Mapping social and biophysical values of ecosystem services on a catchment scale: a case study of the River Cober catchment, West Cornwall

Submitted by Katrina Threadgill to the University of Exeter as a dissertation towards the degree of Master of Science by advanced study in Conservation Science and Policy, August 2015

I certify that all the material in this dissertation which is not my own work has been identified with appropriate acknowledgement and referencing and I also certify that no material is included for which a degree has previously been conferred upon me

Word count: 9967

Abstract

Environmental policies increasingly emphasise the need for natural landscapes to deliver multiple types of benefits, including biodiversity conservation, environmental sustainability, economic profitability and social values. One way of assessing the delivery of multiple benefits is through the concept of ecosystem services, which values nature according to the benefits that humans derive from ecosystems that contribute towards human wellbeing. In particular, social values (the non-monetary values perceived by people) of cultural ecosystem services are under-represented in the current literature.

Here, the social values of ecosystem services (aesthetic, agricultural, biodiversity, cultural, flood mitigation, intrinsic, recreation, tourism) and biophysical values of ecosystem services (agricultural productivity and flood mitigation) in the catchment of the River Cober, Cornwall, UK, are mapped and hotspots are identified using a combination of public participation GIS and remote sensing data. Most social value hotspots are situated in the south (downstream) of the catchment, whilst biophysical hotspots predominate in the north (upstream). Overlaps between social value hotspots of aesthetic, biological diversity, cultural and recreational services are identified, which correspond to the location of a Site of Special Scientific Interest (SSSI), suggesting the presence of a win-win scenario for ecosystem services and biodiversity conservation. A lack of overlap between hotspots of social and biophysical values of agricultural productivity suggests either a mismatch between the properties measured by social and biophysical values (heritage vs. productivity) or difficulties experienced by participants in mapping non-cultural services. No hotspots could be identified for social values of flood mitigation, intrinsic value or tourism.

It is argued that social and biophysical values of ecosystem services should be mapped to different resolutions in order to produce the most impactful data for management applications. Whilst the use of hotspot analyses in simultaneous social/biophysical ecosystem services assessment does risk undervaluing non-hotspot regions, it is a useful tool for facilitating the inclusion of social data into ecosystem services research and the integration of traditionally distinct epistemologies.

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List of Acronyms and Abbreviations

AGH – arable/grassland/heather land covers

AONB – Area of Outstanding Natural Beauty

ASTER – Advanced Spaceborne Thermal Emission and Reflection Radiometer

BAS – British Antarctic Survey

CBD – Convention on Biological Diversity

CEH – Centre for Ecology and Hydrology

CSF – Catchment Sensitive Farming

DTM – Digital Terrain Model

ESRI – Environmental Systems Research Institute

EU – European Union

IPBES – Intergovernmental Platform on Biodiversity and Ecosystem Services

LCM2007 – Land Cover Map 2007

L5 – Landsat 5

L8 – Landsat 8

LiDAR – Light Detection and Ranging

LULC – Land use/land cover

MA – Millennium Ecosystem Assessment

NASA – National Aeronautics and Space Administration

NDVI – Normalised Difference Vegetation Index

NIR – Near infra red

OLI – Operational Land Imager

OS – Ordnance Survey

PPGIS – Public Participation Geographic Information System

SolVES – Social Values of Ecosystem Services

SRTM – Shuttle Radar Topography Mission

SSSI – Site of Special Scientific Interest

TM – Thematic Mapper

TWI – Topographic Wetness Index

UK NEA – UK National Ecosystem Assessment

UN – United Nations

USGS – United States Geological Survey

UsT – Upstream Thinking

VR – Visible red

Author's Declaration

A range of primary and secondary data were used in this dissertation:

- Social value questionnaire data – all data collected by the author

- Tellus SW LiDAR Survey – data acquired by the British Antarctic Survey (Beamish *et al.*, 2014), made available by the British Geological Survey

- Landsat 5 TM and Landsat 8 OLI satellite imagery – data acquired by NASA/USGS. Data accessed by the author via EarthExplorer (USGS, 2015).

- Land Cover Map (2007) – dataset created by the Centre for Ecology and Hydrology (2011), using data from a range of sources (see Appendix 3)

All processing and analysis of these datasets for use in this study was carried out by the author.

Acknowledgements

Chapter 1: Introduction

This chapter introduces the concept of landscape multi-functionality as a central concern of conservation and land management, and suggests the ecosystem services paradigm as an appropriate framework within which the delivery of multi-functionality may be studied and achieved. It then relates these concepts to the ideas explored in this dissertation in the context of the River Cober catchment, West Cornwall.

As anthropological activities edge the Earth into the human-dominated epoch of the Anthropocene (Crutzen and Steffen, 2003; Steffen *et al.*, 2007; Zalasiewicz *et al.*, 2011; Smith and Zeder, 2013), it is becoming increasingly evident that human activities are driving habitats to extinction with extraordinary speed and reach (e.g. Kerr and Currie, 1995; Brooks *et al.*, 2001; Balmford *et al.*, 2003; Hoekstra *et al.*, 2005; Dobson *et al.*, 2006). Not only does widespread habitat destruction and degradation threaten biodiversity itself, but it also threatens the functions and services provided by nature which are critical for human survival and wellbeing (MA, 2005). Successful conservation and land management must balance the delivery of a suite of ecosystem-derived functions and services in the face of intense anthropological pressures.

Modern human-mediated landscapes need to deliver multiple benefits. Historically, the fulfilment of human development needs relied on extensive transformation and simplification of natural landscapes, such as through agricultural conversion and urbanisation (Palmer *et al.*, 2004; Foley *et al.*, 2005; Tscharntke *et al.*, 2005; Scherr and McNeely, 2007; Kellermann *et al.*, 2008; O'Farrell and Anderson, 2010; Meehan *et al.*, 2011). However, an increasing need and support for sustainable land management and policy is putting greater emphasis on the delivery of a wide range of functions to simultaneously achieve environmental, economic and social goals (Crossman and Bryan, 2009). Governments and economists are ever more aware of the long term detrimental consequences that the overexploitation of natural capital can have on future prosperity (Costanza, 1992; O'Riordan, 2004), and conservationists are increasingly aware of the need for empirical evidence of the importance of conservation for human wellbeing in order to promote conservation activities to governments, businesses and the general public (Rands *et al.*, 2010). Therefore, biodiversity conservation and environmental sustainability must be balanced against human demands on natural capital and ecological

systems. One conceptual framework that has been developed for addressing these concerns is that of 'sustainable multifunctional landscapes' (Brandt and Vejre, 2004; Kato and Ahern, 2009): "landscapes created and managed to integrate human production and landscape use into the ecological fabric of a landscape maintaining critical ecosystem function, service flows and biodiversity retention" (O'Farrell & Anderson, 2010: 59). Modern landscapes must balance human land use with the ecological functions; it is only by protecting this balance that human wellbeing can be safeguarded into the future (MA, 2005; O'Farrell and Anderson, 2010).

The ecosystem services concept is of direct relevance to landscape multi-functionality because it offers a means of quantitatively assessing the delivery of multiple benefits. Under the ecosystem services paradigm, multifunctional landscapes may be identified as those which deliver joint supplies of services (Mastrangelo *et al.*, 2014). Combining the concepts of multi-functionality and ecosystem services offers a scientific means of informing land management in order to maximise landscape-derived benefits.

This dissertation analyses a region in the south-west of Britain, the Cober catchment, West Cornwall, and identifies the spatial distributions of a diverse range of ecosystem services-derived benefits across the area. The extent of spatial coincidence between the distributions of different services is identified and discussed in relation to how these distributions can be interpreted to best manage natural resources.

Chapter 2: Literature Review

Chapter 2 reviews the current literature surrounding the concept of ecosystem services, with particular reference to the rationale and methodologies behind spatial assessments. Cultural services and perceived social values of ecosystem services are highlighted as under-represented in most ecosystem services research, and the merits and difficulties of alternative methodologies for their assessment are discussed. The river catchment is explored as an appropriate scale for land management and ecosystem services assessments. The chapter concludes by focusing on the specific research questions addressed in this dissertation in the context of the Cober catchment, West Cornwall.

2.1 The ecosystem services concept

Ecosystem services describe "the benefits provided by ecosystems that contribute to making human life both possible and worth living" (UK NEA, 2015). The ecosystem services paradigm establishes a framework in which nature is valued according to explicit links between ecosystems and human wellbeing. Recognition of the connections between the functioning of ecosystems and the delivery of vital services, such as the provision of water, the maintenance of soil fertility, and the regulation of climate, date back to at least the mid-nineteenth century (Marsh, 1864). However, it took another hundred years for the integration of ecosystem services concepts into mainstream environmental research to occur (Ehrlich *et al.*, 1977; Westman 1977; Ehrlich and Ehrlich, 1981; Ehrlich and Mooney, 1983). The ecosystem services concept rose in popularity from the mid-1990s (Costanza *et al.*, 1997; Daily, 1997), gaining widespread attention through the 2005 Millennium Ecosystem Assessment (MA, 2005), a huge collaborative report which became the cornerstone framework for the analysis of social-ecological systems. The ecosystem services perspective has since grown into a central field of ecological research (Norgaard, 2010).

The Millennium Ecosystem Assessment set out a framework for categorising ecosystem services into four main groups: provisioning, regulating, cultural and supporting services (MA, 2005) (Table 2.1). Whilst this framework has subsequently been adapted by individual organisations and projects (e.g. UK NEA, Mace *et al.*, 2011), and

Table 2.1: **The ecosystem services typology as established by MA (2005)**

Service	Definition	Examples
Provisioning	Services which produce or supply goods for human use	Food production, water supply, medicinal resource supply, fuel supply
Regulating	Services which regulate ecosystem processes of importance to human wellbeing	Climate regulation, flood mitigation, pollination, disease and pest regulation, erosion control, soil regulation
Cultural	Services which provide non-material benefits for human societies	Recreation, tourism, aesthetics, intrinsic value of nature, educational, cultural heritage
Supporting	Services necessary for the delivery of other services	Primary production, soil formation, nutrient cycling

subjected to much discussion and debate over definition and organisation (e.g. Boyd and Banzhaf, 2007; Wallace, 2007; Fisher *et al.*, 2008; de Groot *et al.*, 2010), the use of this four-group typology, or derivatives thereof, has remained the most common approach to ecosystem services research across the literature (e.g. Raymond *et al.*, 2009; Raudsepp-Hearne *et al.*, 2010; Vihervaara *et al.*, 2010; Tenberg *et al.*, 2012).

The ecosystem services concept is of particular interest to policy makers from a wide range of governmental and environmental organisations. The enhancement of ecosystem services and the promotion of biodiversity conservation in mainstream political discussions (much of which occurs through engagement with the ecosystem services concept) form major parts of the UN Convention on Biological Diversity Aichi Biodiversity Targets (CBD, 2015). The relevance of ecosystem services assessments to policy is further highlighted by the establishment of the Intergovernmental Platform on Biodiversity and Ecosystem Services (IPBES), intended to guide national and international governments towards strengthening the science-policy interface between biodiversity conservation and human wellbeing, via ecosystem services (Diaz *et al.*, 2015). Specifically, the quantification of ecosystem services can allow ecosystem-derived benefits to be considered in policy decisions, for example through cost-benefit analyses and scenarios exercises (Fisher *et al.*, 2008; Fisher *et al.*, 2009; Perrings *et al.*, 2011; Maes *et al.*, 2012). Policy makers are increasingly aware that nature-based solutions to many problems, such as flood defence and carbon sequestration, are vastly

more cost effective than technological alternatives (Daily and Matson, 2008; Ervin *et al.*, 2012). Ecosystem services assessment is an integral tool in modern land management and environmental policy decisions.

2.2 Spatial assessments of ecosystem services

Ecosystem services need to be quantitatively assessed if they are to be considered in land management decisions. The delivery of ecosystem services can be measured in a one-dimensional sense by accounting for natural capital and services in aggregate economic terms for a given geographical region of interest (Costanza *et al.*, 1997; Costanza *et al.*, 2014). However, ecosystem service delivery is highly heterogeneous across landscapes (Bennett *et al.*, 2009; Koch *et al.*, 2009; Bianchi *et al.*, 2010). By quantifying and mapping the supply of ecosystem services, targeted management policies can be implemented which allow for the fulfilment of multiple goals, including the simultaneous protection of both biodiversity and ecosystem services (e.g. Balvanera *et al.*, 2001; Daily & Matson, 2008; Goldman *et al.*, 2008; Polasky *et al.*, 2008; Eigonbrod *et al.*, 2009; de Groot *et al.*, 2010).

Early ecosystem services mapping exercises were limited to a narrow range of more easily measured services resolved to coarse scales (Sutton and Costanza, 2002; Naidoo *et al.*, 2008). Increasingly, advances in data acquisition and valuation techniques allow the value, location and extent of services to be mapped at finer scales (Tallis and Polasky, 2009). In particular, developments in remote sensing techniques have facilitated an expansion in abilities to assess ecosystem services in ways which are both cost effective and spatially explicit (Anayu *et al.*, 2012). Ever more products are becoming available, with data acquired from both air and space, which can enable relatively fast and frequent analysis and access to locations which might be inaccessible to ground surveys.

