# A review of the evidence on the interactions of beavers with the natural and human environment in relation to England (NEER017)

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# Executive Summary

## Context

The European Beaver (*Castor fiber*) was once widespread across Europe and northern Asia. It became extinct in England around the 16th century due to overhunting for its meat and fur. Beavers are ecosystem engineers and, as a keystone species, are able to restore wetland ecosystems and produce a mosaic of diverse riparian habitats.

A five-year licence was issued by Natural England in 2015 to legitimise the presence of beavers that had been living wild on the River Otter in Devon, England, enabling an authorised trial of a beaver reintroduction. In 2020 a decision was made by Ministers, following the conclusion and assessment of trial results, to permit those free-living beavers to remain and continue to expand their range naturally. This has resulted in widespread interest in reintroducing beavers to new areas of England.

## Scope

The purpose of this review is to inform decisions relating to reintroducing beavers more widely in England. It does this by reviewing evidence, relevant to England, on the interactions of beavers with the natural and human environment alongside the guidelines for reintroductions and other conservation translocations published by the International Union for the Conservation of Nature. This review focuses on new evidence available since an earlier feasibility assessment published by Natural England in 2009 and the subsequent publication in 2015 of an extensive review carried out by Scottish Natural Heritage. The aim is to identify and assess key evidence across a range of natural and socio-economic factors relevant to decisions on further beaver releases in England.

## Key conclusions

The key findings from each topic reviewed are summarised below. As stated in the scope, this review is restricted to recent evidence available since the 2015 review by Scottish Natural Heritage. Although our knowledge of beavers in a British context has improved since 2015, there remain uncertainties in relation to some potential positive and negative impacts.

Before considering the evidence, it is important to recognise that how the reintroduction of a lost keystone species like the beaver is perceived or judged is highly dependent on the reference point used from which to measure the effects. The existing ecological baseline in many areas of England, reflects highly altered or degraded ecosystems and this is critical context when considering the potential influences of beavers on habitats and species. As beaver populations expand, the extent to which their impacts are considered positive or negative is dependant on management and habitat restoration objectives. For example, is impact judged by referring to the local habitats present at the time the beavers are reintroduced, or by reference to other objectives, such as relating to ecosystem restoration?

The role of beavers in the restoration of more naturally functioning ecosystems cannot be considered without reference to natural controls on beaver populations, which are critical in providing dynamic balance to ecosystems. Restoring natural population controls (or mimicking of those controls) on native species should be seen as an integral part of restoring natural ecosystems.

## Ecological requirements for restoring a beaver population

Restoring the beaver as a widespread native wild mammal in England is ecologically feasible. Evidence collected from the trial reintroductions in Great Britain, carried out since the 2009 feasibility study, confirm there is sufficient suitable habitat in England to support this species at many locations, the climate is appropriate and there is an appropriate source of beavers to use to found the initial population.

## Interactions with habitats

### Running water

Recent evidence published since the Scottish Review complements previous evidence demonstrating that beaver activity can enhance the natural functions of river systems, although the extent of influence is dependent on the natural characteristics of the watercourse and the nature and scale of existing habitat degradation. Key factors affecting the response of watercourses to beaver activity include stream power, gradient and the size of naturally vegetated riparian zones. There is potential for significant habitat restoration opportunities associated with the delivery of large woody material to the channel and beaver activity in riparian zones, helping to restore lost habitat dynamism and diversity.

The scale of ecological change will be highly site-specific and dynamic, but where beaver activity is high there will be an overall shift in the balance of lentic and lotic character and associated biological assemblages, in line with natural functioning of river ecosystems, as long as beaver population levels are subject to population controls that also mimic natural systems.

### Standing water habitats and associated wetlands

Recent evidence published since the Scottish Review is consistent with previous evidence demonstrating that beavers can help restore wetlands and promote biodiversity.

Beaver-induced ponded and wetland habitats have the potential to enhance and restore natural processes in English catchments with a significant benefit to overall wetland function. There have been many changes to the water environment since beavers were widely present and while many of the effects of beaver will be beneficial, there will also be situations where landowner objectives will differ, and conflict may occur.

### Woodlands

Evidence from research published since the Scottish Review is in accord with previous evidence demonstrating that beavers can affect tree species composition and age structure of wet woodlands and woodlands along riparian corridors with subsequent positive impacts for biodiversity.

Beaver activity within riparian woodlands is likely to lead to greater structural complexity and, consequently, greater diversity of conditions within woodlands, particularly in terms of wetness. As a result, there would also be greater diversity in hydro-chemistry, light availability and openness. Overall, beavers can create more heterogeneous and diverse riparian woodlands both across the landscape and through time.

## Interactions with species

### Freshwater fish assemblages

Evidence from research published since the production of the Scottish Review continues to present a complex and often contradictory picture on the impacts of beavers on fish populations. This reflects the high number of variables involved in assessing the potential impact of changes resulting from beaver activity such as the reference point against which change is evaluated (existing or natural reference conditions), spatial and temporal population variation, species diversity and the long timescales necessary to observe ecological responses, particularly at the population level.

Where the impacts of beaver on aquatic habitats are considered at a suitably broad temporal and spatial (catchment) scale, the increase in habitat diversity and dynamism brought about by beavers is likely to result in more diverse fish populations with greater ability to sustain themselves, particularly in the face of climate change. Ensuring there is adequate space for restoring more natural river and lake ecosystem function will help to ensure that benefits to fish assemblages are maximised.

### Bryophytes

Evidence from research published since the Scottish Review is limited.

Increases in habitat heterogeneity and deadwood brought about by beavers are likely to benefit English bryophyte species, but case by case analyses may be required for bryophytes which are very rare or have restricted distribution.

### Fungi and lichens

Since the Scottish Review there has been limited further relevant research related to fungi and lichens. The impacts on lichen species across England are likely to vary and will not be known for many years. While there is no direct evidence in England, published literature from other countries, and expert opinion, suggest that generalists, ephemeral and deadwood species will benefit, whilst specialist epiphytic lichens, especially those associated with old trees, will gradually decline in beaver occupied areas. However, the significance of such changes at a landscape scale are uncertain.

Fungi are dominated by rare species at local levels and are considered highly sensitive to woodland structural change. Both mycorrhizal and deadwood fungal species richness have been shown to increase with tree and woodland age and tree species diversity. In addition, ectomycorrhizal fungal diversity is positively related to canopy cover, whilst saprotrophic fungi of fine woody debris benefit from canopy gaps. Beavers have the potential to influence all of these at local scales. Whether species extirpations at such scales are compensated by increased habitat heterogeneity at a landscape scale is uncertain.

Further research is required to understand the influence of beavers on relevant species and assemblages of fungus and lichen in England.

### Vascular plants

Research published since the Scottish Review is limited, but complements existing studies demonstrating that increased habitat heterogeneity and dynamism is likely to benefit vascular plants at the landscape scale.

Further work is required to investigate the impacts on locally occurring rare or threatened species, particularly those whose habitats are likely to be directly impacted or whose morphologies are known to be favoured for food, making them particularly vulnerable to exploitation by beavers.

### Invertebrates

Evidence from research published since the Scottish Review presents a sometimes contradictory picture on the effects of beavers on invertebrates. Whilst the high variation in microhabitat diversity caused by beavers is expected to benefit riparian invertebrate species overall, the development and presence of beaver dams, which alter physical and chemical characteristics of streams, will create change in the balance of functional characteristics and hence species composition of macroinvertebrate assemblages.

Impacts from beaver activities on remaining populations of freshwater pearl mussels and white-clawed crayfish in England are expected to be complex, with both positive and negative impacts at differing times. Due to the very restricted distribution and vulnerable nature of populations in England, appropriate management and action would be required if beavers colonise rivers where freshwater pearl mussels occur.

Overall, the activities of beavers are likely to have differing effects on different invertebrate groups at different times and locations. Such changes are expected in the process of restoring natural function to freshwater and associated ecosystems, restoring lost diversity, dynamism and ecological resilience in the face of climate change. Local assessments should be undertaken to identify potential risks to those species of conservation concern and/or restricted distribution.

### Amphibians and reptiles

Evidence since the Scottish Review on the effects of beavers on amphibians demonstrates a positive effect. Research on reptiles is more limited, but where studies have been undertaken, they support the existing body of evidence that beavers can improve reptile biodiversity.

The effects of beavers on amphibian species in England is generally positive due to the creation of new ponds and wetland areas which provide habitat for breeding, foraging and dispersal. The grass snake is also expected to benefit from the habitat created. Adders prefer drier soils so local distribution of this species may be negatively affected.

### Birds

Since the Scottish Review there has been limited further relevant research related to birds. Where studies have been undertaken, they support the existing body of evidence that demonstrates the generally positive benefits of beavers for birds through the creation of wetland areas and increased habitat heterogeneity resulting in additional ecological niches for birds to exploit.

There is no evidence that bird biodiversity is likely to be negatively affected by the activities of beavers.

### Mammals

Since the Scottish Review there has been limited further relevant research related to mammals. Where studies have been undertaken they support the existing body of evidence. This demonstrates the positive benefits of beavers for native mammal species through increased habitat complexity and food sources. Beavers may, however, also provide opportunities for increased distribution and abundance of the non-native American mink through improved habitat and prey provision. The significance of this for the native water vole is uncertain and requires further investigation. The impact of American mink generally on water voles may be exacerbated by habitat loss and fragmentation. As mature beaver habitat has been shown to be highly suitable for water voles they should benefit from increased habitat. Whether this improves their resilience to mink predation is uncertain.

## Interactions with people

### Public attitude and perceptions

Evidence since the Scottish review on social science related to beaver reintroduction is limited, but growing, and suggests that stakeholders and the public are generally supportive of beaver reintroductions. There are some notable exceptions to the generally favourable view, typically amongst those negatively affected. Evidence suggests that this is linked to the fact that the impact of beaver reintroduction is not distributed evenly and the costs are disproportionately borne by a small number of individuals while the benefits accrue to society.

There is potential for conflict related to beaver reintroduction in certain contexts and amongst certain groups, including landowners and farmers in specific geographies, anglers and commercial fisheries and specific communities living close to reintroductions.

Conflicts can be heightened when linked to perceived legitimacy of releases, mis-trust between parties and in management processes, power imbalances (including feelings of not being listened to), differences in value sets and identities, and where scientific information is partial, uncertain, or perceived differently. There is evidence that dialogue improves trust and can help reduce conflict, and that engagement can support attitudinal change (though further research is needed to understand how this is sustained).

There is a widely held view that getting the management of beaver impacts right is important and concerns about the lack of agreed measures to address any emergent problems quickly (hence support for culling by some stakeholders).

Better integration between the social and natural sciences is needed to understand the social context of beaver reintroduction and to inform effective management. Social research methods should be incorporated into longer term monitoring and evaluation to understand 'what works' in reducing conflict and supporting co-habitation of people and beavers, both relating to reintroduction and longer term management as beavers start to expand their range.

**Economic benefits and costs**

Reintroducing beavers can generate a range of both positive and negative aspects for society, the environment and the economy. Limited evidence exists on the monetary benefits and costs of wild and reintroduced beavers across a wide range of contexts and this evidence is insufficient to assess the benefits and costs of a full reintroduction of beavers into England. There are three reasons for this; i) evidence on costs and benefits is location-specific and reintroducing beavers to different locations may not result in the same type and/or magnitude of benefits and costs, ii) how benefits and costs evolve with time and beaver population densities needs to be understood better and iii) appropriate management and mitigation strategies need to be identified as part of a reintroduction to maximise the benefits and minimise the costs of beaver activity.

Recommendations for future cost benefit work to allow this analysis are provided and should be considered as a priority for future research.

**Water management**

Strong evidence from England and Europe since the Scottish Review strengthens our understanding that beavers can have a wide range of positive effects on water-related ecosystem services associated with restoring natural hydrological, sedimentological and geomorphological processes. This includes helping to restore: i) catchment water storage, improving the resilience of water supplies; ii) generating natural attenuation of flood flows in rivers, reducing downstream flood risk; and iii) natural processing of nutrients and fine sediments, benefiting downstream water quality. The scope for benefits varies with the scale of influence of beaver activity in different environmental conditions.

Whilst beavers can play a positive role in restoring the natural processes upon which water management depends, it is important not to over-estimate this role in ways that might undermine strategies for addressing impacts on natural processes at source. Impacts on natural processes (abstraction and water diversion, diffuse and point source pollution, drainage, physical modifications to rivers, streams and lakes) are many and varied and need to be tackled through concerted and strategic restoration plans, providing beavers with a foundation upon which to add their beneficial contribution.

Improved understanding of the influence of beavers on water objectives at the catchment scale is needed, together with continued development of tools that help to increase benefits and identify when management is needed to address conflict.

### Freshwater fisheries

The limited understanding of impacts of beaver activity on some commercially significant fish populations and lack of published data considering the potential implications for fisheries make it difficult to fully determine the effects, positive and negative, of beavers on fisheries. Angling and the attitudes of anglers to beavers adds another dimension to an already complex mix of factors relevant to beaver-fishery interactions.

Improved understanding of the balance of benefits and risks to migratory fish populations is needed to evaluate the implications for fisheries for these species. Interactions between beavers and migratory salmonids are of concern given the status of sea trout and salmon stocks in England. Shads, smelt, river and sea lamprey should also be considered as there is potential for loss of connectivity between feeding and spawning grounds resulting from the construction of beaver dams.

The potential effects of beavers on the types of small stillwater fisheries common across England are not widely considered in the available literature, though are likely to be dependent on their proximity to watercourses.

### Forestry

Since the Scottish Review there has been limited further relevant research related to forestry. For the most part, the forestry sector will see minimal impacts from beavers and is well placed to accommodate their impacts provided woodland managers follow the UK Forestry Standard. This requires buffer zones along watercourses, as well as dedicated areas for the protection and enhancement of biodiversity.

### Agricultural land

Beaver activity can have a range of impacts on agriculture, both positive and negative. Research has shown that the costs from negative impacts will be higher on intensively farmed, high value, arable land. The likelihood of any impact, however, will depend on factors such the local topography, soil structure and texture, hydrology, the type of agriculture and proximity to watercourses. Therefore, the regions of England dominated by lowland arable agricultural land on floodplains are likely to be where the potential for conflict is greatest.

At the catchment scale, the potential for positive impacts to agricultural land by beaver activity is most likely through flood attenuation, slowing the flow, and baseflow maintenance. However, those benefitting from beaver activity may not be the same as those who bear the cost, and such an imbalance has the potential to cause further conflict. A range of variables must therefore be considered collectively for any reintroduction project. Analysis using mapping software could pinpoint key areas where conflict is most likely to occur.

### Infrastructure and general land use

Various infrastructure types and networks have a high likelihood of being affected by beaver activity where they lie on floodplains. Whether this is positive or negative and the scale and significance of these resulting effects will vary according to local circumstances and over space and time.

The presence of beavers may benefit some infrastructure network and assets, such as wetland designations, drinking water storage assets and flood mitigation. A clear plan is recommended, based on appropriate criteria, to zone vulnerable infrastructure and identify responsibilities for managing beaver activity.

Any assessment of beaver activity, or interventions considered necessary should be carried out in the context of wider existing legal and policy frameworks. This includes policy and legislation that seeks to enhance natural processes and make space for water. These considerations are likely to reduce the risk and likelihood of beaver activity having a negative effect on infrastructure networks and assets.

### Public and animal health

Detailed research has been undertaken since the Scottish Review to understand the risks posed to human and animal health from beaver translocations and reintroductions. Disease risk analyses for beavers have identified potential hazards that need to be considered for any reintroduction programme. The most important for people is the tapeworm *Echinococcus multilocularis*. This and other risks can be effectively managed, so overall, if beaver reintroductions take appropriate measures, beavers are not considered to pose any increased risk to public health beyond that posed by existing native wildlife populations.

The risk of introducing significant parasites or infectious agents of humans, domestic animals or other wildlife is low if beavers used in reintroduction projects are taken from wild-living populations in Great Britain. If reintroduction projects plan to (i) source beavers from zoological or private collections, (ii) house them temporarily in zoological-type or private collections (unless housed in bio-secure facilities designed for beaver translocations), (iii) if it is proposed to release beavers held in enclosures into the wild, or (iv) release beavers from wild populations sourced outside of Great Britain, then further disease risk analysis is required. Pending this additional analysis it is recommended that beavers sourced from enclosures are only moved to other enclosures within Great Britain.

Any beavers of unknown origin in Great Britain could carry non-native diseases and parasites, though it should be noted that no cases of significant disease/parasite transmission have been recorded in Great Britain. Detailed post-mortem examinations are therefore recommended of any beavers found dead in enclosures or free-living in the wild. Efforts should also be made to use retrospective sample archives to build our understanding of potential hazards.

# Overall conclusions

The beaver is a suitable candidate for further reintroductions within England based on the evidence presented in this report. Restoring beavers to England can generate a range of costs and benefits for the environment, people and the economy, which will vary between locations. If managed appropriately, the quantifiable benefits of beaver reintroduction in relation to natural capital and societal benefits could be much greater than the financial costs incurred. Societal challenges stem from conflicts over land use and the perceived risks to salmonid and other migratory fish populations. Localised adverse effects of beavers on contemporary land use need to be recognised and practical solutions to their management identified and implemented to mitigate, as far as possible, any negative effects.

Ensuring river and lake systems have space to react to the dynamic habitat changes brought about by beaver will be crucial in maximising ecological benefits and will reduce risks to existing biodiversity and socioeconomic objectives. Beaver activity is not a substitute for tackling impacts on catchments (such as pollution, over-abstraction, and artificially exacerbated flood risk) at source, but can enhance water-related ecosystem services, especially where suitable measures have already been taken to restore natural ecosystem function to the headwater areas of catchments.

Continued research and monitoring are needed on a prioritised and long-term basis on the interactions between beavers and species, habitats and socio-economic factors. Due to the individuality of the English landscape, to obtain the most relevant results, research will need to be undertaken in conjunction with future beaver reintroductions. It is therefore recommended that, in the short-medium term, any further reintroductions should include carefully managed studies of beavers in differing landscapes. The influences of beavers need to be considered in the longer term, but interim results can be used in conjunction with research elsewhere, particularly in relation to natural controls on beaver populations, to inform sustainable management decisions where applicable.

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# 1 Introduction

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## 1.1 A history of beavers in Europe

Eurasian beavers (*Castor fiber L.)* are semi-aquatic rodents and a formerly native species in England. They are widely regarded as ecosystem engineers because they can greatly modify the physical environment around them. After the last ice-age beavers occurred throughout Europe, including Great Britain. However, they were widely exploited for fur and other products and driven to near extinction in Continental Europe. By the early 20th century only five isolated populations remained in Europe; in France, Germany, Norway, Belarus and Russia, totalling about 1,200 animals (Halley *et al*. 2012). They probably disappeared from Great Britain between the 12th to 16th Centuries (Manning *et al.* 2014; Raye 2015).

Beaver numbers have now, however, recovered throughout much of their former range in Europe through protective regimes, hunting regulation, active reintroductions and natural recolonisation. Recent reviews of national population studies estimate that the Eurasian beaver population in Europe now numbers between a minimum of 1.2 million individuals (Wróbel 2020) and 1.5 million individuals (Halley *et al.* 2020).

## 1.2 Current status of beavers in Great Britain

In Scotland an official trial reintroduction of beavers took place in Knapdale forest, mid-Argyll in 2009 (the Scottish Beaver Trial). It later became apparent that a larger number of beavers were in a wild state, not least through unauthorised releases in parts of the Tay and Earn catchments (referred to as Tayside) in Perthshire. Confirmed reports of their presence date from around 2006. The largest beaver population in Scotland now occurs on Tayside (n = 433 beavers; range 319 – 547, Campbell-Palmer *et al.* 2018).

No official reintroductions have taken place in Wales at the time of writing, although there are reports of beavers living wild on the Rivers Wye and Dyfi (Heydon *et al*. In press). A feasibility study on beaver reintroduction to Wales was published in 2009 (Halley *et al.* 2009). No records exist of beaver ever being present in Ireland.

