tr>
<td></td>
<td>&gt; 0.001</td>
<td>≤ 0.005</td>
<td>C</td>
</tr>
<tr>
<td></td>
<td>&gt; 0.0005</td>
<td>≤ 0.001</td>
<td>C</td>
</tr>
<tr>
<td></td>
<td>&gt; 0.0001</td>
<td>≤ 0.0005</td>
<td>D</td>
</tr>
<tr>
<td></td>
<td>≤ 0.001</td>
<td>any</td>
<td>F</td>
</tr>
</tbody>
</table>

Notes: In cases where some of the variables for a predicted river type were not within the thresholds usually associated with that river type, low confidence was assigned to the typology. The rules for this were as follows:

Type F & D, Sinuosity < 1.1, Flag as “Potentially Modified”

Type A, B & C, Sinuosity > 1.4, Flag as Low Confidence

Type A, Confinement = UC, Flag as Low Confidence

Type C, D & F, Confinement = C, Flag as Low Confidence

An extensive programme of dataset validation and updating is ongoing using data collected during routine survey work. This will replace the predicted data in the database and be shown as “high confidence” (HC).

The following issues had to be addressed in order to extract the predicted river typology from the map-based data:

**Issue 1: Scale**

This relates primarily to the distances over which channel slope and sinuosity data should be extracted from the maps. For example, slope measured over 1 or 2 km is likely to be different to the slope measured over 100 or 200 m. Rules based principally on location within the channel network were created to define the channel distances over which these variables should be extracted. Rivers at the upstream end of the channel network are small and changes in bed elevation are likely to be of a larger magnitude over shorter channel distances. Calculations were thus carried out over shorter distances.
In contrast, rivers towards the downstream end of the network are bigger and changes in bed elevation are likely to be of a smaller magnitude over longer channel distances. Calculations were thus carried out over longer distances.

**Issue 2: Dataset resolution**

The most accurate datasets available for each variable were often at varying resolutions. This meant that, for example, the river centreline sometimes did not pass through the lowest point in the digital elevation model, thus affecting slope calculations. Procedures were devised to overcome this issue as far as possible.

**Issue 3: Overlapping variables**

River types are generally dependant on different combinations of driving variable values. The values of these variables can sometimes be very similar but result in different types. The dominant variable seems to be channel slope, but there are quite large overlaps between the ranges of slope values at which individual types can exist. Large datasets of variable values for “real” rivers and national datasets for other variables, which may add accuracy to the analysis, are not yet available.

**Issue 4: Threshold values**

The thresholds at the upper and lower end of the range of variable values used in the allocation decision tree were taken from a review of the available literature. Although some of this information relates to Scottish rivers, it is limited in nature and more research is required.

SEPA will use periodic field survey to review and add to the quality of the river type database.

**Annex C River Type Field Survey Guidance**

River type should be identified in the field primarily using the information contained in Annex A. This contains the fundamental characteristics of each river type and sub-type.

If necessary, Annex A can be printed and taken out during field survey. However, given the length of the Annex, a shorter one page summary has been produced below which can be taken instead. A flow chart has also been produced below to help identify channel type.
For the purpose of regulation, distinction between sub-types is not necessary although identifying sub-type will automatically identify the type. This means that it does not matter if there is doubt about the sub-type as long as there is no doubt about the type. For example, if you cannot decide whether the reach is step-pool or plane bed this does not matter because they are both Type B.

**Useful hints and tips for identifying river type**

River type is dependent on the driving factors, i.e. the topographic setting of the channel, flow regime and underlying geology, which means that river type varies along a river with changes in the driving variables. The length of each reach between changes also varies considerably from hundreds of meters to several kilometres. Therefore, when identifying river type think at the reach scale rather than focussing on individual features at particular points.

The complex nature of rivers means that there can be local variability. It can sometimes appear that a river has some features that are not consistent with those identified in the guidance in Annex A i.e. some features of one type and some of another. In this case try to focus on the dominant features and processes at work to decide which type it is.

Often, a change in river type is not abrupt and therefore not always obvious. In some cases, as driving factors gradually change so too does the river type. There can therefore often be a (usually relatively short) reach between two different distinct types which has characteristics of both. In this case try to focus on the dominant features and processes at work to decide which type it is.

Avoid focussing just on the area of proposed work. It is better to maintain a wider focus to try to understand the context of the reach being assessed. When approaching the reach (whether by vehicle or on foot) take the opportunity to observe the wider river setting. What is the river like upstream and downstream? Are there obvious changes in type upstream or downstream? How close are the valley sides to the river? Is there a floodplain?

If possible walk upstream and downstream of the reach being assessed for an appropriate distance looking at river type. This may give you more confidence in deciding what the type at the assessed reach should be.

Bed profiles are often a good indicator of river type. Use the guidance at the end of Annex A to help confirm in your mind what the river type is.
Try to think about what the river type should naturally be. Human modifications to rivers have often changed river characteristics and sometimes very significantly. Where there is obvious modification, such as straightening, bank protection, embankments etc, try to think about what the river might have looked like before it was modified. This can often be quite difficult but you can look for clues such as disconnected floodplain, old channels, bed sediment size and channel gradient. This can be supplemented by looking at historic maps. The best historic maps available, which pre-date most large scale river modifications are the Roy Military Maps from circa 1750.
Figure 31 River type summary sheet

**SEPA geomorphic river typology**

The geomorphic type is described in words, e.g. bedrock, cascade, meandering, etc.

The sensitivity class is a single letter - A, B, C, D or F

---

**A. Bedrock**
- Sensitivity A
- Flow types variable, often high energy. Pools / glides common locally.
- Exposed rock

**B. Cascade**
- Sensitivity A
- Boulders common
- Disorganised bed
- Fast flow types

**C. Step-pool**
- Sensitivity B
- Steep, distinct steps into pools
- The front of each pool is constructed from boulders / cobbles

**D. Plane bed**
- Sensitivity D
- Uniform bed, fairly straight
- Bars infrequent / absent
- Bed armoured - hard to kick sample

**E. Braided**
- Sensitivity C
- Multiple channels
- Bars bare or with pioneer species

**F. Sinuous stable planform**
- Low-gradient passive meandering
- Deep channel
- Little / no erosion
Figure 32 River type identification flow chart

START
Is the substrate predominantly bedrock?

Yes → Bedrock river SENSITIVITY A

No → Is the flow type dominated by chute flow or broken standing waves over very coarse substrate such as boulders or large cobbles?

Yes → Cascade river SENSITIVITY A

No → Are there steep steps across the channel, (bed gradient > 5%), over which water chute or falls, separated by distinct pools?

Yes → Step-pool river SENSITIVITY B

No → Is there more than one kind of bed form or flow type? (i.e. is the channel ecologically diverse?)

Yes → Plane bed river SENSITIVITY B

No → Does the main channel break into 2 or more channels across mobile gravel bars that are bare or dominated by pioneer species?

Yes → Braided river SENSITIVITY C

No → Are there irregular meanders with long sections of severe erosion & extensive gravel deposits, or has the river moved naturally to leave channels abandoned on the floodplain?

Yes → Wandering gravel bed river SENSITIVITY C

No → Is the river stable, with a regular sequence of pools, riffles and point bars, with erosion on outer bank & deposition on inner bar?

Yes → Plane delta river SENSITIVITY C

No → Is the planform sinuous, with a roughly regular sequence of pools, riffles and point bars, with erosion on outer bank & deposition on inner bar?

Yes → Meandering SENSITIVITY D

No → Does the river have a sinuous, meandering planform but very little or no erosion or deposition?

Yes → Low-gradient passive meandering SENSITIVITY F

No → You are unsure about which type of river you are on! Get advice from hydromorphology.

NOW CHECK THE FIELD GUIDE TO VERIFY YOUR TYPE
Annex D Using maps and photographs to identify morphological pressures

This annex provides guidance on how to identify major engineering pressures on Minor Tributaries and Coastal Streams. These watercourses are normally small and as such the scale of maps and aerial photographs makes it hard to identify even significant pressures. It is therefore recommended that a field survey is carried out if possible to validate the results of a desk survey.

Channel realignment

A very straight channel is a good indicator of historic high impact realignment. It is usually not possible to tell from maps or aerial photos if the channel has recovered enough from the historic realignment to be considered low impact realignment. A field visit is normally needed to confirm this. It is, however, worth checking the aerial photos for signs of recovered sinuosity. A good source of aerial photos is the *Peoples Map* website.

Figure 33 Example of very straight channel upstream of houses - obvious historic high impact realignment

![Figure 33 Example of very straight channel upstream of houses - obvious historic high impact realignment](image-url)
Another way of checking if a channel has been realigned is to look at old maps. The best old maps to use are the Roy Military Maps from circa 1750 and which are available on the National Library of Scotland website.

**Bridges/Culverts**

It can be quite difficult to distinguish between bridges and culverts on maps and aerial photos.

Short road, rail or track crossings can easily be either a bridge or a culvert. A field visit will normally be required to confirm this.

Where a road crossing is long or there is an obvious embankment between the edge of the road and the watercourse (a gap on the map where no water is shown) it is likely to be a culvert. The type of culvert can only be confirmed by field visit.

**Figure 34 Gap between edge of road and water indicating that this is a culvert**

![Figure 34 Gap between edge of road and water indicating that this is a culvert](image)

**Embankments**

Embankments can sometimes be identified from OS maps but these are normally large embankments with obviously sloping faces. OS maps typically
represent embankments as small chevrons or triangles. Be aware that some embankments displayed on an OS map are natural landforms i.e. natural steep sloping surfaces such as valley sides.

**REMEMBER**: If an embankment is more than 10m or 1 channel width (which ever is greater), it should be classified as a 'set-back embankment'.

**Figure 35 Triangles adjacent to watercourse indicating a steep slope and therefore probably an embankment**
Figure 36 Triangles indicating a steep slope but this time the contours and irregular alignment indicate that it is a natural slope

Impoundments

The location of impoundments can be determined from OS maps and/or aerial photos (see link above). However, the height of the weir can not be accurately determined from these sources. A field visit will normally be required to establish this if the applicant can not provide any details.

Impoundments noted on OS map. May also be called dam or sluice.
Figure 37 Indication of impoundments
References

NOTE: Linked references to other documents have been disabled in this web version of the document.


All references to external documents are listed on this page along with an indicative URL to help locate the document. The full path is not provided as SEPA can not guarantee its future location.

Key References

WAT-RM-02: Regulation of Engineering Activities
WAT-RM-34: Derogation Determination - Adverse Impacts on the Water Environment

Q-Pulse Documents

Use the doc number as a search string in Q-Pulse to find the document directly.

MlmAS Capacity for Culverts with Artificial Bed (QP: ES-ECOL-S-02)
Morphological Pressure Survey Field Form (QP: ES-ECOL-F-WFD004) Morphological Pressure Survey Guidance (QP: ES-ECOL-P-WFD004) Morphology Classification Summary (QP: ES-ECOL-S-01)

Other References


Peoples Map (www.peoplesmap.com)
Roy Military Maps, National Library of Scotland, Georeferenced maps and applications (http://geo.nls.uk/)

Appendix Three: Table Nine

Ecosystem services removed because they are not considered to be final services

Table 9: Table describing why some river ecosystem services listed above in table eight are not considered to represent final ecosystem services

| Genetic resources | Harrison *et al.* (2010), Gutiérrez and Alonso (2013) and Everard and Quinn (2015) all consider rivers to provide ‘genetic resources’. Gutiérrez and Alonso (2013) consider river corridors to provide genetic resources when they are rich in species while Harrison *et al.* (2010) consider genetic resources are also arise from the genetic variability within plant and animals species. In chapter 1, it is discussed that genetic diversity is viewed by some as an ecosystem service and by others as a supporting function. Following the ecosystem service cascade this research strongly believes that genetic diversity is a supporting service. Indeed, literature demonstrating genetic diversity as a supporting function is abundant (e.g. Díaz *et al.*, 2007; Hajjar *et al.*, 2008, Kandziora *et al.*, 2013). |
| Water Regulation | In ecosystem service literature ‘water regulation’ refers to the ability of catchments to capture and hold precipitation, this ability influences the timing and magnitude of flooding, catchment runoff, aquifer recharge and baseflow maintenance through drier periods (De Groot *et al.*, 2002; MA, 2005; Haines-Young and Potschin, 2013; Le Maitre *et al.*, 2014). Harrison *et al.* (2010), the UK NEA (2011) Gutiérrez and Alonso (2013) and Everard and Quinn (2015) consider water regulation to be a final ecosystem service provided by river environments. However, there is clear logic indicting that the ability of catchments to regulate flow is an intermediate process that contributes to the final ecosystem services of hydroelectricity, water supply and natural flood mitigation. Indeed, Fisher *et al.* (2009a) consider water regulation to be an intermediate process that underpins the delivery of consumable water while Neary *et al.* (2009) highlight that high infiltration rates and high soil storage in forest soils has a significant impact on the moderation of both peak and low river flows. Water regulation shall therefore not be considered a final ecosystem service. |
| Erosion Regulation | Erosion regulation refers to the potential of ecosystems to retain soils and sediments (Terrado *et al.*, 2014). Erosion regulation does not directly contribute to human wellbeing but supports other services. In their research in the Spanish Llobregat basin Terrado *et al.* (2014) consider erosion regulation to contribute to human wellbeing through preventing reservoir sedimentation which helps to maintain hydroelectricity generation. Powlson *et al.* (2011) highlight how erosion control supports the provision of agricultural soils and prevents the sedimentation of fisheries. Furthermore, many studies highlight how erosion control of both the catchment and river banks is necessary as excess sediment can reduce water quality (Bilotta *et al.*, 2012). Erosion regulation will thus not be included as a final ecosystem service provided by Scottish river environments. |
| Seed dispersal/pollination | Harrison *et al.* (2010) consider rivers to have some contribution towards seed dispersal while Everard and Quinn (2015) consider that riparian vegetation provides habitats for pollinator species and species that predate on pests. These biological functions constitute supporting processes. For example, Melin *et al.* (2014) highlight the importance of honeybees in the pollination of the fruit industry of Western Cape in South Africa while Cong *et al.* (2016) refer to both pollination and biological pest control as intermediate ecosystem services which underpin the delivery of final agricultural ecosystem services. |
| **Human Health Regulation** | The UK NEA (2011) considers rivers to provide 'human health regulation', the description of this is:

“Natural freshwater systems can increase well-being and quality of life if visually attractive and supportive of physical recreation” UK NEA (2011, p. 301)

Based on this description it is considered that 'human health regulation' is describing a cultural service and is hence removed from the regulating category. |
|----------------------------|-------------------------------------------------|
| **Soil fertility, formation and nutrient retention** | Gutiérrez and Alonso (2013) consider that when rivers flood they transport sediments, organic and inorganic materials which are deposited on floodplains and contribute to soil formation and soil fertilisation. However just like many of the potential ecosystem services discussed above the processes leading to soil formation and soil fertility are also regarded to be supporting processes (Sandhu *et al.*, 2010; Robinson *et al.*, 2014).

Vermatt *et al.* (2015) consider nutrient retention to be an ecosystem service however they fail to explicitly describe how nutrient retention links to human wellbeing. It can be inferred that nutrient retention contributes to human wellbeing through two mechanisms. Firstly, retention of floodplains following flooding can benefit humans through the provision of fertile soils (Ogden and Thoms, 2002). Secondly, nutrient retention on floodplains can be important for the removal of harmful nutrients and lead to improved water quality (Chatzinikolaou and Lazaridou, 2007; Cukrov *et al.*, 2008; Tian *et al.*, 2011). Crucially, both of these functions are processes which appear to be supporting in nature and not final services. |
### Appendix Four: Table Ten

**Ecosystem services removed because they are not considered to be provided by Scottish Rivers**

**Table 10: Table discussing why some ecosystem services are not considered to be provided by Scottish Rivers**

| Fish as food | All five papers consider rivers and their floodplains to provide food: food provision may be fish for consumption as well as agricultural production on the floodplains. Scotland exports a large amount of consumable salmon, with the export value of Scottish Salmon estimated to be in the region on nearly £400 million (Scottish Salmon, 2016). However the majority of exported salmon originates from aquaculture (Ellis et al, 2016) thus wild salmon found in Scottish rivers are not significantly important for sustenance. Despite not being important for subsistence wild Salmon and other species including Pike, Rainbow Trout, Brown Trout and Greyling are highly valued as recreational species in Scotland (Harris et al., 2008; Butler et al., 2009; Scotia Fishing, 2015). Since fish found in Scottish rivers are not important for subsistence, ‘fisheries’ is removed from the supporting service category and added to cultural services under the ecosystem service of recreation. |
| Health products/natural medicines | The UK NEA considers that rivers provide health products by supporting mineral spas, medicinal plants and medical leeches. It appears that generally natural medicines sourced from river environments tend to be used by traditional cultures with relatively low levels of economic development. Examples include the riverine communities of the Brazilian Unini River (Lago et al., 2016), the indigenous people of the upper Negro river in Brazil (Frausin et al., 2015) and the indigenous people living near the River Nanay in Peru (Ruiz et al., 2011). In contrast to tropical regions it appears that little research has been conducted on the role that European rivers play in providing natural medicines (Harrison et al., 2010). Indeed, the only research paper retrieved focusing on natural medicines obtained from rivers and their floodplains in Europe suggests that natural medicines are unpopular in Europe. Petz et al. (2012) used interviews to determine whether people in the Hungarian and Romanian Tisza river basin collect medicinal plants, generally local people have limited knowledge of the potential benefits of medicinal plants with only a few local people gathering them. It is therefore considered that currently European rivers including those in Scotland are not important for the supply of natural medicines. |
| Reeds, osiers and watercress | The UK NEA (2011) considers that river corridors provide reeds, osiers and watercress as materials for traditional crafts, however such crafts are more akin to the cultural service of artistic inspiration than a provisioning service. Vermaat et al. (2016) consider river floodplains to provide reeds which can be used in thatching. The NEA highlights that while historically there was a large industry based on harvesting reedbeds for thatching this industry has significantly declined. On searching both scientific literature and the internet nothing could be found that indicates reed growth in Scotland is an important economic activity or important for human wellbeing. Furthermore, in Scotland a different thatching style not using reeds is traditional in the highlands and islands (Scottish Thatching, 2016). |
| Navigation | Both the UK NEA and Everard and Quinn (2015) consider rivers to facilitate navigation/transport. Across the world numerous rivers are used for the transport of industrial products, goods and people. For example the river Nile has been an important transport route in the North East of Africa for hundreds of years. The Danube Treaty allows freedom of movement along the river which is important for trade in Europe. Trade along the Asian Mekong River has recently grown in Vietman and Cambodia with exports travelling out the river to Europe and America. Compared to the rivers |
Ornamental
resources

Mineral
Resources

discussed above the rivers of Scotland tend to be narrower and shorter and are
therefore not significant transport routes.
Some rivers across the world provide valuable ornamental resources. For example
many ornamental fish originate from Brazil (Pelicice and Agostinho, 2005) however
Harrison et al. (2010) find that while European rivers provide some ornamental
resources they are relatively insignificant compared to other provisioning services.
Furthermore Harrison et al. (2010) highlight that as a result of attitude changes and
trade regulations the demand for ornamental resources such as collections of rare birds,
animals and butterflies has significantly declined. Ornamental resources will not be
considered an ecosystem service supplied by Scottish rivers.
Everard and Quinn (2015) consider that sands, gravels and clays may be extracted from
rivers for use in building and industrial materials. Limited gravel extraction does occur
in Scotland (SNH, no date) but because extraction is restricted in scale it is not felt to be
a significant service provided by Scottish rivers. Indeed, gravel is not listed as a service
provided by Scottish rivers in other research such as Gilvear et al. (2013) and Sample et
al. (2016). If this research were to be conducted in an area where rivers deposits are
important for building or economic income then the matrix would need to be
reconsidered.

Appendix Five: Empirical Matrix Population
xxxviii


Outcomes of exploration of literature to provide empirical evidence for a river corridor – ecosystem service potential matrix (for provisioning and regulating services) – Tables 15, 16, 17 & 18.

In text colour relates to the following scenarios:

1. The feature positively contributes to ecosystem service provision
2. The feature acts to reduce ecosystem service provision (ecosystem disservice)
3. Empirical studies contrast, some indicate feature supports provision and others indicate feature reduces provision
4. A linkage is likely but more detailed, specific research is required

Table 15: Table presenting and discussing empirical research retrieved in the quest to establish matrix linkages for the ecosystem service of water supply. For each feature the outcome of literature exploration along with a confidence score is presented.