Remote sensing data can be applied to the spatial modelling of ecosystem services in various ways. Land use/land cover (LULC) has been used widely to estimate ecosystem service supply by assigning different service values to different discrete LULC classes (Costanza *et al.,* 1997; Li *et al.*, 2007; Hu *et al.*, 2008; Koschke *et al.*, 2012). LULC maps are generally developed by supervised classification methods of aerial photographs or satellite images using training areas of ground survey data. Typical ecosystem service

values from ground-truthed regions for each LULC class can be transferred to novel regions of the same class (Ayanu *et al.*, 2012). However, basic value-transfer approaches, which assume that ecosystem service value is a simple function of LULC class and geographic area, are particularly sensitive to scale-effects and tend to oversimplify ecosystem services supplies (de Araujo Barbosa *et al.*, 2015). More accurate and sensitive spatial mapping may be achieved by recognising the spatial intra-class variability of service delivery through integrating LULC information with biophysical measures of ecosystem properties and functions. For example, vegetation properties such as photosynthetic activity, of relevance to agricultural productivity, can be derived from reflectance measurements from multispectral sensors, such as those on board the Landsat satellite missions (Seto *et al.*, 2004; Gitelson *et al.*, 2008), and topographic data, derived from remote techniques such as laser scanning, can be used to derive models of hydrological flow to inform patterns of biophysical water regulation (Power *et al.*, 2005; Huang *et al.*, 2011). Incorporating functional and mechanistic models into ecosystem services mapping, alongside LULC information, could help to increase the accuracy of assessments.

2.3 Social values of ecosystem services

In order to achieve comprehensive assessment across all four categories of the MA typology, a diverse range of research techniques and expertise from across the physical, biological and social sciences should be consulted (Carpenter *et al.*, 2009). As well as biophysical and economic assessments, measures of the social perceptions of ecosystem-derived benefits are an important component of ecosystem services research. Public perceptions are critical in local land management and planning decisions, yet social value information is rarely considered in an explicitly quantitative manner (Sherrouse *et al.*, 2014). Social values of ecosystem services, defined as "those [values] assigned by people to places in the world, expressed as nonmonetary preferences" (Bagstad *et al.*, 2015: 2), may correspond directly to services defined by MA (2005) as 'cultural' ecosystem services (e.g. recreation, aesthetics, tourism), but can also include the social perceptions of physical services from the MA's three other categories (e.g. carbon sequestration, food provisioning, water services). Cultural services represent an important non-material dimension of landscape value, whilst social perceptions of physical services can strongly influence public opinions of land management decisions (Sherrouse *et al.*, 2014).

Cultural ecosystem services and social values are inadequately accounted for by most current approaches to ecosystem services assessment (Kumar and Kumar, 2008; Schaich *et al.*, 2010; Daniel *et al.*, 2012). Difficulties in defining and measuring social values has meant that they have often been overlooked because they are "intangible" or "subjective" and thus difficult to quantitatively assess (Daniel *et al.*, 2012). Yet, as Daniel *et al.* (2012) argue, this difficulty can be addressed through cooperation between the traditionally distinct disciplines of environmental and social sciences. Social values research must be accepting of alternative epistemologies and the multiple types of knowledge that people use to assess and interact with their environment. Social values and cultural services should not be disregarded for their perceived intangibility; instead they should be viewed as an excellent opportunity for developments in transdisciplinary research.

Despite this, efforts to quantify and map cultural services have generally focused on valuations of economic utility as a proxy for social value (Table 2.2). Whilst economic valuations may feed easily into existing decision-making frameworks such as cost-benefit analyses, ecosystems offer more than just financial benefits to societies. As Cowling *et al.* state: "prices are not to be confused with values, and prices are not the only values that are important"; whilst social values may be neither economic nor utilitarian in nature, they are nevertheless important in understanding social-ecological systems and are critical to effective decision making (2008: 9845).

Table 2.2: **Methodological approaches to economic valuation of cultural ecosystem services.**

Valuation approach	Explanation	Examples
Travel costs	Amount of money spent to visit a 'natural' area	(Hein *et al.,* 2005; Anderson *et al.*, 2009).
Contingent valuations	Surveying the public to identify the amount of money they would pay to ensure a place or feature continued to exist or a service continued to be provided	(Bowker and Stoll, 1988; Carson *et al.*, 1994)
Hedonic pricing	Modelling the effect of local cultural services, e.g. aesthetic value, on market values, e.g. property prices	(Ready *et al.* 1997; Farber *et al.*, 2002)
Value transfer	Transfer valuation estimates from previously assessed sites to similar novel sites	(Hein *et al.*, 2005)

Increasingly, methods for engaging stakeholders in the collection of spatially explicit data are being used to map social values of ecosystem services. Methods utilising public participation geographic information systems (PPGIS) can facilitate the collection of quantitative spatially explicit non-monetary social value data directly from local communities (e.g. Brown and Reed, 2000; Brown, 2004; Alessa *et al.*, 2008). Approaches to spatially expressing social preferences range from mapping values according to pre-defined management units, such as distinct green spaces within an urban setting (Tyrvainen *et al.*, 2007), to more open-ended methods which derive weighted distributions of preference locations from point markers freely identified by participants on a map of the study area (Brown, 2005; Alessa *et al.*, 2008). These data can in turn be applied to analytical techniques such as hotspot analysis in order to highlight areas of high value which may demand particular management attention.

2.4 Catchment-scale land management

Studies which simultaneously assess multiple ecosystem services, and identify the extent of spatial covariance and co-occurrence between them, are prevalent in the literature (e.g. Naidoo *et al.*, 2008; Anderson *et al.*, 2009; Egoh *et al.*, 2009; Queiroz *et al.*, 2015). However, the spatial extents and resolutions of such studies have often been inappropriate for political and planning applications, the extents being too broad and resolution too coarse for translation to management applications such as conservation planning (Frank *et al.*, 2012; Bateman *et al.*, 2013). To address this issue, Casalegno *et al.* (2014) mapped a number of ecosystem and environmental services across the county of Cornwall, U.K. to a resolution of 1km. Cornwall is a relatively discrete geopolitical unit (Casalegno *et al.*, 2014) and therefore the county boundary is an appropriate extent for ecosystem services assessment of relevance to land management decisions. However, sub-county scale regions are also important spatial extents for management decisions. Increasingly, the individual river catchment is the scale at which landscape policy and management decisions are taking place.

The water cycle is fundamental to social-ecological systems and underpins a huge range of ecosystem services from all four of the MA's broad categories (Everard, 2011). Many influential policy directives focus on water systems in recognition of their central importance in environmental sustainability, including the EU's Water Framework

Directive (2000/60/EC) (EU, 2000), the UK Catchment Sensitive Farming (CSF) initiative (Natural England, 2012; Natural England, 2015b) and private sector schemes such as the South West Water Upstream Thinking (UsT) project (South West Water, 2015). These schemes influence many areas of land management including agriculture, urban planning and wildlife conservation. Understanding how different ecosystem service values are distributed across catchment areas, and the synergies and discrepancies between these distributions, will aid management decisions which aim to maximise the benefits delivered by multifunctional landscapes across a range of service types.

The catchment of the River Cober, West Cornwall is one such region where management initiatives are increasingly focusing on the catchment as an appropriate scale for regulation and monitoring (through CFS 'priority catchment' designation and the establishment of a new UsT project in the region). This dissertation takes the Cober as a case study system for the simultaneous mapping of social and biophysical values of ecosystem services on a catchment scale.

2.5 Research questions

1. How are social values of ecosystem services distributed across the Cober catchment?

2. How are biophysical values of two example ecosystem services (flood mitigation and agricultural productivity) distributed spatially across the Cober catchment?

3. To what extent do hotspots of social values of ecosystem services and biophysical values of ecosystem services coincide?

Chapter 3: Methodology

This chapter outlines the methods used to address the research questions posed in Section 2.5. The Cober catchment is introduced and the approach taken to mapping social and biophysical values of ecosystem services is outlined. Social values were mapped using a PPGIS written questionnaire, requiring participants to weight different social value types according to importance and then identify locations representing each social value on a map of the study area. Flood mitigation and agricultural productivity were identified as example regulating and provisioning services and are mapped according to biophysical properties using remotely sensed data. Finally, the chapter outlines the analytical techniques used to assess spatial coincidence of maps of hotspots of social and biophysical values of ecosystem services.

3.1 The study area

The catchment of the River Cober is situated in the west of Cornwall, UK, stretching from Cornwall's central granite ridge in the north to Helston and Loe Pool in the south (Figure 3.1). Helston is the largest settlement in the catchment with a population of nearly 12,000 in 2011 (Cornwall Council, 2015). The catchment is an area of ancient landscapes, incorporating medieval farmland and various prehistoric remains alongside early mining landscapes (Cornwall Council, 2013). Land use is dominated by agricultural activities, with the majority of the area covered by either arable or grasslands (CEH, 2011; Figure 3.2). The Cober catchment is prone to flash flooding; flooding events can occur with less than two hours' notice between Wendron and the coast (Environment Agency, 2012). 200 properties are at risk in the event of a 1:100 probability river flood (Environment Agency, 2012).

3.1.1 Sites of Special Scientific Interest

The Cober catchment incorporates two Sites of Special Scientific Interest (SSSI): Loe Pool, and Porkellis Moor (part of the West Cornwall Bryophytes SSSI) (Figure 3.3(a)). Loe Pool is a freshwater lake and, together with its immediate surroundings, forms part of the Penrose Estate, managed by the National Trust. It earned SSSI designation owing to the presence of scarce habitat, rare species including higher plants, bryophytes, algae

