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A Case Study from Wild Ennerdale: An Evaluation of Nature-Led Conservation's Capacity to Deliver Ecosystem Services

By Alex Moore



Dissertation submitted in part fulfillment of the requirements for the degree of Master of Science Sustainable Mountain Development

University of the Highlands & Islands

Date

Word Count

Supervisor: Rosalind Bryce

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Abstract

Ecosystem services are essential to life on earth, the way in which society values and manages a landscape can greatly effect the capacity of that area to provide Ecosystem services. In recent decades, the intensification of agriculture has led to a waning capacity to provide ecosystem services in many areas of the UK. New land management strategies such as nature-led conservation and rewilding represent a significant divergence from land management under the Common Agricultural Policy and may have the ability to supply greater levels of ecosystem service capacity across the UK. This study used a method adapted from Burkhard *et al* (2012) in which expert judgement and spatial data are linked to land-covers capacity to supply ecosystem services to produce maps showing the valleys capacity of provide five selected ecosystem services in 2007 and 2015. An interview with a principal manager of the Wild Ennerdale project also informed this study with the information necessary to make conclusions on the effect of nature-led conservation on the capacity of an area to provide ecosystem services. The information gained from the resulting maps and interview data make clear that nature-led conservation has had a significant impact on the ecosystem service capacity in a relatively short timespan, including an increased capacity to provide flood management, carbon sequestration, aesthetic value, and fresh water and reduced capacity to provide timber. However, the results are site specific and vary across the valley. This study has also demonstrated the strengths and weaknesses of the Burkhard method as a fast and effective means of providing information on ecosystem service capacity at a catchment level.

1. Introduction

Ecosystem services are the benefits society gains from the natural world; they are essential to life on earth (Leemans and De Groot, 2003). Anthropocentric pressures such as agriculture and climate change can reduce the capacity of an ecosystem to provide ecosystem services (Villamagna *et al*, 2013). Across the UK agricultural intensification, prompted by the Common Agricultural Policy, has led to environmental damage in mountainous regions. As a result, mountainous regions have seen increased flooding, biodiversity loss, habitat loss and increased instances of landslides (Natural England, 2020).

In contrast, a growing proportion of the UK is now governed under alternative land management strategies such as ecosystem restoration, nature-led conservation, and rewilding. These strategies take a passive approach to land management and give freedom to ecosystem processes.

Notably, in the Lake District National Park the Wild Ennerdale project has been delivering nature-led conservation for over two decades. This project has implemented several significant changes to the management of the Ennerdale valley, including the reduction of sheep grazing, the introduction of cattle and allowing freedom of movement to the river Liza.

This study shall map the capacity of five ecosystem service's provided by the Ennerdale valley using a method adapted from Burkhard *et al* (2012). Two data sets shall be used to establish the capacity of the Ennerdale Valley at the start of the Wild Ennerdale project and as recently as possible, the maps produced from this data can then be compared to establish the effect nature-led conservation has thus far had on the valleys capacity to deliver ecosystem services. An interview focusing on the Wild Ennerdale projects management of the valley shall also be conducted. The information gathered in this interview will be used to link management decisions to changes in ecosystem service capacity.

2. Literature Review

2.1 Keywords

Ecosystem Services, Rewilding, Nature-led Conservation, Ennerdale, Policy

2.2 Introduction

The Ennerdale valley is managed by the Wild Ennerdale project, a partnership between the Forestry Commission, The National Trust, United Utilities, Natural England and local landowners and farmers. The project is using innovative land management strategies with the aim of delivering greater public goods. The following literature review focuses on academic journal articles, publications from The Wild Ennerdale Project and other sources that concern upland land management, ecosystem services, the Ennerdale Valley, rewilding, and land management policies, and will provide the context for the research detailed within this thesis.

2.3 UK land Management and Policy

The UK has struggled with a history of agricultural policy that has unwittingly caused the degradation of ecosystem services across the country. In lieu of effective agri-environment schemes, some landowners are looking to alternative management strategies to increase the stock of ecosystem services being provided by their land. More evidence is needed to confirm rewilding (or nature-led conservation) as a strategy for increasing ecosystem service delivery. A case study of the Wild Ennerdale project may provide valuable information due to its long-standing use as a site of rewilding action including species re-introduction.

The UK is currently suffering the effects of degraded ecosystem services, without which the earth would be uninhabitable. The Economics of Biodiversity Report

(Dasgupta 2021) states that “Governments almost everywhere exacerbate the problem [degradation of ecosystems] by paying people more to exploit Nature than to protect it, and to prioritise unsustainable economic activities...” and indeed this has been a major critique of the Common Agricultural Policy (CAP) which has governed European and UK agriculture since 1962. Although the CAP was reformed several times to modernise and reduce the economic cost of farming in Europe, environmental problems remained as stated by Kuhmonen (2018).

Further evidence of systemic failure to protect ecosystems and their associated services comes from The Landscapes Review (Glover, 2019) which summarises:

“Our system of landscape protection has been hampered by having little influence over the things which have done the most harm to nature. This includes a system of farming subsidies which, although it has improved, for decades rewarded intensification regardless of the consequences...”

The Landscape review was commissioned by the UK government, in response to the 25 Year Environment Plan (Defra, 2018) to assess the way in which the UK protects its “national landscapes”. The findings of this review conclude that without structural reform and greater ambition, ecosystems in the UK shall continue to be depleted by climate change and intensive agriculture.

Evidence for the decline of ecosystems in the UK is detailed in The State of Nature Report (2019). Among the report's key findings was that agricultural productivity and intensive land management were key pressures on UK ecosystems. However, the report also highlights a growing trend in agricultural practitioners recognising the environmental impact of agricultural practices and adopting EU funded Agri-Environment Schemes (AES); or instead reducing the use of fertilisers and pesticides.

Since leaving the EU the UK government set out to create new agricultural and environmental policies to replace the CAP. The Agricultural Bill, The Environmental Bill, and The Environmental Land Management Scheme (ELMS) were the resulting

policies. ELMS places a significant onus on restoring ecosystems via the “landscape recovery scheme” (Defra, 2023).

AES have however been present in European Union policies for many years and Tyllianakis and Martin-Ortega (2021) state that some farmers are willing to take part in these schemes. Unfortunately, these schemes have had little effect on the environmental standards of land management due to low uptake by farmers and landowners, the reasons for this are given by Tyllianakis and Martin-Ortega as i) financial barriers, ii) wrongful application of AES, iii) motivation and preference for AES and finally iv) sociodemographic characteristics, such as farm size, farmer age and training.

The underlying goal of AES is to improve the stock of ecosystem services being provided by nature, but due to poor uptake of AES and/or poor AES design, some landowners and land managers are looking to “rewilding” as a method of increasing the ecosystem services being provided by their land, as shall be explored later in this review. Diversification is a prevalent theme in the UK uplands as low soil fertility and steep slopes impede farming to the degree they are classed as “severely disadvantaged areas” (Defra, 2018). However, UK uplands, which cover approximately 12% of the country, can deliver vast quantities of ecosystem services due to their unique geography that helps to provide fresh water, prevent flooding, provide habitat, and store carbon, making them ideal locations for rewilding schemes (Sandom *et al*, 2019).

2.4 Ecosystem Services

Ecosystems have been an established area of study for close to a century since Tinsley (1935) provided an initial conceptualization. Ecosystems are defined as “dynamic complex of plant, animal, and microorganism communities and the non-living environment, interacting as a functional unit” (Leemans and De Groot, 2003). Ecosystems perform a wide range of functions, many of which are beneficial to society, these functions have been termed “Ecosystems Services”. However, it is

only in recent years that these services have become more formally recognised, studied, and specifically considered in policy.

Ecosystem services are defined in the Millennium Ecosystem Assessment (MEA) as “the benefits people obtain from ecosystems” (Leemans and De Groot, 2003). These services are delivered via a pathway, beginning with ecological structures and processes, and ending with improved well-being in society, with the ecosystem services playing a pivotal role within the pathway (Potschin *et al*, 2016). Ecosystem services have been categorised into provisioning, regulating, supporting and cultural services according to the nature of the benefit they provide to society. These categories are detailed below:

- Provisioning services are those that benefit society directly through goods such as fruit, vegetables, timber and other building materials and clean water among many more. These are relatively simple to identify and quantify as they typically have a market value.
- Regulating services include services such as air and water filtration, pollination, and carbon sequestration. These services benefit society by moderating aspects of the natural world.
- Cultural services range from simple services such as recreation to more complex services such as providing religiously significant sites and phenomena.
- Supporting services provide conditions under which cultural, regulating and provisioning services can exist, these services include photosynthesis, nutrient cycling, and the creation of soil.

There has been some criticism of this conception of ecosystem services. Fairhead *et al* (2012) argue that the MEA concept is anthropocentric and promotes an exploitative human-nature relationship while others state that the concept is too

economically focused and may lead to the over-commodification of nature (McCauley, 2006; Sagoff, 2008; Gómez-Baggethun and Ruiz-Pérez, 2011). However, the definition provided by the MEA remains the predominant concept.

Due to their fundamental role in supporting society and the economy, there has recently been a policy-level focus on ecosystem services and improving the state of nature in the UK. A primary example of this focus is 'The Economics of Biodiversity' (Dasgupta, 2021) which provides insights into the importance of environmental health to the functioning of our economic markets. The review approaches the topic with a traditional economic method but concludes that the economy is embedded within the environment and is therefore limited by it and its wellbeing. While this view has been seen to be "unorthodox" (Groom and Turk, 2021) it has nevertheless reinstated the need for further research into ecosystems, their functions, and the benefits they provide to society.

Ecosystem services are commonly measured quantitatively in terms of their economic value, for services such as timber production this is a simple and informative method. However, measuring cultural and religious services is more complex. Monetary approaches have been developed however, such as those discussed by Hernández-Morcillo *et al* (2013). Qualitative methods have also been developed for cultural services, such as spatial measures of social values and other perceptions of place gathered through preference surveys by Raymond and Brown (2006).

The valuation of cultural ecosystem services has nonetheless been a stumbling block for ecosystem service focused land management for several years. This issue currently acts as a barrier to the ecosystem service approach as a practical option for policy development.

A key aspect of ecosystem services for land managers to measure is the "capacity". There is a disagreement in the literature around the definition of the term "Ecosystem Capacity", Villamagna *et al* (2013) state that it is the potential of an ecosystem to deliver services based on biophysical properties, social conditions, and ecological functions, this is supported by Chan *et al* (2006), Egoh *et al* (2008) and Daily *et al* (2009). Burkhard *et al* (2009) however, states that ecosystem capacity refers to the

generation of an actually used set of natural resources and services, differentiating capacity from “potential supply” which would be the hypothetical maximum yield of a service.

The former definition of ecosystem capacity shall be used in the following study as measuring the potential to deliver a service is arguably simpler and more fitting to the aims of the study.

The capacity of an ecosystem is time and site specific and changes in response to ecosystem pressures such as agriculture and urbanisation. The dynamic nature of ecosystem capacity and the insight it provides into the functioning of ecosystem services makes it a key consideration when changing management strategies. A high ecosystem capacity denotes a high level of ecosystem functioning, as it is this functioning that supplies the services society values. Therefore, by measuring the capacity of an ecosystem to provide ecosystem services, the management decisions taken by land managers can be evaluated to be increasing or decreasing ecosystem services.

A key element to making rewilding and nature-led conservation fit for policy is mapping the ecosystem services that they provide, as stated by Daily and Matson (2008).