<table>
<thead>
<tr>
<th>Water Supply</th>
<th>Description</th>
<th>Confidence Score</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>River width</strong></td>
<td>Many studies from a range of environments report positive relationships between river width and discharge (<a href="#">Shibata and Ito, 2014; Wohl and Wilcox, 2005; Wilkerson and Parker, 2010; Ashmore and Sauks, 2006; Miller et al., 2014</a>). The feature positively contributes to ecosystem service provision.</td>
<td>3</td>
</tr>
<tr>
<td><strong>Broadleaf/mixed woodland</strong></td>
<td>In terms of regulating water for supply broadleaf and coniferous woodland are considered to share similar properties and processes. A synthesis by <a href="#">Roa-García et al. (2011)</a> finds the catchment with highest percentage woodland cover to have the lowest flow variability. <a href="#">Neary et al. (2009)</a> highlight that it is high infiltration rates and high soil water storage capacities in woodland soils that have a significant impact on the moderation of both peak and low river flows. The feature positively contributes to ecosystem service provision.</td>
<td>2</td>
</tr>
<tr>
<td><strong>Conifer woodland</strong></td>
<td>Research suggests young woodland act differently to mature woodland. <a href="#">Webb and Kathuria (2012), Birkinshaw et al. (2014), Scott and Prinsloo (2008)</a> find baseflow to decline following reforestation. <a href="#">Perry and Jones (2017)</a> compare catchments with young and old woodland and find streamflow lower in younger woodland. Reduced streamflow is considered to be a function of high evapotranspiration rates of younger trees. Only one contrasting paper was identified. In New Zealand <a href="#">Beets and Oliver (2007)</a> find annual streamflow to decrease with forest age, this is linked to older trees having greater canopy leaf areas which create more opportunity for interception losses and lower potential for infiltration. The feature positively contributes to ecosystem service provision.</td>
<td>2</td>
</tr>
<tr>
<td><strong>Felled woodland</strong></td>
<td>Felled areas found to increase baseflow. <a href="#">Molina et al. (2012), Peña-Arancibia et al. (2012) and Lal (1997)</a> woodland removal to increase baseflow. Increase is attributed to lower evapotranspiration losses associated with grassy vegetation and agricultural crops compared to native woodland. However effect is reported to be temporary. One contrasting example was identified, in Mexico <a href="#">Castillo et al. (2012)</a> found deforested catchments to have no or significantly reduced flow during the dry season, however since Scotland has a temperate climate this research seems less transferable. The feature positively contributes to ecosystem service provision.</td>
<td>2</td>
</tr>
<tr>
<td>Ecological Type</td>
<td>Description</td>
<td>Outcome</td>
</tr>
<tr>
<td>-------------------------</td>
<td>-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
<td>---------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Floodplain forest</td>
<td>Outcome: More research required – no research looking at the role of floodplain forests in moderating flow for water supply could be found.</td>
<td></td>
</tr>
<tr>
<td>Upland wetland</td>
<td>Upland wetland are found to reduce low flows. In their synthesis Bullock and Acreman (2003) find that 9 papers suggest that upland wetlands act to sustain low flows while 36 papers consider upland wetlands to act in diminishing low flows. Outcome: Upland wetlands do no support water supply. Confidence Score: 3</td>
<td></td>
</tr>
<tr>
<td>Lowland wetland</td>
<td>The role of lowland wetlands on water supply seems unclear. In their synthesis of the hydrological properties of wetlands Bullock and Acreman (2003) find three papers consider wetlands to sustain low flows and five papers indicating they diminish low flows. Little more research identified with the exception of Rutherford et al. (2009) who find riparian wetlands in New Zealand to contribute to baseflow. Outcome: Conflicting evidence, more research is needed, particularly in temperate climates before a conclusion can be drawn.</td>
<td></td>
</tr>
<tr>
<td>Floodplain lake</td>
<td>Only one paper looking at the role floodplain lakes play in moderating flow could be found. In their research of the Araguaia River in central Brazil Lininger and Latrubesse (2016) find that while floodplain lakes attenuate flood events water is released back into the channel before the dry season. Outcome: It seems that more research is needed into the role floodplain lakes play moderating water supply, particularly in the temperate environment.</td>
<td></td>
</tr>
<tr>
<td>Urban areas</td>
<td>The high percentage of impervious surfaces in urban areas is linked to reductions in baseflow (Leopold, 1968; Finkenbin et al., 2000; Kauffman et al., 2009; Rose and Peters, 2001; Chang, 2007 and Hardison et al., 2009). However some processes of urban areas can increase flows. Urbanisation is associated with a reduction in native vegetation which has been linked to decreased evaporation and resultant increases in baseflow (Roy et al., 2009). In catchments where septic tanks are abundant water leaking from tanks has been recorded to increase groundwater recharge (Burns et al., 2005), however this is most common in developing countries (Bhaskar et al., 2016). Leakage from ageing storm, sanitary and combined sewer systems can also act to increase baseflow, (Schwartz and Smith, 2014; Lerner, 2002). As Scotland is a developed country it shall be considered that increases in baseflow through septic tank and infrastructure leakage will be minimal while impervious areas will be abundant thus urbanisation shall be considered to reduce potential water supply. Outcome: Urbanisation acts to reduce water supply. Confidence score: 3</td>
<td></td>
</tr>
</tbody>
</table>
Table 16: Table presenting and discussing empirical research retrieved in the quest to establish matrix linkages for the ecosystem service of natural flood mitigation. For each feature the outcome of literature exploration along with a confidence score is presented.

<table>
<thead>
<tr>
<th>Natural Flood Mitigation</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Morphology</strong></td>
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<tr>
<td>Initially it was considered that stream morphology may influence flood mitigation by potentially reducing the velocity of flood waters. Shallower slopes, rough channels and sinuous channels may all act to slow down flow however so far literature linking channel morphology to flood mitigation has proved elusive! <strong>Outcome:</strong> no relationship, more research needed.</td>
</tr>
<tr>
<td><strong>Channelization (including embankments)</strong></td>
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<tr>
<td>Channelization and embankments provide artificial flood mitigation but they can also alter rivers natural flood mitigation potential. Aggregation of sediments, channel insicion bottlenecking and backwater effects associated with embankments and channelisation have all be found to lead to flooding (Guida et al., 2015; Wyzga et al., 1996; Lóczy et al., 2009; Heine and Pinter, 2012). <strong>Outcome:</strong> channelization and embankments seem to reduce natural flood mitigation potential. <strong>Confidence score:</strong> 2</td>
</tr>
<tr>
<td><strong>Broadleaf/mixed woodland, Conifer woodland and floodplain woodland</strong></td>
</tr>
<tr>
<td>Several comparisons between woodlands and other land uses highlight their flood mitigation potential (Fu et al., 2013; Lana-Renault et al., 2012). Woodlands mitigate floods through several processes, some of which apply to all types of woodland. Broadleaf, coniferous, mixed and floodplain forests contribute to instream and floodplain large woody debris (LWD) which can slow down flood flow (Thomas and Nisbet, 2007; Wenzel et al., 2014). Wooded areas also have higher interception percentages which can mitigate flood events (Lunka and Patil, 2016). Comparing broadleaf and coniferous woodland there does seem to be a difference in interception with conifers reported to intercept more annual rainfall (Calder et al., 2003). <strong>Outcome:</strong> Through several processes broadleaf, conifer and floodplain forest contribute to natural flood mitigation. <strong>Confidence score:</strong> 3</td>
</tr>
<tr>
<td><strong>Young woodland</strong></td>
</tr>
<tr>
<td>Young forest act differently to mature forests in regards to mitigating floods. Case studies report younger woodland to consume less water, have higher runoff and lower infiltration compared to mature woodland (Iroumé et al., 2006; Tian et al., 2008; Choi et al., 2011 Deuchars et al., 1999; Archer et al., 2013; Marshall et al., 2014; Archer et al., 2015). However a global synthesis by Farley et al. (2005) found runoff to increase with forest plantation age. Despite young woodland influencing catchment hydrology there seems to be a lack of research linking young woodland to flood dynamics. <strong>Outcomes:</strong> Younger woodland does not positively contribute to natural flood mitigation although neither does it seem to negatively influence. More research into the role of young woodlands is recommended.</td>
</tr>
<tr>
<td><strong>Felled woodland</strong></td>
</tr>
<tr>
<td>In contrast to live woodland areas of felled woodland are reported to exacerbate flooding (Zhang and Wei, 2014; Robinson and Dupeyrat, 2005; Coe et al., 2011). In particular felled areas seem to be associated with higher runoff which contributes to flood events (Ide et al., 2013; Tetzlaff et al., 2007; Mohammad and Adam, 2010; Safari et al., 2016). <strong>Outcome:</strong> Felled areas contribute negatively to natural flood regulation. <strong>Confidence Score:</strong> 3</td>
</tr>
<tr>
<td><strong>Woodland buffers and Herbaceous buffers</strong></td>
</tr>
</tbody>
</table>
| Riparian buffers are listed in the Natural Flood Management Handbook as a NFM technique yet there is a lack of experimental evidence demonstrating their role in reducing flood risk at both the site and catchment scale (Mclean et al., 2015). Searches for woodland and herbaceous buffers revealed only two papers. In Scotland Mclean et al. (2015) find mixed species riparian buffers to reduce runoff but indicate there might be a limit to flood attenuation. Meanwhile modelling by
**Gao et al. (2016)** indicates that peat-moss riparian buffers can attenuate floods. Compared to herbaceous buffers woodland buffers may also produce LWD. **Outcome:** It seems buffers are likely to mitigate flood events with woodland buffers potentially offering greater attenuation due to LWD. However, there is a need for more research (Mclean et al., 2015). **Woodland confidence score:** 2  **Herbaceous buffer confidence score:** 1

### Upland wetland

In their 2003 synthesis **Bullock and Acreman (2003)** found contrasting evidence relating to the flood mitigation potential of upland wetlands. 27 studies suggested upland wetlands increase floods, advance floods or reduced recession while 30 studies indicated upland wetlands reduce floods, delay floods or increase recession. However a recent synthesis by **Acreman and Holden (2013)** clarifies the hydrological differences between upland and lowland wetlands. Research suggests that rain-fed upland wetlands tend to generate flood events, this is considered to be a result of rainfall increasing with altitude, this increased rainfall leads to upland areas frequently being saturated and therefore having reducing water storage capacity. **Outcome:** Upland wetlands negatively contribute to flood mitigation. **Confidence score:** 3

### Lowland wetland

In contrast to upland wetlands there is a lot of evidence that lowland wetlands act to mitigate floods. In their synthesis **Bullock and Acreman (2003)** found 23 of 28 studies report lowland wetlands to reduce floods, delay floods or increase flood recession. In their 2013 synthesis **Acreman and Holden** find that as lowland wetlands are lower in latitude antecedent conditions are drier and thus storage potential is greater, additionally lowland wetlands tend to be in depressions (hollows) that have greater storage capacity. More recent research finding lowland wetlands to mitigate floods includes **Yao et al. (2014)** and **Miroslaw-Świątek et al. (2016)**. **Outcome:** Lowland floodplain wetlands contribute to flood mitigation. **Confidence score:** 3

### Amenity and agricultural land

Amenity and Agricultural land may offer flood regulation if it is assigned to be washland (**Wharton and Gilvear, 2006**). Washland is land adjacent to the river which is allowed to flood or has been intentionally designed to flood through engineering (**Morris et al., 2004**). Searching literature retrieved only two papers relevant to the role of amenity and agricultural land acting as washland and flood storage. **de Vleeschauwer et al. (2014)** preform hydrological modelling to investigate the role of incorporating open green spaces into a flood-adaption strategy for a Belgium city, modelling a 100-year rainfall services found the use of open green spaces for stormwater storage had only a negligible effect on peak flow. Meanwhile also through modelling **Förster et al. (2005)** find allowing agricultural land along the Elbe River to flood during extreme events would be a cost effective form of flood management. Despite these modelling studies there is a lack of empirical hydrological evidence indicating that amenity and agricultural land can contribute to natural flood mitigation. **Outcome:** more empirical studies and research required.

### Floodplain lake

There seems to be little interest in the role floodplain lakes play in mitigating flood events. Only two papers focusing on flood attenuation were identified however both come from climates different to that of Scotland. In Brazil **Lininger and Latrubesse (2016)** find floodplain lakes to attenuate flood events during the wet season with water generally released back into the channel before the dry season. On the Mackenzie River Delta in the Canadian Artic **Emmerton et al. (2007)** estimated the flood storage of floodplain lakes to be equivalent to around 9.6% of
the flow during the high discharge period that occurs during delta breakup. It seems that floodplain lakes may act to attenuate floods however there is a need for more research, in particular to fill this matrix the focus should be on temperate environments. **Outcome:** no relationship, more research needed.

| **Natural lake** | Research seems to indicate that natural lakes can store flood waters. **Arp et al. (2006)** find glacial snow-melt lakes of the Sawtooth Mountains of Idaho to attenuate peak flows associated with rainfall events but not to moderate snow melt. Other evidence looking at the role of natural lakes comes from modelling studies. Modelling in China by **Peng et al. (2005)** and **Nakayama and Watanabe (2008)** finds that natural lakes can store significant amounts of flood water and reduce downstream floods. Despite evidence suggesting that natural lakes can mitigate flood events their potential to do so is influenced by climatic factors (**Arp et al., 2006; Kusumastuti et al., 2008**). **Outcome:** Natural lakes have the potential to mitigate flood events, although more research into the impacts of temperate/Scottish lakes is deemed necessary. **Confidence score: 1** |
| **Urban areas** | Urban areas are frequently reported to induce flooding and reduce the potential for natural flood mitigation (**Schultz, 2006; Nirupama and Simonovic, 2007; Miller and Hutchins, 2017; Sofia et al., 2017**). Urban catchments are reported to experience larger and quicker flood events (**Mogollón et al., 2016**). Flood dynamics are linked to impervious surfaces (**Perry and Nawaz, 2008; Hawley and Bledsoe, 2011**) and alterations to pervious surfaces (**Gregory et al., 2006; Price et al., 2010; Woltemade, 2010**). **Outcome:** Urban areas will be recorded to reduce natural flood mitigation. **Confidence score: 3** |
Table 17: Table presenting and discussing empirical research retrieved in the quest to establish matrix linkages for the ecosystem service of climate regulation. For each feature the outcome of literature exploration along with a confidence score is present.

<table>
<thead>
<tr>
<th>Feature</th>
<th>Outcome</th>
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<tbody>
<tr>
<td>Broadleaf/mixed woodland</td>
<td>Forests are well known to contribute to climate regulation by storing carbon both in above ground biomass and in soils (<a href="#">Janssens et al., 2003; Canadell and Raupach, 2008; Keith et al., 2009</a>). There is debate surrounding whether <strong>broadleaf</strong> or <strong>coniferous</strong> species sequester more carbon. In their comparison <strong>Chiti et al. (2012)</strong> found soil carbon stock to be higher under broadleaf forest. In contrast <strong>Wang et al. (2016)</strong> find soil carbon storage to be greater under conifer forests, <strong>Wiesmeier et al. (2013)</strong> investigate soil carbon in the forests of Bavaria finding no significant differences in storage between coniferous, broadleaf and mixed forests. Less research has been conducted on the differences in aboveground carbon storage. The research which is present from the Himalayas suggests conifer forests may store more carbon in live biomass (<a href="#">Sharma et al., 2010; Dar et al., 2017</a>). <strong>Outcome</strong>: for the purpose of this research broadleaf, mixed and coniferous woodlands will be regarded to positively contribute to climate regulation. <strong>Confidence score</strong>: 3</td>
</tr>
<tr>
<td>Young woodland</td>
<td>It appears that mature and young forests have different carbon dynamics. Carbon stocks in both soil and biomass are greater for mature forests (<a href="#">Wigginton et al., 2000; Peichl and Arain, 2006; Cierjacks et al., 2010</a>). However, while mature forests may store more carbon younger forests are reported to have higher sequestration rates, this is attributed to forest productivity declining with age (<a href="#">Coomes et al., 2011; Bradform and Kastendick, 2010</a>). <strong>Outcome</strong>: Young forests will also be considered to positively support climate regulation. <strong>Confidence score</strong>: 1</td>
</tr>
<tr>
<td>Felled woodland</td>
<td>Unsurprisingly deforested and cleared areas have been associated with the loss of both carbon stored as above ground biomass and in soils. During deforestation carbon stored in above-ground biomass is removed (e.g. <a href="#">Grünzweig et al., 2015; Nunery and Keeton, 2010</a>) and the potential for more to be sequestered through tree growth is lost. Soil carbon stocks also appear to decline following deforestation (<a href="#">Thuille et al., 2000; Conti et al., 2014</a>). <strong>Outcome</strong>: As soil carbon stocks decline following deforestation felled areas will be considered to reduce climate regulation. <strong>Confidence score</strong>: 3</td>
</tr>
<tr>
<td>Floodplain woodland</td>
<td>The limited quantitative evidence available suggests floodplain forest can act as sources or sinks for greenhouse gases. In the glacial landscapes of New England <strong>Ricker et al. (2014)</strong> find annual carbon storage to be higher in floodplain forests compared to upland sites. Additionally <strong>Cierjacks et al. (2010)</strong> find aboveground and below ground carbon stocks to be higher for a natural floodplain forest on Danube Floodplain than adjacent agricultural land. Floodplain forests are also identified to be sources of greenhouse gases. <strong>Poblador et al. (2017)</strong> find a Mediterranean floodplain forest to be a source of both CH₄ and N₂O. Meanwhile in the tropical <strong>Venezuela Smith et al. (2000)</strong> find saturated floodplain forests to be sources of methane. The mixed picture of floodplain dynamics from varying climates makes drawing a conclusion on their climate regulation effect challenging. <strong>Outcome</strong>: to fill in the matrix there needs to be more research looking at the fluxes of the multiple GHG’s from temperate floodplains.</td>
</tr>
<tr>
<td>Woodland Buffers</td>
<td>To understand the climate regulation dynamics of riparian buffers fluxes of greenhouse gases are converted to annual ‘Global Warming Potentials’ (GWP).</td>
</tr>
</tbody>
</table>
GWPs account for the different warming effects of GHGs. While woodland buffers are found to sequester carbon ([Tufekcio glu et al., 2003; Fortier et al., 2010; Fortier et al., 2015]) they are also identified to release CO$_2$ ([Jacinthe et al., 2015; Mander et al., 2008]). Jacinthe et al. (2015) also find woodland buffers to release methane although Mander et al. (2008) find emissions to depend on species present and Kim et al. (2009) find re-established woodland buffers to be neither methane sources nor sinks. Additionally woodland buffers have been found to release N$_2$O ([Fisher et al., 2014; Dhondt et al., 2004; Hefting et al., 2003]). To begin to understand if woodland buffers act as overall sources or sinks GWP of the multiple fluxes is equated. Equating storage with fluxes produces a range of GWP between –3984 (sink) and 1868 (source) g CO$_2$ yr$^{-1}$ ha$^{-1}$. The evidence presented thus suggests woodland buffers may be sources or sinks of GWP. More research is needed and should focus on the factors that drive variation in emissions. **Outcome: conflicting evidence**

| Herbaceous Buffers | Compared to woodland buffers herbaceous buffers are identified to sequester much less carbon ([Tufekcio glu et al., 2003; Fortier et al., 2010; Fortier et al., 2015]). This is because woodland buffers store more carbon in aboveground biomass ([Tufekcio glu et al., 2003]). Jacinthe et al. (2015) find herbaceous buffers are also sources of CO$_2$ and CH$_4$. Comparatively herbaceous buffers release more CO$_2$ than woodland buffers but annual methane emissions are lower. As with woodland buffers Kim et al. (2009) find herbaceous buffers to be neither sources of sinks or methane. Herbaceous buffers are also identified as sources of N$_2$O but flux is reported to be smaller than woodland buffers ([Fisher et al., 2014; Dhondt et al., 2004; Hefting et al., 2003]). Equating the different fluxes suggests that Herbaceous buffers act a GWP source. Storage for herbaceous buffers is reported range between 122-301 g CO$_2$ yr$^{-1}$ ha$^{-1}$, with total fluxes of CO$_2$ and N$_2$O equating to a between 3156 – 3331 g CO$_2$ yr$^{-1}$ ha$^{-1}$. **Outcome: Herbaceous buffers negatively contribute to climate regulation, although more research is needed focusing on multiple fluxes is recommended. Confidence score: 1** |
| Upland wetland | Similar to riparian buffers to get a complete picture of the climate regulation effect of upland wetlands fluxes are converted into GWP. Multiple papers highlight the carbon storage potential of upland wetlands ([Craft and Casey, 2000; Worrall et al., 2003; Worrall et al. 2009; Bernal and Mitsch, 2012; Craft et al. 2017]), but what about GHG fluxes? Clay et al. (2010) measure the CO$_2$ and CH$_4$ from two welsh uplands and find them to be net sources of carbon. In contrast Levy and Gray (2015) find despite CO$_2$ and CH$_4$ emissions a semi-natural upland Scottish wetland to act as a carbon sink. When the GWP of methane is considered the research of Worrall et al. (2003) suggests their researched upland peat wetland in the North Pennines is a carbon source. However a longer 13-year study by Worrall et al. (2009) find that some years the wetland is a GWP source and others a sink. Only Li et al. (2013b) investigating a temperate upland wetland in Japan was found to focus on N$_2$O. The results of Li et al. (2013b) suggest that wetlands have the potential to release large volumes of N$_2$O. Overall the picture for upland wetlands is contrasting and confusing. Long-term projects are required as fluxes change over time and gases released remain in the atmosphere for different timespans ([Whiting and Chanton, 2001; Mitsch et al., 2013]). **Outcome: conflicting evidence: more research required!** |
| Lowland wetland | Compared to upland wetlands the average GWP storage of lowland wetlands appears to be higher ([Craft and Casey, 2000, Bernal and Mitsch, 2012, Bernal and... |
Mitsch, 2013, Craft et al., 2017, Fennessy et al., 2017). Unlike for upland wetlands a paper measuring and equating carbon storage, CO₂, CH₄ and N₂O was retrieved (Audet et al., 2013). In Denmark Audet et al. (2013) find all studied connected wetlands studies to be sinks. Other research has identified lowland wetlands to be methane sources (Sha et al., 2011; Morin et al., 2017). While studies looking at N₂O present contrasting scenarios. Nag et al. (2017) and Muñoz-Leoz et al. (2011) indicate that lowland wetlands may be sources of N₂O, meanwhile following a yearlong research project of 48 lowland wetlands in an agricultural area of Denmark Audet et al. (2014) report wetlands can act as sources or sinks. As with upland wetlands the picture complex, more studies considering multiple fluxes like Audet et al. (2013) are required. Ideally modelling studies should be undertaken to project how fluxes and storage may change. **Outcome:** Conflicting evidence: more research required.

