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The Cornwall Beaver Project: navigating the social-ecological complexity of rewilding as a nature-based solution

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The story of the Cornwall Beaver Project is presented as the foundation of a review of the literature to consider the effects of beavers on geomorphological and hydrological processes, habitats, biodiversity, and people in agricultural landscapes in the UK. The review includes a comparison of the principles for rewilding as an approach to ecological restoration with IUCNs principles for Nature-based Solutions together with a summary of beaver reintroduction in Europe, and the impacts of beavers on hydrological and geomorphological processes, biodiversity and the human-wildlife conflict that arises from reintroduction. We note that rewilding principles require a paradigm shift in the relationship between humans and the rest of nature and a corresponding application of systems thinking to research, practice and policy. The combination of experiential and formal knowledge is assessed using a social-ecological systems framework to consider the potential of beavers to mitigate climate change impacts on agricultural landscapes in the UK and how rewilders might navigate the social complexity of beaver reintroduction to achieve large scale system transformation. We discuss the different lines of evidence about the impacts of beavers on landscapes as viewed through a system lens and conclude that: (1) beaver dams have considerable potential to store water but their ability to reduce flood risk is difficult to assess because of the complex interactions between the material available for dam construction, geomorphology, and the duration, extent and intensity of rainfall events; (2) beaver dams, especially when combined with buffer zones along water courses have considerable potential to enhance the resilience of agricultural landscapes and support a shift from intensive to agroecological farming; (3) scaling beaver reintroduction will evolve with the application of policies and practices that enhance the ability of land users to adapt and learn how to coexist with beavers. Our review proposes a low conflict strategy for rewilding with beavers that includes changes from a policy of conflict avoidance to a proactive policy to support practices that apply the tools of social-ecological systems science to the body of knowledge about the interactions between beavers and their environment.

KEYWORDS

beaver, rewilding, ecological restoration, nature-based solutions, resilience, social-ecological systems

Introduction

The Eurasian Beaver (*Castor fiber*) and its North American relative (*Castor canadensis*) are well known as keystone herbivores (Rosell et al., 2005; Janiszewski et al., 2014) whose dam building behavior creates wetlands that reduce the effects of extreme floods and droughts, capture sediment, improve water quality and enhances biological diversity (Law et al., 2016; Law et al., 2017; Puttock et al., 2017 Willby et al., 2018; Brazier et al., 2021; Larsen et al., 2021; Wohl, 2021; Orazi et al., 2022).

Rewilding (Jepson et al., 2018; Carver et al., 2021) is a specific approach to ecosystem restoration (Nelson, 2023) that emphasizes the restoration of ecosystem function through the reintroduction of apex predators such as wolves and keystone herbivores such as bison and ecosystem engineers such as beavers. Rewilding that restores the functional roles of animals in ecosystems can expand natural climate solutions (Svenning, 2020; Malhi et al., 2022; Schmitz et al., 2023). Beaver dams moderate stream flow to reduce flooding and enhance water storage (Brazier et al., 2021), they can alter wetland CO2 and CH4 flux and have the potential to increase carbon sequestration by expanding wetlands along water courses (Schmitz et al., 2023).

In addition to its potential as an approach to ecological restoration, rewilding has profound social implications. The idea of rewilding nature is extended to include the rewilding of humans to address the disconnection between humhans and nature, which is proposed as a root cause of the current global environmental crisis (Mafey and Arts, 2023). Ecosystem restoration improves human health through the provision of a wide range of ecosystem services essential for human wellbeing and simply being in nature has positive impacts on mental health (Van Volkenburg, et al., 2023). Wetlands created by beaver reintroduction may increase nature connectedness in the UK and increase the psychological wellbeing of visitors to beaver enclosures and reintroduction sites (Gandy and Watts, 2021).

Despite the social and ecological benefits of rewilding, its use as a conservation strategy in the UK faces opposition primarily from farmers concerned about loss of land and associated loss of income (Aglionby and Field, 2023). The negative impacts of beavers include flooding of crops and human settlement, and various forms of damage to trees, crops and agricultural equipment (Brazier et al., 2021). The undesirable effects of beaver reintroduction can be managed through stakeholder engagement that validates land users concerns, and designs mitigation measures together with a management support service, compensation and lethal control where necessary (Brazier et al., 2021).

The Cornwall Beaver Project (CBP) is an example of rewilding initiated by a farmer who established a beaver enclosure as the first step in a process that aimed to use beavers to reduce flooding in a downstream village and improve the conservation of biodiversity on his farm. Various forms of public engagement followed the establishment of the enclosure to address stakeholder concerns about the proposed reintroduction, create opportunities for learning about beavers and their effects on hydrology and biodiversity within the enclosure. The project proponent was also employed as the Director "Community and Land" by the Beaver Trust (beavertrust.org), a non-governmental organization created to restore beavers to their former range across Britain. The networking and knowledge sharing activities that occurred on-farm together with the broader network developed through the Beaver Trust led to the consideration of strategies for policy development to support widespread reintroduction of beavers in the UK as a measure that enhances the resilience of agricultural landscapes to climate change.

Among the rewilding literature reviewed for this case study there are only two items that referred to social-ecological systems (SES) suggesting that a deeper exploration of the concepts and applications of systems thinking might provide further insights of value to practitioners and policy makers concerned with beaver reintroduction and rewilding in general. Based on a survey of "rewilding pioneers" Hawkins (2023) proposed a SES framework for categorizing qualitative change in landscapes that contribute to the ecological and socio-cultural goals of rewilding. Collectively, these contribute to the system goal of creating "*Landscapes or social-ecological systems that are sustainable, resilient, 'wild'*" (Hawkins, 2023) that encompasses the dynamic relationship between people and nature (Berkes, 2017).

The purpose of this review is to present the experiences of the CBP as a site for learning about the effects of beavers on geomorphological and hydrological processes, habitats, biodiversity, and people in an agricultural landscape. The central issue we address is: can beavers make a significant contribution to the restoration of ecological processes in agricultural landscapes and enhance the resilience of those landscapes to climate change?

After presenting the experiences of the CBP and associated work with the Beaver Trust we compare the principles for rewilding (Carver et al., 2021) as an approach to ecological restoration with IUCNs principles for Nature-based Solutions (Cohen-Shacham et al., 2016). We then present a review of some the literature on beaver reintroduction in Europe and the impacts of beavers on hydrological and geomorphological processes, biodiversity and the human-wildlife conflict that arises from reintroduction.

The final section of the literature review presents an overview of Holling's SES framework (Holling, 2001) that was adopted as a set of principles for enhancing the resilience of ecosystem services (Biggs et al., 2012). These principles enable the integration of the scientific and practical knowledge of people involved in beaver reintroduction to consider the potential of beavers to mitigate climate change impacts on agricultural landscapes in the UK. The resilience framework also provides a way of understanding how to navigate the social complexity of beaver reintroduction and progress from local innovation to large scale system transformation (Westley et al., 2014; Moore et al., 2015). We include the application of adaptive governance concepts (Cosens and Gunderson, 2018) in our consideration of scaling as beaver range in catchments may extend across multiple jurisdictions and require the evolution of polycentric decision-making systems that match the institutional scale of catchment management with the ecological scale of beaver behavior.