“The mapping of ecosystem services... is required in order to improve the recognition and implementation of ecosystem services into institutions and decision-making.”

Burkhard *et al* (2012) answered this call by devising a method for mapping an area's ecosystem service capacity (Campagne and Roche, 2018). The method requires land-cover data to be coupled with expert opinion on the type and quality of service that may be provided by a certain land-cover. A scoring matrix is used to rank the capacity of various land-uses to deliver a suite of ecosystem services and produces maps based on the scoring of this matrix. This method of evaluating an areas ecosystem service capacity has been widely adopted and adjusted to many case studies around the world, including Baró *et al* (2016) who used the method to map

ecosystem services in the Barcelona region of Spain and Verhagen *et al* (2016) who have utilised the method in the UK.

The Burkhard method has incurred some criticism over its use of “expert judgment” to determine the quality of a service being provided by an ecosystem. Campagne *et al* (2017) for example, demonstrated that the results will vary depending on the panel of experts. They suggest the addition of a confidence score to compliment the scoring system proposed by Burkhard so that experts can express their confidence in their judgment of the services being studied. The study detailed here will limit the variation of results by constructing an assessment matrix based on an already established matrix (presented in Burkhard *et al* (2012)), adjusting it to specifically serve Ennerdale with the use of expert judgment.

Nikolaidou *et al* (2017) demonstrated the strength of the Burkhard method in a study measuring the effectiveness of conservation designations in increasing the ecosystem capacity of various sites in Greece. The study found that areas with two designation types scored higher for ecosystem service capacity than areas without designations and that sites with multiple designation sites were “hotspots” of ecosystem services capacity. The positive correlation suggests that conservation efforts, in general, increase the level of ecosystem capacity in an area, as such the ecosystem service capacity of the Ennerdale valley may be significant in comparison to surrounding areas.

The scoring for Burkhard's matrix originates from the informed opinion of a panel of experts and has been used with success in several case studies (Burkhard *et al*, 2021). This Matrix has been adopted and modified either with the use of further expert opinion or indicators that supply quantitative data. Müller *et al* (2016) state that the target of indicators should be “the provision of quantitative information for decision-making processes, ecosystem-based indicators have to represent the complex interactions between biotic and abiotic components” (Pg.1). A large variety of indicators can be used, and the use of multiple indicators is often used for a single ecosystem service to improve the validity of this method.

Below, Table 1 shows the ecosystem services included in this study and the indicators commonly used to quantify them:

Ecosystem Service	Indicator
Flood Management	Land cover (Ha ² of high friction landscape)
Aesthetic Value	Protected areas, distance to scenic site, landscape value, cultural heritage
Carbon Sequestration	Above ground biomass, below ground biomass, land cover, soil Carbon
Fresh Water Provision	Ground water, precipitation, evapotranspiration
Timber Provision	Land cover, density of trees

Table 1 Ecosystem services and their indicators

2.5 Rewilding

The Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES, 2019) argues that systematic change is required to create a sustainable world, therefore new and innovative ways of managing landscapes must be devised. Many of these practices fall under the umbrella term “rewilding” which is defined by Rewilding Britain (2023) as:

“The large-scale restoration of ecosystems to the point where nature is allowed to take care of itself. Rewilding seeks to reinstate natural processes and, where appropriate, missing species – allowing them to shape the landscape and the habitats within.”

However, approaches to rewilding vary substantially between each rewilding project, of which in the UK there are few (Hawkins *et al*, 2022). This wide variety of approaches may be due to the low number of rewilding schemes in the UK and Europe, with each scheme interpreting the term for itself, rather than being prescribed a management strategy.

It is noteworthy that Ward (2019) and Sandom *et al* (2019) demonstrate that “rewilding” continues to be a divisive term, in part because rewilding can be so far removed from the status quo of land management and because the term has been politicised by authors such as Monbiot (2013). For these reasons some projects that might otherwise be labelled rewilding are instead labelled nature-led conservation, process-led conservation, or restoration. In addition, many projects use the term “wilding” as the prefix “re” implies a return to a previous state, which may not be explicitly the intent of the project (Corlett, 2016). Moreover, Corlett (2016) states that there is also a hesitation around the term “rewilding” as the enthusiasm for rewilding caused by popular books such as *Feral* (Monbiot, 2013) and *Wilding* (Tree, 2018), that have pushed rewilding forward while leaving a lack of empirical evidence for its use as a conservation strategy. The Wild Ennerdale project, for example, does not use the term rewilding, despite following many of the principles of rewilding.

However, a body of research connecting rewilding and ecosystem services does exist and has been growing steadily since the late 1990s when the concept of rewilding began to take form and increased rapidly in the 2010s as more rewilding projects began across Europe and the United States (shown in figure 1). However, more research is required to build trust in rewilding and nature-led conservation across a broader sweep of society.

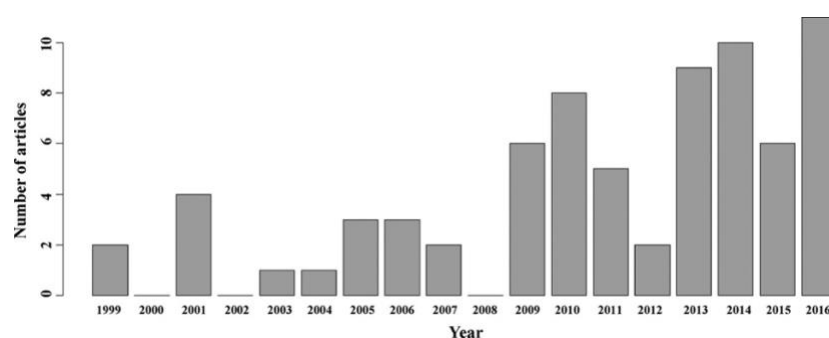


Figure 1. Articles on Web Science concerning rewilding. From Pettorelli *et al* (2018).

Rewilding has been championed as a method for improving and restoring ecosystems, and in turn ecosystem service. Sandom *et al* (2019) make the case that

this feature of rewilding is likely the strongest argument for constructing policies supporting rewilding as a land management strategy.

Cerqueira *et al* (2015) conducted a study of rewilded land in the Iberian Peninsula and concluded that the process of rewilding is a suitable management option for increasing the ecosystem capacity of wilderness areas and abandoned land. The results of this study support Sandom *et al* (2019) findings and highlight the need for more research confirming rewilding's effectiveness in increasing ecosystem capacity.

The reporting of successful rewilding and restoration programmes is helping to build momentum for rewilding in Europe and build a consensus on how best to manage rewilding schemes (Egoh *et al*, 2021). Egoh *et al* (2021) highlight the increasing recognition of the value of restoration in ecosystems worldwide, particularly in a time of rapid global environmental change and showcase successful rewilding programmes from around the world. Generally, the method used by rewilding schemes is one of minimal intervention in natural processes such as vegetation succession combined with species introduction and some form of monitoring. Species introduction ranges from large charismatic animals such as wolves to “ecosystem engineers” such as beavers and wood ants, plants are also introduced in many schemes to improve the biodiversity of selected sites. Reintroductions aim to resurrect natural processes, and therefore ‘keystone species’ are often the subject of these schemes for their unique role in effecting ecosystems. Hale and Koprowski (2018) highlight the need for more research on the ecosystem effect of species reintroduction so that the effect of reintroduction can be better understood.

2.6 Wild Ennerdale

The Wild Ennerdale project has managed an area of 4,400 hectares in the Ennerdale Valley for around a decade. The project is run by a partnership of four landowners, United Utilities, Forestry England, Natural England, and the National Trust. The project serves as an excellent case study for determining nature-led conservation's effect on the capacity of an ecosystem to provide services, due to its

long history and its variety of management actions, such as the introduction of large grazing herbivores.

The Wild Ennerdale Stewardship Plan (2018) states that it is not in the remit of Wild Ennerdale to define “rewilding” but that the vision of the project sits comfortably within the definition provided by Rewilding Britain above. The stewardship plan then moves to state the intent of the project to use nature-led conservation strategies to deliver “greater public goods within and beyond our own boundary of Ennerdale” (pg.13). Public Goods are defined by Helm (2015) as “non-excludable and non-rival goods or services” meaning that they are available to everybody and are easily shared in society. In essence, ecosystem services are public goods provided by nature, such as clean air and water, carbon sequestration, and space for recreation.

The Wild Ennerdale project does not state explicit goals or aims but does make various management decisions, such as introducing species, and interventions according to the vision outlined in the Stewardship Plan. This approach is considered and supported by Hughes *et al* (2011), who suggest that open-ended projects such as the Wild Ennerdale project should be focused on natural processes, mobile landscape mosaics and improved ecosystem services. Furthermore, they state that the evaluation of open-ended restoration projects should be focused on the impacts and benefits of ecosystem restoration rather than on achieving a predetermined goal.

Hodder *et al* (2014) discussed the effects of landscape-scale management on the provision of ecosystem services. Their study consisted of five case studies, each chosen for their landscape-scale nature-led conservation strategies, among these case studies was the Ennerdale Valley. To conduct their investigation land managers from each of the five case study sites were asked to complete a questionnaire relating to their management of the area and their perceptions of ecosystem services. The next stage in the study's method was to study current land-use maps, matching land cover to services identified in the questionnaires. Finally, projected future land-cover maps were developed from expected land cover in the year 2060, and from these maps, results were drawn for the study.

The projected future land map from the Hodder *et al*/ study was based on the plans of the management team at the time, including extensive tree felling and minimum vegetation regeneration. The map shows an increase in broadleaved and mixed woodland in place of conifer woodland along with associated habitat change. The study concluded that over several decades the approach taken to managing the Wild Ennerdale project would have an aggregate effect of lowering the output of ecosystem services. However, while services such as carbon sequestration, aesthetic value and recreation all stood to gain from the management; fibre and food production took considerable losses.

Hodder *et al*/ provide valuable insights into the quantity of ecosystem services being provided by the Ennerdale Valley. However, their projected future maps, which due to their nature have an element of unreliability were also made prior to the introduction of grazing cattle to the valley, the effect of which on the valley's future may be fundamental to the output of ecosystem services. Large herbivores such as cattle have been a major focus of rewilding projects in Europe as they may be able to maintain biodiverse open-canopy woodland (Vera, 2009).

Pettorelli *et al* (2018) surveyed a wide variety of rewilding projects in an attempt to construct adequate policy structures to accommodate rewilding schemes, and in doing so they uncovered several areas that require further research, including increased understanding of the links between actions and impacts and the need for a comprehensive and practical framework for the monitoring and evaluation of rewilding projects.

Considering the research needs identified by Pettoirelli *et al* (2018) and the knowledge gap left by previous research in the Ennerdale valley, a case study investigating the link between rewilding and the valley's capacity to deliver ecosystem services may provide a valuable contribution to the current understanding of rewilding and its long-term implications on ecosystem capacity.

2.7 Conclusion

The following thesis will detail an investigation into Ennerdale's current capacity to provide ecosystem services as compared to its capacity prior to the introduction of nature-led conservation two decades ago. This study shall adapt the Burkhard method for use in Ennerdale to conduct the study in a well-established manner.

This study will seek to provide evidence that the use of nature-led conservation can change the capacity of an ecosystem to provide services to society in keeping with the research suggestions by Hughes *et al* (2011) and Pettorelli *et al* (2018).