and insects, and because of its role as an important habitat for wintering birds (Natural England, 2015b). Porkellis Moor is one of seven disused mining sites which make up the West Cornwall Bryophytes SSSI and is protected under both SSSI and Important Plant Area designations on the basis of nationally rare liverwort species (Natural England, 2015c).
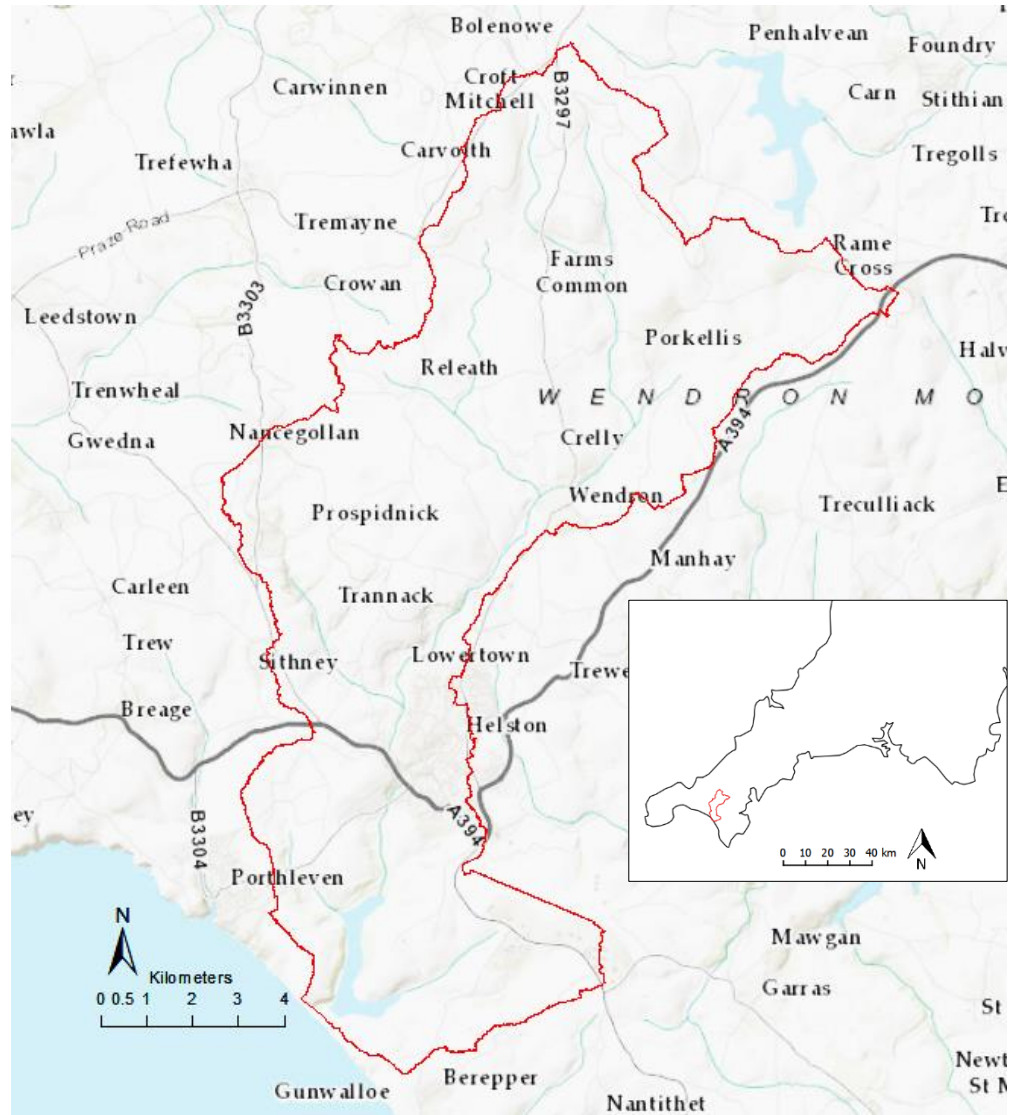
Figure 3.1: **The Cober catchment study area, West Cornwall** (ESRI, 2015). Red line indicates the catchment boundary. Inset: the position of the study area within the county of Cornwall (Natural Earth, 2015).
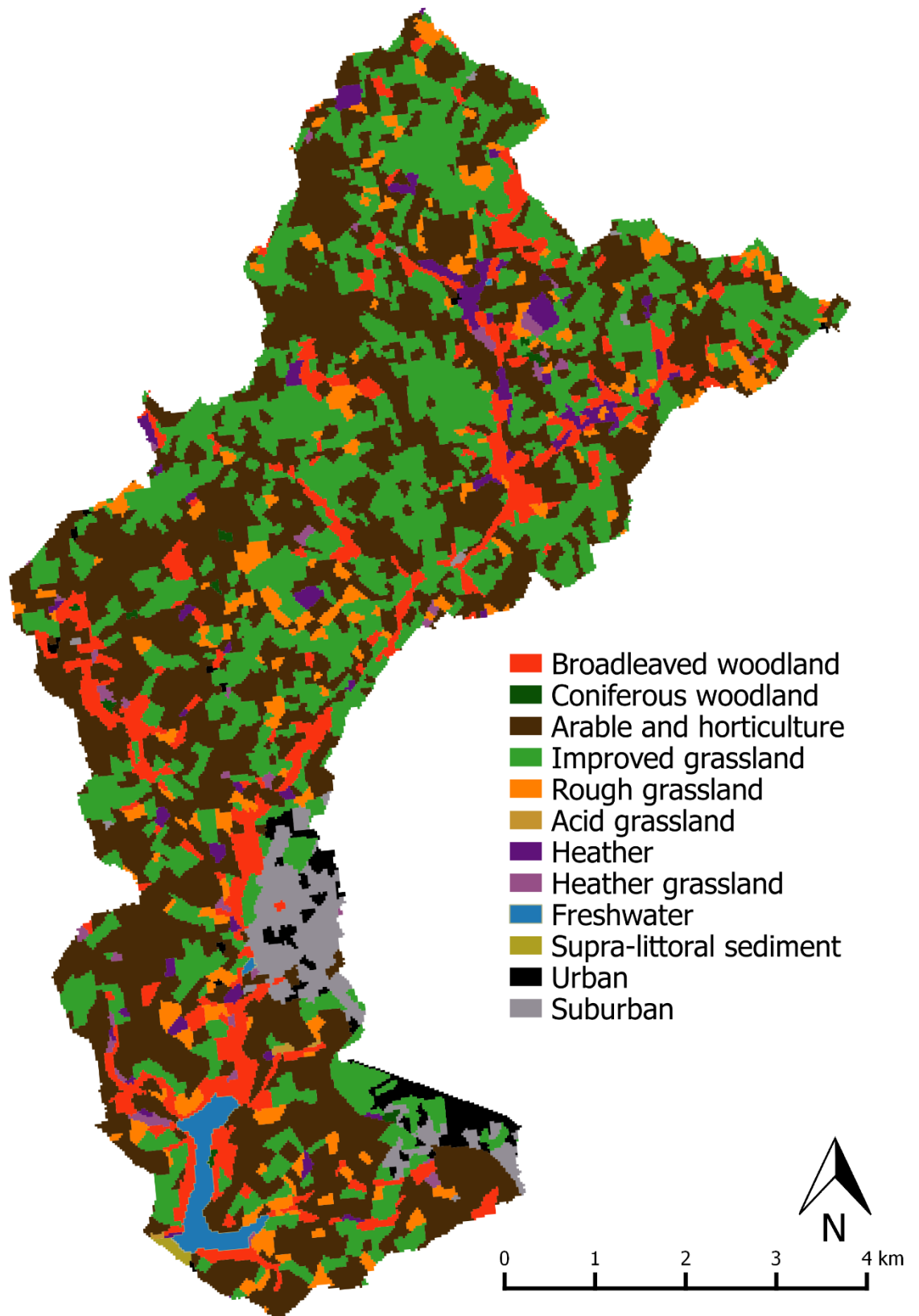
Figure 3.2: **Land cover across the Cober catchment** (cell size: 25m) (LCM2007 – CEH, 2011).
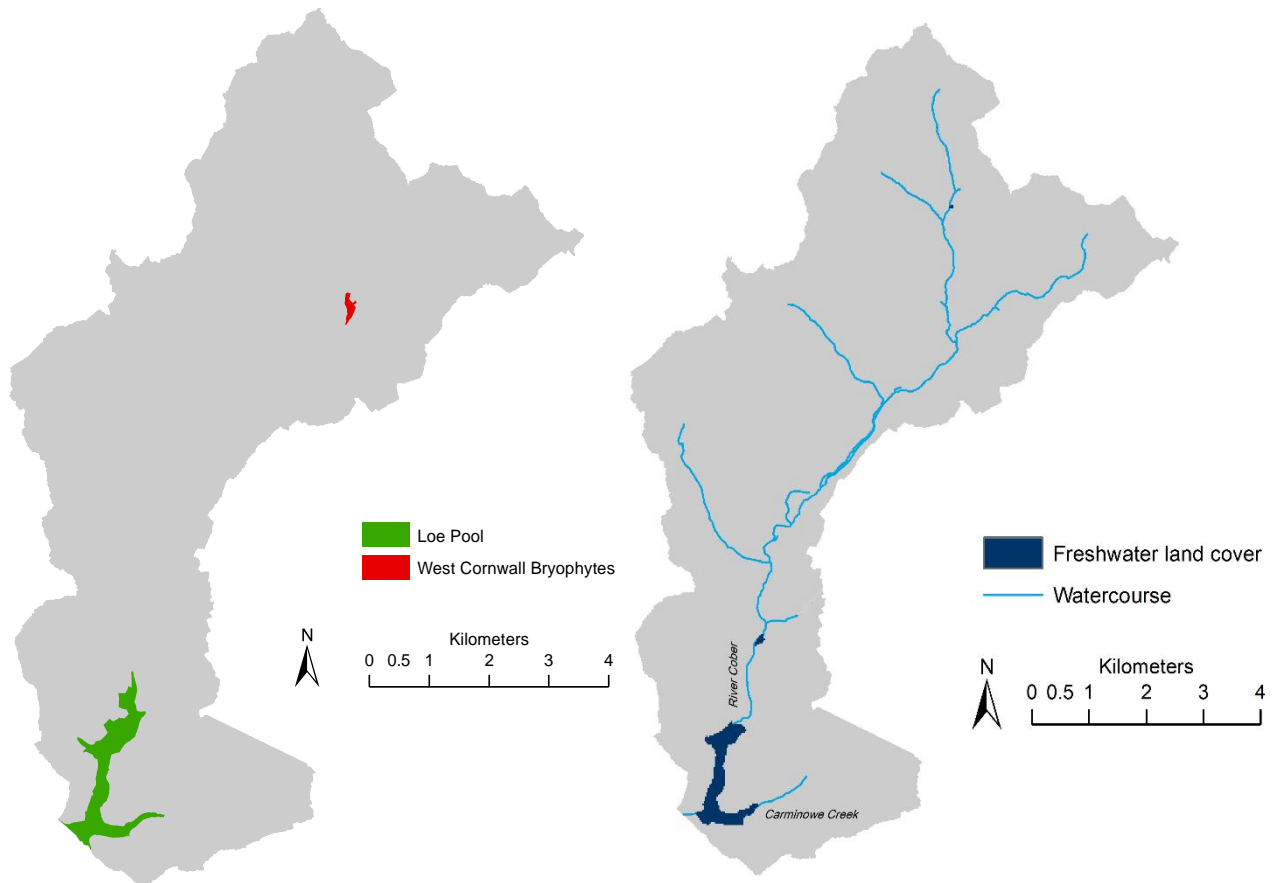
Figure 3.3: **Maps of a) SSSI designation** (Natural England, 2015d) **and b) water systems within the Cober catchment** (freshwater land cover: LCM2007 – CEH, 2011; watercourses: OS, 2015a).

3.2 Delineation of the catchment boundary

Before any other data collection or analysis, the catchment boundary was identified. To delineate the boundary (illustrated in Figure 3.1), the *Watershed* tool within the *Spatial Analyst* toolkit of ArcGIS 10.2.2 was applied to the Digital Terrain Model (DTM) produced by the Tellus South West LiDAR survey (Beamish *et al.*, 2014; see Section 3.4.1). Over 90% of the water that drains into Loe Pool comes from the River Cober (Spencer Toy, 1934). However, the pool is also fed by Carminowe Creek (Figure 3.3(b)) which drains an area to the east of the pool. Catchment-scale initiatives are interested in entire interconnected water systems; therefore for the sake of this study, the combined catchment of the River Cober and Carminowe Creek was taken as the study area and is herein referred to simply as the Cober catchment.

3.3 Mapping social values of ecosystem services

PPGIS methodologies are the principle approaches used for mapping the spatial distributions of social values. These range from simple exercises where participants identify locations of social value on a map (Brown and Reed, 2000), to more complex approaches which also require participants to assign relative weightings to different value types (Brown *et al.*, 2002; Alessa *et al.*, 2008; Sherrouse *et al.*, 2011). Social values are assembled within a contextual hierarchy of relative importance (Brown, 2005). Weighting methods, which allow participants to indicate the relative importance of different value types, enable this aspect of social perceptions to be incorporated into social value data (Brown, 2005). The PPGIS approach used here is based upon the questionnaire format developed by Brown *et al.* (2002), who produced a dataset of weighted points by asking participants to divide a hypothetical $100 budget between social value types and mark locations which represented these values on a map of the study area.

In this study, a written questionnaire (Appendix 1), similar to that of Brown *et al.* (2002), required participants to allocate a hypothetical £100 budget between eight social values of ecosystem services (Table 3.1). Participants were asked to allocate this 'budget' based on their desire "to ensure that… [the social values]…continue to be provided (in the same way as they are currently) within the Cober catchment" (Appendix 1; Section 1). Currency units were used for convenience only; participants were made aware that the £100 'budget' did not relate to actual money, but that it was used simply to allow the expression of value denominations, as in Brown *et al.* (2002) and Sherrouse *et al.* (2011). The typology of social values used here was based on the typology of Sherrouse *et al.* (2011), but adapted to reflect the context of the Cober catchment. After a pilot test of the questionnaire (n=10), the four least-valued social value types from the Sherrouse *et al.* (2011) typology were removed (historic, future, learning and therapeutic) in order to reduce the time and cognitive demands of the survey. In addition, flood defence, agricultural and tourism values were introduced, replacing the original value types of economic and life sustaining values. Agriculture and flooding are important issues in catchment management; by explicitly assessing these social values, direct comparisons

Table 3.1: **The social value types included in the Cober catchment written questionnaire**, adapted from Sherrouse *et al.* (2011) [* corresponds to a 'cultural' ecosystem service, ** a 'provisioning' service, † a 'supporting' service, ‡ a 'regulating' service (MA, 2005)].

Social value type	Social value description
Aesthetic*	This area is important to me because I enjoy the scenery, sights, sounds, smells etc.
Agricultural**	This area is important to me because it provides economic and life-sustaining benefits of agriculture
Biological Diversity†	This area is important to me because it provides a variety of wildlife, plant life, fish etc.
Cultural*	This area is important to me because it is a place for me to continue and pass down the wisdom and knowledge, traditions and way of life of my ancestors
Flood Defence‡	This area is important to me because it defends my property, lifestyle, economic interests or wellbeing from flooding
Intrinsic*	This area is important to me in and of itself, whether people are present or not
Recreation*	This area is important to me because it provides a place for my favourite outdoor recreation activities
Tourism*	This area is important to me because it supports tourism activities, which provide economic and/or cultural benefits to the area

could be made between these values and the biophysical values assessed (see Section 3.4). Tourism was included as an explicit value type on the basis that tourism forms a major part of the Cornish economy (Cornwall and the Isles of Scilly Economic Forum, 2006).

Section 2 of the questionnaire required participants to identify locations of value on a map of the catchment. For each social value to which any 'budget' had been allocated in Section 1, up to four locations could be identified by drawing dots or crosses on a map of the catchment. The OS 1:25 000 scale Explorer Map was used as the backdrop for this map, printed to dimensions of 30 x 42 cm and superimposed with the catchment boundary line (Appendix 1). This scale was selected as a compromise between good spatial resolution, participant ease-of-use and printing costs.

The third section investigated the demography of participants and their familiarity with the catchment region. This section requested information about participants' age and

gender, as well as the length of time they had spent living within West Cornwall, the length of time since their last visit to the catchment and the number of times they had visited the catchment within the last year.