The experience of the CBP and knowledge from the scientific literature are brought together in the discussion where we consider the evidence for the ability of beavers to provide an NbS for drought and flood mitigation and to enhance the resilience of agricultural landscapes. The discussion considers the matter of scaling beaver reintroduction in relation to the creation of new organizations for managing human-beaver conflict. We end the discussion with a section where we present suggestions for improving rewilding practice and policy support based on CBP experience, rewilding literature and SES concepts of adaptive governance that enable people to learn how to coexist with beavers.

The Cornwall Beaver Project

Introduction

This account of the CBP was related to Mike Jones by Chris Jones in a series of discussions in 2022 and 2023. Chris Jones is a conservation-oriented farmer who has lived and worked on Woodland Valley Farm for over 60 years and who leads the CBP with the aim of promoting the restoration of ecological functions of rivers with beavers as a strategy for reducing the impacts of farming, climate change and biodiversity loss on agricultural landscapes and riverscapes. Mike Jones used the CBP story as the foundation for this review and used the literature on beavers and social-ecological systems to consider the application of scientific knowledge to rewilding practice and policy. Mike Jones is a field ecologist who planned and implemented community-based conservation projects and is now a semi-retired educator living in Sweden. Application of social-ecological systems thinking to biodiversity conservation practice and policy was a core part of his work. The authors share a common concern for the future of agriculture under the combined effects of extreme weather and biodiversity loss on degraded agricultural landscapes and view restoration with beavers as an important step towards enhancing the resilience of agricultural landscapes.

Establishing the project

The Cornwall Beaver Project began on Woodland Valley Farm, Ladock in 2014 in collaboration with the Cornwall Wildlife Trust to consider the design and location of an enclosure for a pair of beavers with stream flow monitoring equipment, collection of baseline streamflow data for 18 months before the beavers were introduced, and the construction of an enclosure. The original idea was to determine how beavers might affect streamflow and reduce the risk of flooding in the village of Ladock located 2 km downstream. Ladock was flooded in 2012 and 2013. The frequency of flooding is expected to increase with the trend towards extreme weather as global temperatures rise. A pair of adult beavers from Derek Gow Consultancy were put into an enclosure on Nankilly stream in 2017 and began to build a dam within two days of their release. The owners of Woodland Valley see beavers as a ‘gateway’ to more extensive rewilding because of their ability to restore streams and wetlands that would attract many other species with relatively few undesirable impacts on existing land use.

In 2014, there was no way to obtain a license for the free release of beavers which was the initial aim of the project. It was obvious that we would have a very long campaign to get wild beavers back into the headwaters of the Tresillian river above Ladock and realized that getting a permit for an enclosed release was the only way to make progress towards our long-term goal of using beavers for flood reduction. Without that controlled, experimental approach, we could have wasted many years and made no progress in learning how beavers could restore ecological functions to the landscape and how that would affect farming operations. A beaver colony in an enclosure allowed research, public engagement, learning, and education to begin immediately.

Woodland Valley Farm is 170 acres (69 ha) in extent and managed as an organic grass-fed beef production system with an environmental education center for schools and universities that also serves as a conference and events center. The farm owners are founding members of the Pasture-Fed Livestock Association and regular contributors to the Oxford Real Farming conference that explores alternatives to conventional agriculture.

Nankilly stream is one of three headwater streams that combine some 200 m above Ladock to form the Tresillian river which eventually discharges into the sea via the Fal estuary some 10 miles (16 km) to the southwest. The landscape of Woodland Valley Farm and its neighbors is undulating with relatively deeply incised valleys in parts that are partially wooded. Nankilly stream and other tributaries of the Fal river have considerable potential for the free release of beavers as they provide suitable habitat in places where there is relatively little conflict with farming as most of the streams are lined with woodland.

The beaver enclosure site on Woodland Valley Farm was an 8 acre (3 ha) field called “the moor” located near the head of the Nankilly stream. The field was drained sometime during the 18th century by a large ditch on the north side that diverted most of the stream around the field. Despite the drainage, the original stream channel is still evident, and carries flowing water during high rainfall periods. The soil included a large proportion of heavy kaolinitic clay that prevented cultivation and limited use of the field to production of rough pasture. A small pond was built at the upper end of the field in 1985 to store water for livestock in the event of a repeat of the kinds of drought experienced in the 1970s. The rest of the field was planted with a mixture of birch, oak and willow trees located according to micro-site variation within the field in 1988. Once the saplings had reached a height of about 3 meters in 1994 the field was fenced and used for a small herd of free ranging pigs. The beaver enclosure occupied about 3 acres (1.5 ha) located at the upstream end of the field.

Research and monitoring

Research and monitoring are ongoing and while much of the work is unpublished it is briefly summarized by the Cornwall Wildlife Trust (2022). Published accounts of monitoring projects include a long term and ongoing hydrology monitoring project (Puttock et al., 2021) and a survey of perspectives of people in Ladock about the use of beavers for flood alleviation (Auster et al., 2022a). In addition to this published work, water quality monitoring began in 2021; an MSc thesis study on algae was undertaken; an undergraduate dissertation on silt in the beaver ponds revealed that about 270 tons of silt accumulated with 15% organic matter; and an undergraduate dissertation on the spread of standing water across the site found 2,000 cu m of accumulated water. Various surveys of biodiversity are undertaken by local naturalists including surveys of fish, tree felling by beavers, macro invertebrates, and bats.

Sharing knowledge about beavers

CBP was established with the express intent of promoting beavers and contributing to the adoption of beavers as a part of the Cornish landscape. Social media were used from the outset to support a crowd funding campaign to pay for the establishment of fencing, the animals themselves, camera traps, Bavarian beaver traps and training for project staff. Social media also played an important role in public acceptance of the idea of a beaver project in their community.

The CPB hosted innumerable visits by the public, schools, colleges and stakeholder groups, including farmers, who amongst all others were the most likely to oppose beaver reintroduction. Press releases at critical points of project development brought interest from TV, radio and newspapers. Over time, a variety of nature programs such as Springwatch, Countryfile and the documentary film maker Simon Reeves came to film the beavers.

The community outreach work of the CBP is important because any subsequent unfenced release into the Fal or other catchments will require evidence of public and landowner tolerance if not wholehearted support. In general, some people are concerned about the impacts of beaver on trees, loss of farmland to flooding, crop damage and impacts on fish. Beaver supporters generally view them as good for flood control, don't mind some trees being lost and view beaver ponds as additional habitat for fish. CBP outreach also hosted people starting their own beaver project who came to learn from CBP experience. This contributed to the establishments of other enclosed beaver projects: five in Cornwall (with two others planned) one in Devon and one in London.

Learning from beaver reintroduction sites

Going further afield the proponent of the CBP played a leading role in the development of the Beaver Trust that led to visits to beaver reintroduction sites in Bavaria, Devon and Scotland to learn more about the conflicts that can occur between free released beavers and land users.