### Agriculture

Both arable and livestock agricultural practices are significant contributors of anthropogenic GHG emissions. DEFRA estimate that agriculture is responsible for generating around 7% of total UK GHG emissions, of these emissions 69% is N₂O and 38% CH₄ (Firbank et al., 2013). In the UK arable agriculture is responsible for the majority of agricultural N₂O emissions due to the oxidation of nitrogen used in fertilisers (Thomas et al., 2011; Skiba et al., 2012; Firbank et al., 2013). A significant amount of UK N₂O emissions also arise from nitrogen enriched waters (Thomas et al., 2011; Outram and Hiscock, 2012; Skiba et al., 2012). Meanwhile the agricultural production of methane arises mostly from keeping livestock (Wang et al., 2011; Feliciano et al., 2013b). The storage of manure and slurry also produces CH₄ and N₂O (Husted, 1994; Wang et al., 2011; Thomas et al., 2011; Skiba et al., 2012). **Outcome:** Agricultural practices release GHGs and therefore contribute negatively to climate regulation. **Confidence score:** 3

### Amenity land

Research looking at the role amenity land plays in climate regulation appears to focus on the urban environment. Research looking at aboveground and soil carbon stocks has been conducted on domestic gardens in Leicester. Davies et al. (2011) find domestic gardens to store minimal amounts of carbon. While, in terms of soil carbon Edmondson et al. (2014) found soil organic concentration to be highest in gardens and public areas with trees and shrubs while concentrations were lower in herbaceous areas and lowest in agricultural soils. However, Edmondson et al. do not regard high soil carbon in domestic areas to be a natural phenomenon but a result of garden management including adding organic matter. The only literature retrieved specifically focusing on the climate regulation of amenity land adjacent to rivers is that looking at the local cooling associated with river greenspace in heavily urbanised areas (Giannakis et al., 2016; Manteghi and Remaz, 2015). **Outcome:** It seems that more research is needed to better understand the climate regulation functions of amenity land adjacent to rivers.

### Floodplain lake

So far studies have only focused on the carbon dynamics of tropical floodplain lakes. Peixoto et al. (2015) propose that evidence suggests low latitude wetlands and lakes are perhaps the most methane emitting environments on earth. Release of GHG’s from tropical floodplain lakes seems to be related to macrophyte presence. Peixoto et al. (2016) find floating macrophytes can reduce CO₂ emissions to the point where lakes are net carbon sinks. The opposite relationship seems to be true for CH₄ with Devol et al. (1998) finding Amazon floodplain waters with aquatic macrophytes to release significantly higher volumes of methane compared to open
Natural lakes store and release carbon. Lakes store carbon within buried sediments which have been recognised as globally important carbon sinks (Dean and Gorham, 1998; Campbell et al., 2000; Einsele et al., 2001). In a study of the Canadian boreal biome Ferland et al. (2012) find lake C storage to rank third after forest soils and peatlands equating to around 25% of total landscape storage. While, in Finland Kortelainen et al. (2004) found lakes to contain the second largest stock of carbon after peatlands. However, lake C storage in temperate European lakes seems to be comparatively low (Kastowski et al., 2011). Although lakes store carbon recent syntheses and studies suggest that lakes do not have net positive effects on climate regulation due to the release of CO\textsubscript{2} and CH\textsubscript{4} (Alin and Johnson, 2007; Bastviken et al., 2011). Case studies providing quantitative evidence demonstrating lakes to be sources of CO\textsubscript{2} and CH\textsubscript{4} include Sepulveda-Jauregui et al. (2015), Bellido et al. (2011), Ojala et al. (2011) and Repo et al. (2007), with Schrier-Uijl et al. (2011) and Burger et al. (2016) providing quantitative evidence from temperate environments. Outcome: recent research suggests natural lakes are net sources of GHG’s and therefore will be regarded to contribute negatively to climate regulation potential. **Confidence score: 3**

| Dam-reservoir unit | Research from around the world suggests reservoirs release GHGs. In tropical environments warm temperatures encourage the anaerobic and aerobic bacterial decomposition of submerged terrestrial organic matter which causes reservoirs to be sources of CO\textsubscript{2} and CH\textsubscript{4} (Rosa et al., 2004; Marcelino et al., 2015; Roland et al., 2010). In the colder boreal regions reservoirs created by flooding terrestrial landscapes are also linked to carbon emissions despite lower temperatures (Teodoru et al., 2012). Evidence suggests that reservoirs located in temperate regions such as Scotland may also be carbon sources. Halbedel and Koschorreck (2013) find that despite reservoirs in the German Harz Mountains acting as CO\textsubscript{2} sinks in the summer on the annual scale reservoirs were CO\textsubscript{2} sources. Maeck et al. (2013) provide evidence that temperate reservoirs are also sources of methane. In contrast, in Ohio Knoll et al. (2013) find that on the annual scale the hard-water reservoirs are carbon sinks however hard-water reservoirs are identified to have different carbon dynamics compared to other reservoir types. **Outcome:** Overall it seems that evidence suggests temperate reservoirs contribute to climate change and do not regulate the climate. **Confidence score: 1** |
Table 18: Table presenting and discussing empirical research retrieved in the quest to establish matrix linkages for the ecosystem service of water quality. For each feature the outcome of literature exploration along with a confidence score is present.

<table>
<thead>
<tr>
<th>Feature</th>
<th>Water Quality</th>
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<tbody>
<tr>
<td><strong>Weirs</strong></td>
<td>Literature looking at the impact of weirs on water quality is sparse. <em>Baylar and Bagatur (2000)</em> and <em>Baylar and Emiroglu (2002)</em> find that weir structures aerate water whereas <em>Cisowska and Hutchins (2016)</em> indicate that weirs may retain nitrate and <em>Hester et al. (2009)</em> find weirs can alter localised stream temperature. <strong>Outcome:</strong> There is a need for detailed studies to investigate the water quality impacts of weirs, due to the lack of detailed study no conclusions can be made.</td>
</tr>
<tr>
<td><strong>Channelization</strong></td>
<td>There is some evidence that channelization degrades water quality. In Northern Japan <em>Nakamura et al. (1997)</em> highlight how channelized reaches can be associated with excess suspended sediment particularly during flood events. <em>Ciszewski and Czajka (2015)</em> report that channelization of the polluted Polish Orda and Vistula rivers has led to the increased deposition of fine sediments which are rich in heavy metals and organic matter. In contrast, research conducted in the French Seine-Normandy catchment by <em>Rambaud et al. (2009)</em> found that channelization had little impact on the chemical characteristics however channelization degraded stream health by altering physical characteristics. <strong>Outcome:</strong> While there is only limited research focusing on the impacts of channelization on water quality the papers that have been retrieved suggest that channelization degrades water quality. <strong>Confidence score:</strong> 1</td>
</tr>
<tr>
<td><strong>Broadleaf/mixed woodland</strong></td>
<td>Broadleaf and mixed woodlands regulate water quality through several mechanisms. Mechanisms include the retention of nitrate and phosphate (<em>Greathouse et al., 2014; Hervé-Fernandez et al., 2016</em>), sediment tapping (<em>Burylo et al., 2012</em>) and regulation of stream temperature through shading (<em>Quinn et al., 1997; Imholt et al., 2013a</em>). Broadleaf forests have been associated with acidification and increases in concentrations of aluminium but neither are reported severe enough to be of environmental threat (<em>Ryan et al., 2012; Gagkas et al., 2008</em>). <strong>Outcome:</strong> broadleaf/mixed woodland contributes to good water quality. <strong>Confidence score:</strong> 3</td>
</tr>
<tr>
<td><strong>Conifer</strong></td>
<td>In contrast to broadleaf woodland coniferous woodland is identified to reduce water quality. Despite improvements in stream pH following atmospheric emissions legislation in the small conifer forests of Ireland <em>Feeley and Kelly-Quinn (2014)</em> find streams to experience episodes of low pH and high organic aluminium concentrations. Also in Ireland, <em>Harrison et al. (2014)</em> identify that acidification induced by conifer forestry appears to be a severe danger to Atlantic salmon populations. Furthermore in the Galloway region of Scotland <em>Dunford et al. (2012)</em> report that a relationship between conifer forest cover and stream acidification still appears present. <strong>Outcome:</strong> Conifer forests reduce negatively alter river chemistry. <strong>Confidence score:</strong> 2</td>
</tr>
<tr>
<td><strong>Young woodland</strong></td>
<td>No literature could be retrieved exclusively on young woodlands. An assumption is therefore, it is hypothesised that young woodlands will share similar water quality regulating functions to mature woodlands. <strong>Outcome:</strong> will be considered to positively contribute to water quality regulation. <strong>Confidence score:</strong> 1</td>
</tr>
<tr>
<td><strong>Felled woodland</strong></td>
<td>Felled ground which has been associated with a number of negative impacts on water quality. Impacts of felled ground include increased nitrate concentrations (<em>Neal et al., 2004</em>), acidification (<em>Neal et al., 1992</em>), excessive sedimentation (<em>Motha et al., 2003; Karwan et al., 2007</em>) and increased stream temperature</td>
</tr>
<tr>
<td>Category</td>
<td>Description</td>
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<td>----------------------------------</td>
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</tr>
<tr>
<td>Floodplain forest</td>
<td>Alongside broadleaf/mixed woodland evidence also suggests that naturally occurring floodplain forests are considered to improve water quality through the retention of nutrient (Bechtold et al., 2003; Hogan et al., 2004; Cuevas et al., 2014).</td>
</tr>
<tr>
<td>Woodland and Herbaceous buffers</td>
<td>Riparian buffers can reduce the negative water quality impacts of associated with catchment landuse including urbanization, agriculture and forestry (Anbumoxhiet et al., 2005; Clinton, 2011; de Jesús-Crespo and Ramirez, 2011). There is some debate as to whether herbaceous or woodland buffers are more effective. In their review comparing the effectiveness of different buffer types Lyons et al. (2000) find in general woodland buffers to be better at assimilating nitrogen. In contrast a meta-analysis by Mayer et al. (2007) concludes that buffers of various vegetation types are equally effective at removing nitrogen. Additionally the sediment trapping efficiency of different buffers has be found to be similar by the reviews of Lyons et al. (2000) and Yuan et al. (2009). For both types of buffers width is important in determining effectiveness, generally wider buffers trap more nutrients and sediments (Sweeney and Newbold, 2014; Miller et al., 2015; Yuan et al., 2009). Forest buffers have one benefit not associated with herbaceous buffers, they are able to regulate stream temperature through shading (Clinton, 2011; Wilkerson et al., 2006; Bowler et al., 2012).</td>
</tr>
<tr>
<td>Upland wetlands and Lowland wetlands</td>
<td>Literature looking at the water quality benefits of wetlands does not focus on the differences between upland and lowland wetlands. In general wetland communities are reported to perform a range of functions that improve water quality, these include: nitrification, nutrient removal for biomass production, water oxygenation, aerobic decomposition of pollutants and the removal of heavy metals, pesticides and herbicides through adsorption onto clay and organic particles (Kennedy and Mayer, 2002). The water quality benefits of wetlands are a highly valued ecosystem service (Ghermandi et al., 2010). As such wetlands are frequently constructed to improve water quality (Shutes et al., 2001; Song et al., 2006; Matamoros and Salvadó, 2012; Vymazal and Březinová, 2015).</td>
</tr>
<tr>
<td>Agricultural land</td>
<td>Arable and livestock agriculture causes water quality degradation. In the UK arable agriculture is linked to increases in stream nitrate concentration (Ferrier et al., 2001; Donohue et al., 2006; Rothwell et al., 2010). Both types of agriculture are associated with elevated inputs of suspended sediments (Sherriff et al., 2015; Reaney et al., 2011). Livestock farming is also associated with bacterial contamination and nutrient pollution (Rodgers et al., 2003; Vidon et al., 2008; Jarvie et al., 2010).</td>
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<tr>
<td>Amenity land</td>
<td>There seems to be practically no research interest in focusing on how or if amenity land alters water chemistry. Tu (2011) report recreational land use outside of urban areas to be associated with elevated pollutant levels while Roche et al. (2013) find that compared to grazing areas recreation areas have higher concentrations of faecal indicator bacteria, although neither area exceeded benchmark concentrations.</td>
</tr>
</tbody>
</table>
Amenity land and water quality means no conclusion can be drawn and no link placed in the matrix.

**Floodplain lake**

Literature looking at floodplain lake water quality seems to focus on how input water influences water quality and not how floodplain lakes alter water chemistry [*Lintern et al., 2015; Chalupová et al., 2012*]. Only one paper was retrieved suggesting floodplain lakes can influence downstream water quality. *Lyumbimova et al. (2016)* preformed modelling for flood events which indicated that during such floods washout of floodplain lakes can occur which may take with it any sediments or pollutants which were previously deposited in the floodplain lake. **Outcome**: Need for more research on hydrodynamics of floodplain lakes and downstream water quality.

**Natural lake**

Similar to floodplain lakes, most research looking at natural lake water quality focuses on the influence of surrounding catchment land use. In their modelling study of 1026 American lakes *Read et al. (2015)* found lake-specific characteristics such as depth and volume explained around 54-60% of water quality variance while catchment scale land cover and land use was estimated to explain 45-62% of water quality variance. Research conducted by *Hecky et al. (2003)* and *Nielsen et al. (2012)* also identifies catchment landuse to be an important determinant of lake water quality. There is however some limited evidence that lakes can mitigate the impact of surrounding land use and improve downstream water quality. *Powers et al. (2014)* find in both agricultural and forested catchments total nitrogen yields were lower where lakes and reservoirs were present which may be a result of nitrogen burial or denitrification processes. **Outcome**: More research required to understand the impact lakes have on downstream water quality.

**Dam-reservoir unit**

Dams are reported to degrade water quality through several mechanisms [*Austin et al., 2015*]. As water is stored behind dams thermal stratification occurs with the cold dense water sinking to the bottom [*Olden and Naiman, 2010*]. This means that dams reduce downstream water temperature and alter the timing of annual temperature maximums [*Preece and Jones, 2002; Prats et al., 2010*]. These changes in water temperature caused by dams are ecologically damaging [*Clarkson and Childs, 2000*]. In deep reservoirs sunlight may not reach the bottom, this means photosynthesis cannot occur and water becomes depleted in oxygen. Anaerobic conditions lead to anaerobic decomposition which subsequently creates low pH water which can mobilise various substances including CO₂ and several heavy metals [*Austin et al., 2015; Kasper et al., 2014; Žáková et al., 1993*]. Additionally, *Brismar (2002)* describe that downstream fine sediments and attached pollutants become more mobile when flows are reduced as a result of dams. **Outcome**: Dam-reservoir units reduce good water quality potential. **Confidence score**: 3

**Urban area**

Urban areas appear to be linked to poor river water quality. In their review paper *Whitehead et al. (2009)* highlight that surface water in urban areas is commonly polluted with nutrients, heavy metals, pesticides and other contaminants meanwhile, *Walsh et al. (2005)* consider one symptom of ‘Urban Stream Syndrome’ to be elevated concentrations of nutrients and contaminants. *Donohue et al. (2006)* research factors responsible for WFD failures and suggest that urbanisation is one of the factors main contributing to water bodies failing to meet good ecological status. In Scotland *Ferrier et al. (2001)* highlight the results of the Harmonised Monitoring Scheme which ran from 1974-1995 on large Scottish rivers, results indicated that urban catchments were highly correlated with
ammonium-N, orthophosphate-P and suspended solids. Worryingly the modelling conducted by Astaraie-Imani et al. (2012) suggests that climate change is likely to further decrease urban water quality. **Outcome:** Urban areas reduce water quality. **Confidence score:** 3

**Appendix Six: Design of the cultural service survey**

This is a draft of the survey which was published on Survey Monkey. The live version differed by:
- Use of colour photographs, on downloading the survey from Survey Monkey colour has been lost from images.
- All questions relating to river corridor features began with 'I would go here...', followed by the appropriate statement for each ecosystem service.
I would like to invite you to participate in my study ‘Rivers: investigating cultural benefits’. This survey is being conducted by Victoria Keele from Plymouth University who is a Geography PhD student. Completion of the survey should take 10-15 minutes.

River environments are known to provide many cultural benefits to humans however research looking at how benefits vary between different types of river environments is limited. The purpose of this research is therefore to investigate the cultural activities that people might undertake when they visit different river environments. This study forms part of a PhD project which is looking at the benefits humans get from river environments.

Your participation in this study is entirely voluntary. This survey is anonymous and all results will remain confidential. You are not required to provide your name or any contact details during the survey, you may withdraw at any point however at the end of the survey you will be asked to tick a box confirming that once submitted withdrawal is not possible. The information gathered from this survey will only be used in my PhD thesis and any subsequent publications.

If you require any more information about this survey please contact me:
victoria.keele@plymouth.ac.uk

* 1. Please tick the box to confirm that you consent to participating in this research

  ☐ Yes
  ☐ No
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3. I would go here...

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lix
Cultural Ecosystem Services

Felled woodland
### 4. Environment One

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Please use a few words or sentences to describe what this environment means to you:

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lxi
Cultural Ecosystem Services

Floodplain lake and lowland wetland
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Please use a few words or sentences to describe what this environment means to you:

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### 7. Environment One

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9. Environment One

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Please use a few words or sentences to describe what this environment means to you

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Cultural Ecosystem Services

Waterfalls
10. Environment One

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Please use a few words or sentences to describe what this environment means to you

Please provide your description here.
### Cultural Ecosystem Services

#### Final Questions

12. What is your gender?
- Female
- Male
- Unspecified

13. How old are you?
- 18-24
- 25-34
- 35-44
- 45-54
- 55-64
- 65-74
- 74+

14. What is your level of education?
- Secondary school
- College
- Undergraduate degree
- Postgraduate degree

15. Where do you live?
- Rural area
- Rural-urban area
- Urban area

16. Are you part of any environmental organisations?
- Yes
- No
17. Do you partake in any environmental activities?

- No
- Occasionally (a few times a year)
- Frequently (monthly or more)
Appendix Seven: Exploring cultural service provision from river corridor features

Unfortunately, it is not within the scope of this research to examine every present or absent relationship in detail. Instead, focus occurs from the feature point of view and is given to those relationships which seem notable or unexpected.

To support exploration of matrix linkages the analysis of open question answers is undertaken. ‘Word clouds’ are used as the gateway to open question comments. Word clouds are visualisations of qualitative information, the font size of words relates to their frequency within answers. As tools word clouds are deemed a powerful mechanism for quickly summarising and comparing qualitative information (Cidel, 2010; DePaolo and Wilkinson, 2014). The sole use of word clouds may bias analysis as themes mentioned infrequently will not stand out but are still important (Dhou et al., 2018). In response to this, when appropriate, the analysis of individual responses collected through open questions is conducted, this is supported by table i. Individual responses are explored using coding; words and themes are coded according to which ecosystem service they describe (presented as appendix nine). To explore matrix relationships logically, analysis begins with the feature identified to supply the most cultural services and ends with the features perceived to supply least.
Table i: Table showing the data obtained from the analysis of open questions for each river corridor feature. Number of mentions captures the number of respondents who mention each word in all comments given for that feature. Percentage frequency represents the percentage of respondents who mention that word.

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(i) Waterfalls

Figure i: Word cloud analysis of the open question comments for waterfalls, produced using software built into Survey Monkey

Within the preliminary matrix waterfalls are the feature linked to the greatest number of ecosystem services. Waterfalls are identified to be ecosystem service hotspots providing...
aesthetic value, social relations, inspiration, education/knowledge, and recreation. The matrix reveals strong preferences for waterfalls as places of aesthetic value and recreation. Strong relationships are considered when the average score equals or exceeds three which represents people would visit frequently to experience a service. Indeed, the strongest relationship (3.2) within the matrix is identified between waterfalls and aesthetic value, this mean score indicates most respondents would ‘frequently’ or ‘very frequently’ visit waterfalls for their aesthetic value.

The word cloud generated from the comments (Figure i) seems to affirm the importance of waterfalls for aesthetic value and recreation. ‘Beautiful’, ‘looks’ and ‘wildlife’ represent aesthetic value while ‘walk’ indicates recreational potential. Coding of open question comments supports the stronger relationship between waterfalls and aesthetic value, by some margin aesthetic value is the service most frequently mentioned (16 of 45). The next most popular service occurring in comments is recreation (7 of 45).

The high aesthetic value of waterfalls is consistent with other ecosystem service research (e.g Tenerelli et al., 2016). Cole (2015) detail how the aesthetic value of Scottish waterfalls has been recognised since at least the 18th century. The perceived aesthetic value of waterfalls may arise in Scotland because they ‘break up’ landscapes which may sometimes be seen as desolate or bleak (Cole, 2015). Additionally, the rocky and exposed nature may be deemed as aesthetic (Bogdan et al., 2019). Furthermore, the dynamism of waterfalls likely exerts a strong influence of landscape aesthetic value (Pflüger et al., 2010; Le Lay et al., 2013).

The matrix identifies waterfalls to be particularly valuable for recreation however analysis of the comments does not reveal detailed information about the nature of perceived recreation. Comments reveal little diversity in potential recreational activities.
As eluded by the word cloud walking is the most popular with 6 mentions (Table i). The only other mention of potential recreation comes in the form of ‘adventure‘. This contrasts Hudson (2013) who consider waterfalls to provide opportunities for diverse recreational activities including walking, swimming, kayaking, climbing, and abseiling.