In England, a population of breeding beavers became public knowledge on the River Otter in East Devon in 2013. The origin and numbers of these animals was, and remains, unknown. They may have escaped from a nearby captive population or they may have been illegally released. As the release was not authorised - and the origin of the beavers not known - there was a risk of introducing certain other species, notably parasites of beavers and other animals, into Great Britain. Whilst the initial response of the Department of Environment, Food and Rural Affairs (Defra) was to call for the removal of the beavers, a campaign by local residents, conservation and land management organisations and wildlife enthusiasts to retain the beavers on the River Otter was successful and a beaver reintroduction trial was agreed. The River Otter Beaver Trial (ROBT) project management group was set up to oversee and undertake all aspects of the ROBT. Ministers agreed to permit a formal licensed 'beaver reintroduction trial' and in 2015 Devon Wildlife Trust (DWT), on behalf of the ROBT partners, was granted a five-year licence by Natural England to introduce and study Eurasian beavers within the River Otter catchment in East Devon. The licence legitimised the presence of the beavers, enabling the first authorised trial of a beaver reintroduction in England. In August 2020, following completion of the trial, Ministers came to a decision to allow beavers on the River Otter to remain there permanently and continue to expand their range naturally[1].

There are also several locations in England where small unofficial populations of beavers are living in the wild, as well as populations within fenced enclosures (Figure 1). Beavers are also present in at least two zoo collections.

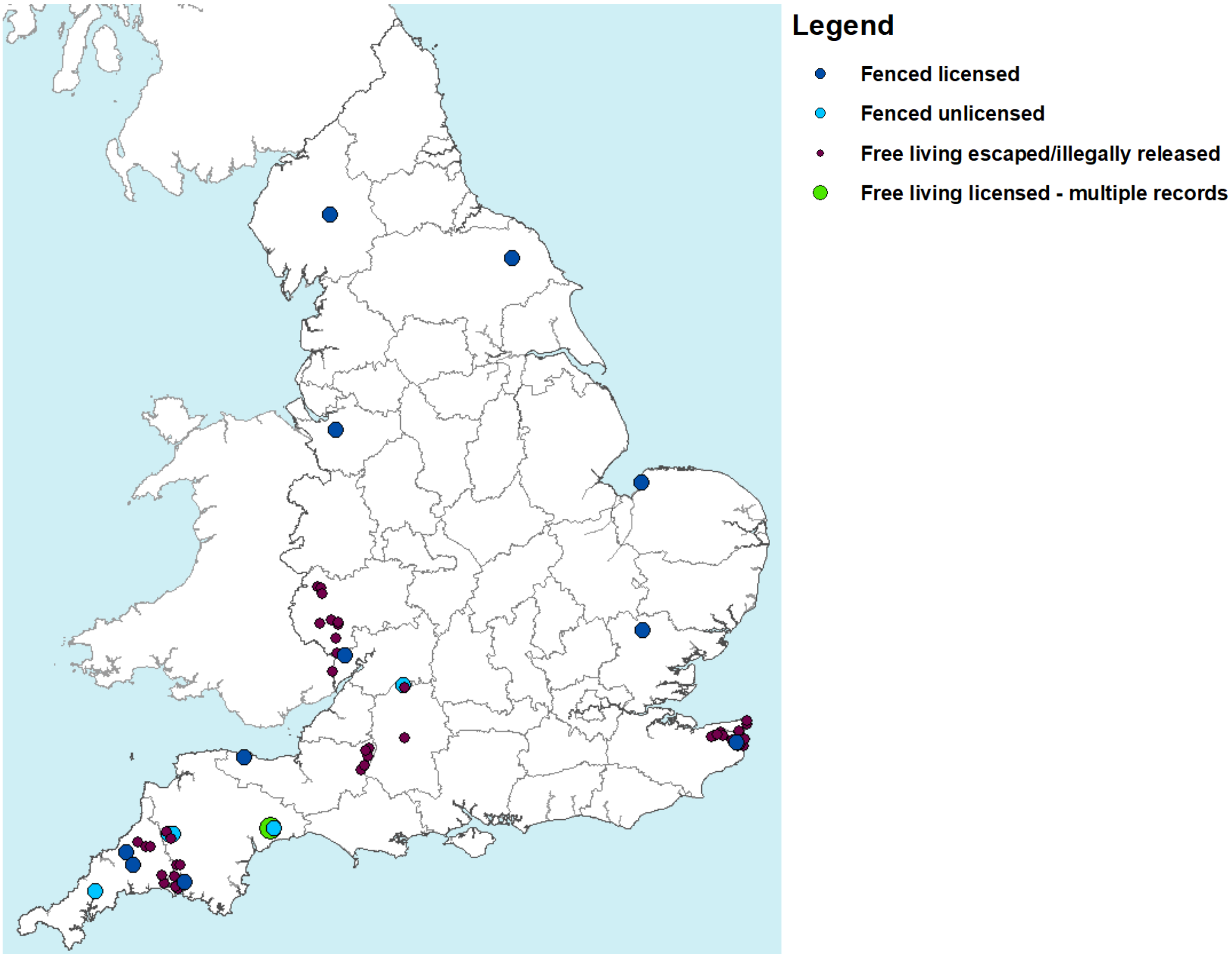


**Figure 1** Reported locations of free-living beavers (since 2015) and locations where beavers are held within fenced outdoor enclosures in England (data up to November 2020).

[1] https://www.gov.uk/government/news/five-year-beaver-reintroduction-trial-successfully-completed [accessed 11/06/2021]

The Red List status[2] of the Eurasian beaver globally is 'Least Concern' (Batbold *et al*. 2016). A Red List assessment was recently undertaken for mammal species in Great Britain (Mathews and Harrower 2020). The status of the established populations of Eurasian beaver in Scotland and England resulted in an 'Endangered' assessment in Great Britain overall. In England the status of beavers is categorised as 'Critically Endangered' and in Scotland they are categorised as 'Endangered'. In Wales they are classified as 'Not Assessed' as there are no known established populations in the wild. The Red List assessment process is designed to assess the status of established populations, so the results should be interpreted with care and reflect the limited distribution of beavers in England and Scotland rather than current threats to the reintroduced populations. The 'Critically Endangered' categorisation in England is due to the fact that beavers have only been very recently reintroduced on the River Otter in Devon and form a very small and restricted population with no possibility of immigration from neighbouring counties. A second population is present in Devon (on a different river catchment) and also in Kent, though little information is available from these sites (Heydon *et al*. In press).

## 1.3 Why reintroduce beavers?

The International Union for the Conservation of Nature (IUCN) defines a reintroduction as 'an attempt to establish a species in an area which was once part of its historical range, but from which it has been extirpated or become extinct' (IUCN/SSC 1998).

Reintroductions and conservation translocations are the deliberate movement and release of plants, animals or fungi into the wild for conservation purposes. It is a technique used to provide a conservation benefit by increasing the abundance of a species or the number of places where it occurs. It can help reverse the effects of biodiversity declines caused by habitat loss, climate change, or other human influences on the environment. There is widespread interest in species reintroduction, particularly beaver, following their disappearance from Great Britain. Beavers, as a keystone species, have the potential to significantly affect the natural landscape, which may have profound consequences for the ecosystem and landscape in the release area. A review of multiple scientific studies found that beavers overall had a positive effect on biodiversity (Stringer and Gaywood 2016). However, all reintroductions and translocations carry some level of risk of changes to the natural environment, on other land-uses or to people, and the benefits and risks of species reintroduction need to be carefully considered.

There is a legal requirement under the Habitats Directive[3] to study the desirability of re-introducing species in Annex IV (of which the beaver is included) 'that are native to their territory where this might contribute to their conservation, provided that an investigation, also taking into account experience in other Member States or elsewhere, has established that such reintroduction contributes effectively to re-establishing these species at a favourable

[2] The Red List is compiled by the IUCN and is a critical indicator of the health of the world's biodiversity. It provides information about range, population size, habitat and ecology, use and/or trade, threats, and conservation actions that will help inform necessary conservation decisions; https://www.iucnredlist.org/about/background-history

[3] https://ec.europa.eu/environment/nature/legislation/habitatsdirective/index_en.htm [accessed 11/06/2021]

conservation status and that it takes place only after proper consultation of the public concerned'.

The need for conservation action for the species also needs to be considered (principle one of the (draft) Defra Code for Reintroductions and Conservation Translocations Defra. In Prep). As the beaver is assessed as 'Least Concern' globally (Batbold *et al*. 2016), reintroduction into Great Britain is not necessary for the security of the global population. However, any further reintroductions would help expand the range to part of its former distribution, and one that it can only recolonise with human intervention because of geographical barriers to natural dispersal.

Finally, the Government's document 'A Green Future: Our 25 Year Plan to Improve the Environment'[4] sets out a series of actions to be taken by the Government to help create a healthier and richer natural environment, within which the reintroduction of beavers is specifically mentioned. This includes a commitment to provide opportunities for species recovery and reintroduction of native species whilst making sure 'proposals provide clear economic or social benefit and are alive to any risk to public, the environment or to business'. Beavers can also provide important ecosystem services such as water purification, moderation of extreme events, habitat and biodiversity provision, nutrient cycling, greenhouse gas sequestration, recreational hunting and fishing, water supply, and non-consumptive recreation (Thompson *et al*. 2020). Therefore, there is a need to consider the further reintroduction of beavers in England.

How the reintroduction of a lost keystone species like the beaver is perceived is highly dependent on the reference point used from which to measure the effects from. The English countryside, riparian zones and connectivity of watercourses have changed drastically since beavers died out and the role of the beaver in English landscapes has been lost from the collective memory so does not form part of our contemporary understanding of the natural environment. Beavers have the potential to dramatically transform landscapes, however, there is also potential for them to come into conflict with other land and river users as existing landscapes are altered. Furthermore, the consequences of some of the possible interactions are difficult or complex to envisage, such as between beavers and intensively farmed agricultural land, as agricultural systems were different when beavers were present in England in the past. It is therefore important to consider how the reintroduction of beavers may influence the current natural and human environment in England.

## 1.4 Purpose and scope of the review

The purpose of this review is to inform decisions regarding any further reintroductions of beavers in England. It does this by reviewing the available evidence on the interactions of beavers with the natural and human environment, relevant to England, in consideration with the IUCN guidelines (IUCN/SSC 2013). This review builds, indirectly, on the information contained within Gurnell *et al.* (2009) 'The feasibility and acceptability of reintroducing the

[4] The publication of a Code and Good Practice Guidance is a commitment of the Government's 'A Green Future: Our 25 Year Plan to Improve the Environment' https://www.gov.uk/government/publications/25-year-environment-plan [accessed 11/06/2021]. Beavers are specifically mentioned on pages 21, 57 and 61.

European beaver to England'. Since this review there have been two significant trial reintroductions of beavers in Britian (one at Knapdale in Argyll, Scotland and one on the River Otter, Devon) as well as opportunities to learn from the large, unauthorised population on the River Tay, in Perthshire, Scotland. This review does not cover, in detail, options for management of beavers following a reintroduction, but does mention certain approaches that can be considered where relevant. A separate document, 'Advice and recommendations for beaver reintroduction, management and licensing in England', covers this in more detail.

This review focuses on new evidence available since the publication of the extensive review carried out by Scottish Natural Heritage in their Beavers in Scotland: A Report to the Scottish Government report published in 2015 (Gaywood 2015 and associated reports and papers) (hereafter known as the 'Scottish Review') and on any issues that are particularly relevant to England in order to highlight considerations to be taken into account when considering further beaver reintroductions in England.

The core of the report is divided into sections, the first of which considers the ecology of the beaver, followed by sections which consider the significant influences beavers have on their environments. Each section provides a brief explanation of issues that are particularly relevant to England, a summary of the findings of the Scottish Review and a review of information published since 2015 or additions to that presented in that report. Areas of uncertainty requiring further research have also been identified and are included in the priorities for future research section.

There are two different species of beaver, the Eurasian beaver (*Castor fiber)* and the North American or Canadian beaver (*C. canadensis*). We draw on relevant studies on both species though it can be presumed reference is to *C. fiber* unless otherwise specified.

# 2 Methods

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This review broadly follows the Quick Scoping Review (QSR) protocol approach outlined in Collins *et al.* (2015). A review of the evidence available since 2015, the publication date of the Scottish Review, has been undertaken. The Scottish Review is accepted as being a thorough review of all literature prior to 2015 relevant to the questions posed for this review, such that it was not considered necessary to review that information again unless it was deemed to be of specific importance or relevance to the English situation.

## 2.1 The Review Questions

The following 20 questions are the focus of the review:

1. What are the important aspects of beaver ecology and biology in relation to reintroductions?

### Biological feasibility – interactions with the natural environment

What are the effects of beavers on:

2. Running water habitats?
3. The overall biodiversity, water level and chemistry of standing water habitats and associated wetlands?
4. The biodiversity of woodlands?
5. Freshwater fish assemblages, their habitats and movement within freshwater habitats?
6. The biodiversity of bryophytes in potential beaver habitat?
7. The biodiversity of fungi and lichens in potential beaver habitat?
8. The biodiversity of vascular plants?
9. The biodiversity of invertebrates?
10. The biodiversity of amphibians and reptiles?
11. The biodiversity of birds?
12. The biodiversity of mammals?

### Social feasibility – interactions with the human environment

13. What are the public attitude and perceptions towards a potential beaver reintroduction?
14. What are the discernible economic benefits and costs associated with a reintroduction of beavers to England?
15. How may beavers affect human-orientated water management issues?
16. What are the effects of beavers on freshwater fisheries?
17. What are the potential effects of beavers on commercial forests?
18. What are the effects of beavers on agricultural land?

19. What are the potential impacts of beavers on infrastructure and general land use?
20. What are the potential impacts of beavers on public and animal health?

The review summarises and evaluates the evidence base in relation to these review questions.

## 2.2 Search terms and strategy

To access the available literature, systematic searches were conducted of both Scopus and CAB Direct in February 2020. The searches were divided into categories based on the interaction of beavers with certain habitats, species or the human environment as these were considered to be the key areas of interest (see Appendix I for the full list of topics, questions and search terms used). Exclusion criteria were that the paper was in the English language and dated from 2015 to present (since the publication of the Scottish Review).

To make sure the dataset was comprehensive relevant references were also identified through online searches and a request was made to stakeholders and partners known to have undertaken research or studies relevant to the review for access to any relevant published or grey literature from the start of 2015 to present. Thirty-three people from 18 organisations were contacted. Responses were received from 14, of which eight were nil returns (a list of those contacted and of those who responded is available in a separate appendix).

The search returned 1293 results. Removal of duplicates resulted in 989 papers. From screening of titles 139 papers were found to be relevant (Table 1).

**Table 1** Number of references included in each stage of the review

| Review stage | Number of references |
|---|---|
| References captured using search terms in all sources (including duplicates) | 1293 |
| References remaining after de-duplication and title and abstract filters | 989 |
| References submitted by stakeholders and others | 13 |
| References of relevance to the review | 139 |

To ensure all relevant publications were included, relevant theses, papers and reports that were cited in the papers from the initial search were also collected, some of which were dated prior to 2015. Although the literature search excluded papers published before 2015, papers considered to be particularly relevant or important in setting the context, have been referred to in this review. Papers of particular relevance since the literature search was carried out in February 2020, and that were discovered or drawn to the attention of the authors, have also been included.

## 2.3 Presentation of results

A summary statement of evidence is provided at the beginning of each section under biological and social feasibility, reflecting the content and strength of evidence within each section. Appendix II describes how the evidence was evaluated (from DFID 2014). All sections under biological and social feasibility, excluding economic benefits and costs, follow the structure below:

- Title
- Summary of main findings and recommendations
- Introduction
- A summary of findings from the Scottish Review
- Further research since the Scottish Review
- English context
- Identification of areas of potential conflict in England
- Potential future implications of wider reintroductions in England

Appendix III includes a summary of potential interactions between beavers and biological and social factors that are additional to findings in the Scottish Review.

# 3 What are the important aspects of beaver ecology and biology in relation to reintroductions in England?

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## 3.1 Summary

The majority of Water Environment (Water Framework Directive) (England and Wales) Regulations 2017 (hereafter referred to as Water Environment Regulations) water body catchments in England have suitable habitat and connected habitat to support a colony of beavers. Beavers are highly mobile within riparian/freshwater habitats and will colonise throughout a watershed if habitat is suitable.

Population density of beavers will vary in relation to climate, vegetation type, habitat quality, hydrogeomorphology and population dynamics. Generally, growth rates are initially slow in newly established beaver populations, increasing as individuals find suitable territories, form pair bonds and produce enough offspring to enable dispersers to form pairs and establish on their own. The length of time required for rapid population expansion varies depending on the characteristics of the river system.

Evidence from Europe demonstrates beavers can be successfully reintroduced into areas of their former native range. However, as there can be no natural colonisation or subsequent mixing with beaver populations outside of Great Britain, the selection of founding individuals for a reintroduced beaver population in England requires careful consideration. Selecting founder stock that maximises genetic diversity and adaptive potential above achieving close phylogenetic relatedness to the historical British population, is likely to be the most appropriate path to follow given the current information (Marr *et al.* 2018).

The current wild populations of beaver in Great Britain all appear to be suitably adapted to living in the British countryside. There is no evidence that these beavers are failing to adapt to the British environment or experiencing compromised welfare. Populations in Tayside, Scotland and Devon, England are displaying evidence of growth and increased distribution, indicating that the species can thrive in Great Britain.

## 3.2 Potential beaver habitat

### 3.2.1 Habitat requirements

Eurasian beavers are large rodents with features specialised for living in semi-aquatic environments. Their activity is largely restricted to freshwater and associated riparian habitats (ponds, streams, rivers, marshes and lakes), particularly where broadleaved woodland is present. Although, in climates that don't experience prolonged winters, they can readily colonise riparian areas without expansive woodlands. Habitat suitability declines strongly further away from river banks (Swinnen *et al.* 2017). While they will move through salt and brackish water, they must have access to fresh drinking water daily. Beavers are generally slow and cumbersome when walking on land and prefer to move through water which requires less energy expenditure, allows them to transport larger food items and provides protection from predators. They are highly adaptable and can modify many types of natural, cultivated and artificial habitats, but their favoured habitat is still or slow-moving water with stable depths of at least 60 cm (Gurnell *et al.* 2009). Where these habitats are unavailable or already occupied by other beavers, they will colonise narrower watercourses and usually construct dams typically made from tree stems, branches, sticks and mud (Figure 2). Dams retain and manage water levels in order to provide beavers with an aquatic refuge; increase their range of access; ensure lodge/burrow entrances remain submerged; reduce water level fluctuations; provide food supplies; and/or ease the transport of building materials. Beaver dams are typically built on watercourses/bodies < 6 m wide and < 0.7 m deep and of less than 2.5-3% gradient (Hartman and Törnlöv 2006). Dams will vary in size, structure and longevity depending on purpose, environmental setting, channel geometry, age and hydrological regime.

**Figure 2** Beavers will create dams in order to retain and manage water levels



Beavers create shelters as underground burrows or in lodges above ground made of branches, sticks and mud (or a combination of both). The entrances to burrows and lodges are normally underwater. Where the river banks of a watercourse allow the excavation of large burrows, large lodge structures may be less likely, though digging below the surface increases. Burrows can be reroofed with sticks and mud where sections collapse.

Beavers are generalist herbivores and consume bark, shoots and leaves of mainly broadleaved woody plants, as well as herbaceous and aquatic vegetation. They show preferences for certain species such as willow (*Salix* spp.), aspen (*Populus tremula*), poplar (*Populus* spp.), and rowan (*Sorbus aucuparia*), but can adjust food choices based on availability (Northcott 1971; Histøl 1989). They will also fell species for dam construction. During spring and summer 25-90% of their diet is comprised of herbaceous terrestrial, semi–emergent and aquatic species of plants (Nolet *et al.* 1995; Krojerová-Prokešová *et al.* 2010). Beavers can fell quite large trees (more than 1 m in diameter), but they tend to favour smaller saplings (less than 5 cm diameter) to obtain bark, side branches and leafy stems (Haarberg and Rosell 2006) (Figure 3). They are central place foragers, in that they move out from water to select and cut trees and vegetation, and transport it back to the water to eat, or to their lodge to feed dependant offspring, or to store for later use. Therefore, foraging intensity declines with increasing distance from the river, although the targeted felling of preferred tree species can occur within a wider foraging range. In Denmark 95% of beaver-cut stems were within 5 m of water (Elmeros *et al.* 2003); in Norway 70% of cut stems were within 10 m and 90% within 20 m (Haarberg and Rosell 2006); in Russia 90% of cut stems were within 13 m of water and 99% within 20 m (Baskin and Sjöberg 2003); and in Scotland most foraging activity on trees occurred within 10 m from the waters edge (Iason *et al.* 2014). In developed landscapes they readily exploit any palatable vegetation in close proximity to water bodies such as amenity banks, grass verges, grazing pastures or agricultural crops if preferred habitats are unavailable (R Campbell-Palmer pers comm).