Tay Valley, Scotland: The wild beaver population of the Tay Valley was established by escapees or deliberate release from enclosures in 2001 in a landscape of high agricultural value (Coz and Young, 2020) leading to conflict that is now being addressed by a scheme to mitigate beaver damage (NatureScot, 2021). Mitigation measures include live capture of beavers for translocation and culling. In 2022 63 beavers were destroyed under license on the Tay and another 45 were trapped for translocation (NatureScot, 2022). The latest survey from Tayside suggests that the population now comprises about 250 territories (roughly 1000 beavers) and has extended its range to the Forth valley (Campbell-Palmer et al., 2018). The Tayside experience tells us that releasing beavers into high value agricultural land without extensive prior consultation and a sound management plan is going to be highly problematic.

Danube River, Bavaria: An engineering project at a cost of one million Euro was planned to address flooding experienced by the town of Winzer in Bavaria and then extensively modified after a family of beavers established a territory upstream of the town. Hydrological studies indicated that the beavers had reduced flood peaks to the extent that a reduced engineering defense scheme was sufficient at one third of the cost of the original project (Schwab and Schmidbauer, 2003). Conflict between beavers and farmers is mitigated by a statutory 6m wide river buffer that may not be cultivated and the employment of two professional beaver control officers. Additional support is provided by an extensive network of volunteers trained in all aspects of human beaver conflict who help landowners find solutions to problems created by beavers (Schwab and Schmidbauer, 2003).

Otter River, Devonshire: In contrast to the Tayside and Bavaria cases, the beaver reintroduction on the Otter River was adopted as a formal management trial at an early stage with a license from DEFRA and the support of a major landowner in the catchment (Howe and Crutchley, 2020). A part of this trial was the implementation of a Beaver Management Group (BMG) which has representatives of government agencies, NGO's, water companies and local stakeholders (Auster et al., 2022b). The creation of a BMG is proposed as a measure for management of existing unauthorized beaver populations (Pouget and Gill, 2021) may be adopted as part of the licensing process for unfenced releases.

There were conflicts between beavers and existing land users at all three reintroduction sites and all three have evolved management systems to address the conflict, each of which is different from the other. Tayside might be regarded as the most problematic because the beavers were escapees that settled on the Tay floodplain with considerable impact on high value farming. The conflict eventually abated, and culling and translocation licenses are now available for farmers suffering significant damage. In the case of Bavaria, the initial reintroduction was regarded as beneficial as a flood mitigation tactic and conflicts with farmers and other land users was mitigated by the evolution of an effective beaver management system. Aspects of the Bavarian experience we adopted for managing human-beaver conflict in the Tay valley (NatureScot, 2021).

Some relevant literature

Here we present some of the scientific and UK policy literature that is relevant to the long term aims of the CBP and that adds to the knowledge obtained during the life of CBP and associated networking. This includes rewilding with beavers as an NbS, a short account of the history of beaver reintroduction, a summary of beaver effects on ecosystem process and biodiversity, and ways of managing conflicts between beavers and other land users. We then present an SES framework, its use as an approach to enhancing the resilience of ecosystem services and its use for scaling local innovation.

Beavers as a nature-based solution

The ecosystem services of streamflow regulation, water quality improvement and biodiversity conservation provided by beavers make them a useful alternative to mechanical methods of restoration (Palmer et al., 2014; Brazier et al., 2021) and thus an NbS (Cohen-Shacham et al., 2016) to the societal challenges associated with global environmental change (Steffen et al., 2015). Freshwater and riparian environments are widely threatened (Reid et al., 2019) and the global abundance of freshwater species have declined by 84% since 1970 (WWF, 2020). Wetlands created by beavers in agricultural landscapes mitigate the adverse socio-economic impacts on five of the nine planetary boundaries that define a safe operating space for human society (Richardson et al., 2023). The five transgressed boundaries (climate change, biosphere integrity, land system change, freshwater system change and biogeochemical flows) will be directly and positively affected by beaver dams. The keystone role of beavers as ecosystem engineers suggests that as an NbS they can make a substantial contribution to the restoration of ecosystem health needed to keep global warming below 1.5°C and secure a livable future for humanity (Pörtner et al., 2023).

Nature-based solutions (NbS) as defined by IUCN (Cohen-Shacham et al., 2016) is a catch-all concept that covers various forms of ecosystem management, ecosystem restoration, ecosystem-based responses to climate change and disaster, green infrastructure, and area-based conservation. The intention is that NbS address societal challenges such as food and water security, health, and climate related risks. Although rewilding is a form of ecological restoration and therefor fits within the NbS framework, rewilding is different from NbS in some fundamentally important respects. Principles common to NbS (Cohen-Shacham et al., 2019) and rewilding (Carver et al., 2021) include landscape scale ambition, the need for adaptive approaches for the management of dynamic systems, and the integration of multiple forms of knowledge in the design of interventions. While NbS are strongly focused on ecosystem services and addressing societal challenges, rewilding emphasizes enhancement of ecosystem resilience, the intrinsic values of nature and a paradigm shift in the coexistence of humans and nature. Rewilding does not address societal challenges except for principle five (Carver et al., 2021) which says that rewilding can act as a tool to mitigate climate impacts.

The differences between NbS and Rewilding are significant in that it represents a shift from the "Nature for people" to the "People and nature" conservation paradigm (Mace, 2014). This shift from an anthropocentric to an ecocentric relationship between humans and nature requires an understanding of SES and related concepts such as resilience, adaptation, and transformation (Folke et al., 2010) and frameworks for their application to policy and practice.

Beaver reintroduction

Beavers were probably hunted to extinction in Britain by the 12th Century and in Scotland by the 16th Century (Lee, 2015). Beavers were mainly hunted for fur, castoreum (an oily secretion from the anal gland that is used in food and medicine) meat and the tail that was prepared and eaten like a fish on Friday's (Nolet and Rossell, 1998). Beavers were returned to the wild in Argyll, Scotland in 2009 (Coz and Young, 2020) and discovered in the wild on the River Otter, Devonshire in 2014 (Brazier et al., 2020). Subsequently reintroductions under controlled conditions have occurred at eleven sites within the UK (The Wildlife Trusts). Similar patterns of hunting to extinction followed by reintroduction, initially for hunting, and increasingly for ecological reasons since the 1970s, occurred throughout western Europe (Nolet and Rosell, 1998). Reintroduction in Europe has returned beavers to much of their original range and the population of *C. fiber* numbered about 1.5 million individuals by the early 21st Century (Halley et al., 2012).