Participants were recruited from local events and interest groups. Although this approach may not produce a random sample of participants, it was used in order to maximise the sample size of responses for the study. The questionnaire generally took at least 15 minutes to complete, therefore it was necessary to use a sampling approach which interacted with people in a context in which they were able to dedicate this time (unlike, for example, randomly approaching people on the street). Similarly, interacting with participants in person, rather than in a detached manner such as administering the questionnaire by post, facilitated a high response rate. A wide range of local interest groups and events based within the catchment were contacted and those which agreed for their members/visitors to be surveyed were attended between June and July 2015 (Helston Light and Life Church, Helston Town Band, Carminowe Valley Gardens, Helston University of the Third Age). To further maximise the number of participants, an incentive was offered in the form of entry into a draw to win a £60 Amazon voucher. Participants were required to be over the age of 18 for the purposes of ethics clearance. Participants were also required to be residents of West Cornwall (verified by post code area) to ensure that they had at least a basic familiarity with the study area.

Mapped points were entered into a point-formatted shapefile for each social value type using ArcGIS 10.2.2. Each point was assigned a weighting according to the amount of the £100 'budget' that had been allocated to the value type which each point represented, divided by the number of points identified for that value type by the participant. For example, if a participant allocated £30 to aesthetic value, and identified three points on the map which represented this value, each point would be assigned a weighting of £10. This meant that the sum of point weights was consistent across all participants (£100). These shapefiles were converted to a raster layer with cell size 250m, where the score of each cell represented the sum of the weightings of all points located within that area. 250m was chosen because it was judged to be the minimum distance between which points could be meaningfully distinguished on the map supplied with the questionnaire (250m corresponded to 7.5mm).

Hotspots were identified using the Getis-Ord Gi* statistic (Getis and Ord, 1992), as used by Zhu *et al.* (2010) and Bagstad *et al.* (2015). Getis-Ord Gi* analysis identifies statistically significant clusters which are higher in value than might be expected by chance (Getis and Ord, 1992). Other methods of hotspot identification have been used in past social value studies, such as mapping the top third or 20% of values as hotspots (Alessa *et al.*, 2008; Bryan *et al.*, 2011). Here, the approach of Zhu *et al.* (2010) and Bagstad *et al.* (2015) is followed because it allows spatially significant clusters to be identified according to a statistical threshold of 95% confidence. Hotspot analyses were conducted using the *Spatial Statistics* toolkit within ArcGIS.

3.4 Biophysical mapping of ecosystem services

Flood mitigation and agricultural productivity were selected as example physical ecosystem services. Flooding and agriculture are important issues within the Cober catchment because it has a history of flooding and encompasses a large amount of agricultural land. In addition, flood mitigation and agricultural productivity serve as examples of both a regulating and a provisioning service (according to the MA typology, Table 2.1), and both represent what Fisher *et al.* (2008) refer to as *final* services (as opposed to *intermediate* services) - those which directly benefit human wellbeing.

3.4.1 Flood mitigation

Hydrological systems can be modelled using a variety of datasets and techniques. Topography is central to understanding the flow of water over a landscape and Digital Terrain Models (DTM), which map bare earth topography, facilitate the derivation of flow pathways for hydrological modelling (Quinn *et al.*, 1991). Many DTMs are available, based on various data sources and resolved to various scales. For example, Shuttle Radar Topography Mission (SRTM) (90m) and Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) (30m) models offer topographic data at global extents and relatively coarse scales, and the Ordinance Survey have two DTM products, Terrain 5 and Terrain 50, resolved to 5m and 50m respectively, which offer coverage of the UK (OS, 2013; OS, 2015b). Here, DTM data from an airborne LiDAR survey of the south west of Britain by the British Antarctic Survey (BAS), the Tellus South West project (Beamish *et al.*, 2014; details in Appendix 2), was used because this dataset is freely available for academic purposes, resolved to a high resolution (1m) and

has a spatial coverage appropriate for the study area. Flood mitigation capacity was assessed by first modelling hydrological flows over this DTM and then considering the effects of land cover on water retention capacity in high wetness areas.

Hydrological analysis of the DTM was carried out in ArcMap 10.2.2 using hydrological tools from the *Spatial Analyst* toolkit. Firstly, sinks (cells with undefined drainage direction) were removed, then layers of flow direction, flow accumulation and slope were created allowing the Topographic Wetness Index (TWI) to be calculated (Equation 3.1).

Equation 3.1: **Topographic Wetness Index (TWI)** (Beven and Kirkby, 1979). a = upslope contributing area (flow accumulation [*] cell size),   β= slope.

$$TWI = \ln\left(\frac{a}{\tan\beta}\right)$$

Topographic Wetness Index is used to map spatial distributions of wetness as a function of landscape topography (Sorensen *et al.*, 2006). Areas of high TWI accumulate large quantities of water and, if that water cannot be retained appropriately, these areas are vulnerable to high surface runoff and flooding. TWI was calculated across the catchment and resampled to a cell size of 250m (by bilinear interpolation) to match the resolution of the social values maps. Whilst high TWI can indicate locations of high wetness based on topography, other factors influence the ability of different areas to retain water and therefore mitigate surface flows which can otherwise lead to flooding.

One major factor in the regulation of water retention is land cover. Vegetated land covers generally have a higher water retention capacity than non-vegetated land covers (Reynolds, 1970; Gomez-Plaza *et al.*, 2001) owing to three main factors: water use by vegetation, increased soil infiltration rates and increased hydraulic roughness (Nisbet and Thomas, 2006). In particular, woodland has been shown to reduce flows on small scales (<100 km^2) when compared to grasslands and arable land covers (Robinson *et al.*, 2003; O'Connell *et al.*, 2004; Marshall *et al.*, 2009; Archer *et al.*, 2012), and heathland (which covers <3% of the catchment) experiences greater runoff than woodland (Gurnell and Gregory, 1987). Therefore, for the purposes of this study, land cover was split into two classes according to its ability to regulate hydrological flows and reduce surface runoff: high regulatory capacity (broadleaved and coniferous woodland) and low regulatory

capacity (grasslands, arable and horticulture, heather). The TWI map was clipped accordingly to produce two separate TWI layers using the LCM2007 dataset (see Appendix 3) (resampled to 250m using a nearest neighbour algorithm). Whilst high TWI in an area of high regulatory capacity can indicate that a location has a high flood mitigation capacity, high TWI in an area of low regulatory capacity may indicate suitability for nature-based flood defence interventions such as reforestation or hedgerow planting (Nisbet *et al.*, 2011; Sutherland *et al.*, 2014; European Union, 2015). Hotspots of TWI for maps of high and low regulatory capacity were identified using the Getis-Ord Gi* statistic.

Differences in soil types are also critically important in hydrological processes which influence flooding (Nedkov and Burkhard, 2012). The Cober catchment is predominantly covered in freely draining acid and loamy soils, with small areas of slowly permeable and seasonally wet soils in the upper catchment (Appendix 4). As the majority of the catchment is covered by freely draining soils, and because more in-depth analyses of soil type distributions were beyond the scope of this study, soil type was not included in flood mitigation mapping.

3.4.2 Agricultural productivity

Agricultural productivity can be mapped using a number of approaches. Some studies use direct measures of yield or economic profitability acquired though agricultural censuses such as the Defra *June Agricultural Survey* (Eigenbrod *et al.*, 2009; Casalegno *et al.*, 2014). However, the resolution of this data is generally too coarse for catchment scale analyses (collected at ward/local authority resolution). Alternatively, land use based value-transfer coefficients can be used; however, this method is unable to identify variation within individual land cover classes (Troy and Wilson, 2006). Here, agricultural productivity was mapped using a remote sensing approach to vegetative productivity measurement to assess within-land use variability.

Satellite imagery data from the NASA/USGS Landsat project (USGS, 2015) was used to derive an NDVI (Normalised Difference Vegetation Index) model, which measures the relative reflectance of red and near infrared spectral bands, and can be used to assess photosynthetic activity. The relationship between NDVI and vegetative productivity is

well established (Asrar *et al.*, 1984; Pettorelli *et al.*, 2005; Gitelson *et al.*, 2006); therefore, high NDVI within known regions of agricultural land use can be used to identify regions of high agricultural productivity, either through the direct productivity of arable crops, or indirectly through the productivity of pasture, which in turn supports livestock. In order to account for the effects of inter-annual variation in agricultural inputs (e.g. fertilisers and pesticides) on productivity, a time series of four images, from 1984-2014, was analysed so that regions of consistently high agricultural productivity could be identified.

Four cloud-free summer Landsat images were selected, three from Landsat 5 (L5) TM (1984, 1994, 2003) and one from Landsat 8 (L5) OLI (2014) (details in Appendix 5). L5 and L8 offer gap-free coverage of the time period selected (Landsat 7 suffered a Scan Line Corrector failure in 2003). Near infrared and visible red bands (Appendix 5) of the Landsat images were clipped to the catchment boundary, then converted from digital numbers to top of atmosphere reflectances and radiometrically corrected using the dark object subtraction model (Chavez, 1996), using the *Semi-Automatic Classification 2.5.1* plugin in QGIS 2.6.1 (Condego *et al.*, 2014).

NDVI (Equation 3.2) was calculated for each of the four pre-processed images. Mean NDVI was calculated across the four scenes. The mean NDVI layer was then resampled (by bilinear interpolation) to a cell size of 250m, to match social value and flood mitigation maps. The mean NDVI layer was then clipped according to inferred land use using the LCM2007 dataset (also resampled to 250m). Class 3 of LCM2007 (CEH, 2011) represents *Arable and Horticulture*, a land cover classification which directly corresponds to an arable land use. An aggregation of classes 4, 5 and 6 (*Improved* grassland, Rough grassland and Acid grassland) was used to infer pastoral land use. Hotspots were identified using the Getis-Ord Gi* statistic, as for social values and flood mitigation.

Equation 3.2: **Normalised Difference Vegetation Index (NDVI)** (Singh, 1989). NIR = near infrared (Landsat 5 TM band 4; Landsat 8 OLI band 5), VR = visible red (Landsat 5 TM band 3; Landsat 8 OLI band 4)

$$NDVI = \frac{NIR - VR}{NIR + VR}$$

3.5 Coincidence of hotspots of social and biophysical values of ecosystem services

Hotspot spatial associations can be assessed in a number of ways. Spatial tests of correlation such as the modified t-test developed by Clifford *et al.* (1989), which account for spatial autocorrelation (implicit in hotspot definition and common in spatial data), can be used to assess covariance between spatial data. However, because of a severe skew in the distribution of data points (very high ratio of non-hotspot to hotspot cells) and the binary nature of the data (a cell is either in a hotspot or it is not), a correlation-based analysis was not appropriate. Instead, the coincidence of hotspots was assessed by calculating the percentage of overlapping area between each pair of hotspot maps, a technique used by Orme *et al.* (2005). Percentage overlap (Equation 3.3) was calculated pairwise for all hotspot maps. For the purposes of these analyses, hotspot extents were defined as the area of hotspots defined to >95% confidence by the Getis-Ord Gi* statistic.

Equation 3.3: **Percentage overlap between hotspot maps A and B**

$$Overlap\ (\%) = \frac{overlapping\ area\ \times 100}{overlapping\ area + nonoverlapping\ area_A + nonoverlapping\ area_B}$$

Chapter 4: Results

Chapter 4 details the results of the study, beginning with the mapping of social values of ecosystem services, and moving onto biophysical values of flood mitigation and agricultural productivity. Finally, the chapter presents results regarding the extent of spatial coincidence between hotspots of social and biophysical values of ecosystem services.

4.1 Social values of ecosystem services

4.1.1 Socio-demographic characteristics

Ninety-one questionnaires were completed. Responses were slightly biased towards female participants (55%) over male participants (45%) (Figure 4.1(a)). Participation was also skewed towards older members of the community: 65% of participants were over the age of 50 (Figure 4.1(b)). Most participants (58%) had been resident in the West Cornwall area for over twenty years (Figure 4.1(c)), and most were very familiar with the Cober catchment area, 77% having visited the area within the last week and 72% having visited more than ten times in the last year (Figure 4.1(d) & (e)).

4.1.2 Allocation of 'budget' and points for social values

Table 4.1 summarises the non-spatial aspects of the value allocation data collected through the questionnaire. Aesthetic and biological diversity values were the most frequently selected value types in the 'budget' allocation exercise. These values also received the greatest mean 'budget' allocation per survey. Flood defence, intrinsic and tourism values were the least selected values. Overall, variability was high, illustrated by high standard deviations for both the mean amount of 'budget' allocated per survey and the mean point weightings.