Waterfalls are the only riverine feature identified in the matrix to potentially supply inspiration. The value of waterfalls for inspiration is further highlighted by the word cloud, there is no mistaking ‘inspiring’ for anything other than inspiration! The inspirational value of Scottish waterfalls is unsurprising considering Cole (2015) identified them to be inspiring to 18th and 19th century travellers.

To better understand the inspiration value of Scottish waterfalls comments were examined, unfortunately those respondents who mentioned inspiration did not provide detail describing what they would be inspired to create during visits. However, inspirational value can be extracted from other research. Historically in the 18th and 19th century Scottish waterfalls inspired the writing of travel journals and sketches (Cole, 2015). Similarly, Haghe (2011) describe the Gimel waterfall in France to have a long history of providing artists with inspiration. Research suggests that in the present waterfalls continue to inspire these more traditional forms of art (Hudson, 2013), but now also encourage recreational photography (Tenerelli et al., 2016).
(ii) Heritage features

Figure ii: Word cloud analysis of the open question comments for heritage features, produced using software built into Survey Monkey

Heritage features are one of three features identified by the preliminary matrix to provide four ecosystem services. Results suggest heritage features are ecosystem service hotspots for aesthetic value, social relations, recreation, and cultural heritage. The identification of heritage features as ecosystem service hotspots is consistent with research in the Netherlands by van Berkel and Verburg (2014). The aesthetic value of heritage features concurs with Tenerelli et al. (2016) who examined cultural services in the French Alps using geo-tagged images. While Ridding et al. (2018) also found areas of historical interest to be hotspots for different types of recreation.

Cultural heritage features are the only feature perceived to supply the ecosystem service of cultural heritage. Unsurprisingly the link between riparian heritage feature and cultural heritage dominates comments. 27 of 45 respondents indicate that they would experience some connection with history, heritage or the past on visiting.

Of interest, there seems to be strong recognition that heritage features are anthropogenic. The word cloud features ‘buildings’, ‘structures’, ‘industrial’ and ‘human’ which all demonstrate acknowledgment of the role humans play in creating heritage features (Figure ii; Table i). Comments support this assertion. 15 comments recognise that landscapes are anthropogenic influenced with words/phrases such ‘human’, ‘man’
‘industrial’ and ‘built heritage’ used (Table i). Interestingly the majority of respondents view human influence as acceptable and not degrading (11 of 15). Several quotes can be used to demonstrate this phenomenon (Q1, Q2, Q3).

“The images are pleasing as the man-made structures appear to fit with the river rather than modify it, the river still holds sway” (Q1)

“The conundrum of places with human artefacts looking more attractive! Clear signs of human activity…” (Q2)

“Man culturally manages these landscapes and whilst they are not displeasing to walk through, and will have some wildlife value, they will mostly be for exercise for me. However, reflection on historic use is always interesting - especially how we have now cleaned up our rivers” (Q3)

The link between constructed riverine elements and the provision of cultural heritage identified here is consistent with Zoderer et al. (2016b) who found the service of cultural heritage to be perceived greatest in landscapes with strong human influences. This linkage appears in accordance with a European view that the service of cultural heritage is provided by human-made historical remnants (Hølleland et al., 2017).

(iii) Woodland

Figure iii: Word cloud analysis of the open question comments for woodlands, produced using software built into Survey Monkey

Woodland is also linked to four ecosystem services (aesthetic value, social relations, education/knowledge and recreation). The preliminary matrix shows a particularly strong preference relationship between aesthetic value and woodland, this echoes the riverine cultural ecosystem service modelling of Thiele et al. (2020).
The word cloud (Figure iii) appears to shout recreation with ‘dog’, ‘walk’ and ‘place walk’ present. According to Table i, ‘walk’ is the second most frequently mentioned word. In conjunction, recreation is the service which appears most often in the comments (12 of 42). Everyone commenting on recreation deems woodlands to be suitable for recreational activities. Aesthetic value is also represented within the word cloud singularly in the form of ‘beautiful’. Within comments aesthetic value is the second most prevalent with 10 mentions. Respondents refer to landscape beauty/attractiveness and the presence of wildlife. Only one indicates woodland photos are unattractive but is in comparison to the previous waterfall photograph. Despite being linked to woodlands no evidence of either social relations or education/knowledge value exists in the word cloud. Furthermore, both are mentioned comparably infrequently in comments. There are five mentions of social relations but one of these is negative. One individual respondent writes that paths through woodlands may lead to lots of people which could ruin your experience. Education/knowledge gain is only eluded to once by a respondent who mentions how they work in such environments.

In general, it appears the results of this pilot survey are synonymous with other research. Research examining the spatial pattern of multiple cultural services in the Netherlands by van Berkel and Verburg (2014) also identified forests to be hotspots. In a temporal study of long-term monitoring sites in the UK Dick et al. (2016) identify the woodland locations to have significantly increased provision of cultural services. Ridding et al. (2018) found woodlands to be hotspots for different types of recreation. The authors suggest that the preference for woodland areas for recreation may arise due to the rarity of woodland in the landscape studied combined with a human desire for landscape variety. Bogdan et al. (2019) find mixed woodlands to be of particularly high perceived
education value. One discrepancy that can be identified is the absence of a preference for inspiration. Research in China by Dou et al. (2019) found that restoration of agricultural land to woodland to be associated with increases in the perceived value of recreation, education, aesthetic value and inspiration. Additionally, in Latvia Paulina and Libiete (2019) believe the representation of forests within landscape paintings of the 20th century show they have great inspirational value.

The perceived valued of woodlands as cultural service hotspots may arise from respondents’ past experiences (Irvine and Herrett, 2018). In their investigation of cultural service provision from long-term monitoring sites Dick et al. (2016) identify several factors which appear significant in increasing cultural service provision. In the case of the Alice Holt Forest designation as a National Park and the creation of new infrastructure including café, visitor centre, walking trails, mountain biking trails and a woodland classroom are considered to boost multiple service provision. Specifically, recreation is clearly encouraged through this improved infrastructure. Education is supported by specific educational activities including craft workshops and astronomy while cultural heritage is facilitated through concerts and plays. Meanwhile in Wytham woods educational value can be attributed to bushcraft courses, ‘forest schools’, filming for television and guided walks (Dick et al., 2016). If survey respondents have past experiences of these activities in woodlands, they may drive their preferences elicited in this survey.

Analyses of the comments reveals there is some awareness that photographs are of are of different forestry scenarios. Three people recognise one photograph to be a conifer plantation. However, as 88% of respondents do not mention the different types of woodland it could be inferred in this research that respondents may not value various
types of woodland differently. This contrasts other investigations. In the New Forest Gosal et al. (2018) identify recreation and aesthetic value to be higher in broadleaf and mixed woodland compared to conifer forests. Gosal et al. (2018) suggest that a preference for broadleaf woodland may arise because they are perceived to be more ‘natural’. Meanwhile in the case of Alice Holt forestry operations have shifted from growing conifer species to broadleaf which is attributed to an increase in recreation and education (Dick et al., 2016). Moving forward, it may be worthwhile to further investigate if different types of Scottish woodland are associated with varying cultural preferences.

(iv) Upland wetlands

*Figure iv: Word cloud analysis of the open question comments for upland wetlands, produced using software built into Survey Monkey*

Within the preliminary matrix upland wetlands are identified to provide exactly the same four ecosystem services as woodlands; aesthetic value, social relations, education/knowledge and recreation. In further similarly to woodlands, only evidence for aesthetic value and recreation are present within the world cloud (*Figure iv*). ‘Walking’ indicates recreation while ‘beautiful’ and ‘wildlife’ are indicative of aesthetic value. 11 respondents comment on the aesthetic value of the upland wetland photographs. Although ‘beautiful’ appears in the word cloud, other terms including ‘views’ ’rugged’ and ‘appealing’ are identified in comments. Recreation is also mentioned 11 times, but once this is in reference to a place they would not visit for certain recreation activities. As revealed by the word cloud and *Table i*, walking seems the most popular
potential recreational activity with 10 mentions. Interestingly walking around upland wetlands is perceived to be potentially challenging and strenuous (Q4 & 5). Both social relations and education/knowledge value are also linked to upland wetlands in the matrix but are not expressed in the word cloud. Of the two only social relations is mentioned in the comments. One respondent suggests upland wetlands would facilitate social relations while another describes how the landscape would be unsuitable for outings with some individuals.

“Exhilarating, rugged scenery. Often difficult walking but very rewarding. Great places for seclusion, atmospheric and wildlife.” (Q4)

“...I would take my gators with me on these walks. I wouldn’t be able to take my girlfriend or lass equipped walkers with me on these days out” (Q4)

In general, the findings of the matrix and word cloud seem in accordance with published research describing uplands to be cultural service hotspots. Research also conducted in Scotland comparing the cultural service provision of the Pentland Hills to urban green spaces in Edinburgh by Schmidt et al. (2016) likewise finds high aesthetic and recreational value in the upland site. Correspondingly, in their examination of recreation and aesthetic value in the New Forest Gosal et al. (2018) found dwarf shrub heath to be the second most valued habitat after broadleaf woodland. Here the preference for aesthetic value is identified to be strong, this could reflect an influence of increased elevation as observed by Bogdan et al. (2019).

Recreational value may also be linked to elevation as Oteros-Rozas et al. (2018) identify European mountains to be important for the provision of hiking and skiing. However, recreational value could also be influenced by landscape management in Scotland. Dick et al. (2016) believe that in Scotland the designation of uplands as NNRs, signage to NNRs and car parks are linked to increased recreation. In terms of types of recreation, the word
cloud indicates the dominance of walking, this is also identified in research on the upland Pentland Hills by Schmidt et al. (2016). However, research examining the recreational value of long-term upland monitoring sites by Dick et al. (2016) suggests that uplands are important for a diverse range of recreational activities including walking, climbing and running.

Value for social relations also corresponds with Schmidt et al. (2016) who asked visitors who they would visit with, 29% said they would visit with friends and 7% in a group. Results somewhat validate views of Grand-Clement et al. (2013) who acknowledged but did not value the provision of aesthetic value, recreation and education from an upland area of Exmoor. One divergence is identified, the results of the survey by Schmidt et al. (2016) identify the upland Pentland hills to be valued greater for cultural heritage than education, the inverse of is identified by this survey.

Of note, words ‘wild’ and ‘natural’ give the impression that upland wetlands are seen as less managed than other river corridor features. However, analysis of the comments reveals 24 of 44 respondents elude to landscape management in their comments. Of those 17 describe the landscapes as ‘wild’ or ‘natural’ but 7 recognise that upland habitats are not entirely natural. Despite their perception of upland wetlands as managed these respondents do not explicitly express dislike for the environment. However subtle notions of displeasure are identified (Q6). None of those respondents who recognise some degree of management mention aesthetic value.

“...I know the catchments have been severely modified by human land use (e.g. loss of woodland, muirburn), but they are as close to 'natural as we are going to get in this crowded island.” (Q6)
The acknowledgement that upland landscapes are subject to management is consistent with Schmidt et al. (2016) who identified a preference for the future management of the Pentland hills to involve the restoration of more natural ecosystems.

(v) Agricultural land

![Word cloud analysis of the open question comments for agricultural land, produced using software built into Survey Monkey](image)

The matrix shows agricultural land to be linked to the provision of three ecosystem services: aesthetic value, social relations, and recreation. Of these links, two are deemed strong, aesthetic value and recreation. Intriguingly, only evidence of these two services is present in the word cloud (Figure v). Recreation is eluded to with ‘walk’ and aesthetic value by ‘wildlife’. Recreation dominates the comments with 24 mentions from 69 responses. As identified in the word cloud and Table i, walking is the most frequently mentioned activity (15 times), however canoeing, camping, running, swimming and fishing are also mentioned. Compared to recreation the incidence of aesthetic value in comments is lower (13/69). Within comments there are four mentions of education/knowledge gain.

Interestingly, the word cloud suggests that respondents find agricultural land a pleasant environment. ‘Relaxing’, ‘wildlife’, ‘nature’, ‘walk’, ‘Peaceful’, ‘tranquil’ and ‘Peace’ all indicate people would have positive experiences visiting riparian agricultural land. Simultaneously, the word cloud also reveals many respondents know photographs are of
agricultural land, comments suggest this influences their perceptions of the landscape. Eight respondents describe the agriculture nature would impact on potential recreation. Interpreting the comments, it seems that five respondents probably would visit agricultural landscapes for recreation, albeit at a reduced or limited capacity (e.g. Q7, Q8). It seems likely that the other three respondents probably would avoid such landscapes (e.g. Q9, Q10). In summary, it appears that despite the agricultural nature most respondents to this survey view agricultural landscapes as positive facilitators of several cultural ecosystem services.

“These particular rivers are rather too pastoral or almost domestic for my taste, so they're the kind of place I might visit for a short outing with less active friends or in mediocre weather” (Q7)

“In relation to the above pictures, to me they represent lowland rivers in (mostly) agricultural settings, where I would go for recreation and peaceful enjoyment…” (Q8)

“...Agricultural activities bordering the river - pastoral and arable probably not so good for walking...” (Q9)

“Personally I would avoid heavily farmed areas because of agricultural sprays but walking along a waterway lets me develop stories” (Q10)

In regard to the cultural value of agricultural land there seems to be a division in research. In the Netherlands van Berkel and Verburg (2014) identify agricultural landscapes to be relative ecosystem service cold-spots but yet they do see valued for aesthetic beauty and recreation. Furthermore, high recreation and aesthetic values for river corridor agricultural land are concurrent with the modelling of Thiele et al. (2020). Thiele et al. (2020) highlight the importance of considering different types of agriculture separately, high values of both recreation and aesthetic value were associated with pasture but low values with arable. To improve survey usability the decision was made to combine arable and pasture into one feature, moving forward it would be advisable to evaluate separately. Dick et al. (2016) also report agricultural landscapes to be of educational
value. Dick et al. (2016) believe that educational value likely arises from Government and NGO schemes encouraging schools and the public to visit farms. In particular, guided nature trails can provide educational experiences of agricultural landscapes (Dick et al., 2016).

Several studies contest the preferences for agricultural land identified here. In their photo elicitation research in the Italian Tyrol Zoderer et al. (2016b) find arable land to be associated with low aesthetic and recreation value. Similarly, following spatial analysis of geo-tagged photographs Oteros-Rozas et al. (2018) identify that extensively farmed landscapes appear to negatively relate to recreation value, it is suggested this may arise due to lack of recreation facilities. Closer to Scotland, research in the New Forest by Gosal et al. (2018) identified arable land to be one of the habitat types least valued for recreation and tourism. Dick et al. (2016) suggest that the cultural valuation of agricultural sites can be influenced their proximity to urban areas and the presence of paths.

Further in contradiction this research does not identify agricultural land to supply cultural heritage. Zoderer et al. (2016b) find the crop dominated landscapes of the Italian Tyrol to be important for cultural heritage, it is suggested that this may be a result of heritage associated with the growing of crops and the presence of settlements within these areas. Similarly, research on low-intensity agricultural in Italy landscapes by Assandri et al. (2018) identified these landscapes to be of cultural heritage value. Outside of Europe Dou et al. (2019) find the spiritual and cultural heritage value of cultivated land to rural communities to decrease following restoration to woodland. These services were perceived to be higher in the cultivated landscapes as they were associated with memories and history which were not present in newly created forests (Dou et al., 2019).
(vi) Amenity land

Figure vi: Word cloud analysis of the open question comments for amenity land, produced using software built into Survey Monkey

Amenity land is linked to three cultural services: aesthetic value, social relations and recreation. With the sequence of analysis chosen here, the word cloud for amenity land is the first one to elude to social relations value with ‘people’ and “family (Figure vi)’. In line with the majority of word clouds already explored, recreation (‘walk’) and aesthetic value (‘wildlife’) are both present.

Comments unveil more detail about how amenity land is viewed to facilitate recreation and social interactions. A form of recreation appears in the comments of 14 of the 55 participants. In particular, Table i shows participants consider riparian amenity land good for walking (13 of 50). A total of 8 people mention social interactions with the word ‘people’ fourth most frequently mentioned (Table i). Family features five times and friends twice, there is also mention of such areas being used for the organised event of Park Run. Of those who deem amenity land good for walking four mention walking with others (friends or family) which suggests that riparian amenity land may be place for synergy between recreation and social relations.

Curiously for amenity land, ‘natural’ and ‘managed’ both appear in the word cloud. The word cloud also paints amenity land as ‘accessible’ and ‘peaceful’. Further investigation analysing the comments emphasises mixed perceptions of amenity land. 20 of 55 comments describe amenity land to by managed and urban while 10 people comment on
the welcoming and accessible nature. Comments therefore indicate that the recreational opportunities provided by riparian amenity land seem accessible, safe and managed. In contrast, two of the seven respondents referring to aesthetic value believe the managed and urban nature has reduced aesthetic value (Q11, Q12)

“It has the benefit of some open, green space - most likely fairly close to or within more urban surroundings. It is not as beautiful, untouched or natural as a more rural setting but brings benefits nonetheless to people and wildlife” (Q11)

“More urban and so less attractive for people like me who live in the countryside anyway. However these riverbanks are easier to access” (Q12)

In this research, amenity land is defined as grassland adjacent to the channel that looks managed, may contain evidence of mowing lines or recreational features such as sports pitch markings/posts or picnic benches. In the quest to build a discussion around preferences for amenity land searches for literature were conducted on Google Scholar, SCOPUS and Web of Science, however these searches were fruitless leading to the notion that research into the value of ‘amenity land’ is limited. Subsequently, the literature search is expanded to include small urban parks which share similar characteristics to amenity land.

In the field of small urban park research support for these findings can be found. Results seem to closely mirror the findings of Rall et al. (2017) who used public participation GIS to map the cultural service value of urban green spaces in Berlin. Rall et al. (2017) report recreation, aesthetic value and social relations to be the most mapped services. Of importance, Rall et al. (2017) suggests that green spaces in urban environments may provide equal cultural service provision to more rural scenic spaces. Bertram and Rehdanz (2015) find European urban parks to be very important for recreation and aesthetic value. Indeed, Ignatieve et al. (2020) highlight how urban lawns have been
important spaces for aesthetic value since their introduction as garden elements in the Middle Ages. The beginning of lawn parks being centres for recreation dates slightly more recently to the public park’s movement in the middle of the 19th century (Trudgill et al., 2010; Ignatieve et al., 2020). The high perceived recreational value of amenity land may arise from a view of the feature as long linear spaces, research conducted on cultural service provision of urban parks by Brown et al. (2014) found linear parks to be associated with greater recreational value. In particular, the word cloud identified walking to be an important recreation activity within amenity land, this pairs with the results of Fischer et al. (2018).

Zwierzchowska et al. (2018) find urban parks in European cities to be important places for social activities. Intriguingly, Bertram and Rehdanz (2015) identified the social value of urban parks to vary significantly. For example, in Stockholm over 80% of visitors visited parks to spend time with friends, compared to just over 55% of visitors in Berlin and Rotterdam. Özgüner (2011) also identified perceived social value to vary between societies.

Compared to waterfalls, heritage features, woodlands and upland wetlands it seems amenity land does not represent a significant cultural service hotspot. This contrasts the nature of urban parks (Breuste et al., 2013; Langemeyer et al., 2015; Bertram and Rehdanz, 2015). This may be attributed to urban parks additionally supplying ecosystem services absent in this matrix. In their comparison of four European urban parks Bertram and Rehdanz (2015) report such parks to be places of inspirational value. Research in Shanghai by Breuste et al. (2013) identified amenity land in urban areas to be of important educational value. Similarly, Hutcheson et al. (2018) determine the Hudson River Park in Manhattan to be of educational value as a result of annual environmental
education programmes. Also, in New York Campbell et al. (2018) elude to urban parks being places for spirituality and refuge.

**(vii) Lowland wetlands and floodplain lakes**

![Word cloud](image.png)

*Figure vii: Word cloud analysis of the open question comments for lowland wetlands and floodplain lakes, produced using software built into Survey Monkey*

Lowland wetlands/floodplain lakes are only liked to aesthetic value and recreation within the matrix. Evidence of both these linkages is present in the word cloud. ‘Beautiful’, ‘birds’, wildlife’ and ‘wildlife watch’ all suggest the landscape is visually pleasing/interesting while ‘walk’ is indicative of recreation. Within the comments there are 21 mentions of aesthetic appearance including the viewing of wildlife, 18 are positive and 3 negative. Of interest, wildlife is the most frequently mentioned word; Table i shows 10 mentions. There are fewer mentions of recreation (10 of 45). As identified by the word cloud (Figure vii) and Table i walking seems to be most popular recreational activity people would visit for (6 of 49). However, comments reveal that respondents consider the landscape suitable for cycling (2) and kayaking (1). Analysis of comments affirms the absence of any other ecosystem service perceived to be supplied by floodplain lakes/lowland wetlands. Indeed, the perceived lack of service provision from lowland wetlands/floodplain lakes may explain why four respondents describe the landscape as ‘boring’ or unexciting.

Similar to amenity land, the word ‘management’ appears within the word cloud, deeper investigation of comments reveals that 15 of 45 respondents perceive the landscape to
be managed. Six respondents regard landscapes to be aesthetically pleasing despite the recognition of management (Q13, Q14, Q15) while two participants see management to degrade aesthetic value (Q16, Q17).