Effects of beavers on ecosystem process

Beaver dams create wetlands that reduce the effects of extreme floods and droughts (Larsen et al., 2021; Ronnquist and Westbrook, 2021), and have the potential to restore UK wetlands, most of which have been drained or reduced to a polluted state and are dependent on artificial management (Howe, 2020). Beaver dams collect sediment that rebuilds channelized rivers and restores their hydrological functions (Brown et al., 2018; Brazier et al., 2021; Wohl, 2021) to the pre-anthropocentric conditions that were once common in Europe and degraded since the mid Holocene by agriculture and industrialization (Brown et al., 2018). Sediments in beaver dams act as sinks that affect different aspects of various biogeochemical cycles including nitrogen, phosphorous and organic carbon (Puttock et al., 2018; Brazier et al., 2021). Nutrients retained in pond sediments are taken up by plants in and around the pond, establishing local nutrient cycles and further slowing the movement of nutrients through the landscape (Rosell et al., 2005) reducing the risk of eutrophication of rivers and lakes and associated loss of biodiversity and water quality (Carpenter et al., 1998). The effects of beaver ponds on nutrient cycles are complex and dynamic, varying with dam wall porosity and pond age (Puttock et al., 2018; Brazier et al., 2021). In the western US, wetland restoration using beavers and beaver-like dams has grown rapidly since 2006 in response to concern about undesirable climate change effects to the hydrology of streams and rivers (Pilliod et al., 2018; Dittbrenner et al., 2022), prompting the US Fish and Wildlife Service to publish a comprehensive guideline for the use of beavers in restoration projects (Pollock et al., 2023).

Effects of beavers on biodiversity

Tree felling and dam building activity by beavers opens woodland canopy, creates wetlands, and changes stream bed morphology providing new habitats and increasing biological diversity (Law et al., 2016; Law et al., 2017; Willby et al., 2018; Howe, 2020; Brazier et al., 2021; Larsen et al., 2021; Wohl, 2021; Orazi, et al., 2022). Law et al. (2016) found that beaver ponds increased species richness at the landscape scale in Scotland. A twelve-year study of changes to an agricultural landscape in Scotland following the introduction of beavers showed an increase in plant species diversity and spatial heterogeneity (Law et al., 2017). A comparison between beaver ponds with adjacent wetlands in Sweden found significantly greater heterogeneity of habitats and greater species divers (Willby et al., 2018). Woody debris increases the complexity of streambed morphology creating habitat for invertebrates and amphibians with additional benefits for fish populations (Brazier et al., 2021). In Germany a comparison of beaver ponds with rivers and adjacent woodlands in a protected area found significantly more species in beaver pond habitats. Eight of the species found in this study were only found in beaver ponds (Orazi et al., 2022). In addition to these site-specific cases from the UK and Europe, Brazier et al. (2021) provide an extensive review of the changes to habitats and biodiversity that result from beaver activity.

Managing beaver-human conflict

Reintroduction of a long absent species to a landscape inevitably creates conflict with human land users and requires a period of social learning and adaptation (Cundill et al., 2011) to achieve a state of "Renewed Coexistence" (Auster et al., 2023). Conflicts and remedies for damage including dam removal, flow device measures to lower water levels, tree protection, and compensation for loss of land and crops are summarized by Brazier et al. (2021) from several sources. Gandy and Watts (2021) emphasize the psychological effects of anxiety and stress on landholders who suffer loss and the need for this to be understood, validated, compensated, and mitigated to reduce conflict. Conflicts between beavers and other land users at beaver reintroduction sites in England and Scotland extend to disagreement, mistrust, and polarization of views among landholders and beaver advocates (Inman, 2021).

Based on their study of beaver-human conflicts in Scotland Coz and Young (2020) argue that conflicts over reintroduction can be reduced by discussions among actual and potential stakeholders to agree a long-term landscape scale plan. Studies of the experience of interactions among stakeholders of the River Otter Beaver Trial and the Tamar Beaver Management Group led Auster, Barr and Brazier (2022) to conclude that collaborative groups for managing the coexistence between humans and beavers are emerging. Auster et al. (2023) emphasize the dynamic adaptive nature of beaver management groups and the need for flexible policy to support the process of humans learning how to coexist with beavers.

Accounts of the 30-year history of beaver reintroduction in Bavaria provide an example of how conflict management leads to the evolution of a system that enables coexistence between beavers and other land users (Schwab and Schmidbauer, 2003). Beaver management practices in Bavaria (Schwab and Schmidbauer, 2003; Nairne, 2019) include a statutory no cultivation zone, devolved governance systems that enables local decision making; a loss compensation scheme, a large network of "beaver consultants" to assist land users experiencing problems with beavers and culling. Some of these practices were incorporated into Scotland's Beaver Mitigation Scheme which provides government grants to mitigate undesirable dam building effects and to create various kinds of stream margin to promote coexistence between beavers and humans (NatureScot, 2021).

Social-ecological systems

The social-ecological systems (SES) framework or panarchy (Holling, 2001; Gunderson and Holling, 2002) provides a set of simple heuristics for developing mental models of evolutionary processes in human-nature systems that can be applied to individual farms, ecosystems, and landscapes. The panarchy is the foundation of ecosystem stewardship (Chapin, 2010) which emphasizes, restoration, and transformation as responses to the accelerating degradation that has arisen as the unintended consequences of modern management practices. Given the complexity of rewilding and nature-based solutions of which rewilding is a subset, the applications of "resilience thinking" (Folke et al., 2010; Curtin and Parker, 2014; Folke, 2016) seems to offer a useful approach to navigating the changes that rewilding will bring to landscapes that are highly modified to enhance the production of goods for human consumption. Virapongse et al. (2016) provide additional information about the SES framework and its ability to support transdisciplinary approaches that develop novel solutions to environmental management challenges by enhancing resilience.

Holling's panarchy comprises the adaptive cycle at three levels of scale to represent a hierarchical arrangement of systems nested within systems and the interactions between them. Small scale systems tend to change rapidly and may lead to change at higher levels of scale, large scale systems tend to resist change and provide stability over longer time frames. Key features of the continually changing adaptive cycle are the social and ecological potential for the system to change i.e., the quantities and qualities of all the social and ecological parts of the system; the dynamic connections between those parts i.e., the feedback interactions among them; and resilience which is a property that emerges from the interactions between the system's parts. The dynamic nature of systems and their different potentials for change determine what will or will not work in any given place and requires site specific planning using tools such as Wayfinder (Enfors-Kautsky et al., 2021) that are derived from the panarchy framework. Interactions between adaptive cycles at different levels of scale can lead to different outcomes. Change in small systems such as a genetic change, social or technological innovation can cascade upward ultimately leading to large scale change. In addition to resisting change large scale systems are a source of the social and ecological components necessary for restoring degraded systems. In the context of production landscapes, the ability of large-scale systems to provide stability and components for the restoration of degraded landscapes is undermined by land use practices that simplify systems to enhance their production capacity at the expense of their capacity for self-maintenance and renewal

(IPBES, 2019). The outcome of cross-scale interactions will be affected by external events such as climate change, energy decline (Hagens, 2020) and markets for ecosystem products among others. Collectively, these external events will affect land use, food and water security where the effects will vary according to the social and ecological context of a specific place.

SES and ecosystem services

Biggs et al. (2012) propose seven principles for enhancing the resilience of ecosystem services (Table 1) based on Holling's adaptive cycle and panarchy (Holling, 2001; Gunderson and Holling, 2002). These principles provide a useful way to consider beaver reintroductions within both "Nature for people" and "People and nature" conservation paradigms (Mace, 2014), and think about beaver reintroduction as a paradigm shifting process. Viewed from the "Nature for people" perspective, beavers produce multiple ecosystem services with values of individual services estimated at millions to hundreds of millions of US dollars (Thompson et al., 2020). Viewed from the "People and nature" perspective, beaver reintroduction is a complex process that requires policies and practices to support site specific approaches that integrate land use, and land users with the ecological characteristics of a place.