3. Methodology

3.1 Introduction

The aim of this study is to carry out a case study in the Ennerdale Valley to determine the effects of nature-led conservation on the ecosystem service capacity of that valley. This study's primary means of data collection was creating maps showing the land cover and ecosystem service capacity. This chapter will detail the research strategy, data collection and data analysis. Study limitations shall also be identified, and mitigation measures discussed.

3.2 Time Horizon

This study used a longitudinal time horizon approach, studying both land-cover maps from 2007 and 2015. This approach shows how the ecosystem service capacity has changed over a relatively short period since the introduction of nature-led conservation. Without the comparison that this approach allows it would not be possible to assert that nature-led conservation has influenced the capacity of ecosystem services in the Ennerdale valley. However, an up-to-date and informative land cover data set is not currently available, and the results are therefore limited to assessing the change of ecosystem services between 2007 and 2015 only and are not representative of the Ennerdale valleys current capacity to deliver ecosystem services.

3.3 Research Design and Sampling Strategy

A scientific approach research philosophy was used in this research to find objective results where possible. This research philosophy is typically used in scientific research (Leavy, 2022). The results of this study should therefore be free of subjective input from the researcher.

The researcher took measures to ensure each judgment was as objective as possible and to remain value-free, referring to relevant literature and collating data from a variety of sources. Additionally, this study is in part a conceptual replication study as it follows an adapted method designed by Burkhard *et al* (2012). Replication studies are valuable for their ability to strengthen cumulative knowledge (Makel and Plucker, 2014)

This research was designed as a case study, as a specific set of characteristics was needed to demonstrate the effects of nature-led conservation on ecosystem capacity. These characteristics are listed below:

- a longstanding project
- appropriate levels of data available
- significant conservation area
- accessible
- participation of a local expert or project manager

Due to the specific criteria for selecting a case study, the sampling strategy for this study was non-probable and purposive as the case study was chosen for its specific qualities.

The Wild Ennerdale project was the chosen case study for this research as it has a unique set of characteristics that demonstrate the effects of nature-led conservation, namely, it is one of the longest-running projects of its type in the UK and therefore has had time for the land management strategy to have a marked effect on the bio-physical characteristics of the valley. An example of this is an increased area of land covered by bog, possibly due to various interventions influencing the hydrology of the valley. It is characteristics such as this that provide the capacity to deliver ecosystem services. In addition, the Wild Ennerdale project is in an advanced stage of nature-led conservation, having completed species introductions and restored ecosystem processes such as sediment flow into Ennerdale Water.

3.4 Ecosystem Services

The ecosystem services being evaluated were chosen in line with a study conducted by Hodder *et al* (2014) with the aim of evaluating landscape scale management's ability to enhance ecosystem service provision. This study was also conducted with the use of land-cover maps and therefore is comparable to the study discussed here. The ecosystems studied were:

- Aesthetic Value
- Carbon
- Timber
- Flood Protection
- Fresh Water

Energy and Food Production were included in the Hodder *et al* study but were omitted from this study due to limited data and supporting expertise.

The selected services are described in more detail below:

Aesthetic Value – Due to ongoing urbanisation and agricultural intensification the demand for aesthetically enjoyable environments is increasing (Glover, 2019). Mountain environments are a common destination for spending leisure time as they are appreciated for their aesthetics, heavily influenced by current and historic anthropomorphic landscape management. Mountain environments have been idealised since the start of the romantic period in the 1800s, the Lake District was central to this movement in the UK, being home to writers such as Wordsworth. Furthermore, mountains are appreciated due to their unique geological features and biodiversity (Carlson and Lintott, 2008; Northcott, 2020).

Schirpke *et al* (2016) conclude that alpine landscapes with long vistas and minimal urban settlements have the highest aesthetic value.

Carbon Sequestration – Carbon Sequestration is the capture, removal, and storage of carbon dioxide from the earth's atmosphere. This ecosystem service is crucial to the mitigation of climate change as carbon dioxide is a greenhouse gas. Terrestrial ecosystems sequester carbon as plants photosynthesise, storing fixed carbon in stabilized forms in biomass and soil, therefore environments with higher levels of above-ground vegetation generally have higher rates of carbon sequestration (Lal *et al*, 2013, pg.39).

Timber Provision – Timber can be harvested from ecosystems containing trees of an appropriate age, it is a valuable ecosystem service that has a wide range of uses. Extensive areas of land are managed specifically to produce timber through the growth and harvest of trees. Much of the land in Ennerdale is owned by The Forestry Commission and is used to grow coniferous trees such as Sitka Spruce.

Flood Mitigation – Natural ecosystems have the capacity to reduce the frequency and severity of floods by regulating run-off via water retention in plants, increasing infiltration via plant roots, and slowing the flow of flood waters in rivers among other mechanisms (Vári *et al*, 2022). A high presence of above-ground vegetation and functional flood plains indicate a high capacity for flood mitigation.

Fresh Water Provision – Freshwater provision is related to both the direct provision of water and services that aid provision such as water filtration and purification. Freshwater bodies, therefore, have a very high capacity while land cover types such as woodlands have low-medium capacities as they contribute to water filtration, lowering the need to treat water (Fiquepron *et al* 2013).

3.5 Data Collection

The data collection method used in this study was based on Burkhard *et al* (2009) concept of land-cover based assessment for determining the capacity to deliver ecosystem services. The method has been developed in recent years with the purpose of creating a quick and informative assessment protocol for future research to follow and to create useful data for environmental management and landscape

planning (Campagne and Roche, 2018). Indeed, this method has been replicated in several studies in many environments to assess ecosystem service capacity (Schmidt, 2008; Campagne *et al*, 2020). Unlike many methods used to assess ecosystem services, it does not use economic evaluation, which has been criticised as being anthropomorphic and not truly representative of ecosystem function (McCauley, 2006; Sagoff, 2008). In addition, economic assessments are timely to produce and assess. Burkhard's method links land cover data to expert judgement on the capacity of each land cover type to deliver ecosystem services.

In the initial stage of this method, land cover maps are judged with the use of an *assessment matrix* with land cover types on the y-axis and ecosystem services on the x-axis. In the intersection each land cover type's capacity to provide ecosystem services is judged on a scale shown below:

0 = no relevant capacity, 1 = low relevant capacity, 2 = relevant capacity, 3 = medium relevant capacity, 4 = high relevant capacity and 5 = very high relevant capacity.

Figure 1 shows the matrix produced by Burkhard *et al* (2012).

	Ecological Integrity										Σ	Provisioning services										Σ	Regulating services										Σ	Cultural services										Σ																						
	Abiotic heterogeneity											Biodiversity											Metabolic efficiency											Exergy Capture (Radiation)											Reduction of Nutrient loss											Storage capacity (SOM)										
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Figure 2 Burkhard Matrix from Burkhard *et al* (2012)

CORINE data was used by Burkhard *et al* (2012) to indicate land-cover types in the study area as it is accessible across much of the EU. However, CORINE data is not available in all areas to a high resolution, additionally, the data set is not yet complete despite heavy prompting by the European Union that member states engage with the programme. Therefore, this data set would not be suitable for mapping landscapes on a smaller scale.

Data to produce land cover maps was instead taken from the UK Soil Observatories Land Cover Maps dataset. This Data is freely available across the UK, is easily accessible and is complete in most areas. The Maps are produced by the Centre for Ecology and Hydrology dataset, who in turn have produced their maps from satellite imagery. The land-cover maps separate land coverage into 23 land-cover types based on the UK biodiversity Broad Habitats, depending on the above-ground cover as identified by satellite imagery. The UK Soil Observatory maps are also verified by members of the public using the “mysoil” mobile app as a method of crowdsourcing data from citizen science. The land cover maps are complete to a high resolution (10m²), allowing for a more detailed investigation of the study area.

3.6 Formation of Assessment Matrix

Burkard *et al* (2017) suggest the use of indicators and spatial data specific to each case study while using the matrix method, but also note that this information is sparse in many areas and timely to produce. Therefore, expert knowledge and judgement are often used as a proxy and the next best alternative (Jacobs and Burkhard, 2017; Kienast *et al*, 2009). Indeed, expert knowledge is often used as a surrogate for empirical data in ecological research (Drescher *et al*, 2013), experts use a combination of observations, formal knowledge, and local understanding to generate semi-quantitative data. In the case of this study, Burkhard’s matrix will be used as a basis for the assessment matrix, which shall then be adjusted and made specific to Ennerdale through expert judgment.

To construct the matrix the land-cover types used in the CORNIE data set had to be matched to the land-cover types used for the UK Soil Observatory and the Centre for Ecology and Hydrology (CEH) data sets. The number of land-cover types used in this study is much lower than in both CORINE data and CEH data as the geological diversity is greatly reduced by the relatively small study area, as such only the land-cover types present in the Ennerdale Valley were matched and assessed while land cover types not present such as coastal specific types were omitted. “Ancient

woodland” and “unstructured coniferous woodland” were then added upon the suggestion of a local expert during an interview as discussed below. The final list of land-cover types included in the study comprises 12, down from CORINE’s 44 and the CEHs 22. Table 1 shows which of the CORINE land-cover types informed land cover types of the initial assessment matrix. For two land-cover types, Montane Habitat and Heather, there was no relevant land-cover type in the CORINE list, as such they are listed as not applicable (N/A) in Table 1.

Assessment Matrix land-cover types	CORINE land-cover types
Improved Grassland	Pasture
Acid Grassland	Natural Grassland
Fresh Water	Water Bodies
Heather	N/A
Heather Grassland	Moors and Heathland
Broad-Leaved, Mixed and Yew Woodland	Broad-Leaved Forest
Coniferous Woodland	Coniferous Forest
Inland Rock	Bare Rock
Bog	Inland Marsh/Peatbog
Montane Habitat	N/A

Table 2 Land-cover types

The Initial Matrix can be seen below with the scores at each intersection having been adapted from the Burkhard *et al* (2012) original matrix. This matrix includes land cover types that are not present in Ennerdale and are omitted from further stages in this research.

	Ecosystem Services				
	Aesthetic Value	Carbon Sequestration	Timber	Flood Management	Fresh Water Provision
Broadleaved, Mixed and Yew Woodland	5				
<u>Coniferous</u> Woodland		4	5	3	0
Arable and Horticulture	5	5	5	2	0
Improved Grassland	2	3	3	1	0
Heather	3	2	0	1	0
Grassland	4	2	0	3	0
Heather	5	3	0	3	0
Bog	4	4	0	3	0
Montane Habitats	5	1	0	1	0
Inland Rock	4	0	0	1	0
Salt Water	4	3	0	0	0
Fresh Water Fen, Marsh and Swamp	5	2	0	1	5
Supra-littorial Rock	3	2	0	4	0
Supra-littorial	4	1	0	4	0
Sediment	4	1	0	5	0
<u>Littorial</u> Rock	4	0	0	3	0
<u>Littorial</u> Sediment	4	0	0	3	0
Saltmarsh	3	1	0	5	0
Urban	0	0	0	0	0
Suburban	0	0	0	0	0

Figure 3 Initial Matrix

3.7 Expert Judgement

The next stage in the Burkhard method is to link the land cover types with expert judgement on the ecosystem service capacity of each land-cover type. An interview was arranged with a principal manager of the Wild Ennerdale Project. Over the course of the interview, the project manager scored each land cover type's capacity to deliver each of the chosen ecosystem services, citing his reasons for each score, particularly when these scores differed greatly from the initial matrix.