“Attractive although managed, but it could be managed better for the environment in general” (Q13)

“More of a manufactured look to the environment but likely to offer some good bird watching, so best visited in small groups, operating quietly.” (Q14)

“Beautiful, managed” (Q15)

“managed environment, not that aesthet but good for walking the dog” (Q16)

“… are highly modified/ canalized which detracts from their visual appearance” (Q17)

In comparison to other research it appears that respondents attach fewer values to lowland wetlands/floodplain lakes. In parallel with this research Chen et al. (2020) found the freshwater dykelands of the Cornwallis River in Nova Scotia to be valued for aesthetics and recreation but also identified dykelands to be important spaces for social relations, education and inspiration. Chen et al. (2020) hypothesise that educational value may arise from field trip suitability. Similarly, Moore and Hunt (2012) identify stormwater wetlands and ponds to have recreation and education value. In their case educational value is deemed to be influenced by several of the investigated wetlands being located within the grounds of public schools and therefore integrated within the school’s curriculums. Furthermore, Moore and Hunt (2012) attribute educational value to the presence of educational signage at many of the studied sites. Meanwhile, in Nova Scotia Greenland-Smith et al. (2016) find the highest value for riparian marsh to be given to cultural heritage, this is followed closely by recreation.
Following the analysis of comments, it seems unlikely that perceptions of management are the driver for low cultural value. The low value of wetlands may be linked to perceived location. In research examining lowland wetlands in Sweden Pedersen et al. (2019) found a wetland located within an urban area had a higher social value than peri-urban wetlands while peri-urban wetlands had greater educational value. The photographs used here were of lowland wetlands/floodplain lakes in rural locations, this could have reduced their perceived value. Alternatively, the low cultural value perceptions may arise from societal underutilisation. For example, Lundy and Wade (2011) use a combination of research and observations to explore the potential and actual ecosystem service provision of a small lowland wetland in North London. They suggest that the wetland has the potential to provide educational and aesthetic value but currently only actually provides aesthetic value.

(viii) Natural lakes and reservoirs

![Word cloud analysis of the open question comments for natural lakes and reservoirs, produced using software built into Survey Monkey](image)

Natural lakes and reservoirs are only linked to aesthetic value and recreation. Both links are identified within the word cloud with the words ‘beautiful’ ‘wildlife’ and ‘walk’ (Figure viii). However, ‘bleak’ suggests some aesthetic dislike of the landscape. Indeed, within comments there is a clear division in perceived aesthetic value, equally nine respondents perceive aesthetic value and no aesthetic value. Comments suggest this
division may be linked to the feature identified within photographs. Of significance, the word cloud suggests that many respondents have identified reservoirs and dams but fewer have identified lakes/lochs. This is supported by reservoir being the most frequently mentioned word (15 of 49) and dam the third (9 of 49) (Table 1). This is important as the photographs used represent two lakes and two reservoirs. Comments reveal 14 respondents refer to reservoirs and four to lochs. Only three respondents seem to recognise photographs are a mixture of reservoirs and lakes/lochs while two are unsure if photographs all represent the same feature. There is also direct mentioning of landscape management in 6 of the 45 comments, of those who consider the landscape unattractive four are referring to reservoirs or managed landscapes (e.g. Q18, Q19)

“The most accessible water environment to where I live. Some reservoirs can look more sterile and uninteresting. Luckily the ones near me have beautiful landscapes and attract a lot of wildlife. But there can also be conflict with activites like jetskis and wakeboarding that spoil the peace and quiet.” (Q18)

“A rather bleak environment offering less detailed interest in terms of botany or bird life.” (Q19)

These results indicate that it would be meaningful for a future survey to consider lakes and lochs as separate features. This is echoed by similar studies. Through historic travel writing, the aesthetic value of lake environments in the UK can be dated back to at least the 18th century (Donaldson et al., 2017). Additionally, the economic value of lake aesthetics was recognised before the development of the ecosystem service concept (Lansford and Jones, 1995). Outside of the UK, Schirpke et al. (2016) find lakes to contribute to high aesthetic value in their ecosystem service modelling of alpine environments. While through the analyses of geo-tagged photographs in Southern Patagonia Pastur et al. (2015) identify lakes to also be of aesthetic value. Crucial for the cultural service management of lakes, it is important to acknowledge that lake properties
such as water clarity, water colour, vegetation, debris and presence of facilities can influence aesthetic value (Tallar and Suen, 2017).

In contrast, it is more difficult to deepen understanding of the aesthetic value of reservoirs due to limited research. One comparable paper is that of Hossu et al. (2019) who use surveys to determine the perceived cultural value of artificial urban lakes within Romania. From their survey Hossu et al. (2019) find urban lakes to be important in the supply of aesthetic value, this validates the matrix linkage but disagrees with the comments of those who recognise the reservoir nature of photographs. Clearly more in-depth research comparing the aesthetic value of lakes and reservoirs is needed to inform cultural riverine ecosystem service management.

Recreational activities are mentioned by 14 respondents. The recreational value of lakes and reservoirs appears consistent with other investigations. In their analyses of geo-tagged photographs in Southern Patagonia Pastur et al. (2015) identify lakes to also be of recreational value. Zhao and Liu (2015) demonstrate the recreational value of Three Gorges Reservoir following economic valuation. In their investigation of urban lakes in Romania Hossu et al. (2019) also find perceived provision of recreation. Literature identifying low recreational values for lakes appears scant but does exist. In their research of Lake Tai in China Pan et al. (2020) found respondents did not attach high recreational values to the lake because they felt that if they could no longer carry out recreational activities near the lake they could do so in parks.

The word cloud and Table I suggest that walking is the most popular recreational activity which would be consistent with Hossu et al. (2019). However, the comments reveal a different story with canoeing/kayaking mentioned most frequently (appendix nine, landscape six). In comparison to other corridor features recreational activities suggested
appear more diverse with water-based activities particularly popular (Table ii). This diverse range of services is consistent with other research, indeed, some papers such as Allan et al. (2015) and Vierikko and Yli-Pelkonen (2019) focus solely on capturing the multiple recreation services provided by lakes. The diversity of recreational activities identified here and in other research indicates that future surveys should consider subdividing preferences for recreation. Indeed, during a meta-analysis of research examining the economic value of lake ecosystem services Reynaud and Lanzanova (2017) make the decision to split recreation into sub-services due to the diversity of recreational activities that can be experienced within lake environments.

**Table ii: Table showing the frequency at which different recreational activities are mentioned in the responses to an open question for ‘reservoirs and natural lakes’ asking participants to ‘Please use a few words or sentences to describe what this environment means to you’**

<table>
<thead>
<tr>
<th>Activity</th>
<th>Times mentioned</th>
</tr>
</thead>
<tbody>
<tr>
<td>Canoeing/kayaking</td>
<td>5</td>
</tr>
<tr>
<td>Walking</td>
<td>4</td>
</tr>
<tr>
<td>Cycling</td>
<td>2</td>
</tr>
<tr>
<td>Fishing</td>
<td>2</td>
</tr>
<tr>
<td>Sailing</td>
<td>1</td>
</tr>
<tr>
<td>Jet skis / wakeboarding</td>
<td>1</td>
</tr>
</tbody>
</table>

(ix) Felled woodland

*Figure ix: Word cloud analysis of the open question comments for felled woodland, produced using software built into Survey Monkey*

Felled woodland is one of two river corridor features perceived to supply no cultural services. The word cloud for felled woodlands appears confusing. ‘woodland’, ‘wildlife’, ‘explore’, ‘walking’, ‘good’ and ‘pictures’ suggest a place people would enjoy visiting while
‘managed’, ‘management’ ‘felled’ and ‘sad’ indicate negative experiences (Figure ix).
Overall, the comments seem to support the lack of ecosystem service provision reported in the matrix. Even recreation and aesthetic value which have so far been identified in the comments for every feature are absent. Each of the seven respondents who comment on landscape aesthetics consider the landscape unattractive. The picture is similar for recreation, despite walking appearing as the most frequently mentioned word (Table i), 6 of the 10 participants who mention recreation consider felled woodland an unsuitable location.

In the case of felled woodland, the lack of perceived service provision pairs with recognition that the landscape is managed. Coding the comments helps put ‘management’ in context, of the 55 who provided comments for felled woodland 23 recognise the landscape is subject to management. Thirteen of those 23 feel negatively towards felling. Indeed, felled woodland seems to stir up negative emotive feelings for 6 of 55 respondents (eg. Q20,). This explains the presence of the word ‘sad’ within the word cloud. However, this feeling is not shared by everyone with four respondents remarking that management may be yielding benefits (e.g. Q21). Others do not comment on management but suggest that the areas in photographs may be good for biodiversity or wellbeing (4 of 54) (Q22).

“Tree felling makes me sad so it physically hurts. I don't seem it out but in some places I walk regularly trees have been felled. I hate it." Q20

“I know that felled woodland creates 'large woody debris' in rivers which brings benefits to wildlife” Q21

“The addition of wood in or surrounding the stream is a further enhancement and gives so many opportunities for wildlife that these areas are always worth careful observation.” Q22
Comments for felled woodland also reveal there seems to be recognition of diversity within the photographs chosen (9 of 54 respondents). In three comments this diversity is reported to make the question challenging to answer (e.g Q23). While five remark that individual photographs are subject to different forms of management (e.g Q24)

“I don’t understand what's happening here, whether it’s a 'good' thing or 'damaging to the environment” (Q23)

“It look like all of them suffer from poor and insensitive management, the upper two look like vey modified rivers, almost canalised. The lower two are nicer with a stronger sense of naturalness, though the bottom right might improve if left to regenerate naturally.” (Q24)

These comments are interesting as unlike woodland, agriculture and natural lakes/reservoirs images are supposed to represent the same river corridor feature. It seems respondents have identified different levels of felling within photographs and this has influenced perceptions and caused some confusion. Varying preferences for different woodland management scenarios is consistent with other research. Karjalainen (1996) presented participants with different photographs of clear-fell approaches, they found small clear-fell zones with a few solitary trees and undergrowth were seen most positively, in contrast large areas of clear-fell with extensive soil preparation and felled trees left in-situ were deemed ugliest. Through a photo-manipulation survey Tönnes et al. (2004) find that the aesthetic value of clear-felled areas improves if $3 \text{ m}^3 \text{ ha}^{-1}$ is retained, furthermore the healthier and more mature the retained trees the more they will be aesthetically valued. Similarly, in North America Ribe (2009) found perceived scenic beauty to be higher forests with greater tree retention, greater dispersal of retained trees and less down wood. Moving forward, it is recommended that a survey focuses on differentiating approaches to felling used in Scotland to better understand perceived cultural service provision.
Within the ecosystem service research field, investigations focusing on the multiple cultural service provision of felled woodland seems scant. Research that does exist paints a similar picture to this investigation. Gundersen and Frivold (2008), Beza (2010) and Lämås et al. (2015) also find felled landscapes to be unaesthetically pleasing. While Urquhart (2007), Edwards et al. (2011) and Tyrväinen et al. (2017) demonstrate the limited recreation value of felled landscapes. Meanwhile Christianwan (2018) highlight how felling leads to the loss of important sacred sites and spiritual value in Indonesia, indeed, the sacred value of forest sites is important in driving motivation for the protection of forests from commercial logging.

(x) Urban areas

Urban areas are perceived to supply no cultural services. Instantly the word cloud reveals that respondents recognise the urban nature of the river corridor. ‘urban’ and ‘city’ jump out at you, ‘town’, ‘industrial’ and ‘Urban rivers’ also show recognition of a human constructed riverscape (Figure x). Directly 14 respondents mention ‘urban’ (Table i), however analysis of the open question answers reveals that 37 of 49 comment on the urban nature of river corridors. For six respondents the urban nature is off-putting, (e.g Q25 & 26). In contrast, nine respondents describe rivers as positive features in urban locations (e.g. Q27, Q28). Interestingly for thirteen people urban river corridors are seen as a place to experience if already in an urban area (e.g Q29,30,31).
“I avoid towns and cities as far as possible.” (Q25)

“Urban environment - not my favourite” (Q26)

“Urban waterways are a nice place to be in town and I would be attracted to them for the contrast with the other built up areas” (Q27)

“This environment tends to be closer to home and useful for local shorter walks” (Q28)

“This is the sort of place that would be valuable to me in its urban setting, e.g. for a quick walk after work…” (Q29)

“Very urbanised- unlikely to choose to go there, but when I lived in cities, I would have used them as the only option.” (Q30)

“Very tamed - but when in a city escapism has to grabbed at every opportunity in order to keep one's sanity!!” (Q31)

Although the matrix denotes no cultural ecosystem service provision, the presence of the word ‘walk’ within the word cloud arising from 11 mentions (Table i) suggests riparian urban areas have potential for recreation. In total, recreation is mentioned in the comments by 17 respondents. However, it appears respondents have contrasting opinions on the recreational potential of urban river corridors which likely contributes to the absence of a matrix link. Four respondents find urban areas unsuitable or unattractive for recreation while 13 describe potential for recreation. Of those who indicate they would experience recreation along urban river corridors seven suggest it would be brief or opportunistic (Q31,32).

“Not somewhere I'd choose to go but might cycle through on a tour and be of interest to me as I am a freshwater ecologist” Q31

“If I am visiting a city I always head for the river…I would always choose to walk along them if it would get me to my destination” Q32

The low cultural value of urban river corridors corresponds with a few other investigations. Using a combination of existing research and observations Lundy and
Wade (2011) produce a matrix of potential and actual ecosystem service provision for the urbanised River Brent in London, all four of the cultural services considered (spiritual value, aesthetics, recreation and education value) were deemed non-existent. The low aesthetic value of urbanised river corridors is consistent with the German research of Thiele et al. (2020). Such low aesthetic values could be a function of low landscape dynamism (Pflüger et al., 2010; Le Lay et al., 2013).

Importantly, the findings of this research also contradict a significant body of literature focusing on urban river corridors and more general urban landscapes. In particular, urban river corridors are believed to provide cultural heritage (e.g. Nagpal and Sinha, 2009; Badiali et al., 2018; Othman and Majid, 2018; Thiele et al., 2020). It is likely the importance of urban river corridors for cultural heritage arises due to the strong anthropogenic influence (Zoderer et al., 2016a). Within this research a link between human influence and cultural heritage provision is suspected for cultural heritage features so it is somewhat a surprise that cultural heritage is also not attached to urban areas, especially considering respondents seem overtly aware of human influence. The lack of linkage in this research may contradict other research due to the non-spatially explicit approach, within the papers outlined above research is conducted on named locations which respondents or researchers have knowledge of.

Other cultural services are also discovered to be provided by urban environments. In their public participation mapping of ecosystems services within the urban river corridor of the Spanish Caldes Stream Garcia et al. (2017) identified the most mapped cultural services to be recreation, cultural heritage and aesthetic value. Of note, Garcia et al. (2017) describe the recreational opportunities provided by the Caldes Stream to be everyday leisure activities for residents, the comments of this survey also indicate that
some individuals would use urban river corridors for convenient and perhaps more mundane recreation. Similar perceptions of the multiple service provision also exist for more general urban research. In their analysis of geo-tagged photographs Oteros-Rozas et al. (2018) found photographs with urban elements to contain indicators of recreation, cultural heritage, spiritual value and social relations. Meanwhile Bogdan et al. (2019) found artificial surfaces to be valued for recreation and education due to their easy accessibility. Ridding et al. (2018) also identify urban areas to be important locations for recreation.
Appendix Eight: Cultural service survey discussion:

Potential meanings for river management

This section draws together the general results of the survey and published research to make recommendations for river cultural service management. The results of the survey appear to indicate three broad categories of river corridor feature; hotspots, coldspots and somewhat ‘warmspots’. These broad categories are used to structure this conclusion.

1. Hotspots

(i) Waterfalls

The importance of waterfalls as cultural service hotspots appears to be pioneering in the river cultural service field. To date, it appears that no research focusing on multiple riverine corridor features has eluded to the importance of these geomorphological features. Furthermore, the cultural value of waterfalls seems unexplored in general cultural ecosystem service research (Hudson, 2013). It therefore seems sensible to recommend that more research is undertaken before serious management recommendations can be made. The results of this survey can be viewed as catalysts for future directions of research which would likely prove useful for river stakeholders. In particular, there are four areas of research which survey results indicate to be required.

Firstly, the results of this survey create an important question; What factors contribute to waterfalls being cultural ecosystem service hotspots? It seems likely that cultural values are attributable to heterogeneity and dynamism, waterfalls combine rock, water and ecology, this makes them interesting and exciting places to visit (Hudson, 2013; Cole, 2015 Bogdan et al., 2019 Pflüger et al., 2010; Le Lay et al., 2013). This combination surely facilitates unique opportunities for inspiration, aesthetic appreciation, multiple types of
recreation and education (Hudson, 2013; Cole, 2015). However, strong evidence examining these causations is needed in the context of Scottish waterfalls. In particular, more research is needed to determine the ecological and geomorphological characteristics that contribute to perceived provision of aesthetic value, social relations, inspiration, education/knowledge value and recreation. It is recommended that open questions and surveys will be useful for determining what characteristics influence the cultural hotspot nature of waterfalls as they allow respondents to express their thoughts and feelings.

Secondly, waterfalls are the only feature to be perceived to supply inspiration, consequently several potential lines of enquiry are generated. What forms of art are waterfalls perceived to inspire? Are they predominantly inspiring traditional forms of art such as poems and paintings or newer types such as photography? Crucially, should waterfalls receive additional protection to ensure that individuals have access to river-based inspiration? This research certainly echoes the call of Hernández-Morcillo et al. (2013) for more studies exploring inspiration as an ecosystem service.

Thirdly, it would be useful to explore in more detail the types of recreation waterfalls are deemed important for, since other research has found them to have multiple recreational uses (Hudson, 2013).

Finally, literature suggests that the influence of waterfall accessibility on cultural service perception should be investigated. Cole (2015) describe that waterfalls in Scotland are often found proximal to roads making them easily accessible and therefore places people are more likely to visit (Cole, 2015). Indeed Rall et al. (2017) identify accessibility to be an important factor in decisions regarding where people should go to experience cultural services. In particular, it could be hypothesised that accessibility influences social
relations, individuals and organised groups often agree to meet in places that are mutually accessible (Peters *et al.*, 2010; Irvine *et al.*, 2013). It is therefore clearly meaningful to investigate if cultural values varied depending on how easy waterfalls are to access.

In summary, this study echoes the recommendations of Hudson (2013) who call for more research into the value of waterfalls. Understanding the cultural service value of waterfalls is important for riverine ecosystem service management including local and national decision making.

(ii) Heritage features

Heritage features are perceived to provide four cultural services and are the only river corridor feature perceived to supply cultural heritage. The inclusion of cultural heritage within river management decisions is an important advancement in the field of riverine cultural research and management (Hølleland *et al.*, 2017). Subsequently it is recommended that stakeholders may want to promote heritage features as destinations to experience cultural heritage alongside other ecosystem service features. If doing so, stakeholders should be careful to balance accessibility and protection of cultural heritage features. Promotion and development of heritage features as places to experience cultural service provision may be preferred over other river corridor features as the results of the survey suggest that for these spaces human influence is seen as acceptable and not significantly degrading.

Furthermore, in regard to future research, results indicate that it may be meaningful to investigate differences in perceived cultural heritage value of heritage features between local residents and tourists. One approach which could be used to investigate the influence of resident in the analysis of geo-tagged photographs. For example, Ghermandi
et al. (2020) undertake analysis of geotagged photos on a social media platform for coastal region of Mexico and are able to determine which sites are provide cultural heritage to locals and tourists.

(iii) Upland wetlands

Similarly, results indicate that upland wetlands may also be suitable areas to promote for the experience of multiple cultural services. It seems that amongst respondents there is a strong awareness that upland wetlands are managed landscapes but for most this management is perceived to be positive and is not viewed to impact cultural service values. Research conducted by Dick et al. (2016) highlights certain management techniques such as the designations of NNRs, signage to NNRs and car parks can increase potential cultural value and experiences in uplands. However, it is pertinent to remember that management needs to be a careful balance between encouraging naturalness and sympathetic enjoyment of the landscape (Schmidt et al., 2016).

(iv) Woodlands

Discussion of the hotspot nature of riparian woodlands revealed that past experiences may be important in driving cultural value (Dick et al., 2016; Irvine and Herrett, 2018). Translating this to riverine management in Scotland, it may be that several woodland locations can be developed as spaces to provide structured cultural services, then individuals may be able to see or experience value in other less managed landscapes. Suggestions for development can be taken from the Alice Holt case study provided by Dick et al. (2016) and include construction of cafes, visitor centres, leisure trails and classrooms. However, stakeholders will need to consider the promotion and development carefully to avoid overwhelming and degrading natural woodland environments (Quine et al., 2013; Löf et al., 2016). Doing so would be harmful both to
woodland ecosystems and attractiveness for cultural service visitation. Indeed, in the comments one respondent described that paths in the woodlands may lead to lots of people which could ruin their experience. Awarding woodlands nature designations may be crucial for ensuring promotion of woodlands as places to visit is environmental sympathetic (Dick et al., 2016).

The results of this survey are supported by other research suggesting the conservation of riparian woodlands should be a high priority in cultural river ecosystem service decision making. Indeed, results encourage woodland planting for the creation of cultural ecosystem service hotspots, this echoes Ridding et al. (2018) who consider the importance of woodlands as ecosystem service hotspots to be a motivation for the planting near urban areas to improve wellbeing. Furthermore, the cultural benefits identified here add a further argument in favour of upland woodland planning for natural flood mitigation (Jackson et al., 2008; Marshall et al., 2009; Iacob et al., 2014).