TABLE 1 The seven principles for enhancing the resilience of ecosystem services based on Biggs et al. (2012).

Principle	Brief Explanation
1. Maintain redundancy and diversity	Diversity comes in many forms: genes, species, landscape patches, cultural groups, livelihood strategies and governance institutions. Diversity enhances the potential of a system to change. Redundancy reduces the risk of systemic collapse by providing options for adapting to a changing environment such as rising temperatures and weather extremes associated with global warming.
2. Manage connectivity	Connectivity refers to the manner and extent to which species or social actors can move across a landscape and affects ecosystem services by affecting the spread of disturbance and recovery after disturbance.
3. Manage slow variables and feedbacks	The slow variables of a system determine its underlying structure and provide the stability necessary for the sustainable production of ecosystem services like food, fiber, fuel, livestock feed and drinking water that are essential to human wellbeing. Feedbacks regulate the relationships between variables within a system; reinforcing feedback supports increase which is regulated by balancing feedback that slows or stops the increase
4. Foster understanding of social-ecological systems as complex adaptive systems	This principle requires an understanding of the properties of complex adaptive systems (CAS) among scientists, policy makers and managers. A key part of a CAS perspective is recognition of the evolutionary change that occurs from the interaction between the parts of a system and the environment within which it occurs.
5. Encourage learning and experimentation	Learning is both an individual and social process that is essential for adapting to the incomplete knowledge and unpredictability that are features of CAS
6. Broaden participation	Encouraging the participation of all stakeholders is a key part of social learning and adaptation as it promotes transparency and knowledge sharing leading to collaboration as opposed to conflict
7. Promote polycentric governance systems	Polycentric governance is a way of managing natural resources that occur across multiple jurisdictional boundaries so that the scale at which ecological processes operate is matched by the scale at which decisions affecting that resource are made

An SES perspective is necessary to evaluate the trade-offs between different ecosystem services that consider the need to maintain the productive capacity of land by paying attention to the "slow variables" of soil and water as well as produce the food, fiber, fuel, and feed necessary for human wellbeing. The undesirable consequences of an inability to adopt a CAS perspective and consider the implications of trade-offs is well supported by documentary evidence (Holling and Meffe, 1996).

SES and scaling beaver reintroduction

In addition to providing a framework for enhancing the resilience of ecosystem services, the panarchy (Holling, 2001; Gunderson and Holling, 2002) provides a way of understanding how innovative ideas such as use of beavers for NbS can be scaled from experimental enclosures and reintroduction sites. There are three aspects to the process of scaling. Scaling out (Westley et al., 2014) is a process whereby interested groups learn from the experiences of others and decide to duplicate experimental beaver enclosures and reintroductions. Scaling up requires changes in the laws, rules and policies (Westley et al., 2014; Moore et al., 2015). Scaling deep (Moore et al., 2015) is about changing the cultural values and beliefs that affect the relationships among stakeholders and their various land uses.

Scaling up and scaling deep recognize that social innovation is a complex, emergent, and largely unpredictable process that involves interactions across the scales of Holling´s panarchy (Westley et al., 2014). Scaling deep is the same as creating a paradigm shift while scaling up can be achieved by applying lower-level levers that change rules, laws and policies that affect things like subsidies, devolution of authority and system goals (Meadows, 2009). The three kinds of scaling processes are interrelated (Moore et al., 2015) and while scaling out provides the foundation for change, scaling up and scaling deep may need to be managed interdependently to both create and exploit opportunities for change. To scale up organizations need to learn from their experience of scaling out and scaling deep and to develop the stamina necessary for leadership to prevail (Moore et al., 2015). O'Brien and Sygna (2013) propose a three spheres model of transformation that is like the three scales of Moore et al. (2015). O'Brien and Sygna (2013) suggest that effective practical action begins at the personal level with a change in beliefs, values, worldviews and paradigms. This enables engagement at the political level to change the systems and structures necessary to support practices that respond effectively to a given problem. Amel et al. (2017) explain why humans find it difficult to change environmentally destructive behavior and propose a broadly equivalent process of influencing change that begins at the personal level. In summary, all three perspectives on change process recognize the need for change at the personal level as a requirement for success in influencing others at higher levels of a social hierarchy.

Scaling beaver reintroduction as an innovation in landscape management requires land users to learn how they can coexist with beavers (Auster et al., 2023). This learning process involves the experimentation necessary for social learning (Cundill et al., 2011) broadening participation and polycentric governance required to enhance the resilience of ecosystem services (Biggs et al., 2012), all of which are essential components of learning how to coexist so that rewilding with beavers can proceed. Scaling up from enclosures and reintroduction sites to river catchments that cross jurisdictional boundaries requires consideration of the evolution of polycentric systems of adaptive governance (Cosens and Gunderson, 2018) that match institutional scale with ecological scale to manage the uncertainty that arises from SES interactions across multiple scales of time and space.

Butler et al. (2021) proposed an adaptive governance framework for rewilding that sets out the steps that might be taken to acquire a "social license to operate" a rewilding project and then continually adapt management practices as land users learn about the changes that unfold because of the interactions between them, the introduced species, and the ecosystem. This adaptive governance approach to rewilding is an advance over the IUCN Guideline for rewilding (IUCN, 2013). The adaptive governance approach addresses concerns raised by (Jepson et al., 2018) about cultural differences among stakeholders and the need to avoid projects designs that deliver pre-determined targets. Butler et al. (2021) note that adaptive governance is an evolving concept that should not be treated as a blueprint for rewilding and that while it increases costs in the short term it avoids the costs of acute or long-term conflict with negative impacts on biodiversity and human wellbeing.

Discussion

Beavers as an NbS for drought & flood mitigation

Do beaver dams provide an effective natural solution to problems of flooding and drought in agricultural landscapes?

In common with other hydrological studies (Larsen et al., 2021; Ronnquist and Westbrook, 2021) stream flow monitoring at the CBP site showed that beaver dams can significantly reduce peak flow (Puttock et al., 2021). Using this evidence to develop an effective strategy for flood risk reduction is complex because of the interaction between beavers, the dams they build, the landscape within which they occur and rainfall. The height and porosity of a dam depends on the materials available for construction (Ronnquist and Westbrook, 2021). The shape of the valley floor determines how much water is held behind the dam wall (Larsen et al., 2021). This varies with the amount of dam wall freeboard and diversion of water across floodplains (Ronnquist and Westbrook). Narrow valleys and incised streams will not hold much water. Flood risk mitigation is further complicated by the duration, extent and intensity of rainfall in relation to the location of beaver dams as well as the antecedent catchment wetness (Breinl et al., 2021). Scaling the CBP to other streams in the Tresillian catchment above Ladock is possible and may avert a significant number of potential flood events but as with all complex systems, outcomes are uncertain because of the interactions between the components of the system: in this case weather, geomorphology, beaver behavior, and available dam construction materials. Mechanical flood prevention measures suffer the same uncertainties associated with rainfall and soil (Breinl et al., 2021) as beaver dams.