4.1.3 Spatial distributions of social values

Figure 4.2 illustrates summed point weightings per 250m cell for each social value type. Hotspot maps are shown in Figure 4.3. Aesthetic, biological diversity, cultural and recreation values all have hotspots in the southern part of the catchment, around the Loe Pool SSSI (Figure 4.3(a), (c), (d) and (e); see Figure 3.3(a) for SSSI map). For cultural

(a)

(b)

(c)

(d)

(e)
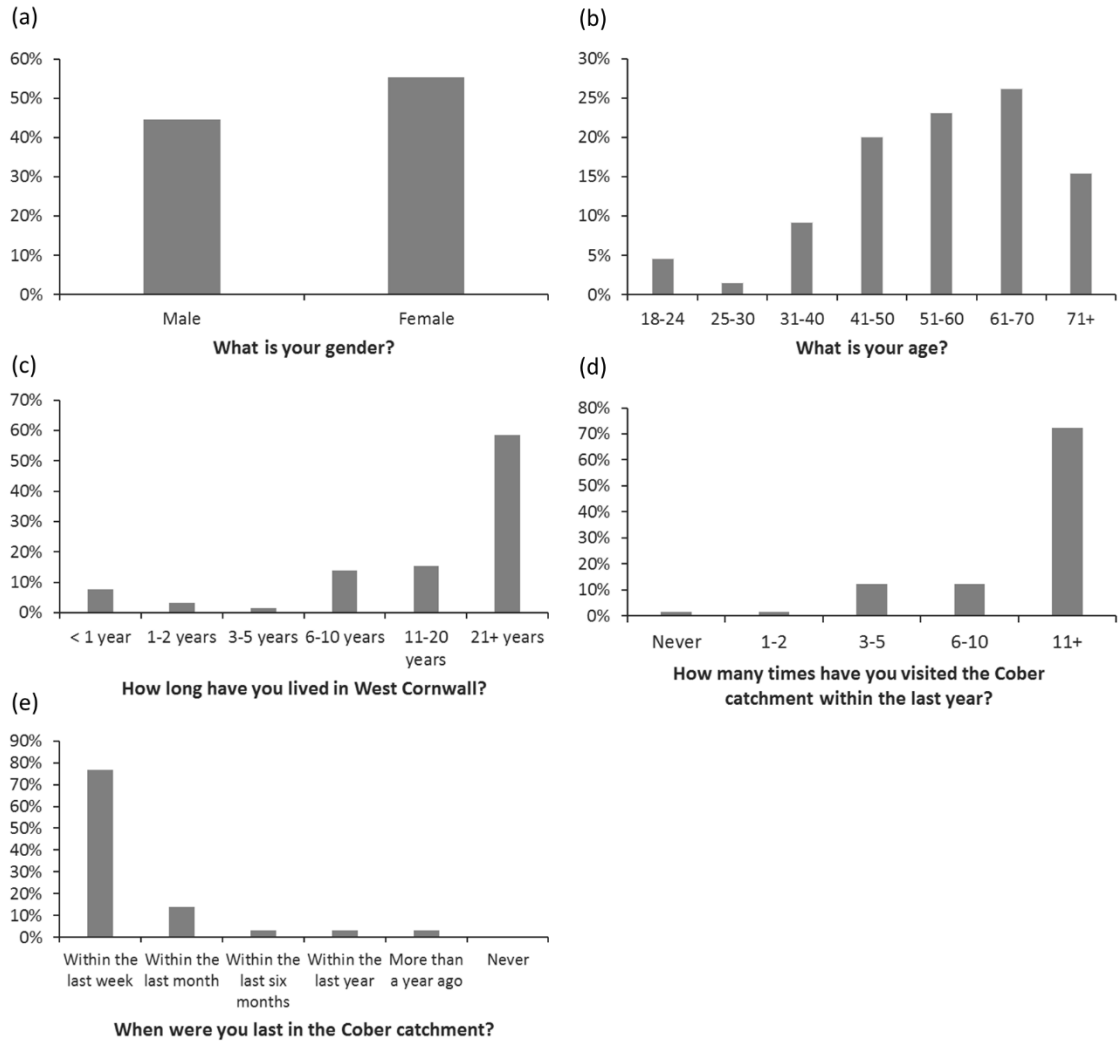
Figure 4.1: **Responses to the socio-demographic and study area familiarity questions from Section 3 of the social value questionnaire.**

value, a 90% confidence hotspot is also detected over Helston town (Figure 4.2(d)). Agricultural value was relatively dispersed across the catchment (Figure 4.2(b)), although a small area of hotspot was identified in the north east of the catchment (Figure 4.3(b)). No hotspots were identified for flood defence, intrinsic or tourism values, which in part could be attributable to a relatively low number of participants who chose to map these values (Table 4.1). Raw distributions of intrinsic and tourism values show high social value allocation around Loe Pool, similar to aesthetic, biological diversity, cultural and recreation distributions (Figure 4.2 (f) and (h)). The distribution of flood defence value (Figure 4.2(e)) closely follows the path of the River Cober (Figure 3.3(b)).

Table 4.1: **Summary of data from the social value 'budget' allocation and mapping exercise.**

Value	Total number of surveys	Total number of points	Total area of cells containing one or more point (m²)	Allocation per survey (£)		Individual point weighting (£)	
				Mean	Standard deviation	Mean	Standard deviation
Aesthetic	62	180	63 125	24.25	21.15	11.86	12.62
Agricultural	39	112	50 000	10.42	17.19	6.79	4.80
Biological Diversity	66	147	45 625	21.42	19.74	12.20	8.17
Cultural	41	83	33 125	9.05	13.06	9.77	8.13
Flood defence	30	48	13 750	7.42	12.71	13.06	10.67
Intrinsic	36	49	18 125	6.69	9.81	10.10	8.55
Recreation	53	96	36 875	13.42	15.51	11.50	12.67
Tourism	38	68	23 750	7.19	7.41	8.16	7.41

4.2 Spatial distributions of biophysical measures of ecosystem services

Figure 4.4 illustrates the distributions of biophysical values of flood mitigation and agricultural productivity and Figure 8 displays hotspots of these values.

4.2.1 Flood mitigation

Areas of high TWI within woodland land covers (Figure 4.4(a)) represent areas of high flood mitigation capacity, whilst high TWI within arable/grassland/heather land covers (Figure 4.4(b)) indicate areas of high wetness and low water retention. Water from these areas is likely to contribute to flooding, and therefore in these locations nature-based flood defence interventions could be effective (Nisbet *et al.*, 2011; Sutherland *et al.*, 2014; European Union, 2015). A relatively small area of the catchment (9.7%) is classified under woodland land cover; therefore, the extent of areas valued as having a high flood mitigation capacity is small (Figure 4.4(a)). Three cells of flood mitigation hotspot are identified, all of which are situated in the north of the catchment (Figure 4.5(a)). Under arable/grassland/heather land covers, most areas have low wetness with small regions of high TWI (Figure 4.4(b)). Three regions of hotspot are identified: in the far north, the mid-west and the mid-east (near Wendron) (Figure 4.4(b)).

4.2.2 Agricultural productivity

NDVI across both arable and grassland was highly dispersed, with most cells (66.9%) exhibiting an NDVI of 0.4-0.6 interspersed with isolated cells of lower productivity (Figure 4.4(c) and (d)). Hotspots for arable productivity were identified in the north of the catchment, including the mid-east near Wendron (Figure 4.5(c)). No NDVI hotspots could be identified for grassland at >95% confidence (Figure 4.5(d)).