The Wild Ennerdale project manager also suggested the addition of “Ancient Woodland” as a land cover type, differing from Broad-leaved, Mixed and Yew Woodland due to its structure, age and species make up which the project manager felt had the effect of delivering a significantly different ecosystem service capacity. He also suggested splitting Coniferous Woodland into two Land-cover types, Structured Coniferous Woodland and Unstructured Significant Woodland, again due to the woodlands differing age and structure having a significant effect on its capacity to deliver different ecosystem services.

The assessment matrix, resulting from the combination of expert judgement, Burkhard's matrix and supporting literature, has some noteworthy differences and is highly specific to Ennerdale. The matrix is included in the Results section of this document.

This interview also included a wide discussion about various management strategies and decisions that have caused significant changes in the land cover of the Ennerdale valley. A verbatim transcript of this interview was themed and coded according to a thematic analysis process as described by Braun and Clarke (2006).

3.8 Ethics

Ethical approval was granted for this research by the University of Highlands and Island Ethics Board prior to the research being undertaken. The local expert that was interviewed gave their informed consent for the researcher to use the information gathered during interview. They were also made aware of their right to withdraw at any stage without providing reason. Contact details were made available for the participant.

3.9 Mapping

To show how the capacity to deliver ecosystem services has changed over the course of the Wild Ennerdale project both past and present land cover maps were assessed. The results of these assessments were then compared and contrasted, showing how the ecosystem service has changed since the introduction of nature-led conservation. The UK Soil Observatory has published two land cover maps, one dated 2007 and one dated 2015. The Wild Ennerdale Project began in 2002 and continues to the present day, and due to the slow-changing nature of biophysical features the 2007 data set is an accurate representation of the valley at the start of the Wild Ennerdale project.

A Geographic Information System (GIS) software was used to produce these maps, an example of which is shown below in figure 2.

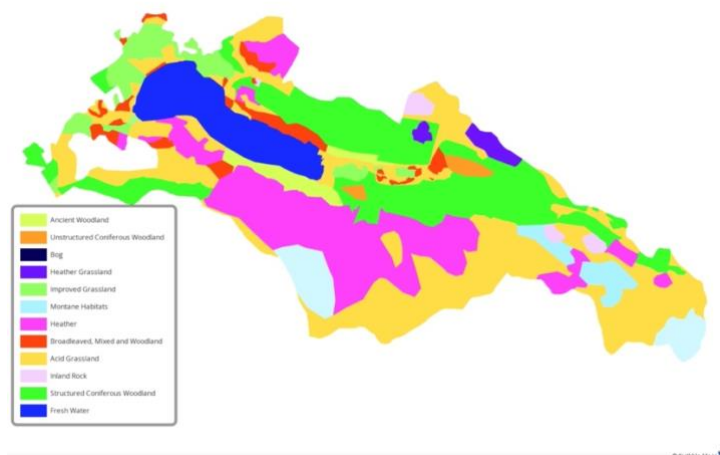


Figure 4 Land Cover 2007

3.10 Analysis Method

After the creation of an assessment matrix and land cover maps for both 2007 and 2015, ecosystem service capacity maps (ESSMs) were created for each of the ecosystem services included in the study. Each ESSM show the distribution of and individual ecosystem service's capacity throughout the Ennerdale valley using a colour scale to highlight low and high ecosystem service capacity. Through comparison of the maps created with the 2007 data set and the 2015 data set clear differences can be seen in the capacity to provide different ecosystem services. Each of the 2007 ESSMs shall be compared and contrasted with its relevant 2015 counterpart and the most significant changes to ecosystem service capacity shall be identified.

A discussion around the ecosystem service capacity change in Ennerdale will then be possible regarding nature-led conservation as delivered by the Wild Ennerdale project. An interview with a principal manager or the Wild Ennerdale project and Wild Ennerdale publications shall inform much of this discussion as changes in ecosystem service capacity will be linked to specific management strategies and discussions. Following this discussion, a conclusion may be reached concerning the effects of nature-led conservation on ecosystem service capacity.

3.11 Limitations

The most significant limitation of this study is the data availability for land cover in the Ennerdale Valley. Limited resources led to this study using data from 2007 and 2015, a difference of eight years. This is a short time frame in which to expect significant changes to land cover as, for example, it takes many years for a section of woodland to grow or for a montane habitat to develop, therefore limited changes may be evident in the two data sets. However, the changes that are evident in the two data sets may indicate trends in the changing capacity to deliver ecosystem services and the biophysical make-up of the Ennerdale valley more broadly and are therefore noteworthy results for this study.

As the UK Soil Observatory data is gathered using satellite imagery and verified by members of the public some errors do exist in places that have not been verified, this can lead to significant errors.

Figure 5 below shows the same area of Ennerdale in three different maps, the first panel (left to right) shows the UK Soil Observatory Land Cover map (2015), the second panel shows a topographic map, and the third panel shows satellite imagery from the same year (Google Earth, 2023). The orange circle in each map shows the same area, in the UK Soil Observatory map a body of water is clearly visible (blue shading denotes water) while the topographic map and satellite imagery show no such lake. It is likely this error occurred due to the dark patch of Coniferous trees resembling water, albeit not closely.

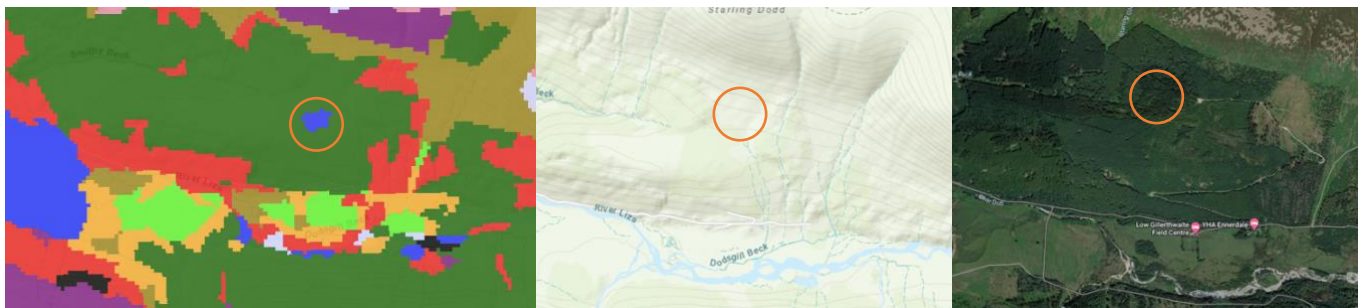


Figure 5 Land cover verification

Errors of the kind discussed above made it necessary to collate data from both The UK Soil Observatory, Google Earth, and The Centre for Ecology and Hydrology datasets as well as information available from the Wild Ennerdale Project to produce new land-cover maps of the study area, from which ecosystem capacities could be effectively mapped. This collation of data produced a more accurate representation of the land-cover in Ennerdale and therefore contributed to the validity of the study's results.

3.12 Summary

The method used to conduct this research has been adapted from Burkhard *et al* (2012). CORINE land-cover types have been matched to the land-cover types provided by the UK Soil Observatory maps and an initial scoring matrix was made up accordingly. This matrix was then adjusted by a local expert to reflect the Ennerdale Valley specifically. The resulting matrix was then used to construct maps of the Ennerdale Valley showing the spatial distribution of ecosystem service capacity within the valley for five chosen ecosystem services. These results were considered alongside information gathered from an interview with a project manager from Wild Ennerdale, from which key themes regarding the management of Ennerdale were identified. The data gathered from the Burkhard method and the interview enabled a discussion concerning the effects of nature-led conservation on ecosystem services capacity in the Ennerdale Valley.

4. Results

4.1 Introduction

This chapter will display and explain the results of the study. Two Land Cover maps have been produced showing the land cover of the Ennerdale Valley in 2007 and 2015, the ecosystem service capacity has then been mapped in accordance with an assessment matrix. Each of the five ecosystem services has been individually mapped for both 2007 and 2015, the most significant changes between each of the maps shall be identified here before a wider discussion considering the impact of nature-led conservation on ecosystem capacity in Ennerdale in the following chapter.

4.2 Interview Analysis

A semi-structured interview with a principal manager of Wild Ennerdale was transcribed verbatim and analysed thematically. The two core themes identified from the interview were:

1. Management in Ennerdale
2. Scoring for the assessment matrix

The manager spoke about several management decisions taken by Wild Ennerdale throughout the interview, often linking them to aspects of the scoring matrix. The management decisions identified during this interview are listed and described briefly below and considered more deeply in the discussion section of this paper:

Creating a vision – In the early stages of the Wild Ennerdale project a vision was created that would guide the management team as they governed the valley. All management decisions are taken in accordance with this vision and support its aims. The vision should guide the team in creating a “wild” space and allowing natural processes to thrive.

Wilding the river Liza – The river Liza is a significant feature in the Ennerdale Valley, at the start of the project the river had few manmade obstructions, those that did exist have been removed or modified to allow the river as much freedom as possible, this has had the effect of allowing sediment flow and enabling the development of functional floodplains.

Reducing Grazing – Grazing pressure was identified by the project as an obstruction to vegetation succession and an environmental hazard more broadly, therefore sheep stocking rates have been greatly reduced in the valley.

Species introduction – Black Galloway cattle were introduced into the valley in small numbers to re-establish the effects of large herbivore grazing that have been missing in the valley since the introduction of intensive anthropocentric management. A proposal to reintroduce beaver is in the advanced stages also.

Allowing novel ecosystem – A “novel ecosystem” is a non-historic assemblage of species often caused by human influence (Truitt *et al*, 2015). A significant “seed bank” now exists within the soil of previously forested land in Ennerdale, because of this it is unlikely that Ennerdale will be able to support native woodland in some areas. The management team have therefore allowed the emergence of a novel ecosystem.

4.3 Assessment Matrix

Below the left panel of Figure 6 shows the initial matrix, converted from Burkhard *et al* (2012) to fit the UKSO land cover types. The right panel of Figure 6 meanwhile, shows the assessment matrix made according to the expert judgment of a project manager for the Wild Ennerdale project and an area forester for Forestry England. The matrix has been adjusted specifically for Ennerdale and thus some of the values are significantly changed. Improved grassland for example is given a value of 2 for aesthetic value in the assessment matrix while it is given a value of 3 in the initial

matrix, this is because the project manager interviewed for this research felt that areas within Ennerdale that show signs of intensive agriculture detract from a “sense of wilderness” that the Wild Ennerdale Project try to foster.

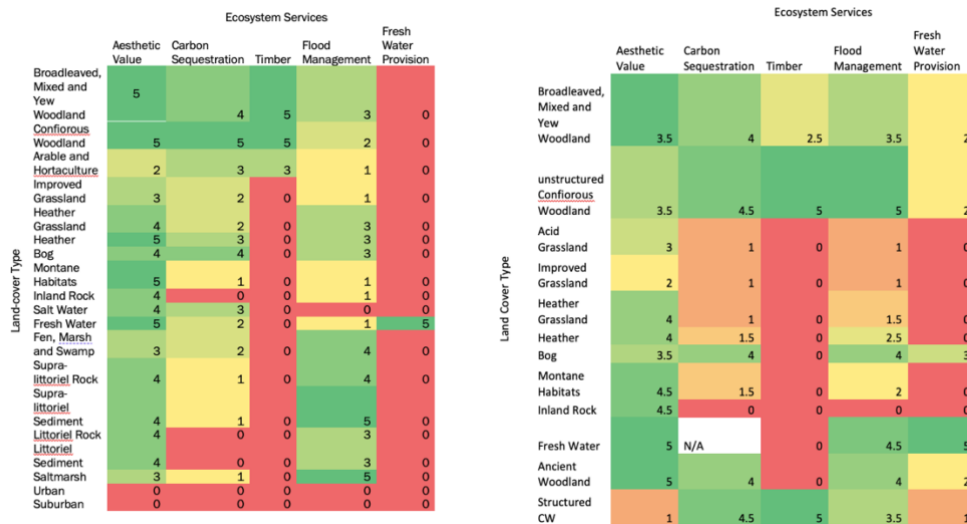


Figure 6 Initial matrix (left) and Assessment Matrix (right)

A notable aspect of the assessment matrix is the number of land cover types included in the matrix, comprising 12, down from the initial matrixes 19. This difference is because many of the land cover types shown in the initial matrix do not occur in Ennerdale and are therefore obsolete in the assessment matrix.