While the ability of beaver dams to prevent downstream flooding is uncertain, their ability to conserve water is considerable (Pilliod et al., 2018; Dittbrenner et al., 2022; Pollock et al., 2023). Water storage capacity in the UK has reached levels where some parts of the country may run out of water within the next 20 years (National Audit Office, 2020). Stabilization of hydrological flows will become increasingly important as floods and droughts become more frequent because of global warming (Garner et al., 2015; Environment Agency, 2022).

Beavers and the resilience of agricultural landscapes

To what extent can the activities of beavers, confined to the streams, rivers and wetlands of drainage basins enhance the resilience of agricultural landscapes? This is a key question raised by Howe (2020) in reference to point source pollution of waterways and the widespread degradation and alteration of landscapes in England.

The social-ecological framework and its application to the concept of ecosystem services (Biggs et al., 2012) provides the holistic perspective that Howe (2020) suggests is needed to fully understand the ecological and biodiversity benefits of beavers. Howe (2020) also notes that reintroduction of beavers on its own cannot reduce the intense pressure on river catchments that need to be addressed at source to restore ecosystem function to headwater catchments. Much of the holistic perspective that Howe seeks may be found by developing an understanding the importance of the relationship between "slow variables", "fast variables" and feedback that is necessary to maintain or enhance the resilience of ecosystem services (Principle 3 in Table 1).

The climate and landscape processes that form soil and river catchments together with their wetlands are entities that change over millennia, unless altered or degraded by human activity which has accelerated exponentially over the last 200 years (Rees, 2020) because of the huge amounts of surplus energy supplied by fossil fuels (Hagens, 2020). Soil loss is a universal problem caused by farming (FAO and ITPS, 2015) and has contributed to the downfall of civilizations since the invention of the plough (Montgomery, 2008). Climate change is advancing rapidly (IPCC, 2023) and at a global level, the availability of water is becoming critical (GCEW, 2023; Naddaf, 2023). In the language of the SES framework, human economic activity is a fast variable exerting reinforcing feedback that is undermining the stabilizing influence of the Holocene climate, soil formation and hydrological cycle that biodiversity and humans are dependent on. Unless society establishes balancing feedback by setting a limit on economic growth (Daley, 2015; Farley and Voinov, 2016; Rees, 2020; Herrington, 2022), nature will impose limits through the synergistic effects of polluted atmosphere and degraded hydrological systems, and a decline in the qualities and quantities of climate, soil, water and biodiversity necessary for sustainable farming.

Beavers have the potential to play a significant role in restoring some landscape function to the pre-anthropocentric conditions that were once common in Europe and degraded since the mid Holocene by agriculture and industrialization (Brown et al., 2018). Beaver dams provide crucially important balancing feedback that contributes to ecosystem stability (Larsen et al., 2021) that given time can restore floodplains degraded by deforestation and arable agriculture (Brown et al., 2018). Beaver activity restores channelized water courses with low biodiversity turning them into wetlands with increased biodiversity in a relatively short period because of the interactions between the beavers, the hydrological, geomorphological and land use features of the environment within which they are released and the response of other species to the new environment created by the beavers (Law et al., 2016; Gaywood, 2017; Willby et al., 2018; Brazier et al., 2021).

The site-level restoration achieved by beavers can, as in the case of Bavaria (Schwab and Schmidbauer, 2003) be scaled out to increase connectivity within landscapes through the creation of a riparian buffer zone that reduces conflict between beavers and farmers. The combination of beaver created wetlands and corridors would complete two of the three-stage, core-corridor-carnivore model of rewilding (Soulé and Noss, 1998; Carver et al., 2021). Observation of land use by beavers in Bavaria suggest that the 6m buffer could be increased to 20m and eliminate 95% of the conflict as beavers only rarely travel more than 20m beyond water (Interreg, 2019). Such buffers would provide the basis for extensive restoration that increases biodiversity and soil organic matter and uses the soil to improve water quality by removing fertilizer and chemicals from agricultural run-off (Puttock et al., 2017; Puttock et al., 2018). The creation of buffer zones between beavers and farmland is consistent with the DEFRA's new plan for delivering clean and plentiful water (DEFRA, 2023), although beavers are not mentioned in this "integrated" plan.

The creation of corridors along water courses represents a "land-sparing" approach to reconciling biodiversity conservation and agriculture. Collas et al. (2022) found strong evidence for a land sparing approach in England and Grass et al. (2019) argue that land-spared corridors in agricultural landscapes allows species to move, saving them from extinction in hostile areas to maintain the resilience of ecosystem services. Land-sparing agri-environment schemes in Europe were found to increase the abundance and diversity of arthropods in agricultural landscapes (Marja et al., 2022). Soil dwelling arthropods play an important role in soil nutrient cycling and maintaining soil structures that reduce loss from erosion (Culliney, 2013). Plant dwelling arthropods (insects) play a critical role as pollinators of agricultural crops (Jankielsohn, 2018). Arthropod decline is due to land conversion for agriculture and use of chemicals (Hierlmeier et al., 2022). The buffer zones along water courses can be regarded as "semi-natural land" in the three-compartment model of the land use framework recommended in the National Food Strategy (Dimbleby, 2021). The process of sustainable intensification (Pretty, 2018) that ultimately aims to restore ecological processes in agricultural landscapes can be applied to high and low yield farmland in Dimbleby (2021) classification. The biodiversity refugia created by beaver wetlands and corridors as semi-natural lands within high and low yield farmland could become a significant source of the biodiversity necessary to restore ecological processes.

An SES perspective on Howe's concern about the limited ability of beavers to restore ecological function to ecosystems in the UK, recognizes a need to shift from intensive "Green Revolution" agriculture towards agroecological methods of farming (Bezner Kerr et al., 2023) with the aim of reducing soil and water loss and greenhouse gas emissions while maintaining food security (FAO, 2018). Soil, water, and nutrient loss increase with the duration and intensity of rainfall (FAO, 2019). Greenhouse gas emissions are increasing the rate of global warming and the occurrence of extreme weather (IPCC, 2023). Food production accounts for approximately 25% of global GHG emissions of which about half comes from crop and livestock production (Ritchie, 2019). Collectively the combination of climate change, soil water and nutrient loss are reinforcing feedback driving a vicious cycle of degradation that undermines the basic requirement of a healthy soil needed to maintain civilization. The decline in arthropods that maintain soil health because of agricultural practices accelerate the degradation process. Despite being confined to wetlands and watercourses beavers have considerable ability to restore the regulating ecosystem services that are essential for sustainable agriculture and the wellbeing of society.

Scaling beaver reintroduction

Overcoming the problems of human-beaver conflict is central to the problem of scaling the reintroduction of beavers for restoration of ecological process in landscapes where humans have no experience of coexisting with beavers. In this section of the review, we reflect on the different aspects of scaling described in the SES literature and based on experience in Bavaria and Scotland, suggest that human-beaver coexistence will emerge. The process of emergence will be constrained until there is a change in the current policy mindset.