4.3 Coincidence between social values and biophysical measures of ecosystem services

High levels of coincidence were found between social value hotspots of aesthetic and biological diversity (89.5%), aesthetic and recreation (68.8%), and biological diversity and recreation (66.7%) (Table 4.2). All social values for which any hotspots could be found (aesthetic, agricultural, biological diversity, cultural, recreation) showed pairwise coincidence of 20% or more, with the exception of agricultural value which is congruent with no other hotspots. The only overlap between hotspots of biophysical value was between agricultural NDVI and TWI for arable/grassland/heather (i.e. between arable productivity and flood defence intervention potential), with an overlap of 9.7% (Table 4.2). No overlap between any social value and biophysical value hotspots could be detected, including ecosystem services which had been explicitly assessed through both approaches (flood defence and agricultural productivity) (Table 4.2).
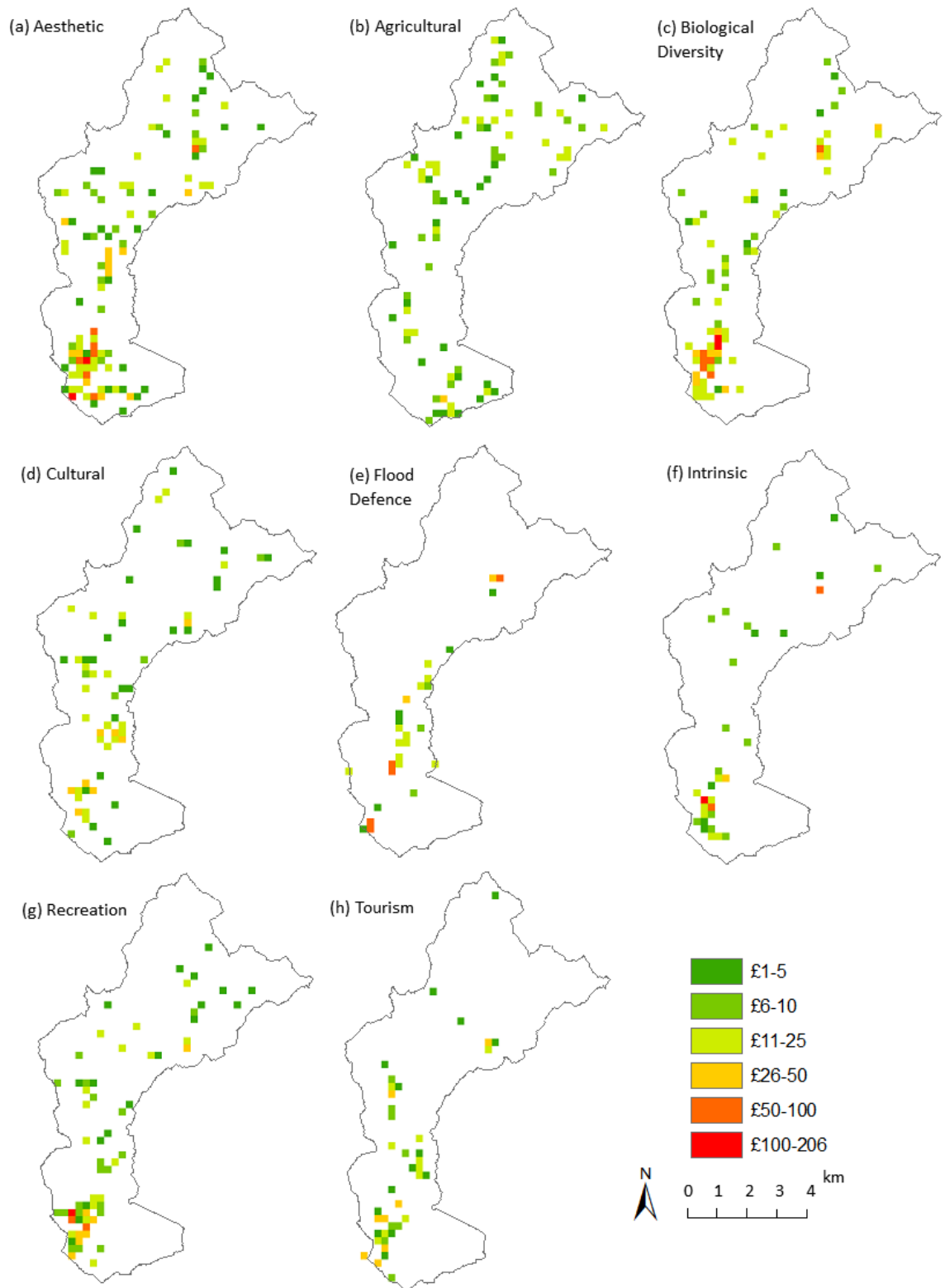
Figure 4.2: **Social value distributions for the eight social value types** (cell size = 250m). The cell score represents the summed weightings of all points placed within that cell. Blank areas denote cells which contained no social value points.
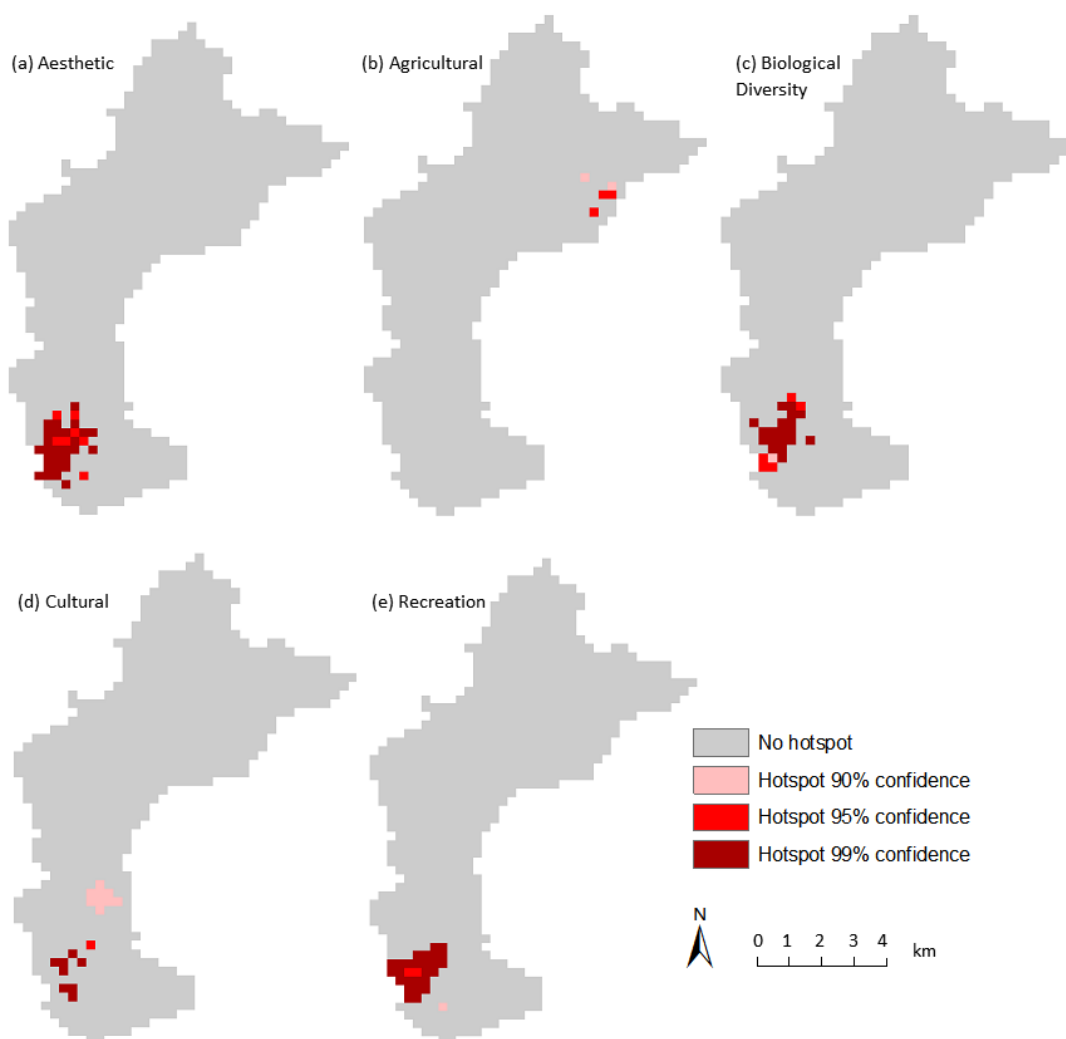
Figure 4.3: **Hotspots of social value as determined by the Getis-Ord Gi* statistic** (Getis and Ord, 1992). No hotspots could be identified for flood defence, intrinsic or tourism values.
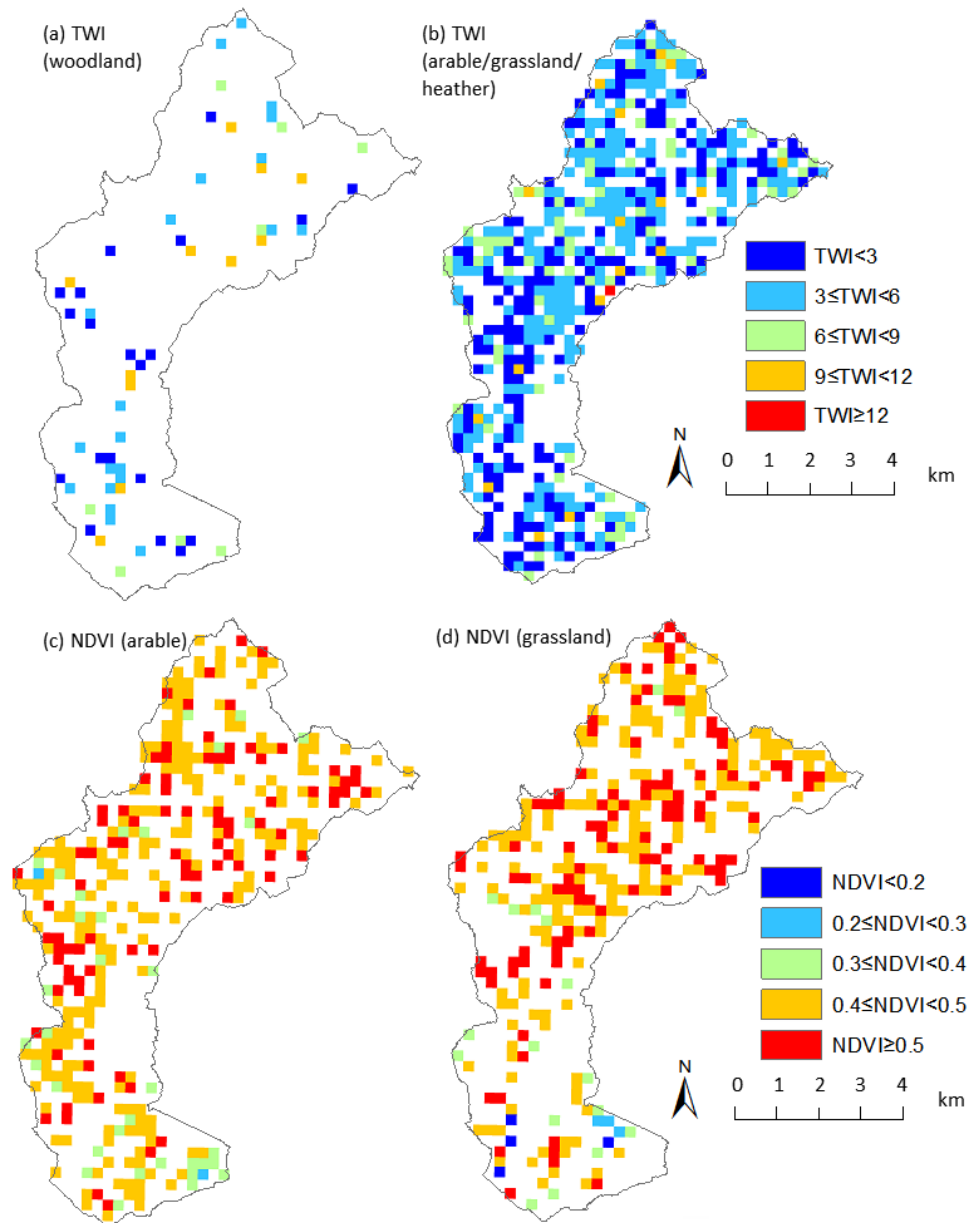
Figure 4.4: **Biophysical value distributions of flood mitigation (a), suitability for future flood mitigation intervention (b) and agricultural productivity of arable (c) and pasture (d)** (cell size = 250m). Blank areas indicate regions which were outside the specified land cover classification for each map.
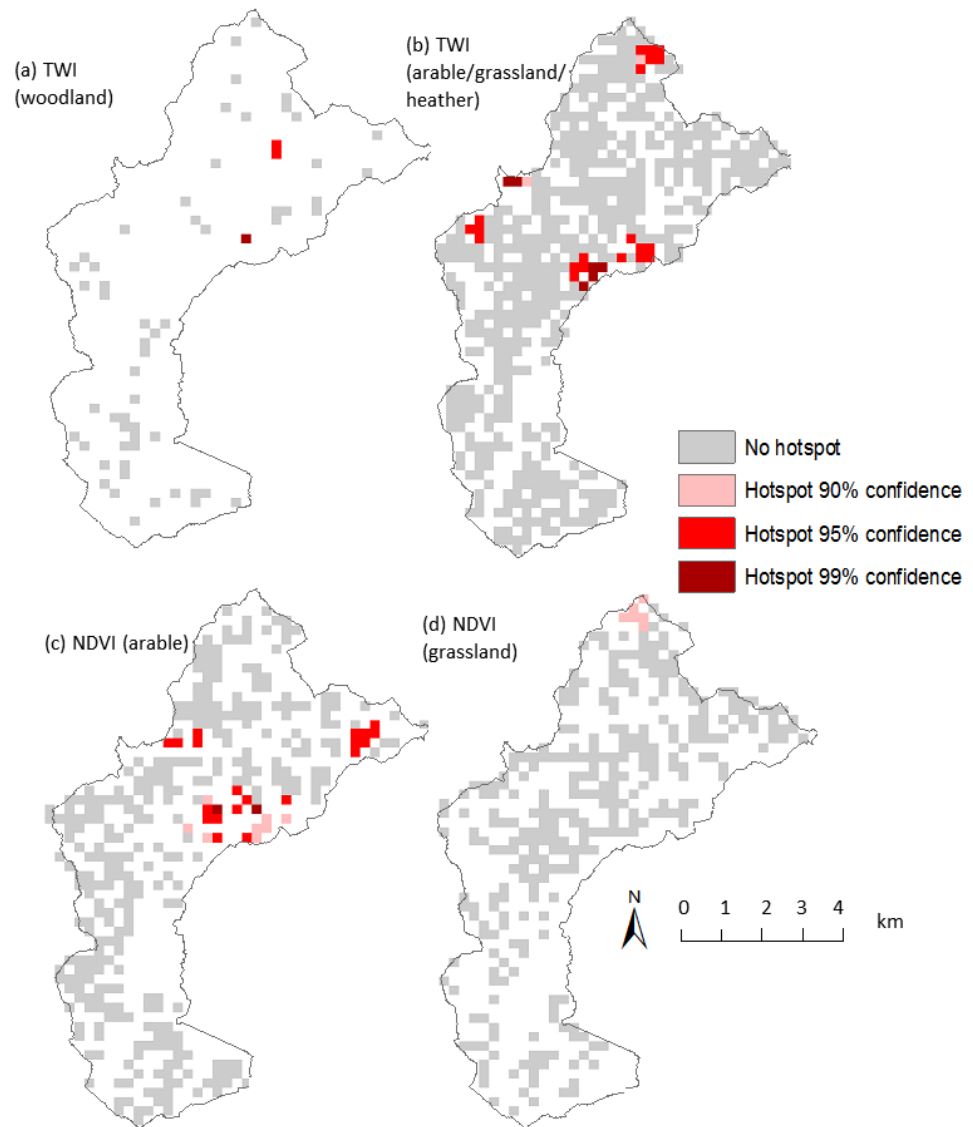
Figure 4.5: **Hotspots of biophysical value distributions for flood mitigation (a), suitability for future flood mitigation intervention (b), and agricultural productivity of arable (c) and pasture (d), identified by the Getis-Ord Gi* statistic** (Getis and Ord, 1992). Blank (white) areas indicate regions which were outside the specified land cover classification for each map, whilst grey areas represent cells within the specified land cover classification for which no hotspot was identified.

Table 4.2: **Spatial coincidence between pairs of hotspot maps** (>95% confidence), calculated as the percentage overlap area (Equation 3) [AGH = arable/grassland/heather land cover].

		Perceived social values of ecosystem services					Biophysical values of ecosystem services		
		Aesthetic	Agricultural	Biological Diversity	Cultural	Recreation	TWI (woodland)	TWI (AGH)	NDVI (arable)
Perceived social values of ecosystem services	**Aesthetic**	n.a.	0	89.5	20.6	68.8	0	0	0
	Agricultural	0	n.a.	0	0	0	0	0	0
	Biological Diversity	89.5	0	n.a.	33.3	66.7	0	0	0
	Cultural	20.6	0	33.3	n.a.	38.1	0	0	0
	Recreation	68.8	0	66.7	38.1	n.a.	0	0	0
Biophysical values of ecosystem services	**TWI (woodland)**	0	0	0	0	0	n.a.	0	0
	TWI (AGH)	0	0	0	0	0	0	n.a.	9.7
	NDVI (arable)	0	0	0	0	0	0	9.7	n.a.

Chapter 5: Discussion

This chapter begins by highlighting the key findings of this study and discussing how these may be used to inform the future management of the Cober catchment. Using the Cober catchment as a case study, issues of scale in simultaneous social/biophysical assessment of ecosystem services are considered. The chapter continues with a critical evaluation of the methodological approaches used in this study. Finally, the chapter closes with a summary of the main conclusions and an exploration of potential avenues for further research.

5.1 Key findings

5.1.1 Hotspots of social values of ecosystem services are predominantly in the south (downstream) of the catchment; hotspots of biophysical in the north (upstream)

For all social value types for which hotspots could be detected, hotspots were situated within the southern half of the catchment, with the exception of agricultural value. Contrastingly, hotspots for biophysical values of ecosystem services were all found in the north of the catchment. This suggests a clear segregation in the spatial delivery of different types of benefits: in general in the Cober catchment, upstream regions provide physical services of agricultural productivity and flood mitigation whilst downstream regions provide cultural services such as aesthetic value and recreation.

5.1.2 Win-win scenarios for aesthetic, biological diversity, cultural and recreational social values at Loe Pool SSSI

Aesthetic, biological diversity, cultural and recreational values all have hotspots of social value situated in and around the Loe Pool SSSI. This coincidence suggests a win-win scenario: all four of these services can be supplied simultaneously within the same area. It is likely that this is because these values are co-dependent. For example, one participant was noted as saying, "I enjoy recreational activities because the area is aesthetically beautiful"; the intensity of one value in a given location may be dependent on others. At the same time, certain environmental variables may drive multiple different social values – for instance, close proximity to water could explain both high aesthetic and high recreational value, even if recreational value does not itself depend on aesthetics. The

way in which societies value aesthetics, biodiversity, culture and recreation are likely to be highly interconnected and inter-dependent.

As well as coincidence between social values, the fact that these hotspots also coincide with the Loe Pool SSSI suggests that this location is also a win-win for ecosystem service delivery and conservation. Loe Pool is designated for the protection of rare species and important habitat (Natural England, 2015b). High social value of biodiversity around Loe Pool suggests that the public is able to perceive this biological value. High values of cultural services such as aesthetics and recreation, alongside this biological importance, suggest that Loe Pool also offers cultural service delivery. At Loe Pool, an area of conservation importance coincides with the delivery of cultural services, offering a win-win between different types of landscape value (i.e. biodiversity and cultural ecosystem services).