**Figure 3** Although beavers favour smaller saplings, they are also capable of felling larger trees

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Beavers do not hibernate, but they do reduce their activity over winter. In Great Britain the mild climate allows beavers to feed through the winter instead of relying on stored food caches. Their diet at this time tends to consist predominantly of tree bark and twigs (R Campbell-Palmer pers comm).

### 3.2.2 Habitat Selection

A literature review of 12 major studies of beaver habitat in North America, found that the dominant habitat factors affecting beaver occurrence or abundance were identified as: stream gradient; watershed size; and the presence of riparian hardwoods adjacent to watercourses - broadleaved trees such as oak (*Quercus* spp.), ash (*Fraxinus excelsior*), American mountain ash (*Sorbus americana)*, or beech *(Fagus* spp.) (Touihri *et al.* 2018). Other reviews assessing habitat quality of beaver release sites found that water depth, river width, bank composition, as well as height, slope gradient, and riparian vegetation cover were the most important criteria (Macdonald *et al.* 1995; Macdonald *et al.* 2000). Gurnell *et al.* (2009) found in general there were four broad characteristics of prime beaver habitat: i) easy access to grasses, forbs and riparian tree species; ii) low-flow water depth, at least near lodge and burrow sites of more than 0.6 m; iii) river channel gradients <0.15 and preferably <0.06, and iv) soft or finer calibre bed and bank materials. The gradient and composition of banks influences burrow and lodge construction, but may also limit the suitability of a site for territory selection (Dieter and McCabe 1989). Beavers tend not to be found in watercourse gradients >15%, with optimum gradients usually placed around 3% (Hodgdon and Hunt 1966). High stream gradient (>10%) will hinder colonisation and increase dam washouts. Low gradient may cause increased management conflicts, especially with agriculture (Allen 1982; Beier and Barrett 1987; Cotton 1990; Jakes *et al.* 2007; Suzuki and McComb 1998).

As a generalist species, beaver can exploit many different habitat types and while it is important to be aware of preferred habitats, potential habitats also need to be noted, because beavers can persist outside their ideal habitats (Hartman 1996). For example, beavers tend to avoid landscapes dominated by coniferous and mixed pine-hardwood habitats but will utilise these areas under higher population densities (Hartman 1996). The suitability of an area for beaver is also affected by how long beavers have been present, and their population size (Barela *et al*. 2020). Studies of habitat selection in high density populations do not necessarily provide accurate information on general beaver habitat preference. Rather, they provide insights into the full range of potential habitats beavers may utilise, as well as habitats which are unusable for long-term occupation (Hartman 1996; Vorel *et al.* 2015).

A beaver habitat model describing topographical and hydrological characteristics and using a scoring system of zero to five was used to assess existing habitat for the species across England, focussing on terrestrial habitat where foraging primarily occurs (Graham *et al.* 2019; Graham *et al.* 2020). Scores of five represent vegetation that is highly suitable or preferred by beavers and that also lies within 100 m[5] of a waterbody. Zero scores are given to waterbodies, areas that contain no vegetation or are greater than 100 m from a waterbody (Table 2).

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[5] Most literature cites 50 m as maximum foraging range of beaver (i.e. Stringer *et al*. 2018) however, to incorporate uncertainty, site development (i.e. beavers damming or canal building allowing them to extend their foraging range) and due to reports of further foraging Graham *et al.* 2019 adopted 100 m as in Macfarlane *et al.* (2017).

**Table 2** Area in England of different habitat characteristics for beaver (derived from Graham *et al.* 2019)

| Beaver Habitat Index | Description | Area km² |
|---|---|---|
| **0** | Waterbodies, areas with no vegetation, or areas greater than 100 m from a waterbody | NA |
| **1** | Not suitable – for example heather, acid grassland, unimproved grass and boulders, bog | 19,532 |
| **2** | Barely suitable – for example reeds, shrub and heathland and boulders, neutral grassland | 17,599 |
| **3** | Moderately suitable – for example coniferous woodland, marsh, shrub and unimproved grassland | 4,644 |
| **4** | Suitable – for example shrub and marsh | 1,680 |
| **5** | Highly suitable – for example broad-leaf woodland, mixed woodland and shrub | 6,938 |

Graham *et al*. (2020) found that, for some current British beaver populations, reaches within category 5 have far greater probability of containing signs of beaver activity. Reaches in categories 3 and 4 may still support beaver but are less preferred and have a similar probability of containing signs of beaver activity. Categories 3 and 4 are slightly more likely to be active than those in category 2.

There is currently approximately 13,000 km² of suitable habitat in England from categories three, four and five (Table 2). This is probably the maximum potential habitat area as local factors will restrict access to water/vegetation. Human infrastructure, for example culverted/constrained sections, walls and fences may render some areas of habitat unsuitable. Similarly flow conditions in some of the watercourses may be unsuitable for beavers.

An analysis by Natural England (derived from Graham *et al.* 2019) shows that 72.5% of the 4,081 Water Environment Regulations water body catchments in England have suitable habitat within categories 3-5 and sufficient connected habitat to support a colony[6] (Figure 4). The total area of suitable habitat in England is 4,922 km$^2$. The proportion of suitable habitat varies between catchments meaning that, if beaver expanded to occupy the whole of England, population densities will inevitably vary between catchments. It is also worth noting that, as beavers can alter habitat to make it more suitable for their needs, they will be able to create more suitable habitat over time, should they be allowed to persist in sub-optimal catchments.

[6] Sufficient habitat is considered to be 300,000 m$^2$ which equates to a 3 km shore length with a 100 m buffer inland

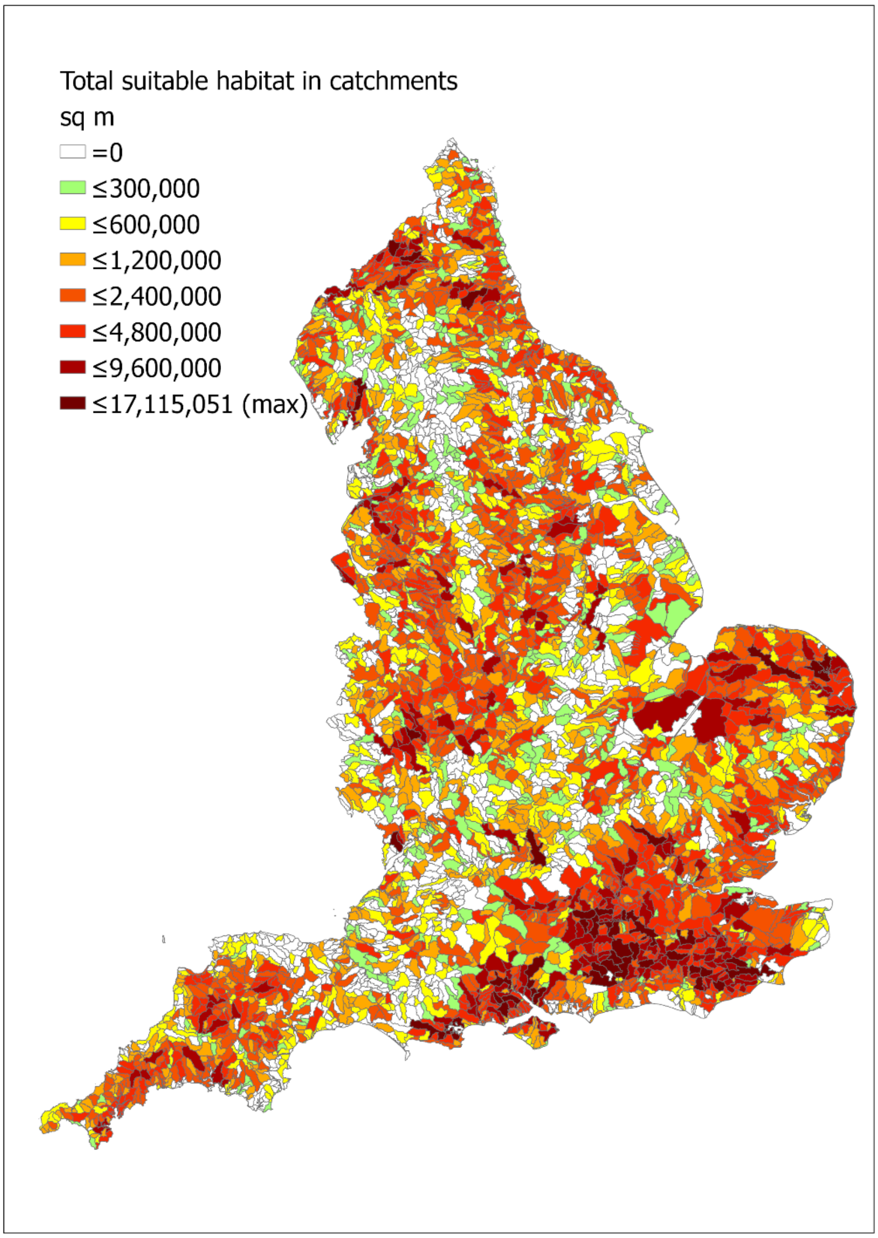


**Figure 4** Water Environment Regulations Water Body Catchments Cycle 2 with beaver habitat index categories 3-5. Each area of suitable habitat is ≥300,000 m$^2$ and may extend between multiple catchments (Natural England, unpublished)

## 3.3 Population dynamics

### 3.3.1 Social and ranging behaviour

Beavers live in family groups typically comprising an adult breeding pair with their offspring from the current and previous years litter. Only the adult male and female breed within the family group. Once paired, beavers tend to remain together until one of them is either displaced by another individual of the same sex or dies. The adult male and other family members all help to rear any kits. Dispersal age of juveniles varies according to age of parents and population density (Mayer *et al*. 2017a), but it is generally around two to three years old (Hartman 1997; Mayer *et al*. 2017c). During dispersal they are capable of travelling long distances along water bodies (average 4.5 km to 5.9 km; McNew and Woolfe 2005; DeStefano *et al*. 2005) and may undertake short trips over land in order to search for their own territories (Mayer *et al*. 2017b).

Population density of beavers will vary in relation to climate, vegetation type, habitat quality, hydrogeomorphology system and population dynamics. This explains the wide range of territory densities reported in the literature, from 0.08 to 0.57 territories per km river length or 2 km riverbank (for a comprehensive summary see Gurnell *et al.* 2009 and Zwolicki *et al.* 2019).

Beavers are very territorial and actively defend their territories largely through chemical communication and aggression. Beaver territories tend to be linear, but the size and number of territories is dynamic and will reflect a number of factors including: the density of beaver populations; habitat quality and quantity; habitat type (stream, larger river lake, or pond); the number of family members; social factors (sex and age); time of year (season); and their settlement pattern (Campbell *et al.* 2005). Although the average size of a beaver territory is approximately 3 km of shore length, this can range from 0.5 to 25 km (Macdonald *et al.* 1995; Herr and Rosell 2004; Campbell *et al.* 2005; Parker and Rønning 2007). Beavers only actively influence part of the banks of their territories (Štofík and Bartušová 2020) which may comprise several blocks of suitable habitat interspersed with stretches of less suitable river banks such as meadows (Swinnen *et al.* 2017). Given that beavers invest in their territory and defend it, it makes sense that territory size is relatively small as the energetic costs to defend a large territory would be prohibitive (Mayer *et al.* 2017a).

Brazier *et al*. (2020) estimated the ecological carrying capacity[7], in number of territories, of the River Otter catchment based upon habitat suitability and ecological requirements of beavers. This territory capacity model predicted the catchment could host between 147 and 179 territories. It is noted, however, that the observed capacity would be expected to be considerably lower as beavers are unlikely to conform to the modelled arrangement of territories, humans and beavers themselves would likely manage numbers and the model assumes that animals cannot exit the catchment. This model does not predict the *likely* beaver capacity, as this requires a more detailed understanding of resource use and population dynamics.

### 3.3.2 Population Establishment

Population growth depends on many factors and varies greatly between sites studied and over time. In general, growth rates in newly established beaver populations are initially slow, due to sparsely distributed individuals (mainly sub adults) with low probability for mating. As individuals find suitable territories, form pair bonds and produce enough offspring to enable dispersers to form pairs and establish on their own territories, growth rates increase. In release projects, if large (~40+) numbers of animals are released, migrating offspring will meet each other sooner and therefore population growth will be higher (Macdonald *et al*. 1995). As dispersers may travel dozens of kilometres from their family territories, the process of population establishment creates a ‘patchwork’ pattern of beaver territories, particularly in

[7] Ecological carrying capacity is the level of production that does not impact undesirably on the surrounding ecosystem(s) (Tett *et al*. 2015).

heterogeneous habitats (Barták *et al.* 2013). A general finding across Europe is that beavers first increase in habitat range before increasing in population (Halley and Rosell 2002). The length of time required for rapid population expansion varies depending on the characteristics of the river system and may take 15 to 20 years on larger river systems (Hartman 1995). When partners are found and new territories are established, the population will accelerate rapidly (Hartman 1994; Halley and Rosell 2002). Thereafter, beaver populations exhibit a classic 'irruptive' pattern, with a slowdown in population increase after the rapid expansion phase; occupation of marginal habitat not capable of sustaining beavers permanently; and a consequent decline in population as the 'capital' of these marginal areas are depleted (Hartman 1994; Busher and Lyons 1999; Halley and Rosell 2002; Petrosyan *et al.* 2016).

The highly territorial behaviour of beaver families can exert a regulatory effect on beaver populations and influence population growth rates, depending on the stage of population growth. In established populations growth will decrease over time as population size approaches the limit imposed by the resources in the environment. Beavers will therefore establish stable colonies at ecological carrying capacity with populations in a dynamic equilibrium if left undisturbed. Factors such as mortality, migration connected to reintroduction, predation, or a lack of partners can limit population increase. Over-browsing by beavers of deciduous trees and bushes for food and building material, followed by territory abandonment, seems to experience a time-lag due to the ensuing regeneration time for deciduous food sources in colder climates (Hartman 1994; Fryxell 2001; Petrosyan *et al.* 2016). This is the most common explanation to population irruptions (Hartman 2003).

A state of dynamic equilibrium in beaver populations in Russia following natural dispersal was reached between 14 to 26 years (Petrosyan *et al.* 2013). The populations of two reintroduced populations in Sweden started to decline after 34 and 25 years (Hartman 1994), with a similar pattern of population development observed in North America (Johnston and Naiman 1990; Fryxell 2001). A study in the Loire Valley in France showed that the number of occupied sites reached a peak and stabilised after 25 years (Fustec *et al.* 2001). Since the reintroduction of beavers in Flanders, North Belgium, 12 years ago, the beaver population has grown continuously, and currently, around 120 territories are occupied in an area of 13,522 $km^2$ (at time of publication, Swinnen *et al.* 2017). Twelve years after the reintroduction, there continues to be a large expansion potential, both in range and in densities within the recolonised area (Swinnen *et al.* 2017).

Šimůnková and Vorel (2015) found that beavers established dense populations faster in smaller catchments than larger catchments in Germany and the Czech Republic. Therefore, the growth of the populations was not similar among differentially sized catchments. They also concluded that the growth was probably based on factors other than habitat quality, such as size of catchment, progress of colonisation front and topography, given the variation they found in their results. Populations that were established in the 1940s in Poland increased at mean annual rates of 0-15% between 1980 and 1988 (Żurowski and Kasperczyk 1988). In Norway it increased with 5-6% annually between 1880 and 1965 (Myrberget 1967), and in Elbe, Germany, there was a 7% annual increase between 1948 and 1981 (Heidecke 1977).

In many of these regions, natural predators (such as wolves) are absent from the landscape, subsequently that important constraint on beaver populations cannot be studied. With a lack of natural predators or human control, an expanding population could exploit food supply beyond the landscape carrying capacity and subsequently decline in numbers (Larsen *et al*. Submitted).

### 3.3.3 Colonisation of habitat

Beavers are highly mobile within riparian/freshwater habitats. They tend to colonise suitable habitat in a linear manner (i.e. dispersal generally follows water courses) though they can travel over land between catchment basins (Halley *et al.* 2012; Šimůnková and Vorel 2015). In general, it is assumed that when beavers are present within a watershed they will colonise throughout if habitat is suitable (Halley and Rosell 2002), but human made/artificial obstacles or habitat fragmentation may cause a barrier effect (Halley *et al.* 2012; Barták *et al.* 2013). Dispersal distances for individuals can range from a few kilometres to tens of kilometres depending on a range of factors, including population density and habitat availability (Żurowski and Kasperczyk 1990; Fustec *et al.* 2001). It is estimated that ~80% of dispersing beavers attempt to establish territories within 5 km of their natal territory (Nolet and Baveco 1996; Saveljev *et al.* 2002), though much greater distances (80 km+) have been recorded.

Dispersing beavers can occupy distant areas earlier than those closer to the previously occupied sites (Hartman 1995; Fustec *et al.* 2001). This indicates they behave as specialists in the beginning of the colonisation process to seek out optimal habitats, but may become more generalists as the population expands and they are forced to occupy less attractive territories (Nolet and Rosell 1994; Hartman 1995; Fustec *et al.* 2001). The selection of preferred habitat variables has effectively been demonstrated to vary according to stage of colonisation; initial = unpredictable occupation of random sites, intermediate = predictable occupation of optimal sites, long-term = unpredictable occupation of sub-optimal locations (John *et al.* 2010).

In the Netherlands, where beavers were introduced into unoccupied habitat, it was found that animals released first still had the largest and best territories (in terms of plentiful food supplies) after five years. Those that were released later had smaller, poorer territories (less food) (Nolet and Rosell 1994; Campbell *et al.* 2005). This pattern of initial colonising beavers utilising the highest quality habitats suggests that territorial behaviour can reduce population densities in local habitats. The sequence of arrival of pairs into unoccupied areas is likely to play an important long-term role in determining the size of the territory, as early arrivals occupy larger and higher-quality territories, even after a few years of colonisation (Campbell *et al.* 2005). This is an important consideration to bear in mind for how release schemes may be undertaken.

Beaver site selection and the habitats they create are variable, often changing precise damming location seasonally and/or with population density, often colonising sites not requiring dams first if given a choice (Campbell *et al.* 2005). Dams can remain relatively infrequent structures on some catchments, even when populations are at full capacity, but frequency is dependent on local conditions and this will not be the case everywhere. Even though beavers can access and reside in steep gradient streams with good vegetation, their dams tend to get washed out seasonally and this limits population expansion and longevity in such areas (Campbell-Palmer *et al*. 2016).

## 3.4 Beaver genetics

### 3.4.1 Choice of founder population

Deciding the composition of individuals to use to create a founder population is of great importance to the success of any reintroduction. The IUCN guidelines (IUCN/SSC 2013) specify that 'Founders should show characteristics based on genetic provenance, and on morphology, physiology and behaviour that are assessed as appropriate through comparison with the original or any remaining wild populations.'

As the beaver was hunted to extinction in the British Isles, the genetic provenance of the 'British beaver' has been lost. Natural recolonisation is not possible, given that Great Britain is an island physically separated from the European landmass by sea level rise around 6500 BC. There can also be no subsequent mixing of populations and/or external gene flow, as is possible on mainland Europe, unless proactive reintroductions occur. The selection of founding members for a reintroduced beaver population in Great Britain therefore requires careful consideration.

The assessment of genetic parameters across potential source populations is a key consideration for selecting suitable founding stock. Adaptive genetic variation and differences in the distribution of phenotypic traits can arise between isolated populations due to adaptation to local conditions and divergent evolutionary processes. These genetic differences mean individuals from separate populations may have varying responses to novel environments, stressors and pathogens which can ultimately affect reintroduction success (He *et al.* 2016).

There are four primary genetic considerations when choosing founder animals for a reintroduction (IUCN/SSC 2013):

1. Individuals that are most similar to those historically present should be selected (phylogenetic affinity).
2. Individuals with low levels of inbreeding and high combined genetic diversity should be selected.
3. On the contrary, it needs to be ascertained that the introduced combination of animals is not likely to suffer outbreeding depression associated with genetic incompatibilities.
4. The founding population should be able to sustain removal of individuals without jeopardising ecological function.