The CBP has played a leading role as a source of knowledge that enabled others to initiate similar projects in other parts of Cornwall and elsewhere in England. This is an example of "scaling out" a social innovation (Westley et al., 2014; Moore et al., 2015) where beaver enclosures are being replicated. The next step of moving from beavers in an enclosure to free-ranging beavers, is a process that will involve a combination of "scaling up" (Westley et al., 2014; Moore et al., 2015) and "scaling deep" (Moore et al., 2015).

The experiences of the Otter River reintroductions provide an example of limited scaling up where human-wildlife conflict and the research that followed an unlicensed reintroduction eventually resulted in beavers being declared a protected species by the Department for Environment Food and Rural Affairs (DEFRA, 2022a) together with the issuance of guidelines and rules for their management (DEFRA, 2022b). While this may provide some stability to the conflict between land users and beaver supporters, these laws, policies, and guidance are a long way from enabling the rewilding goals of restoring ecological function to landscapes (Carver et al., 2021) or an NbS goal of using beavers to improve the hydrological characteristics of rivers as drought and flood mitigation measures. The fact that the legalization of the Otter River was forced by public sentiment in favor of allowing the beavers to stay (Crowley et al., 2017) is an indication of how unwilling DEFRA are to support widespread beaver reintroduction.

The changes in beaver management described in Bavaria (Schwab and Schmidbauer, 2003), England (Auster et al., 2022b; Auster et al., 2023) and Scotland (NatureScot, 2021) illustrate the interdependent nature of scaling and adaptive governance and the CAS concept of emergence whereby new structures and processes emerge through the interactions between the components of a system. The reproductive capacity of beavers means that their need for habitat can grow rapidly with consequences for other parts of a river basin as in the case of Tay Valley (Campbell-Palmer et al., 2018). As beavers spread and people learn about their effects on ecology and land use economics, institutional changes will occur to govern the interactions between these components of a landscape.

Scaling out because of beaver reproduction and the activities of beaver supporters together with learning about the interactions within a landscape, will cause the emergence of new laws, policies and practices that further enable and formalize the coexistence between beavers and humans. If the range of beavers extends beyond the boundaries of a local authority, some form of polycentric governance arrangement may emerge so that different authorities can manage beavers to meet commonly agreed goals. Progress in scaling out and scaling up will be constrained until a paradigm shift in the mental models of policy and decision makers has occurred. This deep scaling (Moore et al., 2015) addresses the foundational beliefs, values and assumptions from which laws and policies emerge (Meadows, 2009) and would address things like the economic and food production goals that are driving intensive agriculture and undermining the resilience of agricultural landscapes. Once the goals of a system are changed, it will reorganize to meet the new goals (Meadows, 2009).

Improving practice and policy for beaver reintroduction

The CBP experience of beaver reintroduction, together with the available scientific evidence on the management of human beaver conflicts and our knowledge of SES concepts suggests that application of adaptive governance by policy makers and the use of SES planning tools would reduce human beaver conflict and enhance the resilience of agricultural landscapes. Effective policy support requires a mindset change that recognizes the value of bottom-up processes for resolving complex problems.

Despite the barriers to rewilding identified by Aglionby and Field (2023) the interest in beaver reintroduction as a method of restoring resilience to agricultural landscapes is growing. There were five fenced enclosures in England in 2017 and about 40 in 2022 with more planned. Beavers escape from fenced sites and the wild beaver population is growing. There are now 11 rivers (Tamar, Taw, Exe, Otter, Bristol Avon, Wye, Dyfi, Kentish Stour, Dorset Stour, Clyde and Forth) with wild beavers. Among the barriers to rewilding identified by Aglionby and Field (2023) conflict between stakeholders and a muddled policy environment stand out as two broad and interrelated categories relevant to beaver reintroduction. The policy environment is muddled by the conflicting demands of stakeholders, the need to balance biodiversity conservation with farming and the need enhance the resilience of agricultural landscapes, and farming to climate change. In terms of SES thinking a defensive policy represents a rigidity trap (Scheffer and Westley, 2007; Carpenter and Brock, 2008) where conflict among the stakeholders based on locked in thinking leads to stasis when rapidly changing environmental conditions require change.

Applied adaptive governance

As a "pioneer farmer" (Thomas, 2022) the CBP favors a low conflict approach to beaver reintroduction that avoids flat landscapes with high value farmland as a sensible way to proceed. This would underline governments commitment to the farming industry, disarming the opposition to beaver re-introduction demonstrated by the National Farmers Union (NFU, 2022) and avoid wasting conservation efforts that attempt to return beavers to high conflict catchments. A proactive low conflict policy would reduce the pressure from "guerilla rewilders" (Thomas, 2022) who might otherwise release beavers in landscape with high agricultural potential and polarize the public dialogue about rewilding.

A low conflict approach would start with the formation of local groups that represents stakeholders at potential reintroduction sites and engage them at the outset in the development of a site-specific plan. Enfors-Kautsky et al. (2021) describe a participatory process for an SES assessment that includes a scenario component to explore plausible future changes that might emerge following a reintroduction. The assessment process and scenarios would provide a basis for decision-making by stakeholders about if, when and how to proceed with a proposed beaver reintroduction. The "Wayfinder" assessment and planning method described by Enfors-Kautsky et al. (2021) concludes with a section on adaptive management that enables stakeholder to navigate the changes that emerge following a reintroduction. This bottom-up approach to planning meets Howe's (2020) requirement for site specific planning in places where land users are amenable and treats each reintroduction as an experiment from which the outcomes (short term effects) and impacts (long term effects) are learned. Learning how to think in terms of SES is a process that requires some unlearning of old habits of thought based on reductionism as well as learning about the dynamics of complex adaptive systems (Rogers et al., 2013). The use of a participatory SES assessment in planning beaver reintroduction and their contribution to landscape resilience would improve the assessment of the risks of systemic failure that arise from the accumulative impacts of humans on landscapes (Wassénius and Crona (2022).

Learning how to apply adaptive governance and manage beavers (or any other kind of reintroduction) can address the barriers to rewilding identified by Aglionby and Field (2023). This would include the provision of facilitation and advisory services to support emerging beaver management groups until they have learned the techniques for themselves. Adaptive governance concepts might also be usefully applied by “armchair rewilders” and “policy entrepreneurs” (Thomas, 2022) to develop the social, political and resource mobilization skills necessary for influencing policy Westley and Antadze (2010). Learning these skills “*could be critical in shaping the UK conservation agenda for years, or even decades, to come.*” (Thomas, 2022).

Policy support

Working together and learning new techniques necessary to establish a beaver reintroduction requires an investment of time and money by stakeholders. It is difficult to imagine collaboration happening without support from government, unless undertaken by wealthy landowners or NGO’s with a strong donor base. For those who can afford them, beaver management groups might successfully implement a beaver reintroduction, but undermine social equity by excluding other groups with good potential for beaver reintroduction without the resources to form a management group. This inequity may promote conflict instead of the consilience needed for large scale beaver reintroduction.