No hotspots of social value of ecosystem services overlapped with Porkellis Moor (West Cornwall Bryophytes) SSSI. This could be because it is less highly valued by the public than Loe Pool. Alternatively, this could be a due to the small spatial extent of Porkellis

Table 5.1: **Possible management interpretations of coincidence of hotspot and non-hotspot areas of social and biophysical values of ecosystem services** (adapted from Bagstad *et al.*, 2015).

		Biophysically modelled ecosystem services	
		Hotspot	**No hotspot**
Social value mapped ecosystem services	**Hotspot**	High management support (if social and biophysical values of ecosystem services are compatible) OR potential conflict between management and traditional uses (if social values and biophysical values are not complementary)	High support for traditional uses; cases where biophysical modelling alone is inadequate to map value
	No hotspot	Public outreach needed to build support for management (e.g. watershed protection programmes)	Areas suitable for development or resource extraction, assuming other important natural resources (e.g. high biodiversity, threatened and endangered species, indigenous cultural significance) are absent

Moor SSSI ($0.050km^2$), making spatial clustering difficult to detect by hotspot analyses such as the Getis-Ord Gi* statistic at a spatial resolution of 250m (one cell=$0.0625km^2$). If Porkellis Moor is truly of low social value, yet highly valuable in other ways (e.g. it provides a habitat for rare species), this could indicate that it is in need of public outreach activities to build support for its management and awareness of its importance (Table 5.1). Further social research is needed to determine to what extent Porkellis Moor SSSI is truly undervalued by the public.

5.1.3   No overlap between social values and biophysical measures of agricultural productivity and flood mitigation

Hotspots of social values of agricultural productivity did not overlap with hotspots of agricultural productivity using biophysical techniques. Where hotspots of social value corresponded to a lack of hotspot in biophysical values, this could indicate high support for traditional uses and could suggest that the way in which people value agriculture is not a simple function of productivity. Instead, the public may also value the heritage and traditions of agriculture (Daugstad *et al.*, 2006; Vouligny *et al.*, 2009), in a way which is not captured through biophysical analysis (Table 5.1). If this is the case, biophysical analyses alone would be insufficient for mapping the full suite of agricultural benefits that landscapes provides.

Alternatively, if the public does assess agricultural value according to the same value system as biophysical measurement, i.e. by productivity alone, this mismatch could be because non-cultural ecosystem services (regulating, supporting and provisioning) are particularly difficult for the public to map (Brown *et al.*, 2012; Brown, 2013). Whilst cultural services are in many ways defined by social value (public perceptions are intrinsic to the way in which cultural services are considered and contextualised), physical services such as flood mitigation and agricultural productivity may be more difficult for the public to map because they require specific knowledge about environmental systems. The ability or willingness of participants to map physical services may be dependent on their level of technical expertise (Ruiz-Frau *et al.*, 2011). Brown *et al.* (2012) call non-cultural ecosystem services "invisible" and question the utility of public consultation in their assessment because social value mapping exercises rarely produce maps which reflect biophysical measures. However, whilst social values may not be an accurate measure of biophysical properties, the fact that members of the public find mapping these

"invisible services" difficult, with a varying degree of difficulty between stakeholder groups, is in itself informative. Future research could focus on differences between stakeholder groups in their ability to accurately predict biophysical measures of ecosystem services.

Whilst social and biophysical values of agricultural productivity show no spatial overlap, patterns of social value for these services do suggest some biophysical knowledge amongst participants. Social value hotspots for agriculture (Figure 4.3(b)) are situated close to some regions of biophysical hotspot for arable productivity (Figure 4.5(c)) (mid-east to north-east). Whilst no overlap is present, this proximity could indicate that the public are able to identify agricultural value to some degree, but only at resolutions coarser than the 250m cell size (see Section 5.2).

Social values of flood mitigation exhibited no hotspots; however, the distributions of points does appear to follow the route of the River Cober (Figure 4.2(e); Figure 3.3(b)). This suggests that the public associates flood mitigation value with proximity to watercourses (possibly due to the presence of artificial flood defences), rather than with the ability of upstream ecosystems to regulate potential flood waters. Much of the discourse surrounding flooding issues within the catchment centre on the role of artificial defences (Environment Agency, 2012; Hall, 2015; Wilkinson, 2015). This may suggest that public engagement around the importance of ecosystems in flood defence could be useful to enhance the public understanding of the regulatory services that ecosystems provide.

5.1.4 No social value hotspots for flood mitigation, intrinsic value or tourism

No social value hotspots could be detected for flood mitigation, intrinsic value or tourism. All three of these value types received low representation in the 'budget' allocation exercise (Table 4.1); therefore, the absence of hotspots could be attributable to a lack of data rather than an absence of spatial clustering. Alternatively, intrinsic value was arguably the most abstract concept of all the value types in the questionnaire and consequently participants may have found it difficult to conceptualise and/or assign it to specific locations within the catchment. In addition, as a service, tourism can be viewed from both the perspective of businesses and local economies, and of tourists themselves.

Participation in the questionnaire was restricted to local residents in order to ensure participants had a basic familiarity with the catchment; therefore, assessment of tourism value of the catchment was generally restricted to the 'local economy side' of this service. Further research into tourists' social values could offer additional insights into the delivery of tourism ecosystem service across the catchment.

5.1.5 Spatial coincidence between arable productivity hotspots and hotspots for TWI in arable, grassland and heather land covers

TWI hotspots in arable, grassland and heather land covers (Figure 4.5) represent areas of high wetness and low water retention, and therefore locations where nature-based flood mitigation interventions could prove effective (Nisbet *et al.*, 2011; Sutherland *et al.*, 2014; EU, 2015). These hotspots show a 9.7% overlap with arable productivity. This coincidence could reflect a causal link between the two – areas of high TWI could be more productive due to a greater water availability. This may also predict possible future trade-offs between arable productivity and flood defence, if land managers consider flood mitigation interventions in these areas.

5.2 Issues of scale

The importance of scale, both resolution and extent, in mapping cultural services is poorly addressed in the current literature. In part, the spatial resolution of social value mapping is limited by the detail available on maps supplied with PPGIS surveys (especially when large extents such as whole catchments are considered). However, even more than this, resolution is limited by the scale to which the public can perceive spatial variability in landscape values. Asking the public to, for example, discriminate between the aesthetic value of two locations 5m apart is likely to be much less meaningful than asking them to identify differences between locations separated by hundreds of metres. In order to produce meaningful data, social value mapping should be limited to relatively coarse resolutions.

In contrast, using coarse resolutions for biophysical mapping of ecosystem services, such as the 250m cell sized used here, may be insufficient for many management applications. Flood mitigation and agricultural productivity interventions within a catchment will generally occur at the scale of the individual farm or field. Therefore, object-based

analyses may be a more relevant analytical approach (see Section 5.4). Also, whilst coarse scales can be useful for decision making for broad extents (e.g. national policy making), if the spatial extent is restricted to the catchment boundary and resolution is limited, this may mask spatial variability and make hotspots difficult to detect. This effect could account for the lack of hotspot identification for grassland NDVI – the catchment scale could be too small to detect substantial variability and the resolution too coarse to detect clustering for hotspot identification.

This mismatch between the resolutions appropriate for social value and biophysical mapping suggests that simultaneous mapping of these different aspects of landscape value may be problematic at a catchment scale. Mapping of both social values and biophysical systems are critical for effective management and the delivery of sustainable landscape multi-functionality, but forcing both to be resolved to the same scale so that they may be directly compared may not be the most impactful way of informing management and policy making.

5.3 Limitations

5.3.1 Social value mapping

Using point data to infer continuous spatial distributions of social value introduces error due to the way in which the space between points is valued. If a location is not identified by a point, it does not mean it is without value. Even given a much larger sample, point data will never be capable of forming a perfectly spatial contiguous distribution. The social value mapping tool SolVES 2.0 and 3.0 (Sherouse *et al.*, 2014) tackles this by using the Maxent algorithm to translate survey point data into continuous distributions using environmental layers (e.g. land cover, distance to water, elevation), which are thought to influence social value distributions to infer between-point value scores – the value of no-data locations is inferred from the value of locations with similar environmental conditions where point data is available. However, statistical comparisons cannot be made between social value maps created in this way and biophysical maps derived from the same environmental layers, because this violates assumptions of sample independence. In addition, the relationships between environmental variables and social values may be much more complex than assumed. Therefore, social value mapping

techniques must balance limitations of between-point errors with those of model oversimplification and limited analytical applications.

5.3.2 Biophysical modelling

5.3.2.1 Flood mitigation

The biophysical mapping of flood mitigation had a number of limitations. The approach assumed constant water retention capacity within land-cover classifications (woodland as high retention; grassland, arable and heather as low retention). In reality, water retention will vary within land cover classifications. Furthermore, land cover is not the only determinant of water retention capacity, soil variability is also central to hydrology (Nedkov and Burkhard, 2012). Similarly, small scale features such as hedges and banks, and artificial hydrological features (e.g. flood defences, drainage systems) will influence flows, causing on-the-ground flow patterns to deviate from topographically-derived models. Future research could apply more complex (and data intensive) methods (e.g. KINEROS and AGWA models, Nedkov and Burkhard, 2012) to the Cober catchment.

5.3.2.2 Agricultural productivity

Biophysical mapping of agricultural productivity was limited by the central assumption of the link between NDVI and productivity. Whilst NDVI is highly associated with agricultural productivity (Asrar *et al.*, 1984; Pettorelli *et al.*, 2005; Gitelson *et al.*, 2006), this is generally restricted to arable productivity; therefore, its use to assess pastoral productivity, via the productivity of grasslands, is likely to incur greater errors. Furthermore, whilst NDVI can assess plant productivity, this does not necessarily relate to economic value. Many crops may not be food crops (e.g. daffodils common in Cornwall), and therefore may contribute less to human wellbeing.

Other limitations include:

- The mean NDVI was taken over four Landsat scenes (1984-2014) so that hotspots of consistently high productivity could be identified and the effects of inter-annual variation in agricultural inputs minimised; however, the mean is vulnerable to distortion by extreme values.

- Scenes from two different Landsat missions (5 and 8) were used in order to cover an appropriate time span. Scenes from both were radiometrically corrected and converted to TOA values, which helps to mitigate errors; however, spectral bands did differ slightly between the two missions (Appendix 5).

5.3.3 Comparisons between datasets

Differences in the timing of data acquisition can introduce errors into comparative analyses. The social value survey was conducted from June-July 2015, whilst Tellus LiDAR data were collected from August-November 2013 (Tellus South West, 2015), Landsat data spanned 1984-2014, and land cover data were derived from remote imagine data acquired from 2005-2008 (Morton *et al.*, 2011). Temporal mismatch could introduce error, e.g. any land cover change between the first Landsat scene (1984) and the LCM2007 data acquisition (2005-8) (Morton *et al.*, 2011).

Additionally, social value assessment treated agricultural productivity as a single service, whilst biophysical modelling separated arable from pastoral land uses. More direct comparison of analogous social value and biophysical maps may require agriculture to be explicitly separated into arable and pastoral practices in future social value mapping exercises.

5.3.4 General

Whilst hotspot analysis is a useful tool for management prioritisation, it overlooks the lower intensity value of space between hotspots. These areas should not be assumed to be devoid of value. In the case of social value mapping, a lack of hotspot may indicate poor awareness of an area's value rather than low social value itself. Management strategies which raise awareness of undervalued areas may be particularly useful when trying to redistribute human use where overuse could damage sensitive environments (van Riper *et al.*, 2012; Bagstad *et al.*, 2015; Table 5.1).

5.4 Further research

In order to inform management more effectively, finer scale biophysical modelling of agricultural productivity and water regulation will be necessary. Ecosystem services-related interventions (e.g. land management for flood mitigation and the minimisation of

agricultural runoffs; agricultural schemes for biodiversity or carbon stock protection) will require more detailed maps than those produced here (250m). The data for such analyses is available – the Tellus LiDAR dataset has a spatial resolution of 1m, and Landsat and Land Cover (CEH, 2011) data are resolved to 30m and 25m respectively. Geographic object-based image analysis (GEOBIA), using baseline maps such as the OS MasterMap, can be used to segment spatial layers into irregular land parcels using management-relevant polygons representing discrete features such as fields, woods, buildings and roads (Kampouraki *et al.*, 2006; Maddena *et al.*, 2008). An object-based approach could also be useful for mapping environmental threats of relevance to the catchment - for example, agricultural runoffs which threaten water quality and are tightly coupled to patterns of hydrological flow. Whilst this approach may be at too fine a scale for social value mapping, it would prove valuable for improving the management and policy applications of biophysical maps.

Further development of the mapping of ecosystem services in the Cober catchment and other catchments could include the incorporation of environmental, as well as ecosystem, services into service mapping, and the production of an overall prioritisation map. In their study across the whole of Cornwall, Casalegno *et al.* (2014) included environmental services, such as renewable energy supply and space for urban development, alongside ecosystem services such as flood mitigation and agricultural productivity. The inclusion of non-ecosystem derived environmental services could be useful for future management decisions. Casalegno *et al.* also produced an overall prioritisation map by weighting services according to a complementarity-based ranking algorithm. This kind of approach could be applied to the catchment scale to allow the simultaneous interpretation of multiple service distributions in an explicitly quantitative manner.