Freshwater has not been given a score for its capacity to provide carbon sequestration, this is because the manager did not feel able to comment on Ennerdale Waters ability to sequester carbon due to a lack of expertise in lentic freshwater environments. There is also some debate in the literature on freshwater bodies' role in carbon sequestration (Kayranli *et al*, 2010).

4.4 Land Cover and Mapping

The area that has been mapped for this study is the Ennerdale Valley. Ennerdale is a valley within the Lake District national park, it covers an area of 4,711 hectares, is 14.5km long and 5.6km wide (at its widest), narrowing toward its east end. The valley's elevation ranges from 40m above sea level at the valley floor to 899m at the

summit of Great Gable. The valley is surrounded by prominent summits such as Pillar, Green Gable, and Great Gable (Wild Ennerdale, 2018). The biophysical features of the valley are typical of a Lakeland valley, comprising of wide stretches of acidic grassland, heather and heather grassland, areas of forestry and broadleaved woodland in the lower elevations. There are some areas of montane habitat, but they are considered to be in poor condition. The rivers Liza and Ehen have their sources in the valley. The river Liza is one of the “wildest” rivers in the UK, meaning it has no obstructions and is not modified (Oyedotun, 2011), this has significant geographical implications that shall be discussed later.

Archaeological evidence suggests that the valley has been inhabited since the bronze age and therefore there has been anthropomorphic influences in the valley for a significant period (Wild Ennerdale, 2018). The valleys primary uses over the past century have been agricultural, mainly the raising of sheep and forestry.

The Valley is an important site of conservation with 40% of the Wild Ennerdale land being designated as site of special scientific interest (SSSI) and contains a variety of Biodiversity Action Plan (BAP) species and habitats.

Below are two maps showing the land cover in the Ennerdale valley in 2007 and 2015 respectively. The original data for these maps were sourced from the UK Soil observatory (2015), with additional data from the Wild Ennerdale Project (2018), Google Earth (2023), and The Centre for Hydrology and Ecology (2023).

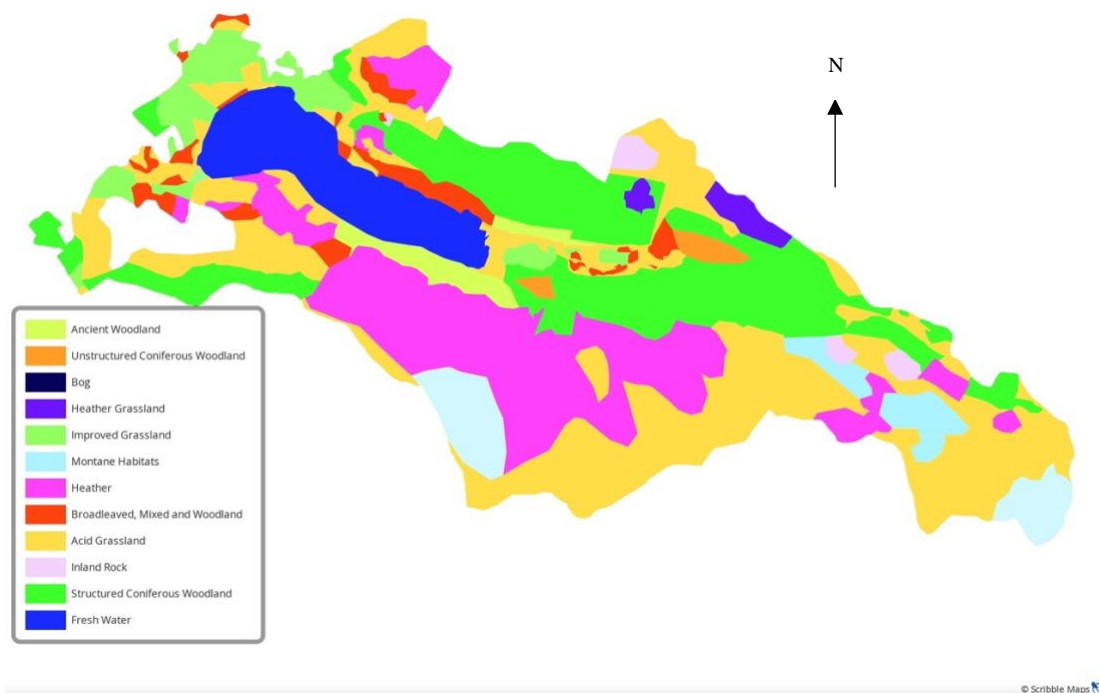


Figure 7 Land Cover 2007

Figure 7 shows the land cover included in the Wild Ennerdale Project in 2007. Extensive areas of coniferous forest can be seen in several areas around the valley, often alongside broadleaved, yew and mixed woodland and ancient woodland. Above the forested areas, large spans of heather grassland and acid grassland extend to the borders of the valley. Patches of inland rock and montane habitat are also shown in this map toward the middle and eastern areas of the valley. Small areas of improved grassland exist where agricultural intensification and grazing have taken place, this is particularly evident in the west of the valley. The central section of the valley, to the west of Ennerdale Water, is a significantly diverse area, this is likely due to the river Liza entering Ennerdale Water, it's being a floodplain, and its relatively intense use under agriculture.

A large area of land is missing from this map as this land is not included in the Wild Ennerdale Project. This area is covered almost entirely by acidic grassland.

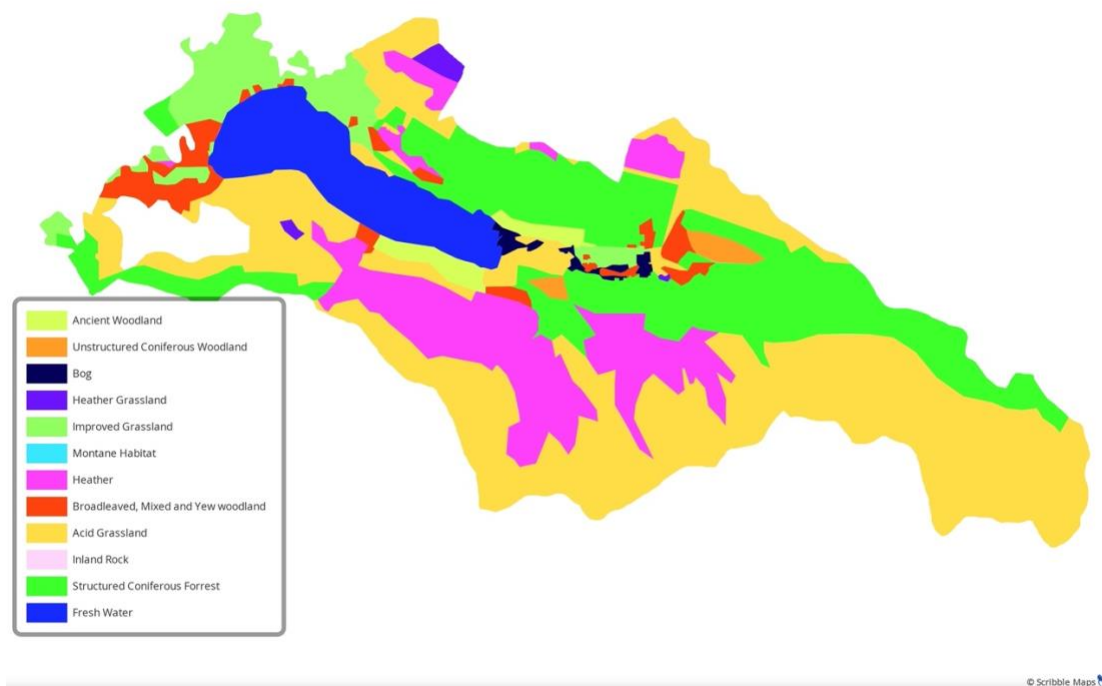


Figure 8 Land cover 2015

Figure 8 shows the land cover of the Wild Ennerdale Project in 2015. These two maps show a very similar distribution of land cover in the Ennerdale valley. There are however some significant differences between the two maps that will effect the valley's capacity to deliver ecosystem services.

Among the most significant change is the expansion of acid grassland, practically in the southern central section of the valley where the expanse of heather present in 2007 has reduced heavily. Heather has a higher capacity than acid grassland for three out of the five ecosystem services that are mapped below and an equal capacity to acid grassland for the remaining two services. This expansion, therefore, has a negative effect on the valley's capacity to provide ecosystem services.

The central area of the valley, east of Ennerdale Water has undergone significant changes. While areas of improved grassland have become acid grassland, a portion of this section has become bog, a land cover type that does not occur in the 2007 landcover map. This too has implications for the ecosystem service capacity of the valley as bog was deemed by the project manager to have a high value regarding several of the services mapped below.

The loss of montane habitat is also notable in Figure 8. This may be due to a lack of public interaction with the UKSO data and thus areas shown as montane habitat in 2007 have not been correctly identified or it may be that the area of acid grassland has expanded into these areas. Also, the loss of inland rock in the 2015 land cover map is notable and is explainable by the same reasoning.

4.5 Fresh Water Provision

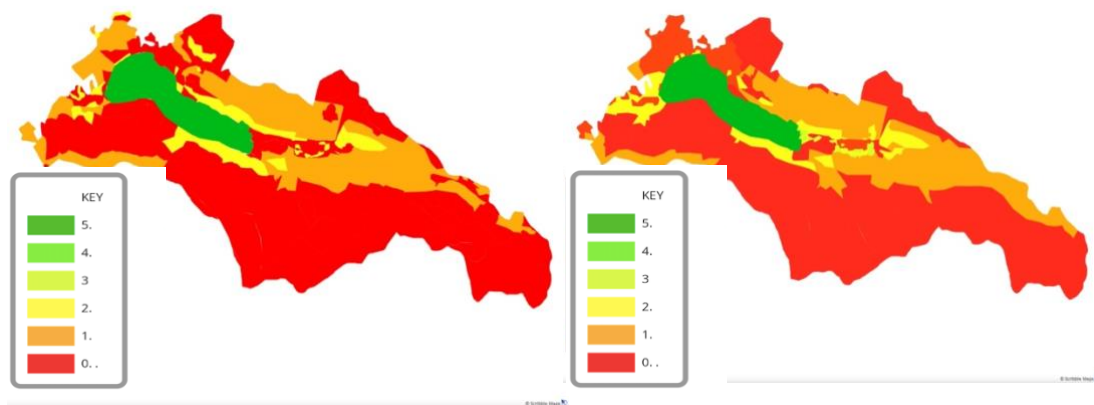


Figure 9 Freshwater provision 2007 (left) and 2015 (right)

Ennerdale Water currently supplies the towns in the west of Cumbria with drinking water (United utilities, 2015), rainwater from frequent precipitation is stored in the lake using a dam on its western side. This means Ennerdale water has a very high capacity to supply fresh water.