Moving forward, survey results and existing research indicate that further research is needed to investigate divergences in perceptions for different types of Scottish woodland as this will have implications for management. Additionally, it would be useful to re-examine the inspirational value of Scottish woodlands, this research found woodlands not to be of significant inspirational value contrasting research in other locations by Dou et al. (2019) and Paulina and Libiete (2019). As inspiration is one of the services least frequently perceived to be supplied by riverine environments further investigation could be used to somewhat validate or disprove matrix findings which would have implications for management.

2. ‘Warmspots’
Alongside hotspots, this research has also identified some ‘warmspots’. These ‘warmspots’ are riverine corridor features that are perceived to supply cultural services but not the same high number as the hotspots. This definition of warmspots contrasts that of Alessa et al. (2008) and De Vreese et al. (2016) who regard a warmspot to be a location with high ecological quality but low cultural service value. Although these features do not provide the same number of services as the hotspots, they still hold significant cultural value and therefore their management requires careful consideration.

(v) Agricultural land

The high recreational value of agricultural land identified in this survey suggests stakeholders in the recreation and tourism industries should collaborate with the agricultural industry to investigate ways to utilise this perceived value in a way which can boost the economy, create environmental benefits and improve wellbeing. In regard to recreation the introduction of recreational facilities such as paths and maps may boost the provision within agricultural landscapes (Dick et al., 2016) considering Oteros-Rozas et al. (2018) attribute a lack of recreational facilities in extensively farmed landscapes to low perceived recreational value. However, such facilities would need to be balanced with environmental sensitivity and farming yields. Educational value can be promoted through government and NGO schemes which encourage people to visit farms and use guided nature trails (Dick et al., 2016).

However, due to the division between this research and other studies (e.g. Zoderer et al., 2016a; Oteros-Rozas et al., 2018; Gosal et al., 2018) it is recommended more detailed investigations of the cultural services provided by agricultural environments are conducted before any management decisions are made. In particular it appears fruitful to evaluate different types of agricularal land separately (Thiele et al., 2020) and possibly...
the influence of right to roam. Additionally, spatially explicit research investigating the influence of proximity from urban areas on the cultural value of agricultural land would be useful for management decisions (Dick et al., 2016). Furthermore, future research should seek to establish the extent to which Scottish riverine agricultural land is an ecosystem service cold-spot in comparison to other riverine features, as has been identified in other research (van Berkel and Verburg, 2014; Gosal et al., 2018), this will have ramifications for management decisions.

(vi) Amenity Land

Retrieving literature for the above discussion revealed that the inclusion of riverine amenity land within this assessment appears somewhat pioneering. Therefore, the results of this survey are significant for riverine amenity land management. Of significance, comparison to urban park research indicates that riverine amenity lands under supply cultural ecosystem services (Breuste et al., 2013; Langemeyer et al., 2015; Bertram and Rehdanz, 2015; Hutcheson et al., 2018; Campbell et al., 2018). Also, of significance, the word cloud and comments reveal a significant proportion of respondents are aware that amenity land is subject to management yet there is no strong feeling of disdain, actually management is somewhat viewed to improve ecosystem service provision. Indeed, comments reveal that management is believed to create safe places for recreation. Furthermore, accessibility which is a sign of management is also viewed positively in comments. This is consistent with Bertram and Rehdanz (2015) and Zwierzchowska et al. (2018) who identified accessibility to be a factor which increases perception of cultural service value within urban parks.

Combining these two notable findings it is suggested that active management could be undertaken to boost the number of cultural services provided by riparian amenity land.
However, it is recommended that actions are carefully considered to prevent overuse, overcrowding and degradation (Rall et al., 2017; Ignatieve et al., 2020). Furthermore, despite their aesthetic and recreational value, lawns are poor habitats and there are frequent calls for management to focus on naturalness to encourage biodiversity (Ignatieve et al., 2020). Additionally, it is worth noting that the management of lawns can be made more challenging where amenity land is created on former industrial or building sites due to poor soil (Ignatieve et al., 2020).

Moving forward, this research concurs with Ignatieve et al. (2020) who suggest there is a need for continued research investigating public perception, cultural service use and management of amenity land. In particular research should consider examining potential management options which allow synergy between cultural services and biodiversity.

(vii) Lowland wetlands and floodplain lakes

Similar to the case of riverine amenity land comparison to other studies indicates this survey has retrieved low values for lowland wetlands and floodplain lakes (Chen et al., 2020; Moore and Hunt, 2012; Greeland-Smith et al., 2016). Only recreation and aesthetic value are perceived to be supplied by lowland wetlands/floodplain lakes. It seems possible that low values occur as a result of the perceived rural location of wetlands or societal underutilisation. Comments reveal that respondents are aware landscapes are management, but the current level of management is accepted, it therefore seems possible that there potential for management to increase cultural value. In particular, similar environments are deemed to be of educational value. To improve the educational value of Scottish lowland wetlands/floodplain lakes the encouragement of field trips (Chen et al., 2020), incorporation in school curriculums (Moore and Hunt, 2012) and educational signage (Moore and Hunt, 2012) could be explored.
Natural lakes and reservoirs

Firstly, it is clear from respondent comments that riverine cultural service management needs to consider lakes and reservoirs as separate features. Analysis of the comments appears to indicate that respondents who perceive photographs to be of reservoirs or management landscapes are more likely to view the feature as aesthetically displeasing. These results also indicate that managers should carefully consider the impact of different management scenarios on the aesthetic appearance of reservoirs. Drawing from the lake-based research of Tallar and Suen (2017) it is advocated that managers are particularly mindful of water clarify, water colour, vegetation, debris and presence of facilities as these properties can influence aesthetic value. However, before management decisions are made more empirical evidence examining the cultural value of reservoirs seems advisable.

Secondly, in regard to the management of large water bodies located along river courses it is recommended that different recreational activities are considered separately (e.g. Allan et al., 2015; Vierikko and Yli-Pelkonen, 2019). Such sub-division is necessary to better identify, understand and manage cultural service synergies, conflicts and trade-offs which can occur between different types of recreation. For example, Meyerhoff et al. (2019) identified conflict between anglers and recreational swimmers in German artificial gravel lakes. Crucially, the management of lake and reservoir recreation needs to be mindful of avoiding environmental stress (Allan et al., 2015).

Thirdly, in the case of lakes and reservoirs it also be advisable for management to conduct some place-specific studies as literature reports other values aside from aesthetic value and recreation can be present. Despite their somewhat narrow focus of the seasonal pattern of supply and demand for recreation of Lake Kuusijärvi in Finland Vierikko and
Yli-Pelkonen (2019) ascertain the lake to be of value for social relations. Similarly, in Romania Hossu et al. (2019) identify urban lakes to be important spaces for the provision of social relations and inspiration. While in their meta-analysis Reynaud and Lanzanova (2017) find lakes to be highly valued for spiritual services. However, this is interesting as literature focusing on the spiritual value of lakes and reservoirs seems sparse when searching SCOPUS and Google Scholar.

3. Coldspots

(ix) Felled woodland

Felled woodland is one of two features identified to be a cultural service coldspot. Comments reveal that the absence of cultural value for felled woodland is unsurprisingly the result of felling management practices. Of significance and in accordance with existing research (Karjalainen, 1996; Tönnes et al., 2004; Ribe, 2009), comments show respondents attach varying preferences to different levels of felling. Consequently, and perhaps logically, if stakeholders wanted to improve the cultural value of felled woodland then management should consider clear felling as little as possible (Karjalainen, 1996), as high tree retention as possible (Tönnes et al., 2004; Ribe, 2009) and greater dispersal of retained trees and less down wood (Ribe, 2009). The cultural value of felled woodlands should not be ignored considered these landscapes do exist within Scotland. It is hoped that this research may act as a catalyst to start research examining the multiple cultural values associated with felled woodlands. In particular, for future management, it is advised that investigations seek to better understand how different approach to feeling influence perceived cultural service provision.
Urban areas

The identification of riverine urban areas to be cultural ecosystem service coldspots is one of the biggest contrasts to existing literature identified within this research (García et al., 2017; Oteros-Rozas et al., 2018; Bogdan et al., 2019; Ridding et al., 2018). In particular, it seems surprising that cultural heritage is absent within urban river corridors (Othman and Majid, 2018; Nagpal and Sinha, 2009; Badiali et al., 2018). Subsequently, it suggested that careful management may be able to boost cultural service provision. Everard and Moggridge (2012) provide a case study example with their evaluation of the restoration of Mayesbrook Park in east London, they consider the restored ecosystem to provide recreation, aesthetic value, social relations and educational value. Social relations were deemed to arise from use of the park for recreational activities but also from volunteering (Everard and Moggridge, 2012). Volunteer-based conservation is known for creating social cohesion and social capital (Firth et al., 2011; Middle et al., 2014) with the added benefit of projects having the potential to significantly improve the aesthetic value of urban spaces (Ohmer et al., 2009). Educational value likely arises as the park site is located within easy access of schools and colleges, interesting Everard and Moggridge (2012) suggest that the proximity of educational institutions also gives the urban river inspirational value but do not qualify this due to uncertainties. Potential cultural benefits of river rehabilitation are also outlined by Vollmer et al. (2015) for the Ciliwung River running through Jakarta in the developing country of Indonesia. Through a combination of surveys and interviews Vollmer et al. (2015) identify that proposed rehabilitation involving the increase of park spaces would increase perceived recreational, aesthetic and cultural heritage value.
Irrespective of the management options considered there are some factors that stakeholders need to be mindful of. Plieninger et al. (2013) and Rall et al. (2017) identify how negative characteristics such as being crowded, noisy, untidy and neglected can reduce perceived cultural services of urban spaces. Often these characteristics are most associated with inner-city urban areas where population density and urban green space us are very high.
Appendix Nine Content analysis of cultural service survey open question answers

Text code:

- Aesthetic value
- Social relations
- Inspiration
- Education/knowledge
- Heritage
- Spirituality/religion
- Recreation

Landscape One: Agricultural land

1. peace, tranquility, reflection, connection with nature
2. Peace, freedom, fresh air, connection with nature, very important to my mental and physical well being
3. A peaceful place where nature takes precedence, well detached from the surrounding industry, intensive agriculture or built-up areas. Also a line to follow through the landscape.
4. this looks like the kind of place I’d enjoy for frequent local walks - not taxing exercise but an easy way to get into the countryside
5. Opportunity for recreation
6. It is a nice pretty landscape which would be peaceful to be in. Walking would be a pleasure or perhaps canoeing.
7. Tranquil. Agricultural activities bordering the river - pastoral and arable probably not so good for walking, tree lined semi natural best.
8. It means peace and quiet, fresh air, opportunities for exercise and time away from a busy life in the city of Edinburgh.
9. Peaceful relaxing
10. Attractive, changeable and interesting to walk along riversides
11. Interesting pictures. I think you get very attached to 'your river' local to where you go. I would maybe avoid areas that had crops running by them and and livestock to avoid any disturbance and access areas I feel more welcome in?
12. natural. relaxing, active (movement and wildlife)
13. Rural, tranquil, away from noise other than wind/water
14. Nature and river environment means a lot to me and my family. It is a great place for long walks, camping trips as well as sanctuary where I can sit in silence, meditate and reflect on my life. I feel very connected with nature through rivers as they are particularly important to us all.
15. Place to relax, spend time, unwind and be with nature.
16. These particular rivers are rather too pastoral or almost domestic for my taste, so they’re the kind of place I might visit for a short outing with less active friends or in mediocre weather. My taste in countryside and in water environments is more for drama and dynamic water flow,
17. Real Natural beauty Restorative
18. Peaceful, relaxing
20. Peaceful
21. farmland. might try walking here when crops harvested or with dog on lead. work outdoors as a water sampler so looks like a place I would visit for work.
22. Peace and quiet, a place to escape and recharge, tranquil
23. Moving water is an enhancement to any environment; I find restful in a tranquil in moderate flow to exciting and exhilarating in strong flows
24. I feel at home beside water - it is calming yet constantly changing, the same yet always different.
25. My identity is rooted in the natural environment. Without this connection to and with nature I am not fully connected to my own nature as a human being.
26. Somewhere to spot good wildlife and flowers, or to have adventures on or off the water
27. Connection with nature and reminder that life is ever changing
28. I love to be out of doors in the natural environment. It is where I feel alive. It restores a feeling of wellbeing
29. My enjoyment of these areas is lessened by the proximity of intensively managed farmland and the narrow and often discontinuous riparian strips - potentially reducing the abundance of wildlife.
30. I"m a beekeeper/beekeeping promoter: rivers are bees' (and pollinators) highways and routes for investigating forage/recolonisation. I've been keeping a week by week record of the blossoming (or pollenning, depending on species) of forage plants, so a walk by our local river lets me update my records, anticipate changes and plan for management of my colonies. A river walk is also amazingly restorative - as a 24/7 carer for my partner, it gives me a precious stress-free time to myself.
31. Somewhere peaceful, restful and a nice place to be
32. The pictures of this environment is man managed, and 'gentle'. It lacks the passion and forceful nature rivers often have.
33. Productivity, freshwater ecosystem processes, relaxation, connectivity with nature, restoration
34. Having started to fill in this questionnaire, I put everything I think about rivers in answer to this first question. It was only when I went on to the next page and realised that the photos are meant to represent different river environments that I understood what you are getting at! I think you need an explanatory page BEFORE you start asking the questions, otherwise people will get pissed off when they realise they have misunderstood, and not complete the survey, just like I was about to before I decided to write this comment! In relation to the above pictures, to me they represent lowland rivers in (mostly) agricultural settings, where I would go for recreation and peaceful enjoyment..
35. Calm
36. Calming, an escape. Peaceful, tranquil
37. Fresh air and freedom.
38. relaxation, stress release, health benefits
40. With out fresh water there can be no life! For me river ecosystems are everything, and I have dedicated my life to sustainable use and equitable access to clean water for all.

41. peaceful and natural - escape.
42. peace, relaxation, family, fun
43. Some where to escape the pressures of work and life.
44. Relaxing
45. Peace; space; wildlife; nature; fun; adventure; health
46. Too agricultural for me to regularly choose to go there
47. tranquil, dynamic, relaxing, always changing, somewhere to enjoy a break from the stress of life, watch wildlife

48. Nature and wildlife - running water is calming. Looks like a perfect destination on a walk or to relax in.
49. It’s just as important to me to walk rivers as well as hills, woods or coasts.
50. Space, energy, well being

52. An ever changing experience with water flow and wildlife constantly changing and you never know what you are going to see round the next bend. I also love the scents and sounds of the water.

53. Landscapes such as this have nostalgic meaning to me, as I frequently swam in rivers as a child with siblings and cousins while my grandparents read and called us out for sandwiches or suncream application.

54. Biodiversity
55. The impact it has depends on the mood I am in, the weather, season, situation (either alone, with a dog or company such as family members). The sound and movement, signifying its synergy with nature, weather and seasons makes it a living entity that gives companionship, comfort, awareness, alarm (if in spate). It is an oxymoron, a constant that is an ever-changing entity that supports an aquatic life source, I respect it

57. managed, route to sea, home to some wildlife, recreation
58. Quite place to think and walk.
59. Essential living and moving part of our natural heritage. Places of peace and recreation and barometers of environmental health.

60. I find it mentally beneficial as well as a place of discovery for various species found at river habitats.
61. The rivers are attractive but they are not very wild
62. Open land for relaxing times but nothing too adventurous.
63. I like the wilder parts of rivers where the ionic cleansing ability helps me regenerate and think The varied sounds of moving water and surround landscape give me rhythms to work to and make music and poetry Personally I would avoid heavily farmed areas because of agricultural sprays but walking along a waterway lets me develop stories, practice timing and offers me sound bytes to include

64. Re-charging the batteries from the stresses of everyday life.
65. I would generally limit when I go to farmland areas as I walk with a dog
66. Peace, nature, wildlife

cxxiii
67. I would be drawn to the water, and wish to walk along the banks. The farmed landscape can often mean the banks are inaccessible though.

68. A beautiful place where you can experience nature in all seasons.

69. Fish - the mysteries of what might be present and the challenge, possibility and pleasure of trying to catch one and, occasionally, being successful. Even when not fishing (which brings a special closeness) but just walking or being there, the life and wildlife that is to be found on and near them... the constant movement and scale of the processes at work.

**Landscape Two: Amenity land**

1. Ambience
2. another local-looking walk where I could take younger relatives to get them active in the out doors
3. Structured events such as parkrun
4. Tranquil, beautiful, managed river bank
5. nice to walk in but very cultivated and with a lower feeling of naturalness. It would be a nice place to be in if it were a town or city.
6. It has the benefit of some open, green space - most likely fairly close to or within more urban surroundings. It is not as beautiful, untouched or natural as a more rural setting but brings benefits nonetheless to people and wildlife.
7. More urban and so less attractive for people like me who live in the countryside anyway. However these riverbanks are easier to access
8. Paths and facilities make this feel like a more welcoming environment. Many people don’t like the feeling of getting lost or feel unsafe being secluded. This be a nice place to go and have your lunch break. I am always disappointed by how much dog waste is left in areas like this.
9. managed amenity land, more people, not so relaxing
10. Heavily managed for access and "comfort"
11. As 2 above; pleasant but not very engaging river scenes.
12. Brings well being Easier to access
13. It reminds me of the River Mole in Surrey. That’s the first river I studied seriously, long before I knew the words fluvial geomorphology. My family lived nearby and I went to school in Mickleham, following the Mole Valley to get there everyday. I first became interested in landscapes there when I heard the story of the sinkhole behind the village hall. Later I took fieldtrips there. I still feel I know every bend in the river. My parents’ and grandparents’ ashes lie beside the river. Therefore it represents personal history as well as geological time.
14. Natural
15. looks very accessible to everyone
16. Quiet and peaceful, easy place to walk and enjoy nature
17. Too suburban, would wander either up or downstream to find wilder areas
18. Same as previous answer. I have failed to see the difference between Q2 and Q3
19. Nice for a non-extreme adventure, to get fresh air and see some wildlife without having to travel to far. Somewhere you can access for a small bike ride or a jog.
20. Useful for dog-walking away from livestock
21. See previous comment!
22. Less natural but more accessible and likely to be close to built-up areas. Seeing wildlife here would be a welcome bonus.

23. It’s the main route on foot to the bus and shops! When I used to commute, a wonderful peaceful way to start the day’s work, and to calm down again afterwards. Did a bat count close by, which gave some of the highest number of bat calls in Scotland - so it’s good to feel right at the heart of a thriving ecosystem right in the town.

24. slightly less peaceful potentially but still worth visiting

25. The pictures are even more managed. This is an environment I would feel more comfortable walking in than the previous one as it is obviously managed for people. I would expect some wildlife experience here too.

26. Peaceful, relaxing

27. These seem to be lowland rivers in slightly more managed urban situations. If I lived in one of these places, the river would be a huge source of enjoyment, peaceful contemplation and wildlife watching. Whenever I find myself in a city, I make for the river if there is a walk way alongside it!

28. Pretty

29. Greenspace for city and town dwellers.

30. While I appreciate the landscaped areas with furniture are necessary for some to enjoy this landscape, it slightly spoils the natural landscape for me.

31. walks with my daughter

32. Family friendly

33. a quite and peaceful area to enjoy the outdoors.

34. Too much of man’s influence creeping in, slightly artificial - but holds some peace and calm

35. crowded, to easy to get to

36. More controlled but still for escapism.

37. Fresh air; space; lunchtime walks

38. Accessible, tranquil

39. a place to visit with friends or family or to take a break whilst in town

40. If there is water is my local park I will gravitate to it for birdlife. It gives some indication of how healthy the river is and can often be a nice surprise. I have seen goosander and dipper on the Kelvin in Glasgow.

41. Open spaces with greater opportunities for mixing with people, for picnics or other activities.

42. A more sculpted landscape, I associate it this more with recent memories or walks with friends living within big towns/cities.

43. Peaceful

44. I travel a lot so look for a river or shoreline walk to experience the destination and its nature, with that comes all or some of the things you are researching above. Each rive has its own story and pace, unique and worth exploring.

45. Important. Dog walkers likely to come here so I would prefer to be elsewhere. Paths straight.

46. as before just a bit more so

47. A bit more tame. Probably more crowded so less appealing

48. More industrial / more human intervention
49. Rather tame and domesticated.
50. Again if overmanaged it does less for me but can still be a rich walk and good for mental health. My locality spray herbicide so sometimes I have to avoid areas.
51. Invariably kicking a ball with my family or walking the dog.
52. Parks and gardens are nice to walk in.
53. Accessible nature, time out.
54. These look like pleasant greenspaces within a more populated area, so would be drawn to these.
55. same as in 2.