Relict Eurasian beaver populations passed through severe bottlenecks of between 30 and 300 individuals (Nolet and Rosell 1998). Babik *et al.* (2005) identified eight surviving relict populations from mitochondrial DNA (mtDNA) which could be separated into two major lineages; a western Evolutionary Significant Unit (ESU) (Elbe Germany, Norway and France) and an eastern ESU (Poland, Lithuania, Russia and Mongolia). To keep the identity of the populations, Durka *et al.* (2005) recommended that they were not mixed. Further work by Horn *et al.* (2014) supported the presence of eastern and western ESUs, alongside another ESU in the Danube - which has subsequently gone extinct. It has been proposed that the distinct populations identified by Durka *et al.* (2005) were an artefact of recent population decline, rather than a consequence of long-term genetic isolation. As such, separation of these populations is not necessary. Senn *et al.* (2014) analysed further samples across Europe and found that the east-west split may not be as distinct as suggested by Durka *et al.* (2005). A new haplotype found in individuals from central Russia grouped within the Western ESU, and individuals from Belarus, situated westerly, exhibited a mixture of haplotypes that spanned the east/west division. However, admixing between ESUs is advanced across Europe and set to continue as populations recover and spread. Thereby, there is limited justification for maintaining the segregation of ESUs or relict populations (Frosch *et al.* 2014; Senn *et al.* 2014).

The past bottlenecks in European beaver populations have resulted in reduced genetic variation in modern populations which can lead to reduced fitness, such as the loss of adaptability to changing environments (e.g Hedrick and Miller 1992). As evidence from Europe demonstrates, beavers can be successfully reintroduced into areas of their former native range, and large populations of beavers have grown from the release of small numbers of animals (Halley and Rosell 2002). For example, Swedish populations have recovered from ~11 breeding Norwegian females, and Finnish populations from as few as three individuals - with Norwegian populations themselves identified as having restricted genetic diversity recovering from ~120 individuals - (Rosell and Parker 2011; Hartman 1994; Iso-Touro *et al.* 2020). Both Swedish and Norwegian populations have recovered without any apparent effect on viability or fertility and without a common display of the more typical abnormalities associated with inbreeding, e.g. dental abnormalities, cleft palates, polydactyla etc (Parker *et al.* 2002; Rosell *et al.* 2012). Ellegren *et al.* (1993) concluded that the rapid expansion of the Scandinavian beaver population during the last 50 to 150 years suggests that the loss of genetic variability has not seriously affected viability or reproductive performance, which has not been the case with other mammal species such as cheetahs and lions (O'Brien *et al.* 1983; Wildt *et al.* 1987). They postulated that this may be due to two factors i) the reintroduction was not prevented by unsuitable ecological conditions, as seen with other mammalian recoveries and ii) the costs of inbreeding vary extensively between species. It is possible that the beaver is tolerant to periods of inbreeding due to its population structure; living in small family groups with dispersal usually limited to the natal water drainage system. The probability of matings between relatives is, therefore, likely to be higher than for many mammalian species. They concluded that loss of genetic variability may not necessarily exclude the survival of an endangered population provided that the ecological conditions are appropriate.

Milishnikov (2004) also suggest beavers have a high tolerance to inbreeding due to the population-genetic subdivision formed through the isolation of colonies from each other. However, Ross-Gillespie *et al*. (2007) studied the naked mole-rat (*Heterocephalus glaber*), another rodent species that live in family groups, and found that, when exposed to a lethal coronavirus outbreak, highly inbred mole rats were more likely to to die than their out-bred counterparts. The authors conclude that loss of genetic diversity, through inbreeding, may render populations vulnerable to local extinction from emerging infectious diseases even when other inbreeding depression symptoms are absent. Therefore, the limited genetic diversity in beaver populations could still result in vulnerability in the future from from such risks even when other inbreeding depression symptoms are absent. As there have been no systematic studies on the effect of inbreeding on beavers, and scientific evidence suggests that inbreeding and low genetic diversity in general are detrimental to population persistence, until further evidence comes to light effort needs to be made to minimise this risk in any reintroduction.

### 3.4.2 Sourcing beavers for an English reintroduction

The best provenance of beavers for a potential reintroduction into Great Britain has been subject to much debate. Gurnell *et al.* (2009) proposed that *C. f. galliae* (Rhone relict population) or *C. f. albicus* (Elbe relict population) should be used for a reintroduction into England ‘as they are adapted for lowland habitat’. Halley (2011) argued that the origin for British beavers was likely a mix of Scandinavian, French, and German populations i.e. unlikely to have been a single colonisation event - and subsequently set out three alternative scenarios for deciding on the choice of source population/s: i) use of the geographically closest, extant, beaver relict population; ii) mixture of individuals from two or more Western populations or, iii) release of individuals of multiple origins, regardless of ESU assignment. This prompted a response by Rosell *et al.* (2012) urging that further genetic data are analysed before populations are mixed. Further work carried out by Horn *et al.* (2014) and Senn *et al.* (2014) does provide this information, although there are still gaps in our understanding.

Marr *et al.* (2018) utilised ancient DNA from British beavers to reconstruct phylogenetic (evolutionary) relationships. They found ancient British beavers did not possess significant phylogenetic distinctiveness from mainland European ancient beavers and showed no phylogenetic affinity to any one modern relict population over another. They found ancient British beavers originated from the western ESU and did not show any phylogenetic affinity with eastern ESU haplotypes. They therefore recommended that, pending the adoption or rejection of Senn *et al.*’s (2014) recommendation for rejecting the segregation of ESUs or relict populations, beavers from the eastern ESU should not be used for a reintroduction into Great Britain.

Given that European populations are no longer considered separate subspecies (Horn *et al.* 2014; Senn *et al.* 2014), sourcing beavers from a particular relict population is no longer considered to be of importance. In practice, reintroductions in Europe have been undertaken using all three of the strategies suggested by Halley (2011) with little regard of genetic analysis (Nolet and Rosell 1998; Halley and Rosell 2002; Halley et al. 2012). Admixing between eastern and western populations is occurring across Europe on several population fronts, both as a result of multiple reintroductions over many decades and natural relict population expansion. Human-mediated mixing of beavers between eastern and western populations has resulted in successful reintroductions, such as in Bavaria, where beavers currently number 14,000 to 16,000 of genetically documented mixed descent; founded by around 43 admixed individuals from Scandinavia, Russia and France (Frosch *et al.* 2014). The genetic diversity in mixed reintroduced populations in Bavaria, Switzerland and Baden-Württemberg is higher than in fur-trade refugial populations in France, Norway and Hesse, Germany (Frosch *et al.* 2014; Senn *et al.* 2014), with no negative effects from outbreeding depression reported. Conversely, populations in the Netherlands and Hesse, where 42 and 18 beavers respectively were reintroduced from the fur-trade German Elbe river relict population (Nolet and Baveco 1996; Frosch *et al.* 2014), have only demonstrated low population growth. The Hessian population still consists of less than 1000 individuals. Frosch *et al.* (2014) highlight that these observations provide evidence for the hypothesis that population growth rates and dispersal might be governed by the level of genetic diversity and inbreeding, but caution that further research integrating ecological and demographic data is needed to form a robust conclusion.

### 3.4.3 Genetic status of the current wild British populations

Expert examination of the skulls from British fossils and extant Eurasian beavers concluded that, morphologically, British skulls were most similar to Scandinavian beavers. Also, factoring in sourcing, disease, habitat adaptation and admixing concerns, beavers from Norway were selected for reintroduction in Knapdale for the Scottish Beaver Trial (Kitchener and Lynch 2000). However, these populations display very low genetic diversity given they are relict fur-trade populations. Knapdale was a trial reintroduction, and not viewed by authorities as the selection of founder individuals for wider population restoration. Since the initial reintroduction, the Scottish beavers Reinforcement Project[8] has seen beavers from Tayside (origin predominantly Bavaria, Germany) released into the area to encourage mixing and increase genetic diversity.

The Tayside and River Otter populations were established outside of statutory procedures and did not follow IUCN reintroduction guidelines, therefore no baseline data were collected for the released individuals. Subsequent analysis was required to validate the species (i.e. Eurasian or North American beaver); investigate Eurasian population origin; and make inferences on genetic diversity (Campbell-Palmer *et al.* 2020).

Analysis of the genetics of a sample of the beavers in Tayside (N = 27, approximately 7% of the suspected population), confirmed they were Eurasian beavers and the population of origin was found to be predominantly Bavaria in Germany, with one individual being assigned to Lithuania/Poland. The genetic diversity of the Tayside populations was slightly less than that found in Bavaria, but comparable overall. However, the majority of individuals (82%, n = 22) were at least as closely related as first cousins, which is not the case in the population of beavers in Bavaria (Campbell-Palmer *et al.* 2020).

The beavers living on the River Otter were genetically determined as being Eurasian beaver and assigned with a high probability to either Bavarian or Baden-Württemberg populations in Germany (Brazier *et al.* 2020). Genetic diversity in the River Otter population was lower than for the likely source populations. Examinations of genetic relatedness revealed that all beavers were closely related, consistent to belonging to a single-family group. It was not possible to be certain of the exact pattern of relatedness between the animals because they were so closely related, but it was approximately equivalent to being between the first order (e.g. parent – offspring/sibling). Although a further four beavers have been introduced into the catchment to try and address this (Brazier *et al.* 2020), there is no evidence of breeding

[8] https://scottishwildlifetrust.org.uk/our-work/our-projects/scottish-beavers/#:~:text=The%20Scottish%20Beavers%20Reinforcement%20Project,and%20the%20Scottish%20Wildlife%20Trust [accessed 11/06/2021]

between these recently released individuals and original animals and/or their descendants. Therefore, demonstrable increases in genetic diversity may take several generations.

The current wild populations of beaver in Great Britain all appear to be suitably adapted to living in the British countryside. There is no evidence (body condition and pathology) that these beavers are failing to adapt to the British environment or experiencing compromised welfare. Populations in Tayside and Devon are displaying evidence of growth and increased distribution (Campbell-Palmer *et al.* 2018; Brazier *et al.* 2020).

Population growth is not however, a reliable indicator of population health. The effective population size (number of animals contributing genetically to the population) also needs to be considered. Should the population be growing because a limited number of pairs continue to reproduce successfully, but others fail to reproduce (for genetic or environmental reasons) then the population should not be considered healthy (e.g. Taylor *et al.* 2017). In addition, as mentioned above, these populations could be at risk from stochastic events such as disease and environmental changes if there is insufficient genetic diversity within the population to adapt to these events.

### 3.4.4 Considerations for potential future reintroductions

As beavers were hunted to extinction within Great Britain, there are no original or remaining wild populations of beaver on which to base founding individuals. Therefore, the argument to replace what has been lost is redundant. The most appropriate strategy, following the IUCN guidelines, would be to use beavers that are best adapted for the British climate, with sufficient diversity to allow for future adaptation and to protect from extreme events like disease/climate change, but not so widely sourced as to lead to outbreeding.

Much previous work investigating east/west lineage differences and the historic subspecies status of eight relict populations has shown limited justification for maintaining what are, essentially, populations from the hunting era generated by human activity. Separate eastern and western populations are not being maintained in Europe and beavers already present in Scotland are predominantly Bavarian and therefore of mixed origin.

From a purely genetic perspective, selecting founder stock that maximises genetic diversity and adaptive potential above achieving close phylogenetic relatedness to the historical British population, is likely to be the most appropriate path to follow given the current information (Marr *et al.* 2018). In practice, this would mean mixing various source populations from across neighbouring regions to maximise genetic diversity; to ensure a British population is healthy; adaptable to changes in the environment; and not at risk of inbreeding or outbreeding in order to sustain a robust, long-term future population.

This may have implications for disease risk and ecological function of those founding populations and this is discussed further in the section on public and animal health.

# 4 Biological feasibility – beavers and their interactions with habitats and species

## 4.1 What are the effects of beavers on running water habitats?

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(The Environment Agency contributed by reviewing the literature, interpreting the evidence and writing of the manuscript)

### 4.1.1 Summary of main findings and recommendations

Limited evidence was available from the Scottish Review to understand the influence of beavers on the hydrology, geomorphology and habitat of Scottish streams and rivers (Gaywood 2015).

Medium evidence from England (Elliot *et al*. 2017; Brazier *et al*. 2020) is consistent with very strong evidence elsewhere that the activity of beavers can modify the supply of water and sediment and increase the supply of wood to watercourses, creating habitat and initiating channel change by flow deflection resulting in more naturally functioning, dynamic fluvial systems (see Brazier *et al.* In Press and Larsen *et al.* Submitted for a review).

The scale and nature of the change brought about by beavers depends on many variables, including location, population density, watercourse type and gradient (Gurnell *et al.* 2002; Gurnell 2013; Giriat *et al*. 2016; Law *et al.* 2016; Dittbrenner *et al*. 2018; Gorczyca *et al*. 2018; McCreesh *et al.* 2019; Brazier *et al*. 2020; Smith *et al*. 2020). Although beaver activity can enhance the natural functions of river systems, the extent of influence is dependent on the natural characteristics of the watercourse and the nature and scale of existing habitat degradation. Key factors affecting the response of watercourses to beaver activity include stream power, gradient and size of naturally vegetated riparian zone. There is potential for significant habitat restoration opportunities associated with the delivery of large woody material to the channel and beaver activity in riparian zones, helping to restore lost habitat dynamism and diversity.

The scale of ecological change will be highly site-specific and dynamic, but where beaver activity is high there will be an overall shift in the balance of lentic and lotic character and associated biological assemblages, in line with natural functioning of river ecosystems as long as beaver population levels are subject to population controls that also mimic natural systems.

### 4.1.2 Introduction

Beavers may influence a watercourse through burrowing, foraging, damming and tree felling. These activities are site-dependent and vary year on year in any one location. The extent of impact will vary across space and time; some of the processes resulting from beaver activity are rapid and some will take decades to develop. Dynamism is a fundamental feature of natural river ecosystems, which characteristic biological assemblages have evolved to exploit (Mainstone *et al*. 2016; Mainstone *et al*. 2018). The dynamism provided by beavers can be seen as an integral part of natural ecosystem function.

Beaver activity will change the amount of lotic (running water), lentic (still water) and wetland habitat supported by a stream or river, and the relationships between them. The system is dynamic; dams may eventually degrade due to abandonment and/or heavy spates, but some may become more semi-permanent features of the environment (Gurnell *et al.* 2009). This dynamic complexity generates natural diversification of in-channel and riparian habitats which is broadly supportive of diverse biological assemblages (e.g. Larsen *et al.* Submitted). The resulting balance between lotic and lentic habitat will depend on site-specific environmental characteristics and the intensity of beaver activity, the latter partly determined by natural population controls and any other additional population management.

Beaver canals will also influence the river system by restoring riparian and floodplain habitats, creating new areas of full and partial inundation, connecting isolated aquatic features, and diverting water into colonised areas (Grudzinski *et al.* 2019).

### 4.1.3 A summary of the findings from the Scottish Review

- Although beavers appeared to have explored much of the stream network in the Scottish Beaver Trial at Knapdale, they exploited little of the river and riparian resources available, and therefore had limited influence on the fluvial geomorphology and river habitat in the area during the five-year trial period.
- Dams had some discernible effects on the hydrology of the lochs and the streams that flowed from them at Knapdale. These included temporary increases in the water storage of some larger lochs, the elevation and stabilisation of the water level in some small lochs, an increase in the dry weather flow in some streams, and a possible delay in the timing of peak stream flow.
- The evidence gathered during the Knapdale trial suggests that the incidence of beaver dam-building will be low when populations are small and have ready access to well-vegetated standing waters. In agricultural settings, or where higher densities of animals occur and are required to exploit sub-optimal habitat, a higher level of habitat engineering and associated hydrological effects should be expected.
- The majority of Knapdale's running waters are narrow, single-thread channels and many of them appear to have been modified for land drainage, with limited use by migratory salmonids. Although Knapdale has been a suitable site to investigate certain beaver interactions, to date it has been of limited value in assessing river habitat changes from beavers in general.

- The paucity of significant beaver activity in the running waters at Knapdale to date has meant that there is a limited understanding of the possible effects of beavers on the hydrology, geomorphology and habitats of Scottish streams and rivers.
- By impounding flow, and therefore storing water upstream, beaver dams may help to combat some of the effects associated with periods of low flow, such as prolonged periods of dry weather.
- Changes in flow, and therefore energy, will result in changes in erosion and deposition and, in turn, changes to the cross-section and planform of rivers and streams. The significance of this will depend upon the location.
- The ponding of water upstream of beaver dams will lead to localised changes to in-stream and riparian habitat and increased habitat heterogeneity.
- Beaver dams will have some effect on sediment transport processes and are likely to lead to localised changes in both the upstream and downstream composition of bed sediment.
- The slowing of flow and storage of water resulting from beaver activity could have local, perhaps wider, flood risk management benefits and would accord with natural flood management aspirations currently being discussed and implemented in Scotland.
- Most of the scientific literature has a reach-scale focus. There appeared to be relatively little information about catchment-scale effects.

### 4.1.4 Further research since the Scottish Review

Since the Scottish review, Larsen *et al*. (Submitted) and Brazier *et al*. (In Press) have undertaken comprehensive literature reviews of the role that beavers play in freshwater ecosystems, incorporating new research. Also, Law *et al.* (2017) describe the use of beavers as tools in habitat restoration and rewilding and similar themes are addressed by Brown *et al.* (2018).

In Poland, Kusztal *et al*. (2017) and Gorczyca *et al.* (2018) showed that the rapid increase in the Eurasian beaver population since their reintroduction in 1974 has determined and accelerated the process of re-naturalisation of rivers in Poland that have undergone partial degradation as a result of human pressure. Giriat *et al*. (2016) estimated that the current rate of sedimentation in beaver ponds along a 7.5km stretch of river in south east Poland was about 14 cm per year, where beaver ponds occupied 17% of the length of the study reach.

Dittbrenner *et al.* (2018) showed that through dam-building activities and subsequent water storage, beavers have the potential to restore riparian ecosystems towards functioning naturally and offset some of the predicted effects of climate change by modulating streamflow. However, the introduction of beavers to areas that could potentially benefit was limited in this study by current land use patterns.

A number of studies have been undertaken into the storage of carbon, nutrients and other elements, including metals.

- McCreesh *et al.* (2019) showed greater organic carbon and nitrogen content of sediments in beaver ponds than non-beaver ponds. Their findings suggest that the reintroduction of beavers could be an effective means to promote restoration of whole ecosystem function by removing excess nutrients from a river system.

- Law *et al.* (2016), Puttock *et al.* (2017) and Puttock *et al.* (2018) showed that beaver modified habitat demonstrated greater nutrient retention, water and sediment storage, flood attenuation and mitigation of diffuse pollution, restoring ecosystem processes locally.
- Briggs *et al.* (2019) indicated that beaver-induced floodplain exchanges create important, and perhaps dominant, transport pathways for floodplain metals by expanding chemically-reduced zones paired with strong advective exchange.
- Bashinskiy and Osipov (2019) suggest a possible impact of beavers on concentrations of phosphorus (inflow from burrows) and zinc (input with branches and twigs).
- Gatti *et al.* (2018) found that beavers in western Siberia increase the stream emission of methane by about 15 times as a result of dam building. The study also showed that Siberian beavers facilitate nutrient recycling by speeding up the nutrient release from particulate organic matter and carbon sequestration by increasing the amount of dissolved organic carbon. This carbon becomes in part recalcitrant when buried in sediments and is, therefore, removed from the short-term carbon cycle.
- However, Smith *et al*. (2020) found that long-term water quality improvements from wetland rehabilitation on either nitrate or total phosphorus concentrations at the sites they studied were limited, with unchanged seasonal summer and winter peak concentrations for phosphorus and nitrate, respectively. This was most likely due to the long-term legacy of fertilizer use on nutrient reservoirs in the catchment’s soils, aquifers and stream network.

Weber *et al.* (2017) and Stout *et al.* (2017) studied changes in stream temperature by beaver dams, and showed the impacts of dams on the hydrology, temperature, biogeochemical processes, and geomorphology of streams and riparian areas. These studies provide preliminary information regarding the number of dams per unit stream length required to begin meeting various restoration goals. Macfarlane *et al.* (2017) identified where dam-building activity is sustainable, and at what densities dams can occur across a landscape. They provided model outputs that can be used to determine where channel–floodplain and wetland connectivity are likely to persist or expand by promoting increases in beaver dam densities. Swinnen *et al*. (2019) studied the location of dams, providing a simple tool for planners to assess the probability of floodplain inundation by beaver dam building, as part of multifunctional riverine landscape management. These studies were further developed by Graham *et al.* (2020) who modelled Eurasian beaver foraging habitat and dam suitability to enable prediction of the location and number of dams throughout catchments in Great Britain. The report developed a Beaver Forage Index (BFI) and a Beaver Dam Capacity model (BDC), classifying the suitability of river reaches for dam construction, and estimating location and number of dams at catchment scales. Modelling was carried out at three catchments in Great Britain. The results show that dams are more likely to occur in low order streams ($\leq 4^{th}$ order) with plentiful woody riparian vegetation, and less likely to occur in larger rivers with limited riparian woodland. However, agricultural landscapes with patchy woodland may still provide marginal habitat which can support beavers. The model also provides the foundation for upscaling findings to estimate landscape scale effects, together with where activity may maximise benefts and may cause conflict.