Other aspects of the valley show low levels of capacity, these areas are various types of woodland, which Figuepron *et al* (2013) show to have a positive effect on the provision of fresh water. The project manager felt that Ancient and broadleaved woodlands had a higher capacity to deliver fresh water than coniferous forest.

Figure 9 shows little change in the valleys capacity to provide fresh water, there is however, a slight expansion of coniferous forest and the development of boggy areas in the central valley. This is due to the short time gap between the two maps, trees grow slowly and therefore large changes are not exhibited. However, the results may show the beginning of a trend involving vegetation succession leading to

increased forest cover in the valley and more extensive areas of bog. This trend may lead to a higher capacity to provide fresh water in the Ennerdale Valley.

4.6 Timber Provision

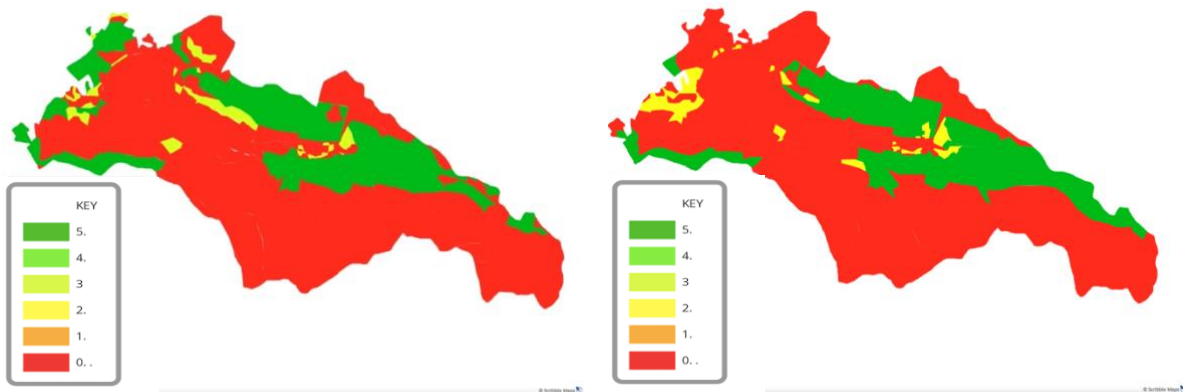


Figure 10 Timber Provision 2007 (left) and 2015 (right)

The results of Timber provision show a nearly binary ecosystem service. This is because a land-cover type can either provide timber or it can't, depending on whether that land-cover type contains trees. However, there are some slight complexities within this largely binary result.

Structured Coniferous forests have a high capacity for delivering timber provision as these forests were planted with the express purpose of creating timber. The trees that make up these forests have a wide variety of uses, are fast growing and therefore have a high economic value. These forests are also planted in a grid format with trees grouped by age so that harvesting is efficient (Burley, 2004).

Broadleaved woodlands were given a medium score as the timber they provide is highly valued. However, these woodlands were not planted with the intent of being harvested and are therefore more difficult to abstract timber from.

Ancient woodlands in Ennerdale contain Atlantic Oakland, a globally important form of woodland and were given a score of zero, as they are protected by the Wild Ennerdale management from being harvested. Land cover types that hold no trees were also given a score of zero, as they have no capacity to provide timber.

Both expansion and reduction of structured coniferous forest has taken place in certain areas between 2007 and 2015 as can be seen in figure 10. The reflected change in capacity is due to tree planting and felling. Notably, the west of the valley has seen a reduction in capacity, possibly due to felled areas of structured coniferous woodland being replaced by broadleaved woodland by the process of vegetation succession.

4.7 Flood Management

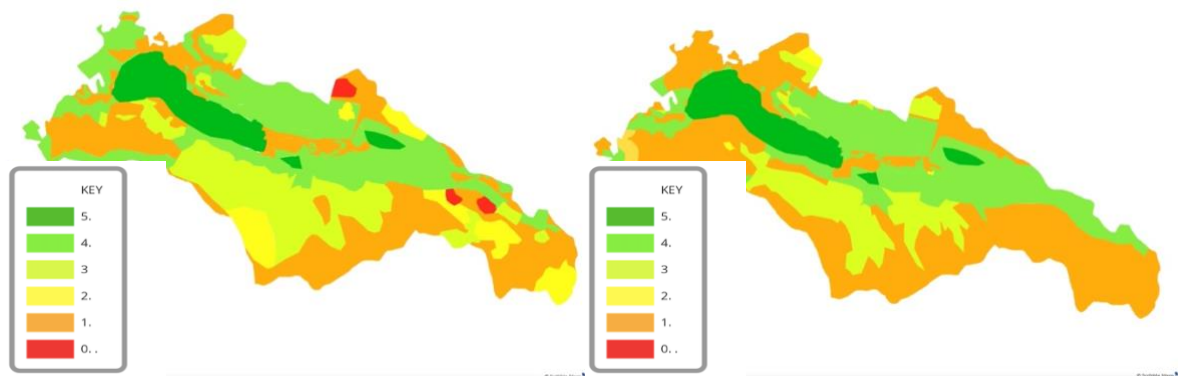


Figure 11 Flood Management 2007 (left) and 2015 (right)

Figure 11 shows a high capacity for flood management in the Ennerdale Valley. Land cover types that intercept, absorb, and slow the process by which rainwater joins the water courses of the valley were given the highest scores. Ennerdale water, the only area of fresh water was also given a high score, the lake is dammed and therefore can be kept at a low level, acting as a barrier to flooding downstream (Altinbilek, 2002).

Inland rock was given a score of zero as it cannot slow the flow of water. This scoring shows as three patches of red in the left panel of Figure 11, which are absent in the right panel of Figure 11, this could be due to the expansion of acid grassland covering these formerly rocky areas, or a mistake in the UKSO dataset that was unable to be verified using google maps.

Acid grassland, which makes up a significant proportion of the land cover of the valley was given a low score, this is because it holds low levels of vegetation and does little to slow water's progress to the valley floor. Acid grassland becomes more abundant in 2015, lowering the overall capacity of the valley to provide flood management. The loss of montane habitat also had a negative impact between 2007 and 2015.

The boggy areas that have developed in the central area of the valley to the east of Ennerdale Water were given a high score as bog typically holds vegetation types that contribute strongly to flood management (Gao *et al*, 2016).

4.8 Aesthetic Value

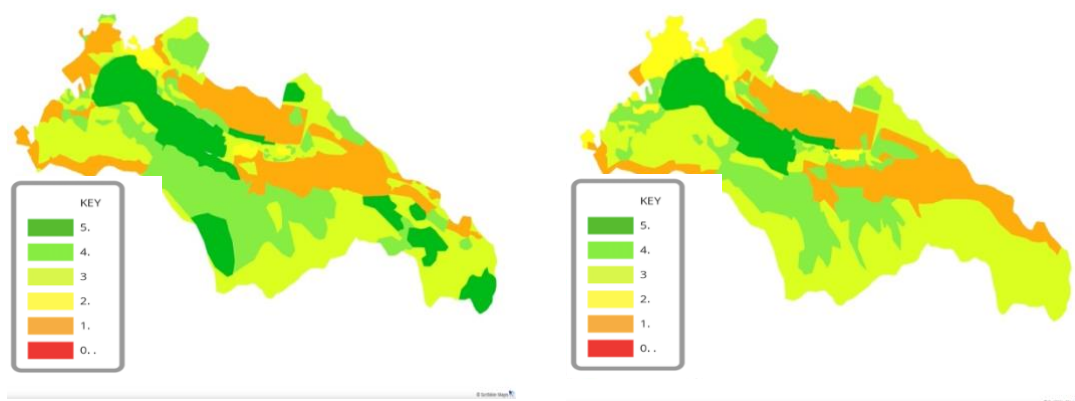


Figure 12 Aesthetic Value 2007 (left) and 2015 (right)

The Ennerdale Valley is highly appreciated for its aesthetics, as are many of the valleys in the Lake District more widely. The area was fundamental to the romantic movement in the late 18th century which has defined the concept of natural beauty to the present day. The Lake District still inspires hundreds of artists and was recently declared a World Heritage Site by UNESCO on account of being a “cultural landscape”, a designation that is reflected in its aesthetics due to centuries of anthropomorphic influences from forestry to farming.

Beza (2010) found that aesthetic value is not only connected to bio-physical features but also includes concepts such as wilderness. Indeed, the Wild Ennerdale project

state that they aim to increase the feeling of “wilderness” in the valley, which may in turn contribute to the aesthetic value of the valley.

Structured coniferous forest was given the lowest score for aesthetic value, this is because the project manager felt that visitors to the valley could easily see that these trees were planted in a structured manner, detracting from the aesthetic value of the forest. Ancient and broadleaved woodlands, on the other hand, were given very high scores as they are typically recorded as aesthetically pleasing habitats (Carlson and Lintott, 2008; Bell, 2009). Ennerdale Water was also given a high score as large water bodies are usually well received and typify the aesthetics of the Lake District.

Perhaps the most significant development for the capacity to deliver aesthetic value in Ennerdale has been the loss of montane habitats. This has had a negative impact as montane habitats are highly appreciated (Beza, 2010). Improved grassland has expanded in the northwest of the valley, also having a negative effect on the valley’s capacity for aesthetic value.

4.9 Carbon Sequestration

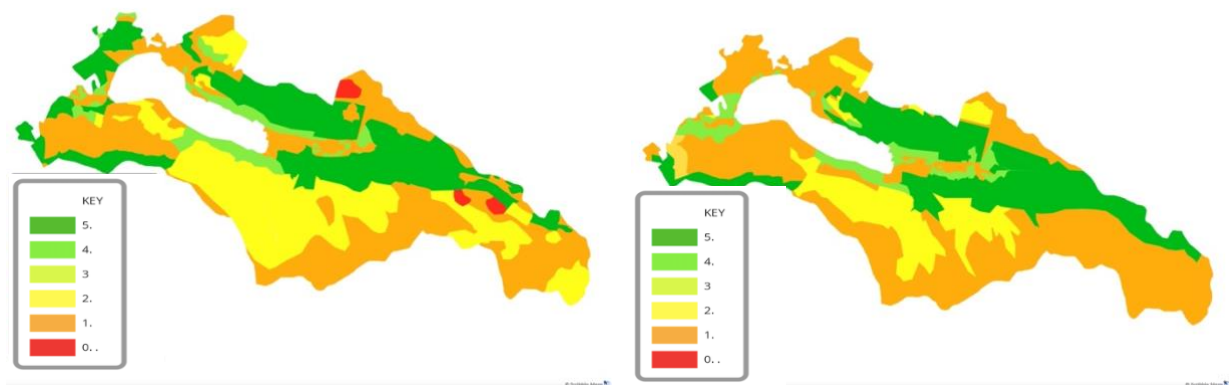


Figure 13 Carbon Sequestration 2007 (left) and 2015 (right)

The highest scores for carbon sequestration have been given to structured coniferous woodland because these woodlands are made up primarily of fast-growing trees as they have a high value for timber production. Due to the speed at which they grow, coniferous trees sequester more carbon than most other land cover types. Ancient and broadleaved woodlands were also given high scores as they

sequester large amounts of carbon, but at a slower rate than coniferous trees (Matthews *et al*, 2022).