5.5 Conclusions and wider context

Ecosystem services assessments should not be viewed as a panacea for conservation. Whilst win-win scenarios can often be identified in areas where biological importance and ecosystem service delivery coincide, so too can trade-offs between competing demands on land uses and management. Ecosystem services assessments are not intrinsically conservation measures, but rather tools for making more balanced and evidence-based decisions about how we manage landscapes in order to receive the

greatest possible benefits from them (Vira and Adams, 2009). Interestingly for conservationists, the protection of nature is often the most beneficial action.

Maps of social and biophysical values of ecosystem services are useful tools for land management decisions and understanding how public perceptions of landscapes relate to physical and ecological functions. In particular, hotspot analyses are a means of expressing difficult-to-monetise cultural ecosystem services such that they may be directly compared to maps of biophysical function or economic value (Bagstad *et al.*, 2015). They encourage the integration of traditionally segregated epistemologies (Daniel *et al.*, 2012), facilitating the development of a much richer understanding of ecosystem and landscape value. Further integration of the social and natural sciences in ecosystem services research will allow ever greater understanding of the multifaceted way in which we value the natural world.

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Appendix 1: Social value questionnaire

Public Attitudes Towards the River Cober Catchment, West Cornwall

It is important to consider public attitudes towards the natural environment when deciding how to manage it. We are researching public attitudes towards an area of West Cornwall: the River Cober catchment (the area of land from which water flows into the River Cober system).
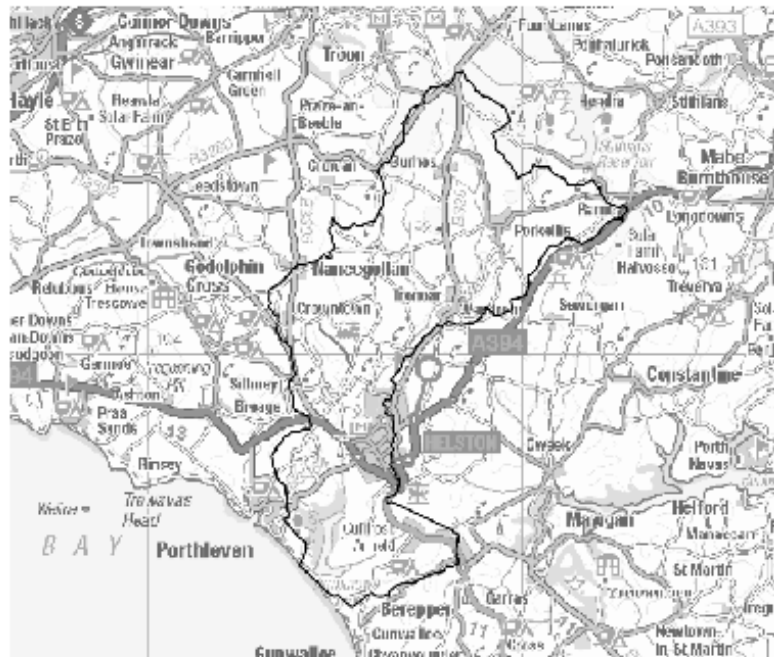
(catchment boundary indicated by the thick black line)

If you live in west Cornwall (postcodes TR3, TR10, TR11, TR12, TR13, TR14, TR15, TR16, TR17, TR18, TR19, TR20 or TR26) we would be very grateful if you would like to participate in this research by completing the following questionnaire.

Participants must be aged 18 or over and all information will remain anonymous. The questionnaire may only be completed once per person.

If you would like to be entered into a draw with the chance to win a **£60 Amazon voucher**, please enter your email address in the space at the end of the questionnaire (if you would prefer not to include your email address you will unfortunately not be entered into the draw).

I live in west Cornwall, I am aged 18 years or over and I consent for my answers to be included in this research   ☐

(please place a tick in the box if appropriate)

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<u>Section 1: What is important to you within the Cober catchment area?</u>

We are interested in how important each of the following different types of value are to you within the Cober catchment environment.

Imagine that you could "spend" £100 to ensure that the following list of values continue to be provided (in the same way as they are currently) within the Cober catchment. You may allocate or "spend" this £100 in any way you wish (i.e. £100 on one and £0 on all others or £50 on, one £25 on another and £25 on another etc.), but the total spend must equal £100 (no higher or lower). Reference to money is not made to actual money.

a) *Aesthetic value* – This area is important to me because I enjoy the scenery, sights, sounds, smells etc.

    £..........

b) *Agricultural value* – This area is important to me because it provides economic and life-sustaining benefits of agriculture

    £..........

c) *Biological Diversity value* – This area is important to me because it provides a variety of wildlife, plant life, fish etc.

    £..........

d) *Cultural value* – This area is important to me because it is a place for me to continue and pass down the wisdom and knowledge, traditions and way of life of my ancestors

    £..........

e) *Flood Defence value* – This area is important to me because it defends my property, lifestyle, economic interests or wellbeing from flooding

    £..........

f) *Intrinsic value* – This area is important to me in and of itself, whether people are present or not

    £..........

g) *Recreation value* – This area is important to me because it provides a place for my favourite outdoor recreation activities.

    £..........

h) *Tourism value* – This area is important to me because it supports tourism activities, which provide economic and/or cultural benefits to the area.

    £..........

TOTAL "SPEND" MUST EQUAL £100

Section 2: Locating values on a map of the Cober catchment

In the previous section, you told us which values are important to you within the Cober catchment. In this section, we would like you to represent those values on a map of the area.

Look at the map supplied with this questionnaire. <u>For each of the values</u> to which you allocated <u>any</u> money in Section 1, choose <u>up to 4 locations</u> within the Cober catchment area that come to mind when thinking about that value. Mark these locations on the map with a dot and label each dot according to which value it represents:

Value	Label
Aesthetic	Ae
Agricultural	Ag
Biological Diversity	B
Cultural	C
Flood Defence	F
Intrinsic	I
Recreation	R
Tourism	T

Section 3: General Information:

a) **What is the first part of your postcode? (e.g. TR11)**

....

b) **How long have you lived in West Cornwall? (please tick one)**

☐	Less than 1 year	☐	6-10 years
☐	1-2 years	☐	11-20 years
☐	3-5 years	☐	21+ years

c) **What is your age? (please tick one)**

☐	18-24	☐	51-60
☐	25-30	☐	61-70
☐	31-40	☐	71+
☐	41-50		

d) **What is your gender?** (please tick one)

☐   Male   ☐   Female   ☐   Other

e) **When were you last within the Cober catchment area?** (please tick one)

☐   Within the last week   ☐   Within the last year

☐   Within the last month   ☐   More than a year ago

☐   Within the last 6 months   ☐   Never

f) **How many times have you visited the Cober catchment during the last 12 months?** (please tick one)

☐   1-2   ☐   11+

☐   3-5   ☐   Never

☐   6-10

If you would like to be entered into a draw with a chance to win a £60 Amazon voucher please provide your email address below:

Thank you for taking the time to answer this questionnaire.

This project is researching the relationship between the spatial distributions of social and cultural values of the Cober catchment and physical measures including biodiversity, flood mitigation and agricultural services, with a view to informing future management decisions in the area.

For more information, please contact kt319@exeter.ac.uk

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[Map attached overleaf]

Appendix 2: Technical details of the Tellus SW LiDAR dataset

The Tellus SW dataset (Beamish *et al.*, 2014) was acquired during July and August 2013 using an Optech ALTM 3100 EA scanning laser with an integrated Applanix GPS/INS positioning system. The DTM represents a topographic model of bare earth to a resolution of one point per $1m^2$ (grid cell) and an average height accuracy of +/- 25cm. Data were processed by Environment Agency Geomatics using Terrascan processing software automated procedures to produce the DTM layer from the calibrated point cloud (Environment Agency, 2014).

Appendix 3: LCM2007 dataset

Land cover data were sourced from the Countryside Survey: Land Cover Map 2007 (LCM2007). LCM2007, based on the Ordinance Survey Master Map topography layer, provides a continuous vector coverage of UK Broad Habitats (as developed by the UK Biodiversity Action Plan and defined by the Joint Nature Conservation Committee (JNCC)) as determined from summer and winter satellite data acquired by Landsat-TM5, IRS-LISS3, SPOT-4 and SPOT-5 sensors (pixel size 20-30m) and AWIFS (pixel size 60m) when other imagery were unavailable. Land cover was determined by a parcel-based supervised maximum likelihood method using a training data set of known land cover from field observation against satellite spectral signatures, achieving an accuracy of 83% (Morton *et al.*, 2011). Classification was made using red, near and mid infra-red spectral bands for optimised discriminatory power between vegetated surfaces. The final raster data set is resolved to 25m and covers 23 distinct land cover classes (Morton *et al.*, 2011).

Adapted from Appendix 1, CEH (2011):

LCM2007 class	Brief description
Broadleaved woodland	Deciduous, mixed, scrub. Stands >5m high with tree cover >20%. Scrub requires cover of >30% for inclusion.
Coniferous woodland	Conifer, larch, evergreen, felled. Includes semi-natural stands and plantations with cove >20%.
Arable and Horticulture	Annual crops and perennial crops (including orchards).
Improved Grassland	Higher productivity than semi-natural grasslands, lack of winter senescence. Includes ley and hay.
Neutral Grassland Calcareous Grassland Acid Grassland	Separated from 'Rough grassland' based on knowledge-based enhancement rules including botanical composition.
Rough Grassland	Rough/unmanaged grassland.
Heather and Heather Grassland (together, '*Dwarf Shrub Heath*' Broad Habitat)	'*Dwarf Shrub Heath*' is divided into two classes, depending on the density of Heather, producing 'Heather' and 'Heather grassland' classes respectively.
Fen, Marsh and Swamp	Includes fen, fen meadows, rush pasture, swamp, flushes and springs.
Bog	Includes ericaceous, herbaceous and mossy swards in areas with a peat depth > 0.5 m.
Saltwater	Mapped to a limited extent around the coastline of the UK.
Freshwater	Based on merging two freshwater broad habitats ('*Standing Open Water and Canals*' and '*Rivers and Streams*'), Water bodies > 0.5 ha are readily mapped, as are very wide rivers (>50 m).
Montane Habitats	Assigned based on altitude.
Inland Rock	Covers both natural and artificial exposed rock surfaces which are >0.25ha, such as inland cliffs, caves, screes and limestone pavements, as well as various forms of excavations and waste tips such as quarries and quarry waste.
Urban and Suburban	'Urban' includes dense urban, such as town and city centres, where there is typically little vegetation. 'Urban' also includes areas such as dock sides, car parks and industrial estates. 'Suburban' includes suburban areas where the spectral signature is a mix of urban and vegetation signatures.
Supra-littoral Rock	Includes vertical rock, boulders, gullies, ledges and pools.
Supra-littoral sediment	Includes sand-dunes, which are reliably mapped in this class.
Littoral Rock	Maritime mask zone on a rocky coastline.
Littoral sediment and Saltmarsh	Saltmarsh is a Priority Habitat and of sufficient extent and spectral distinction to be mapped consistently. The remaining 'Littoral Sediment' is mapped spectrally, although there may be some confusion with the 'Supra-littoral sediment' class.

Appendix 4: Soil map of the Cober catchment region

Soilscapes (2015)

	Blanket bog peat soils		Loamy and clayey soils of coastal flats with naturally high groundwater		Slowly permeable seasonally wet acid loamy and clayey soils
	Fen peat soils		Loamy and sandy soils with naturally high groundwater and a peaty surface		Slowly permeable seasonally wet slightly acid but base-rich loamy and clayey soils
	Freely draining acid loamy soils over rock				
	Freely draining floodplain soils		Loamy soils with naturally high groundwater		Slowly permeable wet very acid upland soils with a peaty surface
	Freely draining lime-rich loamy soils		Naturally wet very acid sandy and loamy soils		Very acid loamy upland soils with a wet peaty surface
	Freely draining sandy Breckland soils		Raised bog peat soils		sea
	Freely draining slightly acid but base-rich soils		Restored soils mostly from quarry and opencast spoil		unclassified
	Freely draining slightly acid loamy soils		Saltmarsh soils		water
	Freely draining slightly acid sandy soils		Sand dune soils		
	Freely draining very acid sandy and loamy soils		Shallow lime-rich soils over chalk or limestone		
	Lime-rich loamy and clayey soils with impeded drainage		Shallow very acid peaty soils over rock		
	Loamy and clayey floodplain soils with naturally high groundwater		Slightly acid loamy and clayey soils with impeded drainage		

Appendix 5: Landsat scene details

Date	Landsat Mission	Path	Row
04/06/1984	Landsat 5 TM	204	25
31/05/1994	Landsat 5 TM	204	25
03/08/2003	Landsat 5 TM	205	25
14/06/2014	Landsat 8 OLI	205	25

Appendix 6: Landsat spectral band details

	Visible red		Near infrared (NIR)	
Landsat Mission	**Band**	**Wavelength (micrometres)**	**Band**	**Wavelength (micrometres)**
L5 TM	3	0.63-0.69	4	0.76-0.90
L8 OLI	4	0.64-0.67	5	0.85-0.88

USGS (2014)

Appendix 7: Risk assessment and ethical approval

Risk assessment Turnitin submission ID: 42862048.

Ethical approval obtained via the University of Exeter On Line Ethics Approval system.