### 4.1.5 English Context

England supports wide variation in running water habitats, from tiny streams to large rivers, in the uplands and lowlands, on a range of geologies and with varying amounts of groundwater base flows (Mainstone *et al*. 2016). In terms of structure and function, English rivers do not differ fundamentally from rivers across Europe. Beaver activities therefore have the capacity to transform watercourses and riparian landscapes in English river catchments in similar ways to their activities in European river systems, helping to restore dynamic natural processes and ecosystems. As in Europe and elsewhere, factors affecting the response of English watercourses to beaver activity include stream power, gradient and size of riparian zone (Gurnell *et al.* 2009; Brazier *et al.* In press). This variation in beaver influence brings with it variation in the potential for both significant habitat restoration benefits.

Beaver dams slow and attenuate water in a channel and alter hydrological regimes (Brazier *et al.* In press). The extent to which they do this will depend on their height and porosity and the frequency at which they occur. Dams push water sideways and can extend flow beyond the original main channel, creating complex wetland habitats and increasing floodplain storage (see Brazier *et al*. In press) whilst also contributing to soil and ground water recharge (Westbrook *et al*. 2006). Water stored in beaver ponds is released slowly through porous beaver dams, thereby elevating stream base flows during prolonged dry periods (Puttock *et al*. 2017). By increasing the amount of water stored in a channel, floodplain or ground water, the ecological effects of prolonged periods of dry weather may be lessened, providing greater ecological resilience in the face of climate-induced drought. Some of the findings of the Scottish literature review showed that beaver dams moderate stream flow, increase surface water and riparian groundwater storage, and regulate hyporheic flows (i.e. flows in the groundwater–surface water mixing zone) (Nyssen *et al.* 2011).

Dams vary significantly in their size, structure and longevity depending on physical factors such as hydrology, topography and building materials (Graham *et al.* 2020) but also ecological factors. Hafen *et al.* (2020) found that primary dams, that maintained a lodge pond, were significantly larger than secondary dams, which are used to improve mobility and the transport of woody material, concluding that beaver ecology, in addition to channel characteristics, exert a primary control on dam size.

Localised changes in the connectivity between channels and their riparian zone and floodplains are likely, including ‘alternating patches of high and low water table’ (Gurnell 1997). Studies in Devon indicate a more stabilised base flow, storing water during dry periods and raising ground water tables (Gibson and Olden 2014). Westbrook *et al*. (2006) found that in a broad alluvial valley in the Rocky Mountains, Colorado, beaver dams and ponds elevated the water table during both high and low flows by causing river water to run around them as surface run-off and groundwater seepage. In this study, beaver dams attenuated the expected water table decline in the drier summer months for 9 and 12 ha of the 58 ha study area, although it needs to be appreciated that effects will be site specific and likely to vary within different habitats and topographies.

Beaver canals (Figure 5) may increase channel–floodplain connectivity, including via the connection of previously discrete floodplain water bodies with a stream or river, thereby contributing significantly to the local hydrogeomorphology of floodplains (Hood and Larson 2015).

**Figure 5** Beaver canals can increase channel–floodplain connectivity

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Woody debris is a key driver of geomorphic complexity, which is a fundamental component of the natural functioning of rivers, and is critical for aquatic life through providing habitat (in its own right and through the diversication of in-channel and riparian habitat mosaics) and carbon (Gurnell *et al*. 2002; Gurnell 2013; Harvey *et al.* 2018; Thompson *et al.* 2018; Wohl 2013) (Figure 6). Beavers increase both large and small woody debris in river systems (Gurnell *et al*. 2002) and beaver dams can be thought of as an extension of the sporadic 'jams' of woody material that occur widely in natural or lightly managed river systems (Gurnell *et al*. 2009). Small woody material provides an increase of e.g. willow recruitment (Levine and Mayer 2019), stabilisation of depositional features and promotes rates of aggradation whilst larger material increases bed heterogeneity through localised scour and deposition (Brazier *et al.* In press).

**Figure 6** Naturally forming woody 'jams' created by branches falling from riparian trees, diversifying habitat through the creation of scour pools, riffles, differential bank arosion and hence channel sinuosity.

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Beaver activity can help restore the natural functioning of river systems, although the potential is dependent on the nature and scale of existing habitat degradation. For instance, an artificially incised channel on an energetic river system will present a very hostile environment for dam creation, and may require restoring to a more natural channel dimension before beavers are able to contribute to its further natural diversification. Or it may take beavers longer to effect habitat change due to the level of habitat degradation. In lowland, low-energy systems, dam creation on a dredged watercourse where its natural coarse bed material has been removed is likely to lead to the accumulation of deep and uniform beds of fine sediment where the watercourse has no upstream gravel supply. In this case, the active reinstatement of coarse gravels cannot be substituted by the actions of beavers.

Knapdale is a naturally low nutrient status environment, with limited human nutrient enrichment and limited artificially enhanced fine sediment delivery; this is in contrast to many English river catchments. River and stream channels that are heavily enriched are likely to suffer from high algal biomass production behind beaver dams, with associated impacts on the biota (Mainstone 2010). The watercourse may also be carrying excessive amounts of fine sediment from upstream erosion, which can lead to very deep, fine sediments in beaver ponds that are uncharacteristic of the natural river and only suitable for a limited number of species. Rivers and streams that have more natural nutrient and sediment regimes are much more likely to benefit from beavers, adding heterogeneity of habitats associated with high quality environmental conditions.

Beaver dams in smaller watercourses on the River Otter have resulted in avulsion, channel rerouting, and minor changes to channel planform (Brazier *et al*. 2020). Depending on location, flows can be slowed, resulting in increased channel stability and a more geomorphologically complex system overall. Both these potential changes are positive within the context of restoring a naturally functioning, dynamic fluvial system. The nature and significance of impact can vary depending on the location and river system.

Beaver dams can affect the storage, movement and supply of sediment and associated nutrients (Butler and Malanson 1994). The sediment accumulating in the ponded reaches upstream of beaver dams will be sorted, with larger particles being deposited at the head and finer material in the main body of a watercourse as is the case with woody ‘jams’ generated in the absence of beavers. A change in the composition of bed material downstream of dams is also likely to occur as a result of sediment being retained behind dams. Water clarity tends to improve downstream of a beaver dam, as a result of flushing of fine and sorting of coarse sediment in reaches between ponds (Brazier *et al*. In Press). Conversely, collapsed beaver burrows and dams and local changes in flow dynamics may create erosion and release sediment. Both processes are intrinsic to a natural sediment system but can have adverse consequences in systems with artificially elevated nutrient and fine sediment delivery. Burrowing activity of beavers may also increase channel complexity and sinuosity by acting as a focal point for erosion (Williams *et al.* 2004).

The number and density of settlements and associated infrastructure assets is likely to differ in England compared to Scotland. This is relevant to the potential to maximise biodiversity enhancement and ecosystem service benefits and to minimise risk. Beaver impacts on infrastructure and general land use are addressed in section 5.7.

### 4.1.6 Identification of areas of potential conflict in England

Whilst, from nature conservation and ecological perspectives, the reintroduction of the beaver is seen as restoring a missing component of freshwater and wetland ecosystems, an over-emphasis on the ability of the beaver to address fundamental impacts on natural catchment processes could result in a loss of focus on wider strategic habitat restoration efforts.

Renaturalising hydrological, sediment and water quality regimes to restore stream and associated wetland systems requires concerted action in headwater areas to change land use/land management and reduce abstraction and artificial water transfers. Portraying beaver reintroduction as a means of dealing with pollution and hydrological regulation *within the stream and river habitat resource rather than at source,* can potentially detract from land-based strategies that address upstream impacts in ways that deliver ecological and ecosystem service benefits to and from catchment headwater areas. There is no such problem where beavers are reintroduced to headwater areas that are already exclusively under natural and semi-natural vegetation to address such impacts at source, and beavers can play a central role in critical conservation action to naturalise mire-stream transitions, as well as habitats further downstream (Mainstone *et al*. 2016).

It is recommended that consideration is given to understanding the potential influence of beavers on the classification of the ecological status of water bodies under the Water Framework Directive (translated into domestic law by the Water Environment Regulations). The re-establishment of beavers constitutes a significant shift in natural reference conditions for rivers and lakes which was not factored into the classification methods for ecological status, meaning that there is potential for beaver reintroduction to be detected as an impact rather than as part of restoration of natural ecosystem function. Care should be taken to ensure any conclusions drawn from classification results bear in mind the environmental changes brought about by this shift in natural reference conditions.

### 4.1.7 Potential future implications of wider reintroductions in England

Beavers will have significant influences on hydrology, fluvial geomorphology and habitat of riverine systems including their riparian zones and wider floodplain interactions. These influences will vary across space and time, with both rapid and long-term outcomes, and are broadly considered to be ecologically beneficial within the context of restoring naturally functioning river ecosystems (Mainstone *et al*. 2016). Restoration of natural ecosystem function does however imply that natural population controls need to be in place, and without them the ecological changes brought about by beaver may become out of balance. Measures for reflecting natural controls on population levels need to be part of management planning for beaver populations in the long term.

At a site-specific level, the scale of change in locations supporting rare species requires care to avoid potential population loss. The diversification of habitat conditions generated by beavers will often generate new habitat opportunities for rare species, but the transitioningfrom existing locations to these new habitats may need managing (Mainstone *et al*. 2018).

Many English river systems are modified or degraded and potentially present opportunities for restoration through the presence of beavers. Recent modelling could provide the basis on which to extend recent findings and use to maximise benefits and produce potential conflict (Graham *et al.* 2020). However, it is important not to overstate the ability of beavers in this regard, and to continue to address key stresses on river ecosystems at source including: diffuse and point source pollution control, restoration of channel dimensions (including reinstatement of coarse bed sediments lost by historical dredging), dynamic channel movement, targeted removal of flood defences, and restoration of natural hydrological regimes. Any proposals for beaver reintroduction should consider any potential exacerbation of impacts on already degraded ecosystems and should seek to target systems that have reasonable levels of natural function.

Clear criteria should be considered of where a wild release reintroduction contributes to understanding beaver behaviour and how this might contribute to longer term knowledge. Where beavers are reintroduced into the wild, and how quickly, will have implications on the speed of potential benefits being delivered and also on how ready England is to understand and implement the appropriate range of mitigation options. If beavers remain in the wild, the influence on running waters over time will extend beyond original reintroduction sites and so understanding is needed where, strategically, benefits can be maximised and risks minimised.

Targeted appropriately, natural capital and associated ecosystem services should increase from beaver reintroduction as a result of contributing to restoring natural ecosystem function, creating effective climate change adaptation and resilience at a catchment scale. These include the potential for slowing and storing surface water as well as groundwater and baseflows. Temperature may be buffered (Weber *et al*. 2017), and sediment transport processes and associated bed habitat may benefit (Puttock *et al*. 2017).

# 4.2 What are the effects of beavers on the overall biodiversity, water level and chemistry of standing water habitats and associated wetlands?

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## 4.2.1 Summary of main findings and recommendations

Strong evidence from the Scottish Beaver Trial showed that beavers created ponds and wetland habitats, with an associated increase in biodiversity and habitat niches (Gaywood 2015; Law *et al.* 2017). There was limited evidence to suggest that beavers affected the abundance or diversity of aquatic plants or plant communities in lakes and adjacent wetlands (Gaywood 2015).

Medium evidence from England demonstrated that beaver dams on the River Otter, and within an enclosure in Devon, stored water, creating new wetland and pond habitats, and trapped sediment and diffuse pollution from intensively farmed landscapes (Puttock *et al.* 2017; Brazier *et al.* 2020).

Medium evidence from elsewhere indicates that beavers can help to restore wetlands and create ponds, promote biodiversity and mitigate the effects of climate change on hydrological regimes in some areas (Bergman *et al*. 2018; Law *et al.* 2019).

In summary, beaver-induced ponded and wetland habitats have the potential to greatly enhance and restore natural processes in English catchments with a significant benefit to lake, pond and wetland habitat functioning and extent.

There have been many changes to the water environment since beavers were present, and there is limited research indicating how heavily impacted water bodies may respond to beaver activity. Where many of the effects of beaver will be beneficial there will also be situations where objectives will differ and conflict may occur.

## 4.2.2 Introduction

Beavers have the capacity to both create new standing water and wetland habitats and impact existing habitats. For the purpose of this section the term ‘lake’ includes both natural and man-made standing water bodies, such as lochs, gravel pits and reservoirs. The infrastructure associated with man-made water bodies, is discussed in section 5.7 Infrastructure and general land use.

### 4.2.3 Summary of the findings from the Scottish Review

- Pond complexes inhabited by beavers represent a variety of habitats which exhibit different stages of colonisation by biota and therefore support a diversity of species. The diversity of plant species present in beaver ponds has also been found to increase with time.
- Flooding of terrestrial environments results in the creation of wetland habitats adjacent to fully aquatic environments, increasing the number of niches associated with the standing water.
- Where ponds are formed as a result of dam-building on stream systems, there may be an overall biodiversity gain, and downstream wetland and standing water habitats may benefit from better water quality with the dams creating sediment traps.
- Beaver activity had a clear and measurable effect on lake aquatic plant communities in Knapdale. Where beaver numbers were greater, aquatic plant cover was reduced but species diversity was little affected.
- Beavers may affect aquatic plants directly through herbivory and also indirectly by influencing hydrological regimes through dam building.
- Reed beds in some lake locations were reduced in extent, in part by the dragging of material through the reeds. More diverse habitat has resulted and a greater outflow from the lake occured.
- Accumulation of woody debris had no clear effect on aquatic vegetation. It may lead to erosional losses but is also likely to increase the complexity of littoral habitat for other aquatic biota.
- Potential over time to lead to increased nutrient levels and decreased dissolved oxygen, which may change the plant ecology detrimentally in some situations.
- Ponds and wetland complexes may act as a pollutant sink and buffer against effects of drought.
- Where and when plants are eaten is unpredictable and all beavers would not be expected to eat the same species, to the same extent.
- Potential increase in aquatic plants and understorey vegetation as a result of some canopy removal.
- Spread of Canadian pondweed (*Elodea canadensis*) could not be attributed specifically to beaver presence.
- Uprooting of isoetids (short tufted species with stiff, linear, basal leaves growing on the bed of shallow water bodies) occurred but the impact was regarded as trivial.
- Rhizomatous aquatic vascular plants were generally preferred over non-rhizomatous species with great fen-sedge (*Cladium mariscus*) and common club-rush (*Schoenoplectus lacustris*) very heavily impacted by foraging - their cover being disproportionately reduced over time. White water-lily (*Nymphaea alba*), water horsetail (*Equisetum fluviatile*) and bogbean (*Menyanthes trifoliata*) were, however, also negatively impacted and yellow water-lily (*Nuphar lutea*) was preferentially taken in Tayside.
- Plant species grazed were generally edge/emergent/floating rather than submerged species.

### 4.2.4 Further research since the Scottish Review

Bashinskiy (2020) undertook an analysis of the literature on the impacts of beavers on lake ecosystems and concluded that beavers are an important conservation tool for small lakes and their biotic components. This study also highlighted how beavers can alter water chemistry. Dam building on lake outlets has led to increased concentrations of dissolved organic carbon and decreased concentrations of dissolved oxygen within lakes. Digging activity by beavers can result in large quantities of soil being released into the water body. This has led to phosphorus concentrations and suspended matter being positively correlated with number of burrows along the shoreline (Bashinskiy and Osipov 2019). The impact of beaver activities on water quality is generally greater on smaller water bodies, in larger water bodies impacts can be more localised.

The River Otter Beaver Trial (Brazier *et al.* 2020) reports both the development of new wetland habitats in drained parts of floodplain following beaver damming of ditches, and expansion of wetland and aquatic habitat in existing wildlife sites. The rapidity of the development of wetland and ponds, and colonisation by previously absent wetland birds were particularly notable.

Research looking at sediment and nutrient storage in a beaver engineered wetland (Puttock *et al.* 2017) indicated that beaver ponds may help to mitigate the negative off-site impacts of accelerated soil erosion and diffuse pollution from agriculturally dominated landscapes such as the intensively managed grassland in this study.

A study in North America (Bergman *et al*. 2018) states beavers can help to restore wetlands and mitigate the effects of climate change on hydrological regimes in some areas. The study looks at whether availability of woody plants, conditions conducive to the availability of aquatic vascular plants, and/or other features of basin morphology are associated with the persistence and density of beaver occupancy in 23 lakes over a 50-year period. Percentage cover of floating-leaved aquatic plants was a leading positive predictor of beaver colony density in lakes.

Law *et al.* (2017) illustrate that beaver can, with time, transform agricultural land into a comparatively species-rich and heterogeneous wetland environment. This offers a passive but innovative solution to the problems of wetland habitat loss that complements the value of beavers for water or sediment storage and flow attenuation.

Hood *et al*. (2015) indicate that exclusion or removal of beavers could limit ecosystem processes and resilience, especially in areas with otherwise isolated aquatic habitats and limited connectivity. Conversely, reintroduction of such an ecosystem engineer into areas targeted for restoration could result in significant increase in habitat heterogeneity and connectivity. The ability for beavers to create channels to connect multiple standing waters, potentially increasing the ability of species to move between water bodies and therefore increasing their resilience, was also highlighted in Bashinskiy (2020).

### 4.2.5 English Context

As a result of the enormous human modification to natural hydrological patterns in English landscapes over centuries, most naturally occurring wetlands have been completely lost (Hume 2008; Mainstone *et al*. 2016). Many of those that remain are fragmentary and regulated by ditches and other water management infrastructure, with the loss of much of their hydrological, chemical and biological complexity (Mainstone *et al*. 2018). Consequently, the English landscape offers many opportunities for increased biodiversity and habitat through the creation of beaver dams that create ponds and also push water sideways, extending the flow beyond the main channel, creating complex wetland habitats and increasing floodplain storage (Grygoruk and Nowak 2014). Part of this suite of habitats will include flooded areas created by beavers which can become standing water habitat in their own right. Natural pond-creating processes are effectively absent in England; beavers have the capacity to create ponds naturally, putting these water bodies back into the landscape. It should be recognised that some locations will have more or less capacity for the formation of these wetland and pond habitats due to the width of the riparian zone available and adjacent land use.

Not only do beavers increase the area of standing water habitats in riverine systems and in existing lake habitats, they also create open water features in wetlands, both mineral wetlands and peatlands, where they did not previously occur (Morrison *et al*. 2014). This may be particularly beneficial in an English context given the loss of much of the spatial and temporal hydrological complexity and open water features in wetlands in the lowlands and uplands. Over time, flooded and ponded areas may fill with sediment and create beaver meadows which have been reported to contribute to carbon sequestration and adaptation to climate change (Wohl 2013, Bergman *et al*. 2018). While an increase in standing water habitats within wetlands would generally be considered a positive change, there may be some sites, such as Sites of Special Scientific Interest, where high value features have developed in positions in the floodplain that are vulnerable to damage or loss as a result the creation of standing water through beaver activity. This issue is best dealt with at site-level, following the principles laid out in Mainstone *et al.* (2018).

Sediment input into online standing waters may decrease due to upstream damming by beavers or increase if there is extensive erosion by the presence of beavers upstream (Puttock *et al*. 2017). Any effect will depend on the nature of the sediment, and the quantity and nature of the standing water it is entering. These effects are normally only transient, as beaver dams degrade or are destroyed by spate flows, and should be considered a part of natural sediment dynamics. In catchments where there is excessive delivery of fine sediment resulting from intensive management of the catchment, beaver dams may give temporary relief from excessive siltation of lakes, but only at the expense of excessive siltation in the river and stream system upstream. The impacts of siltation on both standing and running water habitats can only be properly dealt with at source, prior to entering the surface water network.

The lake types in Table 3 are the Habitats Directive Annex 1 habitat types found in England. Due to the different characteristics of these lake types they are likely to be used and impacted by beavers differently. The table shows that by far the most abundant type of lake in England is the natural eutrophic lake type (this does not mean that they are naturally algal dominated lakes, just that they would naturally have higher nutrient concentrations than mesotrophic lakes). The recent Article 17 reporting also showed that the majority of England's lakes for all types are not in good condition (Hall 2019).