**Landscape Three: Felled Woodland - Services**

1. more managed, less naturalised,
2. *some of these pictures look very much like my local river walks - sometimes difficult to navigate through the undergrowth*, but full of interesting plants and potential wildlife encounters.
3. Difficult walking, frustrating.
4. *Some of it is disturbed and difficult to access on foot.*
5. It look like all of them suffer from poor and insensitive management, the upper two look like vey modified rivers, almost canalised. The lower two are nicer with a stronger sense of naturalness, though the bottom right might improve if left to regenerate naturally.
6. This is rather an odd category as I wouldn’t go to see or experience felled woodland specifically, but I may come across it on occasion while in the outdoor environment. I know that felled woodland creates 'large woody debris' in rivers which brings benefits to wildlife.
7. I work for a river charity and see management of rivers in these images - although they do not look attractive they are probably more biodiverse and better for nature.
8. Part of the environment looks degraded through forestry operations.
9. These look like more managed sites which may be harder to walk through. I would go here for work reasons or if I was exploring a new area / looking for a particular species?
10. Disturbed landscape, not so easy to walk/wander through, not so attractive at this stage of its management.
11. Too managed and destructive. Typical land and woodland management that is imposed by certain regulations and H&S considerations.
12. Barring the third, these are messy interim riverscapes with the scars of woodland management. I don’t quite see what you’re aiming to achieve with these.
13. Less attractive Difficult terrain Private property?
14. Change. Everything changes. Nothing changes. When I was born my Grandad planted a seedling copper beech. When my parents got their first garden just after the war my tree was planted there. When I was six the tree and I were the same height. I believe the people who bought my parent’s garden after their deaths have felled my beech but I have a seedling from it, in a pot and ready to plant out on my croft when other trees and shrubs are big enough to give it some shelter. In surrey the beeches survive on the thin chalk soils. Here it will have to cope with waterlogging and salt winds. Growing up in SE England but now living in rural Caithness, I’ve gone from
the most wooded county to one that has very few trees. On my croft I have planted woodlands, partly for shelter, partly because I love trees and missed them. I'm struck by how slowly trees grow on my North Sea cliff top and am shocked by how overgrown many suburban areas in SE England now are. I recognize the need for pruning and felling. On the other hand I like the creation of new wooded environments, collect seedling sycamores that my southern relatives regard as weeds and carefully grow them on until they are big enough to plant out in tubes or spiral shelters. I was delighted when my first tree here got to be taller than me. I know your survey is about rivers but it was the trees that prompted my thoughts for this answer.

15. dog walking opportunity
16. The addition of wood in or surrounding the stream is a further enhancement and gives so many opportunities for wildlife that these areas are always worth careful observation
17. Same as previous two answers. The biodiversity will be enhanced by the dead wood
18. Difficult to navigate. somewhere you come across whilst exploring other habitats
19. I don't understand what's happening here, whether it's a 'good' thing or 'damaging to the environment'
20. Probably a better are to examine for wild flowers and interesting plants. Therefore worth studying quite closely.
21. Bottom left looks natural cf the other 3 - which affects my value judgement.
22. It's ambiguous, and depends on the reason for felling: trees die and need to be removed; poor-environment conifer forestry is harvested, which leads to open ground which often (for a few years) yields large amounts of nectar forage from rosebay willowherb, foxglove, heathers, dandelions. Conifer forests are being felled here - replanting included public consultation, and will apparently largely be native woodland - so that's welcome. But seeing native trees felled for no good reason is sad - especially in a very wet area lie ours, where trees would stabilise riverbanks and be a flood prevention measure.
23. clearly less peaceful and less attractive, but still with merit in terms of getting outdoors
24. Seeing landscape managed in this way is both encouraging and worrying. I value the opportunity to explore these environments, rather than being 'led'. However, I would look carefully at how they are managed, especially the water ways, and be sad in some cases.
25. Pictures 2 and 3 mean ecological recycling, 4 is productivity/jobs and 1 poor riparian diversity
26. There seem to be more management going on here, except in the lower left picture - which looks like natural tree fall/dead wood accumulation. I'd tend to avoid places where recent clear-felling etc. had been done, because its wholesale disruption of the environment is disturbing (to me and the wildlife that lives there) and annoying (to me - I can't speak for the wildlife!). I’d happily visit the lower left picture though.
27. Sad
28. Regeneration, New life
29. While woodland management is of course necessary, the appearance makes the river less inviting and appealing.
30. deforestation, these pictures make me feel sad
31. Most pictures say 'not for you' (for land management)
32. Deforestation of riparian zones is a terrible practice, but should be understood better as I’m sure the practice is not going away any time soon.
33. insignificant and not nature showings its in charge
34. destruction
35. In some ways seems devastated - but being outside always has a spark
36. Management; habitat;
37. Managed river restoration
38. a place with potential wildlife interest or wildness which I might stumble upon and explore on my own but not necessarily choose to visit
39. Any waterways can surprise you with the life they hold so it's always worth taking a look.
40. Sometimes can be atmospheric but often quite ugly. Sad to see trees felled for no good reason.
41. I appreciate managed landscapes/forests for their social and ecological value (job creation, biodiversity).
42. It has potential
43. This is my local environment, on an estate with lades that feed 2 dams but no river. It has cycle paths (no mentioned) and Core Paths for walking. We also have Drove Roads (cultural heritage) that led animals to market (cattle, sheep, geese) they needed over-night watering stops so essential that these were linked to access to water sources.
44. Tree felling makes me sad so it physically hurts. I don't seem it out but in some places I walk regularly trees have been felled. I hate it.
45. clearfell photo is destructive, top right more sympathetic
46. My place of work and the perfect combination - woodland and water!
47. I find this habitat completely encompassing. Away from people and the biodiversity that can be found in these areas are exciting and awe inspiring. I feel happy and mentally at peace.
48. Pictures show established management practices / might not be perceived by some as a natural or beautiful environment
49. Manmade and unattractive.
50. Clear felling hurts to be in, I feel the plants disruption Selective felling is ok
51. I work in forestry so this looks more like my work environment so I would go here to work or to talk to others about my work
52. Interesting habitat, peace, nature, wildlife
53. I would be curious to explore, but access might be difficult due to the fallen timber. It would be a more playful place rather than one to walk in.
54. Not the same attractions as a specific destination as those with fish and scale but nevertheless offering something else in terms of the life supported. While learning may not be a reason in itself, there is always something to be learnt just walking and poking around in nature.

**Landscape Three: Felled Woodland – management and emotions**

1. more managed, less naturalised,
2. some of these pictures look very much like my local river walks - sometimes difficult to navigate through the undergrowth, but full of interesting plants and potential wildlife encounters

3. Difficult walking, frustrating

4. Some of it is disturbed and difficult to access on foot

5. it look like all of them suffer from poor and insensitive management, the upper two look very modified rivers, almost canalised. The lower two are nicer with a stronger sense of naturalness, though the bottom right might improve if left to regenerate naturally..

6. This is rather an odd category as I wouldn't go to see or experience felled woodland specifically, but I may come across it on occasion while in the outdoor environment. I know that felled woodland creates 'large woody debris' in rivers which brings benefits to wildlife.

7. I work for a river charity and see management of rivers in these images - although they do not look attractive they are probably more biodiverse and better for nature

8. Part of the environment looks degraded through forestry operations

9. These look like more managed sites which may be harder to walk through. I would go here for work reasons or if I was exploring a new area / looking for a particular species?

10. Disturbed landscape, not so easy to walk/wander through, not so attractive at this stage of its management.

11. Too managed and destructive. Typical land and woodland management that is imposed by certain regulations and H&S considerations

12. Barring the third, these are messy interim riverscapes with the scars of woodland management, I don't quite see what you're aiming to achieve with these.

13. Less attractive Difficult terrain Private property?

14. Change. everything changes. Nothing changes. When I was born my Grandad planted a seedling copper beech. When my parents got their first garden just after the war my tree was planted there. When I was six the tree and I were the same height. I believe the people who bought my parent's garden after their deaths have felled my beech but I have a seedling from it, in a pot and ready to plant out on my croft when other trees and shrubs are big enough to give it some shelter. in surrey the beeches survive on the thin chalk soils. Here it will have to cope with waterlogging and salt winds. Growing up in SE England but now living in rural Caithness, I've gone from the most wooded county to one that has very few trees. On my croft I have planted woodlands, partly for shelter, partly because I love trees and missed them. I'm struck by how slowly trees grow on my North Sea clifftop and am shocked by how overgrown many suburban areas in SE England now are. I recognize the need for pruning and felling. On the other hand I like the creation of new wooded environments, collect seedling sycamores that my southern relatives regard as weeds and carefully grow them on until they are big enough to plant out in tubes or spiral shelters. I was delighted when my first tree here got to be taller than me. I know your survey is about rivers but it was the trees that prompted my thoughts for this answer.

15. dog walking opportunity
16. The addition of wood in or surrounding the stream is a further enhancement and gives so many opportunities for wildlife that these areas are always worth careful observation

17. Same as previous two answers. The biodiversity will be enhanced by the dead wood

18. Difficult to navigate. somewhere you come across whilst exploring other habitats

19. I don't understand what's happening here, whether it's a 'good' thing or 'damaging to the environment'

20. Probably a better are to examine for wild flowers and interesting plants. Therefore worth studying quite closely.

21. Bottom left looks natural cf the other 3 - which affects my value judgement.

22. It's ambiguous, and depends on the reason for felling: trees die and need to be removed; poor-environment conifer forestry is harvested, which leads to open ground which often (for a few years) yields large amounts of nectar forage from rosebay willowherb, foxglove, heathers, dandelions. Conifer forests are being felled here - replanting included public consultation, and will apparently largely be native woodland - so that's welcome. But seeing native trees felled for no good reason is sad - especially in a very wet area lie ours, where trees would stabilise riverbanks and be a flood prevention measure.

23. clearly less peaceful and less attractive, but still with merit in terms of getting outdoors

24. Seeing landscape managed in this way is both encouraging and worrying. I value the opportunity to explore these environments, rather than being 'led'. However, I would look carefully at how they are managed, especially the water ways, and be sad in some cases.

25. Pictures 2 and 3 mean ecological recycling. 4 is productivity/jobs and 1 poor riparian diversity

26. There seem to be more management going on here, except in the lower left picture - which looks like natural tree fall/dead wood accumulation. I'd tend to avoid places where recent clear-felling etc. had been done, because its wholesale disruption of the environment is disturbing (to me and the wildlife that lives there) and annoying (to me - I can't speak for the wildlife!). I'd happily visit the lower left picture though.

27. Sad

28. Regeneration, New life

29. While woodland management is of course necessary, the appearance makes the river less inviting and appealing.

30. deforestation, these pictures make me feel sad

31. Most pictures say 'not for you' (for land management)

32. Deforestation of riparian zones is a terrible practice, but should be understood better as I'm sure the practice is not going away any time soon.

33. insignificant and not nature showings its in charge

34. destruction

35. In some ways seems devastated - but being outside always has a spark

36. Management; habitat;

37. Managed river restoration
38. a place with potential wildlife interest or wildness which I might stumble upon and explore on my own but not necessarily choose to visit
39. Any waterways can surprise you with the life they hold so it’s always worth taking a look.
40. Sometimes can be atmospheric but often quite ugly. Sad to see trees felled for no good reason.
41. I appreciate managed landscapes/forests for their social and ecological value (job creation, biodiversity).
42. It has potential
43. This is my local environment, on an estate with lades that feed 2 dams but no river. It has cycle paths (no mentioned) and Core Paths for walking. We also have Drove Roads (cultural heritage) that led animals to market (cattle, sheep, geese) they needed over-night watering stops so essential that these were linked to access to water sources.
44. Tree felling makes me sad so it physically hurts. I don't seem it out but in some places I walk regularly trees have been felled. I hate it.
45. clearfell photo is destructive, top right more sympathetic
46. My place of work and the perfect combination - woodland and water!
47. I find this habitat completely encompassing. Away from people and the biodiversity that can be found in these areas are exciting and awe inspiring. I feel happy and mentally at peace.
48. Pictures show established management practices / might not be perceived by some as a natural or beautiful environment
49. Manmade and unattractive.
50. Clear felling hurts to be in, I feel the plants disruption Selective felling is ok
51. I work in forestry so this looks more like my work environment so I would go here to work or to talk to others about my work
52. Interesting habitat, peace, nature, wildlife
53. I would be curious to explore, but access might be difficult due to the fallen timber. It would be a more playful place rather than one to walk in.
54. Not the same attractions as a specific destination as those with fish and scale but nevertheless offering something else in terms of the life supported. While learning may not be a reason in itself, there is always something to be learnt just walking and poking around in nature.

**Landscape Four: Floodplain lake and lowland wetland**

1. beautiful wetland habitat, I could spend all day here
2. managed environment, not that asthetic but good for walking the dog
3. managed/created, mostly looks nice
4. similar to previous comments, highly modified landscape and water courses. They feel unnatural (possible exception of bottom right and top right)
5. This environment is valuable in what is likely to otherwise be dominated by agriculture and urban landuse. Personally I gain more inspiration and enjoyment from more upland environments however.
6. Very urban and altered by human landscapes
7. Man made

xxx
8. Wetland areas, maybe not so beautiful to me, but interesting in terms of the wildlife you might be able to spot, dragonflies, birds, cotton grass, etc.
9. tranquil, wildlife activity
10. Attractive although managed, but it could be managed better for the environment in general
11. 1 is overmanaged; 2 looks like a moderately intriguing semi-natural habitat; 3 & 4 are rather domestic for my taste.
12. Looks as though wellingtons would be needed!
13. I’ve created a stream in my garden and dug over an acre of ponds and scrapes in the low part of my croft looking a bit like your top RH photo. I wake up to it every morning. So many birds have come here since I dug the ponds and swans visit occasionally. I love everything about water in the environment. The most magical bit in my own patch of land is when I see the moonlight reflecting across my garden pond, my croft ponds and across the sea. I bet I’m the luckiest of your respondents.
14. looks like it would be good for dragonflies
15. Heavy modification, a loss of wildness, a lost opportunity
16. Like the previous three it is water so the previous answers apply. It is less interesting than a river with strong currents but will have a different set of flora and fauna.
17. Good for bird spotting. The canal through Inverness is good for a gentle cycle.
18. A relaxing and peaceful place to walk
19. 2 on the right look like they’d support more wildlife. 2 on left are highly modified/ canaled which detracts from their visual appearance.
20. More of a manufactured look to the environment but likely to offer some good bird watching, so best visited in small groups, operating quietly.
21. See earlier comments. Our area floods every few years - adds excitement to the winter, as well as sadness - but it’s life affirming to see devastated areas recover and bloom.
22. These show areas that are likely to be very high in biodiversity and wildlife watching opportunities. I would visit these for this specific reason, as well as physical activity such as walking.
23. These look like more artificial water bodies, canals, fishing lochs etc. I’d still go there, but wouldn’t find them as exciting as a wild river. Personally I don’t do fishing, or writing poetry etc. but there would still be wildlife to watch. (I don’t include this as 'learning or teaching about the environment’ - I observe wildlife in order to have a personal relationship with the environment, not to be educated!).
24. Kind of boring
25. Sanctuary for birds and wildlife.
26. I find these flatter landscapes a bit boring to be honest.
27. Agricultural runoff is a major issue in my home state of Ohio here in the U.S. It is also often the scenery I will see when floating the local watersheds.
28. too much man made control of nature and too calm
29. Again being outside - has a unique experience everywhere
30. Beautiful, managed
31. a tranquil place where I might walk my dog along a path or look for wildlife
32. Canals are frequent features of walks closer to my home in Glasgow. The top right picture reminds me of Lochwinnoch and Baron’s Haugh, where I visit frequently for walking / birdwatching.
33. Fantastic habitats for watching wildlife and enjoying wild flowers. Very beautiful and natural environments that connect me to ancestral pasts.
34. I would be more likely to kayak in this environment than walk. Vast and open landscapes like this remind me more of East Midlands than Scotland.
35. Biodiversity
36. As before, cycle paths or walking
37. I walk a lot along canals with my dad. I walk a lot at a local reservoir. When you go to these places a lot you find beauty even when it seems bleak or drab.
38. Lowland wetlands. Not so appealing
39. Good opportunity for bird watching
40. This is showing rivers/waterbodies in a more managed landscape e.g. drainage channels in fields/ canals / fishing lochs.
41. Open space and tranquil, but not overly exciting.
42. I enjoy watching biodiversity letting nature gather round me and learning
43. Peace, nature, wildlife, birds
44. These look like places to explore nature along the unmanaged edges - more to stand and look rather than walk
45. Wildlife (especially bird-) watching takes over from fishing as the main attraction. Photography more likely to feature as a motivation (I’m not otherwise artistically creative)

Landscape Five: Cultural Heritage Feature

1. it’s always interesting to see old industrial buildings in unexpected places - who lived and worked here? Intriguing
2. Industrial
3. Man made structures, industrial uses - rivers are very useful to us and have been for centuries
4. more complicated waterscapes with clear cultural references of various types. Probably interesting places to walk around and I would enjoy the buildings and artefacts.
5. Heritage brings an added dimension of interest to ones experience of a riverine environment. In that respect I find it valuable.
6. These are more attractive human additions to the rivers- although modern buildings offering the same functions probably wouldn’t be so pleasant to look at.
7. Interesting industrial heritage, impact on the natural environment
8. More urban environments are not what I would naturally seek as areas of solitude, but can provide a haven for wildlife and peace and quiet in the city. These environments usually provide a story of previous use and provide an interest or connection to the importance of water in the past and how things have changed in terms of use, ownership and pollution.
9. Interesting cultural heritage
10. Pleasant use of existing cultural features, historical background
11. I is the Hermitage so much more my kind of river environment - drama, geological interest etc. ‘Cultural’ interest not very strong, perhaps over-familiar, I go there reasonably often in passing. Others are interesting from a cultural rather than a landscape point of view, but are rather what I might describe unkindly as lowland/English type river scenes - low-velocity, historic heritage sites. You make me realise how much I value flow and movement in my river scenes (and preferably hill or mountain settings).

12. Find industrial landscapes rather ugly

13. Memories of places like these that I know - meltwater in a Highland Glen or a Welsh mountain valley, the stepping stones across the Mole at Box Hill (and I've some across one of my garden ponds), the way industrial constructions mellow into their riverside environments, thinking particularly about mills in Yorkshire and the waterwheel in Dunbeath. I'm building myself a new career (I always wanted to be an artist, but my Mum and Dad thought I'd have a more secure career as a geographer) interpreting landscapes in silk and thread that reflecting on the words I find in the local literature where the place has inspired writers and poets.

14. industrial, historical, interesting and fun (stepping stones)

15. Connection with people and history

16. The images are pleasing as the man-made structures appear to fit with the river rather than modify it, the river still holds sway

17. Sites of interest I may come across on a bike ride that make you stop and wonder about

18. Human influence on nature

19. The conundrum of places with human artefacts looking more attractive! Clear signs of human activity - but +/- historic and at least 2 of the rivers are otherwise quite natural looking (and pleasing).

20. I always find historical sites interesting and educational.

21. This used to be my work, it's good to go back, and to enjoy the feeling that others have been here before.

22. Man culturally manages these landscapes and whilst they are not displeasing to walk through, and will have some wildlife value, they will mostly be for exercise for me. However, reflection on historic use is always interesting - especially how we have now cleaned up our rivers.

23. These pictures show rivers in their interactions with humanity, whether as a source of power for industry, or as barriers to be overcome by bridges or stepping stones. I like to visit industrial archaeology sites (e.g. Finch Foundry or New Lanark) and see how important water was as a source of power before fossil fuels came on the scene.

24. Variety interesting scenic (except for the block of flats)

25. Heritage, important local and regional history.

26. I quite like the juxtaposition of built heritage to the river and enjoy exploring such places.

27. Human history cannot be separated from rivers, and should be celebrated! However, dams are incredibly harmful to river ecosystems and should be avoided in the future, while old ones are removed.

28. still too controlled by man for my liking

29. Things to look at - different forms and shapes to get lost in.
30. Cultural heritage.
31. A place with a range of interests that I might visit with friends from abroad or family when on holiday to enjoy and learn about.
32. Some of these scenes feel very Scottish to me and remind me of walks I have done at places such as Inverbervie, the Falls of Clyde, on Deeside and in the Cairngorm National Park.
33. Fascinating connection to our historic past and how people used to live and work. Also beautiful settings where you can enjoy wildlife and craftsmanship of structures.
34. Brilliant, love these scenes for cultural heritage lessons!
35. It has potential.
36. The sound that the water makes when captured or funnelled and released to produce energy is amazing. Seeing it action reminds me of the innovation and inspiration used to enable this. As a food product developer I enjoy this to create, being near to nature allows you and your brain to go back to what is essential to life on earth and water is this. We live on 'Planet Water', with the largest portion of the earth covered in water (not earth) and still so much to learn about this environment.
37. These sorts of places are interesting.
38. Again a bit busier although old bridges are nice points of interest when paddling.
39. These habitats, whilst attracting a higher number of people, show a way to our past and how we used to live. I find this interesting and can become engrossed, which helps take away the knowledge that more people are around me.
40. Rivers in more urban environments are perhaps more accessible to all.
41. Man influenced environment. Ok but not that exciting - although those do look the stepping stones at Lerryn!
42. Built heritage is not as interesting to me as natural heritage though sometimes it's part of paid work.
43. These look like places I would take friends and family.
44. Interesting history.
45. Human/visual interest.
46. The power and human interaction with water provides a different point of interest...and still there is the life within and around it.