One of the conditions necessary for adaptive governance to emerge is a supportive policy environment (Armitage et al., 2009) where the role of policy is to learn about governance of complex systems and to protect the conditions of emergence (Ruitenbeek and Cartier, 2001). A change in DEFRA policy for beaver reintroduction from passive conflict avoidance to proactive support that empowers local management groups to learn how to manage conflict is required for beaver rewilding to progress from isolated enclosures and small-scale reintroduction. Recent government publications suggest that this shift in policy from top-down to support for bottom-up planning is happening through the Environmental Land Management Scheme (ELMS) in the DEFRA’s agricultural transition plan (DEFRA, 2020). The ELM scheme (DEFRA, 2020) addresses biodiversity conservation, flood mitigation and diffuse water pollution which are problems to which beavers provide an NbS. The Environment Food and Rural Affairs Committee Report (EFRAC, 2023a) summarizes many of the concerns about beaver reintroduction and measures that can be taken to address those concerns based on lessons learned in the UK and Europe. The ELM scheme proposed in the agricultural transition plan DEFRA (2020) includes changes in subsidies that could enable farmers to learn how to coexist with beavers, but full details for implementation have not been released (Aglionby and Field, 2023). Government’s response to the species reintroduction committee (EFRAC 2023b) affirms government’s aims for achieving biodiversity targets through habitat restoration and corridors and recommends budgetary support through ELMS.

While government support for rewilding in general may be not be forthcoming (DEFRA, 2023), there are signs of a shift in policy direction that would support the emergence of beaver management groups and enable coexistence between beavers and humans. It remains to be seen how this support will be provided and what aspects of beaver reintroduction it will support.

Conclusion

The intention of the CBP was to rewild the Tresillian river with beavers to reduce the incidence and severity of flooding in Ladock village, as an NbS to a problem that is conventionally addressed with engineering solutions such as dams and levees. The accumulations of sediments and biodiversity benefits that arose from the creation of the beaver dams in the CBP enclosure are emerging over time. The research and monitoring information being collected at the CBP enclosure are consistent with the outcome of beaver reintroduction on the river Otter (Brazier et al., 2021) and a considerable body of evidence in the scientific literature on the biological, hydrological, and geomorphological benefits of beavers.

Rewilding principles (Carver et al., 2021) represent an ambition to shift biodiversity conservation from “Nature for people” and its concerns with ecosystem services and economic values of nature, to “People and nature” and its concerns with social-ecological systems, resilience, and adaptability (Mace, 2014). This implies a systemic transformation in current approaches to landscape management from reductive science and prescriptive policies to transdisciplinary ecological and social science, the experiential learning by stakeholders in rewilding projects, and policies that support social learning, emergence, and adaptation. The story of beaver reintroduction presented in this case and the application of principles for enhancing the resilience of ecosystem services (Biggs et al., 2012) to different aspects of beaver impacts on landscape processes, illustrate the transformational potential of beavers, rewilding principles and SES thinking to biodiversity conservation and agriculture.

Beaver dams have considerable potential as an NbS to reduce the impacts of drought by conserving water (Pilliod et al., 2018; Dittbrenner et al., 2022; Pollock et al., 2023), while their ability to reduce flooding depends on the interactions between material available for dam construction (Ronnquist and Westbrook, 2021), stream geomorphology (Larsen et al., 2021), rainfall duration, extent and intensity of rainfall and soil wetness (Breinl et al., 2021). Rainfall characteristics and soil wetness will similarly affect mechanical flood reduction measures. A study to estimate the costs and benefits of engineered versus beaver flood mitigation measures would be useful for planning future flood risk reduction measures.

An SES perspective on the contribution of beavers to the resilience of agricultural landscapes emphasizes the importance of slow changing components such as soil and hydrological systems that create stability in a landscape, and reinforcing feedback of comparatively fast changing human activity that is degrading these components. Maintaining the stability of hydrological and soil ecosystems is essential for the resilience of agriculture, especially in the face of accelerated climate change. Beavers can play a significant role in slowing the degradation process, especially if buffer zones are created between beaver inhabited streams and agricultural land. Beaver dams, wetlands and buffer zones would act as reservoirs for the biodiversity which is another key component of ecosystem resilience (Biggs et al., 2012). Unless economic policy places a limit on growth and farmers learn agroecological methods for farming with nature, climate change, soil, water, and biodiversity loss may result in the collapse of agricultural landscapes. Ecosystem renewal following collapse described in Holling's panarchy (Holling, Gundersen & Holling) are part of the evolutionary process that maintains life in a changing world and is best achieved by ensuring that the components needed for successful reorganization are conserved.

Well established beaver populations, wetlands and buffer zones provide a foundation for post-collapse recovery serving as both a natural insurance policy and a risk reduction measure. Post collapse recovery would include a transition towards agro-ecological methods of farming (Bezner Kerr et al., 2023) and the third stage of sustainable intensification (Pretty, 2018).

Scaling beaver reintroduction from enclosures and limited reintroduction sites requires a combination of learning, adaptation, and social skills for navigating the complexity of interactions between beavers and humans in a process of adaptive governance (Cosens and Gunderson, 2018) that enables beavers and human to coexist. The literature search undertaken as part of this case study found an adaptive governance framework for rewilding that was developed in the US and is consistent with much of the SES literature on adaptive governance. Studies of beaver human interactions in England, Scotland and Bavaria show how systems for adaptive governance evolved in Bavaria and are evolving in Scotland and England under the influence of Bavarian experience.

Scaling up requires the development of skills needed to navigate the social and political environment necessary to achieve changes in policy and legislation. Scaling up also requires a mindset change ("scaling deep") from the anthropocentric perspective of nature as a source of ecosystem services to an ecocentric perspective of humans and nature coexisting in an interdependent relationship sought by the rewilding principles (Carver et al., 2021). Achieving a mindset change begins at an individual level (O'Brien and Sygna, 2013; Moore et al., 2015; Amel et al., 2017) and at a societal level is a long-term process (Meadows, 2009). The slow process of mindset change is recognized in rewilding (Jepson et al., 2018; Hawkins, 2023). Rewilding principles require that people involved in planning and policy learn how to apply the social-ecological systems framework to achieve the goal of rewilding (Hawkins, 2023) as an adaptation that enhances the resilience of landscapes and to surrender the belief that living, self-organizing systems can be understood through reductive science and controlled through policy prescription.

It seems unlikely that policy support for rewilding in England will be forthcoming soon (EFRAC, 2023b) although some aspects of beaver reintroduction may be forthcoming through the ELM scheme (DEFRA, 2020).

Author contributions

MJ is the senior author, undertook the literature review and assessment of the potential of rewildling with beavers as a nature-based solution. CJ provided the story upon which the review is based and proposals for policy and practice based on his knowledge of beaver management in agricultural landscapes. All authors listed have made a substantial, direct, and intellectual contribution to the work and approved it for publication.

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Conflict of interest

Author CJ co-owns the company Woodland Valley Farm.

The remaining author declares that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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