**Table 3** The different Annex 1 lake habitat types present in England, the area they cover and whether they are in good condition

| | H3110 | H3130 | H3140 | H3150 | H3160 |
|---|---|---|---|---|---|
| **Lake type** | Oligotrophic waters containing very few minerals of sandy plains (*Littorelletalia uniflorae*) | Oligotrophic to mesotrophic standing waters with vegetation of the *Littorelletea uniflorae* and/or of the *Isoëto-Nanojuncetea* | Hard oligo-mesotrophic waters with benthic vegetation of algae (*Chara* spp). | Natural eutrophic lakes with *Magnopotamion* or *Hydrocharition*-type vegetation | Natural dystrophic lakes and ponds |
| **Rough equivalence to Water Environment Regulations type** | A sub-set of low alkalinity lakes found in the lowlands | Low and moderate alkalinity | Marl | High alkalinity | Peat |
| **Area of Annex 1 habitat type in England (ha)** | 1011.46 | 8946.53 | 583.99 | 20350.83 | 1274.63 |
| **Percentage in good condition (excluding unsurveyed sites)** | 0.7 | 28.03 | 48.48 | 3.13 | 0.96 |

The Scottish report mainly concentrated on two lake areas in Knapdale and Tayside (particularly the Dunkeld to Blairgowrie SAC and surrounding area). The lakes in both Scottish locations are considered to be oligotrophic to mesotrophic standing waters with vegetation of the *Littorelletea uniflorae* and/or of the *Isoeto-Nanojuncetea* (H3130) (Figures 7 and 8). While there are issues with diffuse water pollution and occurrence of waterweed (*Elodea*) in the Tayside sites, both sets of lakes have abundant submerged aquatic plants.

**Figure 7** Beaver dam on Loch Dubh, Knapdale which caused the development of Mesotrophic fen/swamp and wet woodland (Figure 8)



**Figure 8** Mesotrophic fen/swamp and wet woodland developing after loch outflow dammed by beavers in Knapdale

Although lakes of this type are found in England, with a particular abundance in Cumbria, the majority of lakes in England are identified as H3150, naturally eutrophic. The majority of English lakes suffer from nutrient enrichment. When the nutrient concentration increases, there is an increasing likelihood of an impoverished aquatic plant assemblage, often with only a few nutrient tolerant species in low abundance. This can be seen in many of England's lakes such as the Broads and the Meres, amongst others (Phillips *et al.* 2015; Burgess *et al.* 2014). It is important to consider the extent to which the results from the Scottish examples would apply to such impacted lakes. Due to the current condition of English lakes it is possible that a greater proportion of all three plant functional groups (submerged, floating and emergent plants) may be impacted by beaver herbivory than in the Scottish trials and this needs to be given consideration. This is because there will be a lower abundance of aquatic plants available for the beavers to consume and fewer species providing less food choice.

Lakes which have not been impacted to the extent described above are more likely to respond to the presence of beavers in a similar manner as the lakes in the Scottish trials, in that whilst beavers may bring about a change in species abundance and even species composition, there are few reports of species losses at a landscape scale. The biggest risks are for species that are uncommon in the landscape.

There is a lack of evidence on how beavers behave in man-made isolated water bodies such as gravel pits, although there is a suggestion that beavers may prefer lakes with an outflow (Bashinskiy 2020). Consequently, such hydrologically isolated water bodies may not be the chosen habitat of beavers. However, the availability of any suitable habitat at potential release sites may override such preferences.

Aquatic plants form a major component of beaver diets, although these are mostly rhizomatous species such as the common bulrush (*Typha latifolia*). Aquatic plants play a crucial role in the balance between algal-dominated and clear plant-dominated conditions in standing waters (e.g. Moss 2013). Whilst there is currently no evidence to suggest beavers affect this balance, it is worth considering if this will be the case in all situations as it is so crucial for lake functioning. Beavers are most likely to impact emergent plants and water lilies as there is evidence of these being a preferred food source (Bergman *et al*. 2018). Emergent vegetation is an important part of the lake habitat used by many species and has a role in lake functioning, providing stability to a lake shoreline and some reduction in nutrient concentrations.

Marginal aquatic plants, usually emergent species, have declined in a number of English lakes. This has been documented for the Norfolk Broads and Lake Windermere, but little studied elsewhere (Boorman and Fuller 1981; Phillips *et al.* 2015; Rushworth 2014). The proposed reasons for this include: boat traffic, water quality, shading, water level management, grazing by stock and also in the past by coypu (*Myocastor coypus*) in the Broads (coypu have been absent from the Norfolk Broads since 1989). Of particular note is the lesser bulrush (*Typha angustifolia*) which characteristically formed 'hover' in the Broads, but currently is at a lower abundance than it was historically. Beavers are known to eat bulrush, but it does not grow at the Scottish trial site. The Scottish review illustrated that herbivory was greatest on emergent and floating species, some of which are still recovering their former abundance in England. Beavers may prevent their recovery *via* herbivory or they may have a positive effect on emergent species as they will reduce shading of the margins by reducing tree cover. It is known that a reduction in shading of the edge of the Broads can increase the growth of marginal emergent species (Kelly and Southwood 2006).

The Scottish Beaver Trial found there was little effect on the submerged plants. Although there was a lower abundance of submerged plants in beaver lakes the species diversity remained the same. However, in many English lakes few submerged species survive, due to water quality and carp feeding behaviour[9]. It is unknown how beavers would behave in lakes with a low abundance and number of aquatic plants species.

Water lilies are amongst the few species that persist in lakes with poor water quality. They can also persist in lakes where carp feed amongst the sediment. Water lilies have been found to be one of the species preferred by beavers, with beavers persisting at sites with greater abundance of floating leaved vegetation (Bergman and Bump 2018). Whilst beavers caused only a small reduction in abundance of water lilies in the Scottish trials, this impact may be greater if there are no alternative food sources in the impacted English lakes.

These aquatic plants co-existed with beavers for a long time before beavers became extinct in England. So, when lakes are in good condition, the evidence from the Scottish trial and elsewhere suggests that at a landscape scale there should not be an adverse effect. There is no evidence on the impact of beavers on lakes with impoverished floras like those common in England. However, Bergman and Bump (2018) show that lakes are more likely to be continuously occupied by beavers if they have a greater total cover of aquatic plants. This suggests that beavers may move on to find more favourable habitats if they find themselves in such situations. Therefore, it could be expected that beavers kept enclosed within sites containing lakes with few aquatic plants would have the greatest risk of a negative impact. This is because they would be forced to consume the only food available, but if they were free to roam they may move on to better sites rather than decimate the small remaining aquatic plant populations.

Conversely, beavers may also be beneficial to English stillwaters as their tree felling behaviours may also increase the growth of marginal plants (Kelly and Southwood 2006), which have the capacity to reduce nutrient concentrations within lakes. The introduction of an increased amount of woody debris to the shallows will also provide habitat, and a food resource for fish and invertebrates.

### 4.2.6 Identification of areas of potential conflict in England

As mentioned in relation to running waters under Section 4.1.6, it is recommended that consideration is given to understanding the potential influence of beavers on the classification of the ecological status of water bodies under the Water Framework Directive (translated into domestic law by the Water Environment Regulations). Care should be taken to ensure any conclusions drawn from classification results bear in mind the environmental changes brought about by beavers to our understanding of natural reference conditions.

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[9] Carp rummage in the sediment uprooting the less well-anchored submerged plants and are stocked in the majority of England's lowland lakes.

The creation of new standing water, ponded areas, wetlands and lakes can create conflict with other uses/objectives for local land and water body use including agriculture, private gardens, water body users and drainage.

Some specific species or habitats may be negatively impacted by a change to, or creation of, wetlands, ponds and lakes by the presence of beaver. Assessment of sites for priority and/or protected species or designated sites would need to be considered and addressed on a case by case basis.

### 4.2.7 Potential future implications of wider reintroductions in England

Beaver-induced ponded and wetland habitats have the potential to greatly enhance and restore natural processes in English catchments, with an overall net gain in biodiversity and diversity and extent of wetland and open water habitat. There have been many changes to the English water environment in the centuries since beavers were present and, while many of the effects of beaver will be beneficial today, there will also be situations where objectives will differ and conflict may occur.

Flooded and ponded areas and complex wetland habitats created by beavers have the potential to provide resilience to drought which will become increasingly important with climate change (Puttock *et al*. 2017; Brazier *et al.* 2020 In Press).

Beaver presence has the potential to restore the natural wetland hydroseres and zonations, especially where lake levels have been lowered and surrounding wetlands previously drained. This has the potential to be a significant benefit to lake and overall wetland functioning (e.g. Sikora and Cieśliński 2017), including the re-wetting of peat and even re-instatement of peat formation. The policy and legislative framework will bring with it the need for full understanding of how various needs and objectives work together, including any potential effect that beavers may have on existing standing waters in relation to River Basin Management Plans. The use of Eurasian beaver as a tool to assist implementation has been discussed by Törnblom *et al*. (2011).

Beaver activities most likely to impact existing standing water habitat are: foraging and herbivory in the riparian and shallow water zones, damming at any inflow and outflow, and burrowing in earth embankments. However, such impacts should be seen in the wider context of restoring dynamic, naturally functioning freshwater and wetland habitat mosaics.

In England, there are a range of existing lakes and ponds that vary in their range of ecological types and, in some cases, will have associated designations and operational functions. They may all have a combination of uses including permanent reservoirs and those that include recreational facilities. Where mitigation or management of beavers is considered necessary for the operational purpose of the waterbody, this should be carried out in accordance with associated legislation and supporting guidance.

# 4.3 What are the effects of beavers on the biodiversity of woodlands?

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## 4.3.1 Summary of main findings and recommendations

There is limited evidence from the Scottish Review that beavers can affect woodland composition. A risk was highlighted relating to deer browsing the re-growth from trees felled by beaver, which affected the success of regeneration and could potentially result in habitat degradation or loss (Gaywood 2015).

There is strong evidence elsewhere that beavers can affect tree species composition and age structure of woodlands with subsequent positive impacts for biodiversity (Herbison and Rood 2015; Rentch *et al*. 2015; Law *et al*. 2017; Misiukiewicz *et al.* 2018).

There is no direct evidence in England on the effects of beavers on woodlands, but evidence from published studies indicate that beavers will likely have positive impacts on woodland biodiversity in under-managed riparian woodland across the country, provided browsing of regrowth by deer or other herbivores is managed.

## 4.3.2 Introduction

Beavers affect woodland primarily through the felling of trees and damming watercourses. Felling may affect tree species composition and age structure of a woodland, which will broaden in even-aged forests, and is likely to create more open habitats. This may drive woodlands towards an overall younger age structure in high impact areas (i.e. close to watercourses and lodges). Damming may inundate and kill trees, leading to increased volumes of deadwood, and change the abundance of different habitats, in particular increasing areas of standing water habitat and wetter woodland types.

## 4.3.3 A summary of the findings from the Scottish Review

- The majority of trees felled were within 10 m of the water's edge.
- The tree species preferred most by beavers also produced the most vigorous regrowth, such as willow and ash (almost no aspen occurs at Knapdale). However, the regrowth was significantly impacted by deer (family *Cervidae*) browsing and frost.
- The woodland became more open, with a grassier ground flora, following the introduction of beavers.
- Most of the felled trees were removed by the beavers for construction, caching or consumption. Despite this, there was some increase in fallen dead wood in the areas most heavily used by beavers.
- Felling, feeding, and dam building, all change the dynamics of deadwood within woodland. Felling and feeding will broadly increase fallen deadwood levels, while

inundation in particular will, in the short term, increase levels of otherwise rare standing deadwood.
- If the canopy is opened this will increase light levels, potentially increasing tree recruitment. However, a key risk is the interaction between beaver-impacted habitats and high-density populations of herbivores such as deer, due to potential impacts from browsing on regrowth (i.e. suckering and coppicing) or new recruitment.

### 4.3.4 Further research since the Scottish Review

Limited research published since the release of the Scottish reports has reinforced the evidence base for already expected and known effects. For instance:

- Beavers have significant positive impacts on the creation of deadwood, although this is primarily indirectly through flooding rather than felling. Frequent flooding of a given area may limit the source of deadwood, consequently there are unknown impacts on the long-term large deadwood resource (Misiukiewicz *et al.* 2018).
- Thompson *et al*. (2016) studied deadwood generation/dynamics in boreal wetlands and riparian forests under intensive forest management. They found beaver-induced flooding created abundant volumes of deadwood in areas rarely experiencing other disturbance types. The roaming lifestyle of beavers led to repeated flooding which produced pulses of deadwood. The authors concluded that beavers are an economic option for deadwood creation and accumulation compared to costly and time-consuming man-made restoration.
- Beavers have a beneficial impact on plant species richness, with new evidence pointing to the benefits beavers can make when restoring systems from degraded agricultural land (Law *et al*. 2017).
- Beavers can influence the abundance of species they highly prefer across a catchment (Herbison and Rood 2015).
- Beavers open the canopy and, in high impact areas, can move woodlands toward younger age structures, but also generate open space, including beaver meadows (Rentch *et al*. 2015; Law *et al*. 2017).

### 4.3.5 English context

The findings from the Scottish Review are highly relevant to the English situation. There is a broad overlap for many woodland species and types assessed as part of the Scottish Review (Stringer *et al*. 2015). As documented in the Review, the major impact of the beaver activity listed above is likely to be in wet woodland and riparian woodlands. The Habitats Directive Annex 1 woodland type most likely to be affected is therefore H91E0 Alluvial forests with Alder (*Alnus glutinosa*) and Ash (*Fraxinus excelsior*)[10]. The woodland Annex 1 habitats found in England but not assessed in Scottish studies are:

- Atlantic acidophilous beech forests with holly (*Ilex)* and sometimes also yew (*Taxus*) in the shrub layer (*Quercion robori-petraeae* or *Ilici-Fagenion*).
- *Asperulo-Fagetum* beech forests.

[10] https://sac.jncc.gov.uk/habitat/H91E0/ [accessed 11/06/2021]

- Sub-Atlantic and medio-European oak (*Quercus spp*) or oak-hornbeam (*Carpinus betulus*) forests of the *Carpinion betuli.*
- Old acidophilous oak woods with *Quercus robur* on sandy plains.
- English yew *(Taxus baccata*) woods of the British Isles.

None of these habitats could be described as wet woodland, and they are unlikely to occur in the immediate riparian zone, so there is not expected to be significant overlap between beaver habitat and these habitats in England. Many of the sites notified as SACs for these habitats are old growth examples with large numbers of ancient trees. Although beavers can fell trees of >1 m in diameter, they tend to favour small saplings (Haarberg and Rosell 2006).

Ash is a preferred species for beavers and, usually, a good re-sprouter. However, Ash dieback (*Hymenoscyphus fraxineus*) reduces a trees ability to cope with coppicing, and trees may die more quickly as a result of beaver impact (Forestry Commission England 2018). Ash is a common riparian tree, and arguably more common in England than Scotland. It is expected that, beaver influence on ash is likely to be highly heterogeneous across the landscape.

The broad benefits of beavers to woodland species, highlighted in a number of the Scottish publications, as well as from other areas, will likely remain true in an English context (Rosell *et al*. 2005; Stringer *et al*. 2015; Stringer and Gaywood 2016).

Specific effects that may particularly impact English woodlands can be predicted utilising the recently published National Forest Inventory's Woodland Ecological Condition of Great Britain (NFI-WEC) (Ditchburn *et al*. 2020). This assessed woodland condition against 15 key metrics. For wet woodlands in England, 49% are in unfavourable or intermediate condition for their vertical structure. The UK State of Nature report (Hayhow *et al.* 2019) also highlighted that a lack of woodland management was a key cause of biodiversity decline (Hayhow *et al*. 2019). The impacts of beavers on vertical structure could be a crucial beneficial impact for riparian woodlands in England.

The NFI-WEC reported that 80% of English wet woodlands have low levels of deadwood (<20 $m^3$ per ha), with 42% of English native woodlands predicted to have no detectable deadwood. Beavers may have a beneficial effect for deadwood, however predictions are complex. While beavers will increase levels of woodland deadwood over the short to medium term, impacts on large deadwood over the long-term are unknown.

While the decline in active management of woodland is believed to be a significant factor in the loss of diversity in woodlands in general (Hayhow *et al*. 2019; Ditchburn *et al*. 2020), wet woodlands have been particularly severely affected by modifications to hydrological processes in catchments and floodplains, in common with all other wetland habitats (Natural England In prep; Mainstone *et al*. 2018). The major impacts have been through land drainage both within woodlands and in surrounding landscapes, and groundwater abstraction, leading to desiccation of surrounding land and loss of wetland features within open and wooded habitats. In addition, the widespread nutrient enrichment of surface water and groundwater has had severe effects on the composition of wet woodlands, with an increasing dominance of a few species such as nettle at the expense of more diverse communities. Through dam building, beavers have the potential to increase standing water which may benefit wet woodlands.

Wet woodland and river restoration programmes in important areas of alluvial woodland, for example, the New Forest[11], have typically used heavy machinery and large capital works programmes to achieve similar outcomes to those likely to be brought about by beavers. The potential benefits to this habitat from beaver activity could be very significant at much lower cost. Due to their significant ecosystem engineering abilities, over the longer term, however, impacts on trees and existing woodland will need to be carefully monitored, in particular interactions with high-density deer populations.

### 4.3.6 Identification of areas of potential conflict in England

A potential area for conflict between beaver and woodlands in England is beaver herbivory interacting with high-density populations of other herbivores as was identified in the Scottish Review. This is a key issue that is not unique to beavers; high-density deer populations are a key threat to England's SSSIs. Deer density is high in many areas of England; with a more diverse mix of deer species and different legislation to Scotland. Deer will be an issue for any form of woodland management promoting regeneration, an activity essential for biodiversity conservation (Hayhow *et al*. 2019). For beaver influenced habitats, the interaction will be highly variable across the landscape. The NFI-WEC reported that tree regeneration within wet woodlands at local and population levels was favourable at only 8% and 17% of sites respectively. Long-term monitoring is needed to evaluate whether the interaction with deer becomes an issue.

Grey squirrels (*Sciurus carolinensis*) also pose a threat to woodlands through the damage they cause to trees by bark stripping. Although trees younger than 10 years are not normally damaged because their stem and branches are too small to support a grey squirrel, naturally regenerated trees aged between 10 and 40 years are particularly at risk (Mayle *et al*. 2007). Monitoring is advised to assess whether this could pose a risk to woodland regeneration in the longterm.

It would be beneficial for individual trees of particular value (sentimental or otherwise) to be identified in advance of beavers becoming established in an area so that appropriate measures than be undertaken to protect them from felling (e.g. through the use of wire mesh tree guards or anti-game paint; Campbell-Palmer *et al.* 2016).

### 4.3.7 Potential future implications of wider reintroductions in England

By increasing habitat heterogeneity, diversifying woodland age structure, and causing an influx of deadwood, beavers will likely have large and significant positive impacts in under-managed and often drained riparian woodland across the country.

[11] http://www.iucn-uk-peatlandprogramme.org/sites/www.iucn-uk-peatlandprogramme.org/files/New%20Forest%20LIFE%20III%20Project%20Report.pdf [accessed 11/06/2021]

# 4.4 What are the effects of beavers on fish assemblages?

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## 4.4.1 Summary of main findings and recommendations

There is limited evidence demonstrating how beaver activity may influence fish populations in Scotland, with no negative impacts noted (Gaywood 2015). There is limited evidence demonstrating that beaver activity influenced spatial variability in fish populations in the River Otter, England (Brazier *et al*. 2020). Potential impacts to anadromous fish could not be assessed within these specific study locations due to an absence of such fish species at these sites.

The evidence relating to the potential benefits and/or impacts to fisheries by beavers is equivocal, reflecting the high number of variables when assessing the potential impact of changes resulting from beaver activity, spatial and temporal variation, species diversity and the long timescales necessary to observe ecological responses, particularly at the population level. Strong evidence demonstrates that the activities of beavers can be associated with positive impacts for fish through increases in habitat heterogeneity and complexity (Hägglund and Sjöberg 1999; Pollock *et al*. 2004; Mitchel and Cunjak 2007; Parker and Rønning 2007; Tate *et al.* 2007; Kemp *et al.* 2010; Kesminas *et al.* 2013; Smith and Mather 2013; Bouwes *et al.* 2016; Majerova *et al.* 2015; Puttock *et al.* 2017; Weber *et al.* 2017; Johnson-Bice *et al.* 2018; Puttock *et al.* 2018; Majerova *et al.* 2019; Brazier *et al.* 2020) and a survey of European and North American fish experts conducted as part of a review on the qualitative and quantitative effects of beavers on fish found that the majority considered beaver to have an overall positive impact on fish populations (Kemp *et al.* 2012). However, medium evidence is also demonstrated for potential negative impacts such as inhibitions on free movement throughout the river, localised changes in habitat structure, prey availability, increased predation, thermal regime, etc (Hägglund and Sjöberg 1999; Collen and Gibson 2001; Elmeros *et al.* 2003; Mitchell and Cunjak 2007; Taylor *et al.* 2010; Kemp *et al.* 2012; Virbickas *et al.* 2015; Cutting *et al.* 2018; Johnson-Bice *et al.* 2018).