Heather, heather grassland and acid grassland were given low scores as comparatively little vegetation growth occurs on these land cover types, therefore sequestering less carbon.

The most significant areas of change for carbon sequestration are in the central section of the valley where bog has developed. Bog has a high rate of carbon sequestration (Alexandrov, 2020) and has therefore increased the capacity for this service. The eastern section of the valley has also increased its capacity to sequester carbon because of the expansion of structured coniferous woodland in that area.

Furthermore, the expansion of acid grassland and loss of montane habitat on the southern hillsides of the valley has reduced this area's capacity to sequester carbon. However, the expansion of acid grassland that may have led to the loss of inland rock has slightly increased the valley's capacity to sequester carbon.

4.10 Summary of Results

The main themes of the results of this study have been:

- The development of several bog areas in the central section that has had a positive impact on the valley's capacity to provide flood management, carbon sequestration, aesthetic value, and freshwater provision.
- The expansion of acid grassland may be the cause of the loss of montane habitat areas and inland rock areas, which has lowered the valley's capacity to provide aesthetic value and carbon sequestration.
- The expansion of structured coniferous woodland, which has improved the valley's capacity to provide carbon sequestration and in areas where structured coniferous woodland has replaced acid grassland, improved the

valley's capacity to provide flood management but lowered the valley's capacity to provide aesthetic value.

- The expansion of improved grassland in the west of the valley has lowered the capacity to provide aesthetic value, flood management and freshwater provision.

The net change, evidenced by the maps above, in the Ennerdale valleys capacity to provide ecosystem services between 2007 and 2015 was minimal. This is due to a low change in land cover and a short time span between the two datasets. There are also several examples of possible data errors evident within the results of this study, including large areas of inland rock being present in 2007 and not in 2015, it is possible that these errors have impacted the validity of these results. However, as detailed above, several key themes of changing land-cover and ecosystem service capacity are evident in the results of this study. These themes provide valuable information relating to the early management decisions taken by the Wild Ennerdale project and show the effect these decisions have had on the capacity to provide ecosystem services.

Furthermore, this study has demonstrated a fast and effective method for mapping ecosystem service capacity on a catchment scale that may be valuable to land managers of projects such as Wild Ennerdale. Maps constructed using data reflecting the current land-cover in Ennerdale could be very informative and help to drive the project's vision of nature-led conservation and evaluate its effects on the valley's bio-physical make-up and capacity to provide a suite of ecosystem services.

5. Discussion

5.1 Introduction

This discussion shall consider the results detailed above and evaluate them in the context of nature-led conservation (rewilding). The Wild Ennerdale project has undertaken many management decisions within the Ennerdale valley which have led to some of the changes detailed within this study, these decisions have the potential to greatly effect the ecosystem service capacity of the Ennerdale valley, although this is not their aim or design purpose.

Throughout this discussion management decisions will be linked to relevant ESSMs, and where possible trends and future expectations will be identified. Information gathered during an interview with a principal manager of the Wild Ennerdale project shall also inform much of this discussion.

5.2 The Vison

The Wild Ennerdale projects decision making is informed by the projects “Vison”, which the groups states “Capture[s] their philosophy and ambition” (Wild Ennerdale, 2018. Pg.7). The 14 guiding principles of this vison are listed below:

- Protect and enhance the sense of wildness.
- Give freedom for natural processes to enable more robust, resilient and better functioning ecosystems to develop.
- Only intervene where complementary to the vision or where a threat to the vision is posed.

- Operate as a partnership in all aspects of decision making, implementation and research providing mutual support across partners.
- Celebrate and apply the learning experiences that all partners gain from their involvement.
- Promote Wild Ennerdale and its constituent partners' involvement within it.
- Focus practical management, monitoring and decision making at a landscape scale using the Stewardship Plan as the main tool for guidance.
- Strive to put people at the heart of the environment through public enjoyment, engagement and connection with nature.
- Support business opportunities that are appropriate and fitting with our branding and vision.
- Promote the management of partner assets within the valley to reflect the vision.
- Share information and promote case studies to demonstrate and inspire others, prompting engagement across a wider sphere of influence. (Wild Ennerdale, 2018. Pg.7-8)

5.3 Wilding the River

The river Liza flows from its source underneath the mountains Great Gable and Green Gable into Ennerdale Water on its eastern side, a journey of approximately 10km. The Liza provides vital breeding grounds for Arctic Char, a nationally endangered salmonoid (Winfield *et al*, 2019).

The river Liza is considered a “wild” river, as it has no obstructions (Hernandez and da Costa, 2022). To achieve this a riverside fence and a concrete pipe bridge were

removed and efforts to prevent bank erosion were ceased. In addition, a pipe bridge was removed on Wondell Beck, increasing gravel flow into the Liza. A fundamental ideological change to the management of the Liza has been disconnecting the administrative boundary of the river from the dynamic river boundary, reducing pressure to control the river (Browning and McCullough, 2015). This means that rather than attempting to keep the Liza on a constant path with the use of stone-filled gabions to support the riverbanks, the river is now free to change its course according to its own dynamic.

During a storm event in 2009, the Liza made new river channels through forested land and caused significant damage to an established footpath. The management team sought to build a new footpath at a slightly higher elevation rather than hampering the river's wildness by reinstating the old footpath (Browning and McCullough, 2015).

This style of river management and maintenance differs greatly from the status quo in the area. Rivers in the UK typically have a high level of intervention to keep them on a constant path and reduce local flooding as identified by Fenner *et al* (2019). Management strategies include “dredging”, a process in which sediment and debris are removed manually from riverbeds, often increasing the flow speed and deepening the river. This management style has become subject to criticism in recent years as it may cause, rather than prevent, flooding in some areas (Saad and Habib, 2021). In response to this “natural flood management” is a growing area of interest for land managers across the UK (Wingfield *et al*, 2019. Venkataramanan *et al*, 2020). The Wild Ennerdale’s management of the Liza typifies some elements of natural flood management. However, allowing rivers to meander at will across valley floors is space intensive and disruptive to other land uses, such as grazing. These changes in river management are likely responsible for the land-cover changes and associated ecosystem services capacity change exhibited in the central section of the valley, shown in each of the ESSMs.

Perhaps the most significant result of this change in river management has been the increase in the Arctic char population in Ennerdale Water. In recent history, due to a lack of gravel in the mouth of the Liza, the redds used by the char were ineffective

and therefore the population had fallen to roughly a dozen spawning individuals. In addition, the diverse habitats needed for the lifetime of an arctic char were missing from the valley, including deep pools for adult char and woody debris-filled channels for the fry (Johnston, 2008). These habitats have re-emerged due to the more diverse actions of the Liza since rewilding management began in 2002. The arctic char population has now increased by around 1000% to approximately 600 individuals, with the help of a rearing programme managed by Natural England in which char were reared in a hatchery and returned to Ennerdale Water (Browning and McCullough, 2015).

Although the recovery of the arctic char population does not relate to any of the selected ecosystem services involved in this study, the results do show elements of change in land-cover that help to explain the population expansion of the arctic char. Specifically, the changes in the central area of the valley can be seen to change from largely improved grassland and areas of broadleaved trees into extensive areas of bog. This change may have occurred because of management decisions concerning the river Liza. Allowing, for example, the destruction of standing trees that would create obstacles for the river and slow some areas of the river down, creating a more diverse range of habitats including those favoured by Arctic Char.

Likewise, the decision to rewild the river Liza and the expansion of bog areas in the central area of the valley has contributed to flood management in the valley. Natural flood management is achieved through the manipulation of two processes: attenuation of the discharge and tributary inputs of discharge (Lane, 2017). The increased area of bog will enhance the attenuation of the valley, as bog areas hold plant species that absorb a lot of water. This can be seen in Figure 11.

5.4 Recognising Flood Plains

A limitation of the mapping method used for this study is the inability to score specific areas of land differently from other areas of the same land cover type. This is not generally a requirement when assessing the capacity to provide ecosystem services, but there are some exceptions. One such expectation relevant here is the low-lying

areas of the valley on either side of the river Liza which act as flood plains during storm events. These flood plains contribute significantly to the flood management of the valley and if scored for their capacity on account of this attribute would score much higher than when considered for their land-cover type alone, such as the mapping method requires.

The high value of the valley's flood plains was exhibited in 2009 when a storm of significant proportion caused flooding in several Lake District valleys (Stewart *et al*, 2010). Thirlmere, along with other reservoirs in the area could not supply water in the aftermath of the storm due to sediment and colour taint exceeding acceptable levels (Browning and McCullough, 2015). Meanwhile, Ennerdale Water was able to maintain supply as usual because very little debris made it further than the midsection of the lake, therefore protecting the water quality close to the abstraction point. This was the result of maintaining functional flood plains and a “high friction” (holding trees and other vegetation) landscape, which are lacking in other catchments in the area (Acreman and Holden, 2013). This high friction landscape is identifiable in both the 2007 and 2015 land cover maps to the east of Ennerdale Water, by the presence of wooded areas. An interesting development in the area is the loss of improved grassland, coinciding with the expansion of acid grassland, this development may have occurred because of the decision to reduce grazing in the valley, as discussed below.

5.6 Altered Grazing and Introduction of Large Herbivores

A principal management decision for the Wild Ennerdale project was greatly reducing the stocking levels of sheep in the valley, thereby reducing grazing pressure. All plants can withstand a level of grazing, but while some such as dwarf shrubs and mature trees are very hardy, others such as those found in montane habitats and young trees are easily eradicated by sheep grazing. Others, while not eaten by sheep, are damaged by trampling, bog mosses for example or severely effected (Hester *et al*, 1996).

Continuous high-pressure sheep grazing, such as has been exercised in the Lake District over the past decades leads to a loss of plant diversity and simplification of vegetation structure (Martin *et al*, 2013). Also, deep-rooted plants and blanket mosses are generally absent from areas subjected to high grazing pressure, this has resulted in high rates of water run-off, worsening flooding in effected areas. Another symptomatic effect of overgrazing is an increased number of landslides, owing to a poor root structure to stabilise soil (Nisbet and Broadmeadow, 2004), this has been seen in the Lake District in recent years.

Conversely, ecologists argue that moderate grazing will increase plant diversity due to reduced competition between species (Natural England, 2020). However, while this may be generally true in areas of low elevation, in mountainous environments such as the upper slopes of the Lake District, grazing may act to simply damage whichever species are able to survive in that environment (Nisbet and Broadmeadow, 2004; Natural England, 2020).

In 2007 sheep stocking levels were greatly reduced in Ennerdale and in partnership with a local farmer the Wild Ennerdale project began grazing Black Galloway Cattle in low numbers. These cattle graze year-round and are unrestricted in their grazing regime, travelling freely within the valley. Additionally, the project manager noted during interview that the stocking numbers for cattle are very low when compared to that of sheep; sheep being stocked at a rate of 1 ewe per 3 hectares and cattle being stoked at a rate of one cow per 20 hectares. The cattle browse more frequently in the lower altitudes of the valley but have been seen as high as 700m. The move to cattle was motivated by the project's vision of “giving freedom for natural processes to enable more robust, resilient and better-functioning ecosystems to develop” (Wild Ennerdale, 2018). Cattle graze in a similar way to Red Deer, Aurochs and European Bison, which would typically have inhabited ecosystems such as that present in Ennerdale, and therefore hypothetically graze in a beneficial way for the biodiversity of the area (Vermeulen, 2015; Wild Ennerdale, 2018).