Landscape Six: Reservoirs and Lakes

1. Not beautiful in itself, but the surrounds could be lovely - great place for light canoeing day out with friends.
3. These are quite variable because of the landscape character around each one. I like the landscape with more trees. All would be good to go sailing or canoeing.
4. Open space, fresh air and opportunity for exercise and enjoyment - especially kayaking and fishing.
5. Wide open spaces.
6. Often visitor centres attached to reservoirs/dams which are interesting to understand processes.
7. Reservoirs do not tend to be of natural beauty, but they provide some kind of comfort to me in their solitude. Quite often they are in remote locations that involve a long drive, walk or cycle to access and for that reason I have a fond connection.
8. recreational resource mainly, exposed not much shelter for 'sitting still' activities
9. Sometimes bleak and too uniform, sometimes good for wildlife
10. All reservoirs? 1 is a nasty concrete dam among dull hills, not interesting, 4 just a redundant trig from dam building I imagine, 2/3 pleasant but uninspiring.
11. Love water
12. Power There’s nothing on this scale local to me, hence my lower visiting response. Thoughts come to mind of Cruachan and other HEP schemes but now I’m thinking of the vision of people who have harnessed the resources of their landscapes throughout history. Near to me is The Great Dam of Ulbster, small on a national scale but a massive engineering undertaking for men with nothing more than shovels and perhaps a horse. Nearby there are equally impressive structures - the fort at Garrywhin, the brochs whose remains I see from my windows - so much of our 'natural' landscape has impacted on man as we’ve impacted on it.
13. looks remote. probably visit for work more than pleasure. Peaceful
14. Flat, bleak landscape, managed
15. Uplands, wild, high the start of things. Fewer agricultural pressures
16. Our Highland Reservoirs are rarely beauty spots with ugly drawdowns but our Natural Lochs are beautiful spots to camp, explore, spot wildlife and canoe on or cycle round
17. Not so accessible as other environments, but still enjoyable
18. Bigger, probably all modified water bodies/reservoirs. But some artificial reservoirs gain a significantly natural feel and support at least more tolerant of cold, deep, dark water wildlife - and can have interesting margins. Think Loch Tummel National Scenic Area. That said, some like the top left may be windswept and bleak.
19. A rather bleak environment offering less detailed interest in terms of botany or bird life.
20. Few opportunities due to distance and family commitments
21. Walking around larger bodies of water is quietening and can be quite spiritual. Wildlife will be different to faster flowing river systems so I might visit this environment specifically for some wildlife experience. I would also be encouraged onto the water by boat/kayak.
22. These look like reservoirs, where rivers have been dammed to provide power or drinking water etc. I feel sorry for rivers that have had this done to them, but I suppose we all have to drink. They can still be beautiful places and support some wildlife, but I hate the bare draw-down zones when the water level is low. (On the other hand, you can sometimes see the remains of old roads, villages etc, which have been drowned, which is interesting.)
23. Serenity peaceful calm
24. Calming, open countryside, peaceful. Listen to the wider world.
25. While I would always prefer a natural loch over a man-made reservoir I think reservoirs can also be beautiful.
26. Says 'not for you' (managed; potentially dangerous - dam)
27. Again dams are terrible, but have been viewed as a necessity for water storage as the human population has grown and we have become more reliant on agricultural production. However, the resulting lakes do provide much needed recreational opportunities for local people.
28. scenic and calm, but prefer rivers - they are alive
29. To be outside - because its outside
30. Hydro scheme
31. A place to enjoy with friends on a summer's day, have a picnic
32. These scenes remind me of walks I have done in the Clyde Murishiel Regional Park and in the Kilpatrick Hills.
33. The most accessible water environment to where I live. Some reservoirs can look more sterile and uninteresting. Luckily the ones near me have beautiful landscapes and attract a lot of wildlife. But there can also be conflict with activites like jetskis and wakeboarding that spoil the peace and quiet.
34. Familiar landscape to me for stocked fishing lochs.
35. Nothing - somehow large expanses of reservoir do little for me
36. My local environment, with heritage and cultural significance, SSI, bird watching
37. I do lots of walks around lakes. They make good circular walks.
38. Place to paddle.
39. Higher number of people attracted here, but great opportunity for possible eagle sightings amongst other species.
40. Personally, I prefer vast bodies of water (e.g. dams) - I also find the technology behind hydro power fascinating
41. Not a massive fan of reservoirs.
42. Reservoirs are exposed so not so comfy to be at In islands lakes are great places for wildlife and receded lakes are nice to walk round where orange tips gather
43. Accessible nature
44. Slightly bleak, the sort of landscape that would be dull in bad weather but more enticing in sunshine. The water looks more inaccessible.
45. The fish are back in the picture...and perhaps more trout/sea-trout than salmon in still waters. But also a fascination with the civil engineering involved in reservoir construction. And there is still that mystery of the life that lies beneath as well as that which surrounds Stillwater.

**Landscape Seven: Upland wetland**

1. a day out in the hills is always more interesting when it includes an upland river to cross or sit by.
2. good views, can be difficult to access
3. Upland semi natural rivers, open spaces.
4. upland areas which I presume are more remote. Tend to be natural water course, though the landcapes are still modified the sense of naturalness would attract me to these places. The noise of the water course would also be an attraction. They would make me feel calm and relaxed.
5. A highly valuable environment which is the sort of place I would chose to spend my free time if at all possible. Whether walking by rivers or looking down upon them from mountain tops, they bring me a 'feel good' factor that other more urban or lowland environments do not.
6. Rivers of a more natural look- although still managed and altered by human activity-ones I see on a daily basis
7. I love the uplands. Largely unspoilt by infrastructure and people, but balanced by their management, be it grouse moor, deer stalking, tree regeneration. They offer some of the best 'secret swimming' spots.

8. wild, remote, open and accessible

9. Wild open countryside inspiring calm

10. All more like my idea of a river, untrammelled, freer-flowing, informal, rock exposed in the bed - too small to inspire, running through what look like conventionally pastoral and probably overgrazed landscapes, but with at least the hint of wildness.

11. Now you're closer to home. Uplands. Headwaters. Where are the sheep?

12. looks remote, but beautiful. could be peaceful on calm days, but wild and exposed in bad weather

13. Wild, escape, empty of people

14. Juvenile rivers, clean, unspoilt, full of juvenile fish and masses of insects, wild.

15. Usually something you go through on most hill walks. great for plants and wildlife

16. Wilder and more upland and natural looking. Very little-no riparian strips that aren’t grazed flat. Would feel the need to plant some trees!

17. This is where I feel most at home

18. Good wild land atmosphere here where one may have an unexpected encounter with wildlife. Definitely raises the pulse walking in places like this.

19. Clean fresh air, changing view/environment, cultural understanding of ancient importance of springs and streams; they have an inherent liveliness that lower reaches lack

20. This is getting more like it. I value and cherish this environment, and although I might want to see some habitat diversity, I know that there is low man-input here. I am familiar with this type of environment and understand it and what it can mean to me. I feel priviledged to have this to enjoy.

21. These look like upland rivers, which are my uisge beatha (water of life, in Scottish Gaelic)! A peaceful (usually) or dramatic (when in spate) environment which intrigues and excites me. You don't include 'looking for/watching wildlife' in your set of reasons, but if I'm by a river I am always looking for otter spraint, watching out for dippers, kingfishers, goosanders etc, or even watching leaping or spawning salmon at the right time of year. This is one of my main reasons for going there. - Does natural history not count as 'culture'? - It it one of Britain's great cultural traditions! (This is a different experience from 'learning or teaching about the environment. It is about having a personal relationship with the river in question, and experiencing it in all its moods throughout the year. You should read 'Highland River' by Neil Gunn!) I know the catchments have been severely modified by human land use (e.g. loss of woodland, muirburn), but they are as close to 'natural as we are going to get in this crowded island.

22. Interesting calm peaceful

23. Wilderness, wild and rugged.

24. I prefer this more natural, wild environment.

25. 'Special trip' or holiday (as opposed to everyday)

26. Headwaters and wetlands are where it all starts! I love finding the source of the water!

27. wild and remote and alive, proper escapism
28. Wow! Just that feeling of outside
29. Beautiful wild
30. A place to explore on a day out or holiday to experience wildness and wildlife on my own or with family
31. This environment to me means BOG. I would take my gators with me on these walks. I wouldn’t be able to take my girlfriend or lass equipped walkers with me on these days out.
32. Exhilarating, rugged scenery. Often difficult walking but very rewarding. Great places for seclusion, atmospheric and wildlife.
33. Munro-bagging
34. Biodiversity
35. Travel to National Nature Reserves (NNRs), rural, remote, restful, peaceful, beautiful
36. I used to walk all the time on Dartmoor. These places are freedom even though they can be wild and bleak.
37. A place I spend much of my work life. Peaceful, solitary, vast and beautiful.
38. Less likelihood of seeing people and great to be out amongst nature. Normally found when I’m hiking up a mountain which gives a great sense of achievement and provides invaluable habitat for many species.
39. More rural, upland water environment - whilst I wouldn’t go for a walk particularly to visit a river like this, it is nice to look at
40. Wild, open, unspoilt and beautiful landscape
41. Peace, breathability
42. Peace, wildness, wildlife, geology
43. Appealing and ‘wild’ with informal access
44. This is about walking more than fish - though they can combine - and the wilder places in which these streams are set than just the waterscape itself (although it can provide intimacy and surprise as well the please of movement and refreshment on a hot day).

Landscape Eight: Urban Rivers

1. if forced to walk through a city I would gravitate to a path by water. often surprising wildlife in urban surroundings
2. Industrial, difficult to do much recreation
3. Urban rivers and canals - often nice in cities.
4. Urban waterways are a nice place to be in town and I would be attracted to them for the contrast with the other built up areas. They are not pretty or appealing ways to treat rivers however.
5. This is the sort of place that would be valuable to me in it’s urban setting, e.g. for a quick walk after work. However, given more time (such as weekends or holidays) I would prefer to experience rivers in a much more rural, upland and natural setting.
6. Very urbanised- unlikely to choose to go there, but when I lived in cities, I would have used them as the only option.
7. Urban therefore more accessible
8. Canals are very prescriptive, offering a destination. Can be very busy with commuters, dog walkers, families etc..Fine if in the city, but not heart and soul for me.
9. a pleasant route through populated area
10. Pleasant urban/suburban areas suitable for non-strenuous walking
11. Too urban for my taste, fair enough if I wanted a less fully urban route to walk somewhere (I use the Water of Leith in Edinburgh in this role) but not somewhere I would go for its own sake.
12. Likely to visit this type of urban river landscape
13. Far away from what I’m now used to. Urban. Industrial. Controlled. Chanelled. I’m taken back to walking beside the canal in Leeds and finding greenness beside water even in heavily industrialised places.
14. looks like a city. probably most interesting when in spate
15. Built & managed environment, urban & hard edged, unclean water
16. Totally modified, inaccessible, dangerous spiritless
17. Not somewhere I’d choose to go but might cycle through on a tour and be of interest to me as I am a freshwater ecologist
19. An attempt by humans to control nature
20. This environment tends to be closer to home and useful for local shorter walks. Wildlife in these areas remains an important element.
21. Means potentially interesting cultural heritage/industrial archaeology, but it wouldn’t be my first choice for recreation - though when it provides an alternative route to a destination (eg town etc) I would take a slightly longer route in these areas instead of just roads and pavements.
22. If there is no where else to go in a city/urban area, at least you know the water will give you some sense of place and feeling of something not totally concrete.
23. Urban rivers. If I am visiting a city I always head for the river, if there is a walkway alongside it. Water is always interesting and there is usually some wildlife to be seen. There are some lovely waterside routes through cities e.g. the Water of Leith in Edinburgh, and I would always choose to walk along them if it would get me to my destination.
24. Looks dirty would still probably have a wander down but it wouldn’t be my favourite too much concrete
25. While I understand the necessity of flood defences they often do create a visual barrier and disconnect with the natural feeling of a river. Perth is a rare good example of how well-designed defences can enhance the look.
26. Most scenic route to/from somewhere not a place to visit in itself.
27. Not a big fan of urban water ways. I’m not a big believer in command and control practices, and think we should be doing everything we can to reverse their legacy!
28. nature is an inconvenience - not for me
29. Very tamed - but when in a city escapism has to grabbed at every opportunity in order to keep one’s sanity!!
30. Urban river
31. nice to look out on water flowing and some greenery but not a very pleasant place to walk or escape to - too man-managed and artificial
32. Usually I would be on my way to something else rather than choosing to come here for walks or photography. Often busy with people, noisy and rubbish/litter in the waterways.

33. Commuting scenes opposed to recreational. High value culturally, though.

34. I avoid towns and cities as far as possible.

35. Town, city, urban, waterways, quays, industrial

36. I walk along canals with my dad. They are a symbol of where I am from but they are rarely pretty.

37. Too busy - not for me

38. Whilst not particularly attractive and does not make you feel like you are away from it all, it does provide excellent habitat for many species.

39. Although very urban, often these rivers have walkways alongside which are great for recreation e.g. running

40. Urban environment - not my favourite.

41. I live far from city so rarely encounter this to my knowledge

42. Dog walking

43. Not natural enough. Not great habitat

44. Not a big draw in itself but often the best the surrounding environment has to offer...and still there can be life (and surprises).

45. Artificial managed waterways - a lot of construction

**Landscape Nine: Waterfalls**

1. this is the sort of place I seek out when I’m stressed or need a bit of space to let my mind relax

2. Wild landscape

3. I like these semi natural fast flowing rivers with waterfalls, and in woods.

   Movement, spray, inspiring.

4. I’d enjoy the sense of drama and the noise of the waterfalls. They would be exciting places to be and I would want to get as close as possible to the water, perhaps to watch salmon leaping or the like. The strong feeling of naturalness would be compelling and I would want to linger in these places.

5. Very beautiful, peaceful, inspirational and highly valuable - it’s natural beauty at it’s very best.

6. Wild and wonderful- but possibly not that accessible

7. Attractive wooded/highland location

8. Waterfalls, enclosed tree canopy, mossy, lichens, migrating salmon, sunbeams.

9. invigorating, active, exciting environment

10. My kind of country, wild, un-spoiled, exhilarating

11. Much more my taste (though 2 are from the Hermitage again so that has social and cultural accretions from visits over many years, and I know the setting so I don’t see it as authentically ‘wild’ but as Romantic in the 18/19th century sense). These do appeal to my preference for informal quasi-‘natural’ water environments with a hint of hills and wildness.

12. Love waterfalls
13. These are scenes I see if I go south by road or train. I live in the lowlands beyond the highlands so I get to such places rarely these days. I suppose they are part of my background, familiar but now remote.

14. great place to walk

15. peaceful, calm, associate images with the sound of moving water - a positive experience, natural and wild, a place I would like to spend time

16. White water, steep banks, natural, noisy and exciting

17. Excitement

18. I'm pretty sure I recognize the falls in top left and bottom right as one of my local and frequent walks. the bottom left also looks very familiar! Great places. The surrounding land is modified but with sensitivity. Quite a lot of wildlife.

19. Fresh, untamed, natural, source

20. I always like to be close to water and to hear its movement. It has a feel good factor

21. Enjoy the water movement, the more adventurous wildlife you get here - feels peaceful despite the action

22. This is more like it. It may be difficult to access and walk along, but knowing it exists (intrinsic value) is good enough. This is our life source; it shows the forces of nature which cannot be harnessed (hydro's?) and will have it's unique wildlife associated with it. I find more spiritual feeling in places like this than any others, whether within woodland or not.

23. Waterfalls! Why are they so infinitely fascinating? The noise, the spray, the humidity, the dippers or grey wagtails nesting there? I love them, and often walk up my local gen to a couple of small but spectacular waterfalls. They are always different, depending on how much water is coming down. Ironically, it's called 'The Fairy Glen' but it doesn't need fairies to make it magical!

24. Just beautiful

25. There is something special about waterfalls, their dynamism entertains and excites.

26. This is where my heart truly lies!

27. nature left to its own devices – perfect

28. Because of the feeling of power!

29. Beautiful wild

30. beautiful wild natural rivers with wildlife unmanaged by humans, sounds of waterfalls, smells of woods and water, dippers' songs, salmon leaping, a place to lose track of life's stresses and talk to God

31. More quintessentially Scottish scenes. I would definitely be looking for dipper here.

32. Seclusion, beautiful and dramatic scenery, lots of wildlife. Get away from it all and feel at one with nature

33. Blowing away cobwebs, salmon spotting.

34. My kind of country

35. NNRs, sight-seeing destinations, powerful water, natures forces, untamed, wild, remote

36. I love rivers for their green ness and wildness.

37. This is completely away from everything. The kind of habitat you can get lost in and forget about daily troubles and stresses of life. Hear and surround yourself with nature, including the running of the water and bird song.

38. Fantastic, beautiful, peaceful, inspiring

cxlii
39. I find high energy river systems pleasing to look at
40. Cleansed Wild Beautiful Inspiring
41. Wildness, sounds of water, freedom, unspoilt landscape
42. Dog walking
43. a dramatic feature as a point of destination for a walk...and all other features of being beside water on the way to and fro. There's a limit though ......
44. Peace, nature and wildlife, adventure
45. Beautiful and uplifting

Landscape Ten: Woodland

1. perfect setting for a run through the woods with a buddy or two, or maybe alone with the dog
2. good access, good for dog walking, peaceful
3. Rivers in woods - nice. Forestry shades rivers and is planted too close. Have you heard of the Clyde and Avon Valleys Landscape Partnership - worth looking up their website as there is a lot of information on linking natural and cultural heritage around rivers.
4. These are nice woodland (except for top right plantation) they look like gardens with the paths and steps and I suspect would be pretty as a consequence. I would enjoy them and appreciate the paths to ease of access - perhaps for lazy days or with family.
5. It's valuable, peaceful and beautiful - a nice mix of woodland and water - the sort of place for family fun and adventures on a Sunday afternoon.
6. Lovely and accessible, peaceful
7. Managed for access, nice enough.
8. calming, close to woodland, water a feature rather than dominant
9. Very varied woodland landscapes, inviting calmness
10. Too mixed a bag to say anything very helpful. 2 & 3 are too formal and managed, 1 and 4 have the pleasing sense of pathless informality and 'naturalness' though they're very limited views so I don't have a sense of the wider setting.
11. Beautiful
12. On a grander scale than I see every day, but trees and water again. My favourite landscape elements.
13. another great place for a walk
14. Wooded but with sufficient light to keep the river interesting
15. Looks like a normal day at the office for a freshwater biologist and somewhere nice to travel through on an adventure
16. Much as last group but not so natural/ attractive.
17. Peaceful, calm, restorative
18. I always like to be amongst trees for a time in any walk. It creates a sense of wellbeing.
19. It means quiet, peace, echoing birdsong, solitude (due to limited long distance views) and a wide variety of wildlife
20. Less impressive, but it would still give a sense of wildness and although managed and 'led' a feeling of being away from human presence.
21. Woodland watercourses. They have the added bonus of trees as well as flowing water! Not so keen on the conifer plantation, top right picture, but I’d visit all of the others for a quiet walk and to observe wildlife. I suppose these environments appeal because they offer shelter, seasonal changes and the living interest of flowing water.
22. Peaceful interesting
23. There is also something special about a river flowing through beautiful, natural woodland.
24. I could use more of this in my life!
25. Ok for a quick nature fix
26. Pleasant and controlled
27. a lovely place to walk the dog in tranquil surroundings with the possibility of wildlife
28. These places are generally easier to access and are good walks for Autumn.
29. Pathways make it easier to negotiate the terrain and find your way allowing you to focus on the beautiful scenery and wildlife. The better the path though the more people, which can spoil your enjoyment and peace.
30. Gentle strolls. I appreciate the woodland/river mix
31. Biodiversity
32. Local environment that I explore frequently, most used and familiar for me, my outdoor home with nature
33. Green trees and woods by rivers are magical and peaceful. I went to a place I knew by the Plym when I was very stressed and stared into a deep pool for hours. Then a brown trout came into my sightline. I found it very soothing.
34. Bit wilder, more woodland, more peace.
35. Again, away to get away from everything. Nature surrounds you and troubles forgotten in that moment in time.
36. More natural setting with scattered trees (excluding the plantation)
37. Space Breath Opening
38. Fairly pleasant environment
39. Dog walking
40. This seems to about pleasant woodland walks and more about the trees and woodland wildlife than the water itself...although that adds life, sparkle and interest.
41. Peace, nature wildlife
42. Interesting off the beaten track - would like to explore these places, and walk the dog
Appendix Ten: River Ecosystem Service Long-profiles
(i) Protected Dee

![Graph showing area weighted ecosystem service score vs. distance downstream for various services including Water Supply, Agriculture, Timber, HEP, NFM, Climate Regulation, Water Quality, and River Corridor Area.]

- Water Supply
- Agriculture
- Timber
- HEP
- NFM
- Climate Regulation
- Water Quality
- River Corridor Area

- Aesthetic Value
- Social relations
- Inspiration
- Education/knowledge
- Cultural Heritage
- Spirituality/religion
- Recreation
- River Corridor Area

Reach Area (ha)

Area Weighted Ecosystem Service Score

Distance Downstream (km)
(ii) Unprotected Don

![Graph showing ecosystem service scores and reach area for the Unprotected Don river.]
(iii) Protected Thurso

A diagram showing the area weighted ecosystem service score as a function of downstream distance, with various ecosystem services including water supply, agriculture, timber, HEP, NFM, climate regulation, water quality, river corridor area, aesthetic value, social relations, inspiration, education/knowledge, cultural heritage, spirituality/religion, and recreation.
(iv) Unprotected Forss Water
(v) Protected Teith

![Graph showing Area Weighted Ecosystem Service Score vs Distance Downstream](image-url)
(vi) Unprotected Forth

- Water Supply
- Agriculture
- Timber
- HEP
- NFM
- Climate Regulation
- Water Quality
- River Corridor area (ha)

- Aesthetic Value
- Social relations
- Inspiration
- Education/knowledge
- Cultural Heritage
- Spirituality/religion
- Recreation
- River Corridor area (ha)
(vii) Protected Almond
(viii) Unprotected Earn

The diagrams illustrate the area-weighted ecosystem service scores over distance downstream for the Unprotected Earn. The graphs show data for various ecosystem services, including Water Supply, Agriculture, Timber, HEP, NFM, Climate Regulation, Water Quality, Aesthetic Value, Social relations, Inspiration, Education/knowledge, Cultural Heritage, Spirituality/religion, and Recreation. The reach area in hectares is also indicated on the graphs.

The upper graph focuses on distance downstream in kilometers, while the lower graph uses distance downstream in meters. The area-weighted ecosystem service scores are plotted against these distance metrics, allowing for a detailed examination of service distribution and changes over the river's length.