Where the impacts of beaver on aquatic habitats are considered at a suitably broad temporal and spatial (catchment-) scale, the increase in habitat diversity and dynamism brought about by beavers is likely to result in more diverse fish populations with greater ability to sustain themselves, particularly in the face of climate change. Ensuring there is adequate space for restoring more natural river and lake ecosystem function will help to ensure that benefits to fish assemblages are maximised.

## 4.4.2 Introduction

Beavers, as habitat engineers, have the ability to dramatically alter the water environment in ways that have the potential to impact fish in both positive and negative ways. The consequences of habitat changes will vary depending on a multitude of factors including the fish species in question, its life-stage, river/lake typology, beaver dam characteristics and longevity, and other environmental conditions such as flow and temperature. Impacts are also likely to be dynamic and will vary both spatially and temporally (Kemp *et al.* 2010; Johnson-Bice *et al.* 2018).

The main mechanisms of interaction between beavers and fish are associated with beaver dam building activities and the resultant changes to habitat connectivity and shift from lotic (flowing) to lentic (still) habitat upstream of the dam, and conversely downstream and adjacent to dams with the development of a mosaic of flow patterns. The presence of beavers can have significant impacts on channel morphology and floodplain connectivity, sediment storage and delivery, hydrology, temperature regimes, and aquatic biodiversity, all of which have the potential to affect fish populations (Kemp *et al.* 2012).

The complex range of interactions between beavers and fish is an important factor when considering beaver reintroduction. The pressures impacting fish populations (such as agricultural intensification, human population growth, water availability, climate change, and wider marine issues in the case of migratory species) have changed considerably over the centuries since beavers became extinct in England. Consideration is needed to determine whether beavers could add additional pressure to some already threatened and protected fish species or restore and improve conditions for these species alongside natural habitat restoration and creation, so providing a collective increase in Natural Capital and associated ecosystem services.

### 4.4.3 A summary of the findings from the Scottish Review

- The impact of beaver activity on the upstream and downstream migration of freshwater fish, and on the habitats on which they depend to complete their life cycles, is poorly understood.
- Attention has been focused on Atlantic salmon (*Salmo salar)* and brown trout (*Salmo trutta*) because of their cultural and economic significance. The impact of beaver activity on other fish species is not fully understood.
- The complex ecology means that many of our native fish species have the potential to interact with reintroduced Eurasian beavers and, in fact, these fish will have co-existed with beaver for millennia prior to their extinction in Scotland.
- The mechanisms by which beavers change environments and affect biodiversity include creating ponds and wetland, altering sediment transport processes, importing woody debris into aquatic environments, creating important habitat features.
- There may be potential benefits of beaver presence for migratory salmonids, but there may also be possible adverse impacts, especially on the spring stock component of Atlantic salmon located in the upper reaches of catchments and therefore more likely to be affected by beaver dams.
- Despite the paucity of native freshwater fish species in Scotland, their diverse ecology would suggest that some species may benefit more than others from beaver mediated habitat modification and habitat creation.

    - Species, such as cyprinids and trout, may benefit from the creation of beaver ponds. Species such as pike (*Esox lucius*), perch (*Perca fluviatilis*) and European eel (*Anguilla anguilla*) may also benefit, given their ability to utilise a wide range of running and standing water habitats.
    - Species, particularly migratory salmonids, may experience adverse impacts.
    - Such studies are few and it is clear that a better understanding of the interactions between beaver activity and freshwater fish is necessary.
- The scale and direction of the impact of beavers on fish will differ according to the species concerned and its ecology.
- The conclusions reached in the available studies are varied. This is also complicated by the fact that some of the data available come from areas where beavers have been reintroduced and management is varied.
- Impacts are expected to be complex, with variation in the positive and negative impacts for different species, across different sites and at different times. Overall, it seems likely that, even in the absence of human intervention, some species will not be affected, or may benefit, at the catchment scale. There are other species where the impacts are less clear, and this is particularly pertinent in relation to migratory species. Appropriate research and monitoring will help to identify impacts and inform management, which in turn can be designed to help mitigate any negative impacts and foster positive impacts.
- In relation to protected species specifically the report concludes:
    - Atlantic salmon (listed in Annexes II and V of the Habitats Directive) – there is a high likelihood that beavers will interact with this species, and that there will be some impact, both positive and negative. There is uncertainty over what the precise impacts will be. Overlap between potential beaver habitat and Atlantic salmon habitat has been estimated at 47–73% in six study catchments.
    - Brook, river and sea lamprey (*Lampetra planeri*, *L. fluvialtilis* and *Petromyzon marinus*) (brook and sea lamprey are listed in Annex II of the Habitats Directive and river lamprey in Annexes II and V) – there is a high likelihood that beavers will interact with these species, and that there will be some impact, both positive and negative. There is uncertainty over what the precise balance and direction of those impacts will be.
    - Allis and twaite shad (*Alosa alosa* and *A. fallax*) (listed in Annexes II and V of the Habitats Directive) – there is a low likelihood that beavers will interact with these species directly as they inhabit lower reaches of larger rivers where dam building is less likely.

The additional points below are relevant when considering the evidence presented in relation to the Scottish Beaver Trial (SBT) at Knapdale:

- Although Knapdale was well suited to assessing the impact of beavers on a range of habitats and species, it was not an ideal place to study the impacts of beavers on fish because no anadromous fish were present within the study area.
- The impact on individual fish species and local populations is extremely difficult to predict due to the short time period over which post-release monitoring was carried out, coupled with high variation in the number of young produced year to year by different fish species.
- Impacts such as increased riparian tree-felling and exposure of the water to sunlight, increased amounts of woody material and other plant material present in the rivers, dam-building and related effects on geomorphology, river habitat and the movement of fish

species, will all result in an overall change to the freshwater system. This may benefit some fish species, although the impact of dams on movement may have a particular impact on some species under certain conditions and at certain times of the year.

### 4.4.4 Further research since the Scottish Review

**Impacts on fish movement**

A number of recent studies have sought to resolve the question of fish passage at beaver dams. Virbickas *et al.* (2015) presents the findings of a two year study of anadromous salmon and trout restoration success on two, third order tributaries of the Šventoji River in Lithuania. They found that beaver dams impeded the upstream migration of adult anadromous salmonids, as evidenced by a lack of detection of spawning redds in upstream sections in both years of the study. Tagging experiments demonstrated that successive dams were passable to some juvenile sea trout travelling upstream, with only the single upmost dam potentially impassable. There was also an increase in abundance of juvenile salmonids in the stream section between beaver dams in November, demonstrating the ability of juveniles to pass at least the lowest dam. Construction of an additional four dams during the duration of the study resulted in a fourteen-fold decline of Atlantic salmon parr compared to the previous year which was only partly explained by the general declining trend of salmon parr in the river basin. The authors conclude that in their study of Lithuanian streams, fish movements were impeded by the construction of beaver dams, particularly adult spawning migrations. They highlight that whilst the impact of beaver dams on salmonids is temporally variable and a process of continual adjustment, beavers can alter vital habitat features which are critical for fish survival and reproduction in small streams that are easily dammed. Due to limited salmonid habitat availability in the lowlands of the Eastern Baltic, where generally rivers are slow running with sandy bottoms and dominated by cyprinid fish communities, they stress the importance of free passage as far upstream as possible to optimise salmonid recruitment.

Juvenile salmonid passage across dams built by European beavers was investigated by Malison and Halley (2020) in a low gradient Norwegian river. The study compared the movement of juvenile salmonids (Atlantic salmon and brown trout) in beaver-occupied and beaver-free tributaries with data taken from both sites in one year. They found that juvenile salmonids were able to pass beaver dams in both the upstream and downstream direction but a significant reduction in overall movement in dammed sections compared to clear channels was observed, i.e. fish performed more repeated upstream and downstream movements in sections free from dams. The authors suggest that beaver dams could restrict daily home ranges of juvenile salmonids rather than act as a complete barrier to movement. Alternatively, home range size could be reduced owing to enhanced habitat complexity and increased productivity created by beaver dams. As redd counts were not undertaken as part of the study, it could not be confirmed whether the presence of juvenile salmonids upstream of the dams was due to adults successfully passing the dams to spawn upstream or juvenile movement upstream following spawning (or both). The authors note that the beaver dams were quite small and frequently inundated or broken in higher flows and that the presence of the dams and ponds in the landscape was quite rare in comparison with many areas in North America. The authors conclude, therefore, that it is unlikely that expanding beaver populations will negatively affect the juvenile stages of salmon and trout populations in the province.

Cutting *et al.* (2018) investigated the upstream passage of adult Arctic grayling (*Thymallus arcticus*) in a low-gradient mountain stream in Montana, USA, comparing passage in a 'normal' flow year to that in a 'low' flow year. Overall, passage success over unbreached dams was high (88%), suggesting most dams during the duration of the study posed little threat to upstream migration. However, passage fell to below 50% at specific dams and declined during the low flow year when cumulative probability of passage across the upmost dam fell to below 20%. Increasing flows across breached dams, but not unbreached dams, was found to negatively impact passage, potentially due to the creation of a velocity barrier. Where dams had no or two hydrological links, passage probability also declined, most likely in response to a lack of hydrological cues and a corresponding reduction in scour depth of downstream pools. There is a suggestion that spawning distribution may have shifted from the historic upper reaches to be concentrated in the middle reaches due to the presence of beaver dams, which the authors suggest may impact current and future population viability. Differences in swimming velocity in dam-free sections suggested that the presence of dams was energetically costly to the grayling and may delay arrival at spawning ground with subsequent consequences for reproductive success and juvenile growth. The authors conclude that the results provide a framework that can be applied to reduce barrier effects when and where beaver dams pose a significant threat to the upstream migration of fish populations while maintaining the diverse ecological benefits of beaver activity when dams are not a threat to fish passage.

An extensive before and after study on the population of steelhead (*Oncorhynchus mykiss*) in a catchment in Oregon, USA (Bouwes *et al.* 2016), found neither beaver dams nor beaver dam analogues (simulated beaver dams designed to partially replicate many of the basic functions of a natural beaver dam and also stable structures on which beavers were encouraged to build on) were a barrier to spawner or juvenile migration. There was no change in upstream spawner migration as a consequence of beaver dams based on detections of PIT-tagged spawners at upstream arrays, with 92% of tagged spawners above detection site prior to dam presence compared to 93.5% post-manipulation. Several spawners were documented as having passed 200 dams upstream. Over 1000 PIT-tagged juveniles were also recorded migrating downstream.

Malison *et al.* (2016) report that a large proportion of the rearing habitat was cut off behind numerous, apparently impassable, dams in a river system occupied by beaver in the Arctic. Consideration should be given to differences in pristine Arctic catchments in this study due to their undisturbed and braided character (dominated by springbrooks, a stream type) compared to English rivers which are generally altered to varying degrees. The report notes that there is potential for the presence of beavers to degrade pristine fish habitat as well as improve degraded habitat. In the English context 'pristine habitat' would be described as un-impacted habitat which is underpinned by the natural biotic and abiotic processes that support it. The resulting habitat mosaic would be suitable for all aquatic species typical of a geographic area and river typology, rather than pristine 'fish' habitat *per se*. The species present within such a habitat will themselves interact with and modify that habitat. If a species that would normally be present within a habitat is extirpated by human activity, it is unlikely that such a habitat could be considered fully naturally functioning and therefore not pristine (Mainstone *et al*. 2016).

There is limited, but informative, data available on fish species other than salmonids from a number of recent studies. Bashinsky and Osipov (2016) observed Ukrainian brook lamprey (*Eudontomyzon mariae*) spawning below the lowest beavers dam which, when combined with an absence of lamprey in the higher parts of the catchments, suggested that beavers dams may present a complete barrier and may negatively affect the life cycle of the species in the study. They also found that adult and yearling pike could become trapped in beaver ponds until high flow events. Popkov *et al*. (2018) and Rohzkova-Timina *et al*. (2018) found that beaver dams inhibited the movement of fish (pike and perch) between lake and river habitat, resulting in fish mortalities associated with low lake oxygen levels. Recognising where such impacts are caused or amplified by poor background environmental conditions is important in such cases. Virbickas *et al.* (2015) found that the river sections downstream of beaver dammed sections had significantly higher abundance of minnow (*Phoxinus phoxinus*), bullhead (*Cottus gobio*), stone loach (*Barbatula barbatula*) and trout compared to upstream sections, whereas roach (*Rutilus rutilus*) and perch were significantly more abundant in upstream section in comparison with downstream section. Brazier *et al.* (2020) reported higher density and biomass of brown trout and higher numbers of bullhead and minnow in downstream sections. Upstream section assessments were made in the impounded section immediately above the dam and a reduction in the abundance of bullhead was observed.

**Habitat**

The ability of beavers to restore habitat for Pacific salmonids in an incised channel is the focus of Bouwes *et al*. (2016). In a catchment scale experiment in Oregon, USA, using Beaver Dam Analogues to simulate natural beaver dam construction, the before-after comparison of the steelhead population documented a 175% increase in productivity compared to a control catchment. Juvenile survival increased 52% compared to the control. Fish density increased, though this resulted in a density dependent decrease in growth. The large increase in productivity was mainly attributed to an increase in habitat quantity – new channels cutting through the floodplain increased the area of side channels by 1216% - but a potential additional role of increased habitat complexity is also suggested.

The potential mechanisms by which increasing habitat complexity can enhance population productivity is further explored in Wathen *et al.* (2019). The study, carried out in the same catchment as Bouwes *et al*. (2016), demonstrated that habitat variability enhanced the ability of individuals to select different habitat types depending on their requirements. Within beaver complexes, individual movement was found to be more variable due to the wider range of suitable habitat available compared to the control site. The authors conclude that increased spatial partitioning (i.e. specialized movement behaviour) is a potential mechanism which increases the carrying capacity of steelhead in habitats altered by beavers. They also suggest diversification of foraging behaviours (associated with greater diversity of invertebrate prey) could be another potential factor causing increased abundance of steelhead.

Several studies from North America have suggested that beaver ponds provide important habitat for Pacific juvenile salmonids. However, Malison and Halley (2020) noted that only a small number of juvenile salmonids (3.8%) were recorded utilising this habitat and, contrary to expectation, they did not observe any trout using the ponds either. They note that if ponds are not preferred rearing habitat, this may suggest a deviation from the evidence obtained from the study of juvenile Pacific salmonids. However, their data represent a single year of study and no ecological response was observed in other ecological variables (e.g. invertebrates). Johnson-Bice *et al.* (2018) highlight that maximum benefit to salmonids occurs after 2-4 years of beaver dam construction, so studies such as Virbickas *et al.* (2015) and Malison and Halley (2020) may not to fully capture the ecological response at the small spatial scales of habitat modification observed in these studies.

Virbickas *et al.* (2015) considered it likely that beaver dams had an adverse impact on salmon parr due to flooding or dewatering of their habitats. Salmon parr were absent above the dams in one catchment and the abundance of trout parr was significantly lower above the dams in comparison to downstream sections in both rivers. The authors attribute this to a loss of suitable habitat in combination with restrictions in juvenile and adult movement associated with beaver dams. However, an observed increase in the abundance of juvenile salmonids in beaver ponds coinciding with the autumn migration of spawning adults suggests that beaver ponds may provide refuge habitat from potentially aggressive adult males during this period.

Petro *et al*. (2015) investigated the feasibility of relocating beavers as a method to enhance in-stream habitat for salmonids in the Pacific Northwest, USA. Site selection for relocation was based on modelling of beaver dam suitability and where dams would increase intrinsic potential of coho salmon (*Oncorhynchus kisutch*). Mortality of relocated beavers was high due to predation by cougars (*Puma concolor*) and illness, with stress a possible additional contributor. They observed that relocated beavers constructed few dams and those that were constructed were regularly destroyed by high flows, resulting in no instream habitat for coho salmon.

In a study on the consequences of beaver presence on a non-salmonid species in the Upper Snake River Basin, USA, Dauwalter and Walrath (2018) found a positive response; northern leatherside chub (*Lepidomeda copei*) – a rare type of drift-feeding minnow - were present more often at sites with complex streamflows, and that this complexity was linked to beaver dam activity.

Gibson *et al.* (2015) investigated how beaver ponds influence the structure of mixed native and non-native fish assemblages in the Verde River system, Arizona, USA. Non-native species were found to dominate fish assemblages to a greater extent in pond habitat compared to lotic habitat. The study reported that the extent to which this is likely to impact the native fish communities in lotic habitats will depend on the extent which the dam’s influence extends beyond the pond and that there is potential for upstream beaver pond habitat to act as a source population for non-native species.

The impacts of beaver on standing water habitats are covered in section 4.2, however, as standing waters represent an important habitat for fish, interactions between beaver and fish in these habitats should be noted. The literature generally refers to the physical impacts of beaver on standing water habitats, rather than the fish populations contained within them. The impacts likely to be of most relevance to fish species and assemblages include beaver herbivory, sediment inputs from the surrounding catchment and ease of fish movement between lake inlet/outlet water courses.

Beaver herbivory may impact on aquatic plants (Stringer *et al.* 2015) with associated impacts on fish cover, predator/prey interactions, substrates for egg deposition and water quality. Herbivory in littoral and riparian areas may also lead to changes in hydrosere development, with tree felling producing a more open canopy and an associated increase in emergent vegetation, potentially to the benefit of fish populations. Light grazing pressure may lead to a more diverse, species rich plant community with the development of an increased mosaic of micro-habitats available to resident fauna, including fish (Law *et al*. 2014). Alternatively, heavy grazing of vegetation may lead to a reduction of habitat structure, to the detriment of associated fish species and assemblages.

A number of fish species associated with lakes in England, such as brown trout and bullhead, require clean gravels for spawning, either within the lake basin or within/adjacent to inlet/outlet streams. Other representative fish species are considered glacial relicts and include species such as Arctic charr (*Salvelinus alpinus*), vendace (*Coregonus albula*) and whitefish (*Coregonus lavaretus*), these are some of the rarest and most sensitive fish species in English freshwaters. Smothering of spawning gravels by deposition of fine sediment resulting from excessive inputs from the surrounding lake catchment has been cited by Winfield *et al.* (2004) as a negative pressure on these species. Beaver have the ability to alter sediment movements within catchments, therefore, in situations where beaver reduce the inputs of fine sediment to lakes containing sensitive fish species they may be expected to have a positive impact, conversely where they increase inputs they may have a negative impact.

Many species of fish move between lake basins and their inlet/outlet water courses. The extent to which beaver activity either helps or hinders these movements will dictate whether beaver activity has a positive or negative impact on fish populations.

**Temperature**

Majerova *et al.* (2015) investigated the impacts of increasing beaver dam construction on temperature at different spatial and temporal scales in a mountain stream in Northern Utah, USA. At the reach scale, there was an overall downstream warming effect due to beaver dam building activity, with temperatures increased by 3.8% (0.38˚C) over the three years of study. This was attributed to a large (230%) increase in mean reach residence time and increase in surface area, and consequent influence of solar radiation, which negated any cooling effects of water volume or increased groundwater input. Individual beaver dams were found to influence the system in different ways, reflecting differences in the construction and nature of beaver dams, with multiple dams leading to cumulative increases. However, the beaver dam scale revealed more complexity in temperature variation with warmer and cooler niches created. Temporal changes were also observed with a lag in peak daily temperatures observed during the study period.

The thermal heterogeneity of beaver dams is further explored in Majerova *et al.* (2019). In this North American study, the warming effects of multiple beaver dam complexes resulted in a 2°C increase in longitudinal stream temperature. Although some temperatures in some river sections were unsuitable for fish during the low flow and warm season, the observed habitat diversity was predicted to have beneficial effects during colder times of the year. Thermal stratification was not observed in the pool but did occur in the backwater, likely as a result of varying depth and low velocities that minimise lateral and vertical mixing and increased residence times. Combined with vegetation growth, the cool bottom layers of the backwater are likely to represent important thermal refugia for fish during summer months and create fish habitat due to the vegetative cover.