The introduction of large herbivores is seen by some as an integral part of ecological restoration (Vermeulen, 2015). Large herbivores help to maintain the natural processes of vegetation succession. This is because of the way in which cattle graze

and because their hooves leave large incisions on the ground in which seeds can germinate. The effect of grazing cattle in Ennerdale has been increased habitat diversity and increased area of “edge”, which the Wild Ennerdale project say has “helped blur the boundary between woodlands and fields, forest and farming, creating softer boundaries which are great for wildlife and [are] visually attractive” (Wild Ennerdale, 2018).

This large-scale change to the grazing regime in Ennerdale may account for some significant changes in land cover and changes in the capacity to provide associated ecosystem services. Most notable among these changes is the expansion of acid grassland visible in Figures 7 and 8. This expansion has mainly affected the south and southeast of the valley, in the higher elevations. These areas would have been extensively grazed by sheep prior to 2007, but now are left mostly undisturbed. This has allowed the vegetation to recover and expand. In the results of this study, it is evident that this expansion has acted to reduce the areas of montane habitat that were present in 2007 and encroach on the large areas of heather and heather moorland. These land cover types remain a prominent feature in 2015 but are greatly reduced.

The reduction in heather and heather moorland has lowered the valley's capacity to provide flood management as dwarf shrubs intercept more rainfall and promote infiltration, acid grassland does this but to a lower extent, therefore providing a lower capacity. The capacity to provide aesthetic value has also been lowered as a result of the expansion of acid grassland and the reduction of montane habitats as seen in figure 12. Acid grassland was given low scores of aesthetic value while montane habitat was given high scores. The reduced diversity of habitat may also reduce the biodiversity of the valley over time, which may further reduce the aesthetic value, as many people enjoy seeing charismatic species. Further research would have to be conducted to confirm these speculations. Carbon sequestration has also been lowered as a result of the expansion of acid grassland, as seen in figure 13, as there is a lower level of above ground vegetation.

In total, the results of this study show that between the years of 2007 and 2015 the greatly reduced grazing pressure has had a negative impact on the valley's capacity

to provide three of the five ecosystem services included in this study and no effect on two (fresh water and timber production).

These negative results may reflect the short period between data sets, the process of vegetation succession is slow and the results that the Wild Ennerdale project expects to see from introducing cattle and removing sheep may take decades to appear. The project manager spoke during interview about the expansion of native and ancient woodland that he has seen in areas of the valley, consistent with the removal of sheep. This expansion has taken place after the 2015 data set and therefore cannot be seen in the results of this study.

5.7 Forest Management and the Emergence of a Novel ecosystem

The Ennerdale valley holds extensive areas of forest, covering approximately 20% of the valley (Wild Ennerdale, 2018). Largely this forest is a mono-culture coniferous forest planted by the forestry commission, which has owned and managed sections of the valley since 1925 (Forestry Commission, 1951). Since the start of the Wild Ennerdale project the Forestry Commission have moved to “uneconomic management” of the forested land in Ennerdale (Cleasby, 2010).

Due to long-term forestry operations in the valley, a significant seed bank has accumulated in the soils around forested areas. This means that it is unlikely that Ennerdale will be able to support a native broadleaved woodland in areas previously or currently used for coniferous forest for many decades. Considering this the Wild Ennerdale project is seeking to establish a “novel ecosystem” or a non-historic assemblage of species (Hobbs *et al*, 2009), to achieve this Wild Ennerdale has begun a programme of tree planting, focusing on native species which will grow alongside existing coniferous saplings.

Expansion of coniferous woodland can be seen in the 2015 land cover map in the east of the valley, this is due to a mixture of planting for forestry purposes and vegetation succession, made possible by the seed bank mentioned above. This expansion has increased the valley's capacity for each of the ecosystem services

included in the study, except aesthetic value. Mono-culture forestry was not deemed to deliver aesthetic value by the project manager during an interview, this view is seconded by (Liu *et al*, 2018). With the addition of broadleaved species, this area of woodland would likely contribute more significantly to the aesthetic value of the valley, as they were given a higher score. Furthermore, a novel ecosystem of coniferous and broadleaved woodland may increase the ecosystem service capacity of the valley, owing to greater biodiversity and delivering hybrid qualities of both land-covers (Hobbs *et al*, 2009).

In the years since 2015, planting of native broadleaved species has taken place in this area. A repeat of this study with up-to-date data or in the near future may provide insight into the value of novel ecosystems in nature-led conservation projects.

Tree planting and the creation of a novel ecosystem have interesting implications for the vision of the Wild Ennerdale project. Vegetation succession is a natural process and is the partial cause of the expansion of coniferous forest in the east of the valley, however, this process is currently expanding a non-native species. Alongside this, tree planting is a non-natural process but is expanding native species in this area of the valley. Perhaps the planting of native trees could be considered an intervention complementary to the vision or needed to counter a threat to the vision.

The acceptance of an emerging novel ecosystem is a divergence from typical a rewilding viewpoint (Lorimer *et al*, 2015). Rewilding projects frequently aim to nurture a historic ecosystem to some degree, and the removal of non-native species is often a feature in management decisions. This aspect of Wild Ennerdale's management strategy perhaps validates their reluctance to use the term "rewilding".

Regarding the ESSMs, the introduction of a new land cover type may be an appropriate action in the case of a repeat study to represent land covered by coniferous and broad-leaved trees. This new land cover type would also have to be scored for each of the ecosystem services included in the study. Depending on the diversity and distribution of species in this new ecosystem the capacity to provide

specific ecosystem services may be enhanced or reduced and should be monitored and managed over the coming years.

5.8 Looking to the Future

The Wild Ennerdale project is entering its second decade and has therefore not had sufficient time for the full impacts of nature-led conservation to take root in the valley (Marrs *et al*, 2018; Broughton *et al*, 2021). Additionally, the new grazing regime was only introduced in 2007 and may have significant effects in the future, and the project is currently proposing to introduce beaver into the valley, again this will effect the valley's capacity to provide ecosystem services considerably. These aspects are considered briefly below.

5.9 Beaver introduction

A large-scale Beaver introduction has been proposed in the Ennerdale valley. This introduction will have significant implications for both the land-cover in Ennerdale and Ennerdale's capacity to provide ecosystem services.

Beavers are ecosystem engineers, meaning that they create, significantly modify, and destroy habitat (Brazier *et al*, 2021; Wright *et al*, 2002), since going extinct about 400 years ago these processes have been largely missing from UK ecosystems (South *et al*, 2001). Beavers primarily modify the ecosystem through the construction of dams and the felling of trees, this is generally seen to have a net benefit for biodiversity as the habitat created by beaver dams is rare and valuable to a variety of species (Wright *et al*, 2002). The proposed project would be the largest-scale beaver introduction in England to date, with beavers having access to 495 acres (Brazier *et al*, 2020). Furthermore, the habitat creation would likely have a sizable impact on the land-cover of the valley which would impact many of the ecosystem services included in this study, particularly flood management and aesthetic value and freshwater provision. Future ESSMs would likely show a large green area in the central section of the valley, consistent with the area of beaver introduction,

reflecting a high capacity for ecosystem services. This area is likely to see a reduction in acid grassland and improved grassland due to an expansion of bog.

Additionally, beavers have been found to create habitat for Otters, Great Crested Newts and Water Vole, highly charismatic species that may increase tourism to the area and provide opportunities for economic development (Wright *et al*, 2002). A common concern with beaver introductions is the negative effect they may have on forested areas; however, beavers are “central-place foragers”, meaning that their impact is concentrated on areas near water courses, therefore, limiting their negative environmental impact (Siemer *et al*, 2013).

5.10 Vegetation Succession and Open Canopy Forest

Vegetation succession and light grazing by large herbivores may result in open canopy forest areas, as Vera (2000) suggested. The emergence of an open canopy forest would have implications for the capacity to provide ecosystem services, possibly positive (Veldman *et al*, 2015). These ecosystems are important for biodiversity, hold large amounts of above-ground vegetation and will therefore increase capacity for flood management and carbon sequestration (Bergmeier *et al*, 2010). In the event of a repeat study, a new land-cover class may need to be included to reflect the unique qualities of open canopy woodland or wood pasture.

5.11 Recommendations for Future Study

Further mapping of land-cover should be carried out in Ennerdale, in rewilding projects and across the UK. With up-to-date and accessible data the Burkhard method can be adapted and applied to any area at a catchment scale to provide insightful results on the capacity to provide ecosystem services. This tool would become a valuable resource for land managers across the UK particularly in conservation sites (Burkhard *et al*, 2012).

Consideration should be given to creating a programme of mapping in which areas such as Ennerdale have their ecosystem service capacity mapped every ten years.

Repeated mapping of this kind would allow an insight into the effects of various land management strategies and provide scope for evaluation, this repetition would also build a catalogue of the changes rewilded areas undergo throughout the life span of rewilding projects. A programme of this type would complement emerging policies such as the 25 Year Environment Plan, which calls for increased monitoring of environmental health across the UK (Defra, 2018).

There may be scope for further customising the Burkhard method when considering small areas and individual catchments. One of the significant limitations of this study was the inability to designate areas of the same land-cover type with different scores, leading to some areas being undervalued for specific ecosystem services. A mechanism could be created within the Burkhard method to overcome this limitation by considering some site-specific features in the mapping of ecosystem services. This would create a more meaningful representation of catchment scale ecosystem service capacity and be more informative for land managers.

6. Conclusion

The Wild Ennerdale project represents a significant divergence to land management strategy in the Lake District, and to a lesser extent UK uplands generally. Notably, the project has introduced nature-led conservation to the valley and taken management decisions consistent with rewilding, including species introduction, restoring ecosystem functions, and giving freedom to natural processes. The project is in its second decade and substantial changes are now evident in the valley.

This study aimed to evaluate the change in ecosystem service capacity in Ennerdale. Towards this aim, the Burkhard Method was adapted for use in Ennerdale with the help of a local expert. This method produced a series of ecosystem service capacity maps. These maps have made it possible to see the changes in the ecosystem service capacity for five specific ecosystem services. Significantly, developments in the central area of the valley have led to an increased capacity to provide flood management, carbon sequestration, aesthetic value, and fresh water. Elsewhere in the valley, there were reductions in capacity, such as a loss of capacity to provide aesthetic value at the highest elevations of the valley due to reduced montane habitat. However, this reduced capacity may highlight a limitation in the method that does not account for the charismatic features of the valley, which would provide a high capacity for aesthetic value regardless of land-cover type.

Using information gathered from an interview with a principal manager of the Wild Ennerdale project and Wild Ennerdale's Stewardship Plan, the observed changes in ecosystem service capacity, made available through the Burkhard method, were then linked to management decisions made by the Wild Ennerdale project. Allowing the river Liza to change its course at will and restoring gravel and sediment flow by removing obstructions in the river, for example, helped to significantly improve the Arctic Char population in Ennerdale Water. While reduced sheep grazing has allowed increased vegetation succession, which has in turn caused a loss of

montane habitat and allowed for the emergence of a novel ecosystem in the east of the valley. In total, it is possible to conclude that nature-led conservation has altered the capacity of the ecosystem services included in this study, for some services there has been an increase in capacity, and for others a reduction.

A repeat of this study in the following years may produce informative results regarding the progress of nature-led conservation in Ennerdale, especially following the introduction of a beaver population in the valley. Further research in this field will build a substantial portfolio of information regarding the effects of nature-led conservation on the provision of ecosystem services and help shape upland management in the UK.

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