Weber *et al.* (2017) report, for a study in North America, a beneficial effect of beaver dam complexes for cold water fish populations occupying environments that may be at or near their thermal maximum. Maximum summer stream temperatures were found to be lower in stream sections featuring a high density of beaver dams. Prior to the presence of beaver dams (and beaver dam analogues), maximum daily temperatures are reported to have commonly exceeded 25°C in August. Following dam proliferation, daily temperatures rarely exceeded 25°C whereas temperatures at a control site experienced a similar annual temperature regime. It is also reported that this temperature buffering continued for several hundred metres downstream into unimpounded reaches, thereby greatly increasing the availability of thermally suitable salmonid habitat. Observations suggested an increased distribution of groundwater upwelling zones within beaver complexes that were 10°C cooler than surface water temperatures, providing important thermal refuge critical to survival in warmer waters.

In a study of beaver dams in Oregon, USA, Bouwes *et al.* (2016) observed a 1.47°C reduction in temperature in reaches with beaver dams compared to those without and that daily temperature fluctuation was dampened. Daytime and night time temperatures were cooler and increased temperature heterogeneity was observed including cold refugia. Similar temperature heterogeneity within the beaver dam complexes is reported by Wathen *et al.* (2019) for the same catchment.

The majority of studies present the view that increased temperature complexity, associated with increased habitat heterogeneity, offers greater potential for some fish to select optimal temperatures during daily and seasonal variations although this will vary across river typologies, season and circumstance.

**Water quality**

In a study of the impacts of beavers on the ecosystems of rivers in the Privolzhskaya Lesostep' State Nature Reserve, Russia, Bashinsky and Osipov (2016) found that water quality in older beaver ponds deteriorated due to reduced oxygen concentrations which resulted in a decrease in abundance of fish. In their review of beaver-salmonid studies in the Western Great Lakes Regions, USA, Johnson-Bice *et al*. (2018) also found a generally negative effect of beavers on dissolved oxygen levels.

There are a number of recent papers regarding morphological change and decreased sediment levels in beaver modified habitat (reviewed in section 4.1 running water) which may also offer potential habitat benefits for fish. In addition to the well-documented requirements for clean gravels for spawning by a variety of native English fish species in lotic environments, the benefits of reduced siltation of spawning gravels by catchment derived fine sediment to Coregonid species in English lakes have been highlighted by Winfield *et al*. (2004).

**Species diversity/biomass**

Bashinsky and Osipov (2016) found fish species diversity was greatest in undammed streams and lowest in young beaver ponds in their study in Russia. However, overall fish biomass was greater in beaver ponds. In their review of 89 studies on the environmental effects of beaver, Ecke *et al*. (2017) found a lower overall fish abundance/diversity upstream compared to downstream of beaver impoundments. However, when considering salmonids specifically, there was no overall adverse net effect on salmonid abundance or migration due to beaver dams.

Virbickas et al. (2015) found no difference in species diversity or Shannon Weiner diversity index in the different sections of two Lithuanian streams due to the presence of beaver dams, but reported a more even representation of species in the community upstream of the beaver dams compared to downstream.

Brazier *et al*. (2020) reported that two beaver-impacted reaches (ponded water behind dams) in Devon, England contained higher biomass of brown trout. Different life stages were supported with mature adults in pool and juveniles in downstream riffles. Bullhead numbers were however reduced in the ponded water behind the dams, probably due to the unsuitability of the habitat here for this species. Total fish abundance in the beaver pool was 37% higher than the other three reaches. The report recognises the short timescale of the trial and that the trial did not offer opportunities to study all fish types, although a variety of other species were also included.

### 4.4.5 The English Context

Evidence from research published since the production of the Scottish report continues to present a complex picture on the impacts of beavers on fish populations. This reflects the high number of variables when assessing the potential impact of changes resulting from beaver activity, spatial and temporal variation, species diversity and the long timescales necessary to observe ecological responses, particularly at the population level.

The overall balance of impact (potential positive and negative) of beavers on fish will be dependent on a multitude of factors including the fish species in question, its life-stage, water body typology, beaver dam characteristics and longevity, and other environmental conditions such as flow and temperature, and may vary across space and time, beaver population density and the prevailing constraints on the local fish species composition and abundance. Where the impacts of beaver on aquatic habitats are considered at a suitable temporal and spatial scale that removes individual bias, the balance of evidence indicates a strengthening of the natural processes that underpin those habitats, resulting in an increase in fish habitat quality and the potential for positive population level effects.

### Diversity of native fish species

The number of fish species occurring in Scottish rivers is naturally limited and dominated by very few species. The Scottish Fisheries Classification System (FCS2) for the River Basin Management Plan reporting is based on two fish species; Atlantic salmon and brown trout. In contrast, the FCS2 in England (and Wales) includes 23 prevalent native fish species (WFD-UKTAG 2008). There is a paucity of information regarding the interactions of the full range of fish species with beavers (Kemp *et al*. 2010; Gaywood 2015).

In English rivers, the individual habitat preferences of the wide range of native fish species typically results in changes in community structure along the upstream-downstream gradient (Environment Agency 2004). These habitat requirements have been used to classify different river zones based on the species typically found in these habitats moving from the upstream 'trout' zone, to the midsection 'grayling' and 'barbel' zones to the 'bream' zone in the lowest river section. This reflects changes in stream gradient, width and depth and their subsequent effects on stream velocity, temperature, substrate and other biological factors. Similar factors are known to influence beaver damming activity.

Beaver dams are generally built on small, shallow streams, generally lower than 4$^{th}$ order and of less than 2.5-3% gradient (Collen and Gibson 2001; Hartman and Törnlöv 2006; Johnson-Bice *et al*. 2018). Consequently, their damming activities are most likely to overlap with the distribution of species such as trout, salmon, bullhead (where they occur), stone loach and lamprey species, but may extend to other species depending on individual catchment characteristics. This zonation may therefore play an important role in assessing the risks and benefits for fish of beaver reintroduction in England.

Favourable impacts associated with the creation of lentic habitat are reported for species such as roach, pike and perch (Gaywood 2015), but these benefits will only be realised if the species are present in the locality of beaver activity (Bylak *et al*. 2014). A study found that beaver dams can act as a complete barrier to the movement of roach (Elmeros *et al*. 2003), and therefore potentially similar coarse fish species, so some downstream populations may not be able to exploit beneficial upstream habitat. However, there is evidence that should such species be present upstream of dams, the productive juvenile habitat within beaver ponds may act as a source for downstream populations (Fausch *et al*. 2002).

The wider catchment restoration benefits of beavers on factors such as sedimentation and hydrology may extend throughout fish zones, including fish species resident within lake habitats. Positive or negative benefits must also be considered in terms of locally non-native fish species, together with nationally native species. An example of this may include where the distribution or migratory activity of a locally non-native fish species was impeded by beaver activity, potentially to the benefit of other locally native species.

### European Protected Species

The European Protected Species considered in the Scottish report (Atlantic salmon, brook, river and sea lamprey, Allis and Twaite shad), are also present in a number of English river catchments. In addition to these, bullhead and spined loach (*Cobitis taenia*) are Annex II species listed as an interest feature in a number of English Special Areas of Conservation

(SACs). Reports suggest significant declines upstream of beaver dams in bullhead (Virbickas *et al*. 2015) and the Siberian bullhead (*Cottus poecilopus*) (Bylak *et al*. 2014) and significant increases in minnow, bullhead and total fish abundance downstream of dams (Virbickas *et al*. 2015). The River Otter Beaver Trial (ROBT) observed a reduction in the abundance of bullhead in beaver pool habitat, even though the availability of suitable habitat between ponded reaches and downstream of dams was reported to have increased (Brazier *et al*. 2020). Beaver dams may represent a complete barrier to movement in this species (barriers of 18-20 cm have been found to be impassable to upstream bullhead movement; Utzinger *et al*. 1998) and/or habitat degradation may exclude them from beaver pool habitat. Access to upstream habitat may be reliant on the occurrence of a bypass channel and will be monitored further as part of the ROBT. No information is available on the potential impacts of beaver on spined loach, though they may benefit from the availability of slow, silted pond habitat as they are morphologically adapted to live and feed within silt as adults.

**Nationally protected species**

Certain fish species or assemblages may gain additional protection under domestic conservation legislation as ‘Ecotypic or genetically distinctive fish populations’. Examples of these species include: Arctic charr, vendace and whitefish. In England these species are found in lake habitats, however, they require clean gravels in littoral areas or inlet/outlet streams for spawning. Siltation of spawning gravels due to the delivery of excessive fine particulate matter from the surrounding catchment has been stated as having a negative impact on these species (Winfield *et al*. 2004). While the outcome is uncertain, it is therefore possible that the ability of beaver dams to slow fine sediment movement and delivery to downstream lake habitats may prove beneficial to the continued survival of these rare fish species in England.

**Invasive non-native fish species**

There are a number of non-native fish species present in English waters and the potential impacts of beavers on their distribution and abundance requires consideration. Non-native fish species that favour pond habitats have been reported to gain advantage from from beaver reintroduction in North America (Gibson *et al*. 2015). It is currently unknown if similar opportunities would be exploited by English non-native species such as pumpkinseed (*Lepomis gibbosus*), sun bleak (*Leucaspius delineates*), zander (*Sander lucioperca*), wels catfish (*Silurus glanis*) (and other catfish species), common carp (*Cyprinus carpio*) and top-mouth gudgeon (*Pseudorasbora parva*). In addition, locally non-native species may be positively or negatively affected by habitat change.

**River typologies**

The range of river typologies in England is more extensive and different to those found in Scotland with potential significance to the interpretation of existing data from other countries (see Gurnell *et al*. 2009). This includes the Southern England chalk streams, of which a number are SACs, with Atlantic salmon as a designated feature. There is no available literature specifically covering chalk streams for potential impacts, both positive and negative, although some known changes to habitat and temperature may be of potential importance to southern chalk streams and karst aquifers (Weber *et al*. 2017). Most research into the interactions between beavers and fish has been conducted in mountainous areas (Johnson-Bice *et al*. 2018) and there is recognition that findings from such studies may not be applicable to British catchments (Parker and Rønning 2007). Two recent studies in more lowland catchments in Lithuania (Virbickas *et al*. 2015) and Norway (Malison and Halley 2020) carried out empirical studies regarding fish passage and present a mixed picture on the likely impacts of beavers on salmonids in the studied catchments. Bouwes *et al*. (2016) note that in low-gradient systems with a reduced range of water velocities, beaver dams may not create the same heterogeneous environment as they do in relatively higher gradient systems. The increased range of typologies in England may provide opportunities for restoration to the benefit of fish, but there are also likely to be risks and challenges.

**Modified rivers**

The relatively high proportion of highly modified rivers in England is an important consideration. Benefits for salmonid species through beaver activity are often associated with channel widening due to water passing around beaver dams and water spreading across the floodplain (e.g. Bouwes *et al*. 2016). Fish passage is also often enabled by natural rerouting of water around beaver dams (Lokteff *et al*. 2013; Cutting *et al*. 2018). Disconnection of the channel and floodplain is considered one of the primary pressures which led to the relatively recent extirpation of the burbot (*Lota lota*) from the UK (Worthington *et al*. 2012). In Scotland, concerns over the applicability of results of studies conducted in different regions in relation to the Scottish situation is highlighted (Kemp *et al*. 2010). Feedback from an Expert Opinion Survey within the study, made up of European and North American experts and practitioners, suggested that in an intensively managed landscape, such as in Great Britain, in which some rivers may be constrained from physically responding to European beaver activity in a natural way, the widely reported benefits of beaver activity on fish stocks may, in these locations, be outweighed by negative impacts (Kemp *et al*. 2010).

**Climate and river flow**

The climate and water resource situation in England are considered to influence the applicability of some study findings. Benefits for salmonids associated with reduced winter ice cover may be of limited relevance to English river catchments, as noted for other temperate countries (e.g. Virbickas *et al*. 2015). Benefits for salmonid productivity associated with year-round increased stream temperatures may not be applicable in some English catchments where upper thermal tolerance is already reached/being approached for salmon and trout in some rivers (both in summer and winter, during spawning). Consequently, it is thought there may be less advantage from the presence of beavers for salmonids in warmer streams with lower altitude/gradient (Collen and Gibson 2001; Kemp *et al*. 2010; Bouwes *et al*. 2016; Johnson-Bice *et al*. 2018), although thermal buffering and stratification may provide benefits (Weber *et al*. 2017). Passage issues for salmonids have been found to occur during low flow conditions (Parker and Rønning 2007; Cutting *et al*. 2018), with the potential for fish to become stranded during periods of drought (Tambets *et al*. 2005). Kemp *et al*. (2010) highlight the importance of considering climate change predictions and the potential impacts to fish passage during prolonged periods of low flow. The situation may be more enhanced in English rivers due to the warmer, drier climate and higher demands on water resources in some locations. As reported in other countries, there is potential for this to be balanced by the benefits for fish populations offered by stabilised flows (mitigation of high and low flow events), habitat heterogeneity and connectivity, woody debris refuges and possible refuge during periods of drought. The frequency and magnitude of extreme high and low flow events is predicted to increase in the future due to climate change, therefore, it is possible that, where they can be achieved, habitat benefits for fish delivered by beaver activity may increase over time.

**Atlantic salmon population status**

The status of salmon stocks across England has been of growing concern in recent years. Annual assessments in England and Wales have been undertaken since 1997 and the most recent assessment (based on 2019 abundance[12]) indicates that 24 out of 42 (57%) of principal salmon rivers in England are considered to be 'At Risk', with a further 15 (36%) 'Probably at Risk'. This reflects a combination of factors impacting both marine survival and freshwater productivity (Parrish *et al*. 1998). As reflected in the Scottish Review, smaller tributaries in England may provide important habitat for early running spring salmon, which tend to be the larger, multi-sea, winter fish, which may be disproportionately impacted by beaver damming activity. Greater understanding of the balance between potential benefits (associated with improved habitat heterogeneity and habitat benefits downstream and adjacent to dams) and potential negative impacts (to migration and loss of suitable spawning habitat), together with the most appropriate scale (temporal and spatial) of assessment is required to make informed decisions on catchments where salmon populations are present.

**Brown trout population status**

As highlighted in the Scottish Review, the potential of beaver activity in small streams to have a disproportionate importance for brown trout production is considered of particular relevance to the English situation, especially in the context of anadromous trout populations. Whilst salmon and brown trout, particularly anadromous 'sea' trout variants, have broadly similar ecological and habitat needs there are subtle differences which separate the two species reflecting their specific life history strategies where interaction with beavers could be different to Atlantic salmon (reviewed in Armstrong *et al.* 2003). As identified during the reviews in Scotland and elsewhere, the habitat requirements of salmon and trout directly overlap with those habitats known to be utilised by beavers. This does not infer that the level of overlap equates to the total area over which interactions between salmon and sea trout occur, nor does it predict the scale or direction of any impact. Any effect is dependent on the beaver population density and other habitats available (Kemp *et al*. 2010; BSWG 2015; Gaywood 2015; Johnson-Bice *et al*. 2018).

### 4.4.6 Identification of areas of potential conflict in England

While there are potential restorative benefits of beavers for fish as a natural consequence of a more complex habitat mosaic, which must be assessed at the appropriate spatial and temporal scales, there may also be situations where their presence results in changes that

[12] Salmon stocks and fisheries in England and Wales in 2019. Preliminary assessment prepared for ICES, March 2020. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/907284/SalmonReport-2019-summary.pdf [accessed 11/06/2021]

may negatively impact fish populations. The greatest areas of conflict are believed to exist in relation to salmonid species due to the previously identified overlap of preferred habitat for both species (Kemp *et al*. 2010; BSWG 2015; Gaywood 2015; Johnson-Bice *et al.* 2018). However, this may also reflect a lack of knowledge relating to other fish species. All fish species should be considered, where possible and when information is available.

**Potential conflict 1: Fish movement and habitat connectivity**

Whether beaver dams prevent, impede or delay the movement of fish is dependent on a large number of variables which are likely to be site specific and complex (Kemp *et al*. 2010; Kemp *et al.* 2012; Virbickas *et al*. 2015; Cutting *et al*. 2018; Johnson-Bice *et al*. 2018). The dynamic nature of beaver dam building activity and abandonment/destruction over time introduces additional temporal complexity in the assessment of issues relating to fish passage. Although an area requiring further research, the generally held view is that the majority of dams are not a significant barrier to salmon and trout movement in most situations (Collen and Gibson 2001; Mitchell and Cunjak 2007; Parker and Rønning 2007; Kemp *et al.* 2010; Taylor *et al*. 2010) with water passing through, under, over and around dam structures (Lokteff *et al*. 2013). Where barrier issues are documented to occur, it is generally under low flow conditions, but may also be specific to the dam location and individual dam characteristics (Elmeros *et al*. 2003; Kemp *et al*. 2010; Taylor *et al*. 2010; Virbickas *et al*. 2015; Cutting *et al.* 2018). For example, fish movement may be prevented at dams where no alternative flow path is created (Cutting *et al*. 2018), where there is insufficient pool depth to allow fish to jump dams or dewatering of sections downstream of a dam (Kemp *et al*. 2010). Another example is in small streams where beavers are more efficient at damming and dams are less likely to be washed out by high flows (Virbickas *et al*. 2015; Malison *et al*. 2016). Where passage is negatively impacted, spawning distribution can be restricted with potential for subsequent impacts on the reproductive performance of the populations due to density dependent mortality (Cunjak and Therrien 1998; Parker and Rønning 2007; Cutting *et al*. 2018). This impact may be temporary in duration depending on flow conditions in subsequent years or whether the dam remains (due to flow washout or management action). Juvenile salmonids appear able to navigate at least some dams (e.g. Virbicaks *et al*. 2015; Malison and Halley 2020), with passage issues most likely associated with upstream migrating adults (Taylor *et al*. 2010; Virbickas *et al*. 2015). Passage issues may also need to be considered for smolt in England due to the high potential for low spring flows in some catchments. Where dams remain passable, the energetic costs of negotiating multiple beaver dams within a system may impact reductive potential of the population (Cutting *et al*. 2018) or migration delays may increase the risk of predation (Gauld *et al*. 2013), factors which will be difficult to assess. The scale of any impact will depend on a wide range of factors, including dam location, number of dams, river catchment, availability of alternative habitat and population status.

The impact of beaver dams on movements of other fish species is less well documented. This may be due to a number of factors, including: a reduced likelihood of occurrence in areas likely to be dammed by beavers, being considered ‘non-migratory’, or the potential value placed on species considered of lower economic value. Available data generally compares species abundance downstream and upstream of a dam, which may reflect the suitability of the relative habitats rather than passability of the dam. No impact for eels was noted in the Scottish Review, reflecting their ability to negotiate through semi-porous structures in small amounts of water. Potential passage issues for bullhead (Bylak *et al*. 2014; Virbickas *et al*. 2015), lamprey species (Elmeros *et al*. 2003; Bashinsky and Osipov 2016), pike and perch (Bashinsky and Osipov 2016; Rohzkova-Timina *et al*. 2018) and roach (Elmeros *et al*. 2003) have been reported. The implications of beaver dams restricting the movements of freshwater resident species will depend on the location of the dam, dam longevity and the availability of alternative habitats.

**Potential conflict 2: Impacts on spawning and juvenile habitat**

The habitat upstream of beaver dams becomes ponded and silted as reduced flow energy causes sediments to fall out of suspension and become deposited on the bed upstream of the dam (Puttock *et al*. 2018). The distance of upstream habitat impacted will vary depending on stream gradient and the size and number of beaver dams (Collen and Gibson 2001). This can result in a loss of suitable spawning habitat for salmonid species (and potentially other gravel spawning species, such as bullhead, grayling (*Thymallus thymallus*) and dace (*Leuciscus leuciscus*), depending on the location of a dam within the catchment) due to their need for clean spawning gravels (reviewed in Kemp *et al*. 2012). Ponded habitat may also reduce the area of suitable habitat for juvenile salmonids (e.g. Virbickas *et al.* 2015; Malison and Halley 2020), though older brown trout benefit from deeper pool habitat (e.g. Bylak *et al*. 2014; Brazier *et al*. 2020). Conversely, accelerated flows caused by scour and/or head loss immediately downstream of the dam, or in areas where woody debris has been introduced, may improve the habitat for spawning (Kemp *et al*. 2010; Johnson-Bice *et al*. 2018 and references therein; Brazier *et al*. 2020). By capturing sediment in the upper reaches of catchments, beaver dams may also offer wider benefits for spawning habitat throughout the catchment, including lake habitats, by reducing suspended sediment (as reviewed in Collen and Gibson 2001; Kemp *et al*. 2012). Reduction of sediment input may provide benefit to all species of freshwater spawning fish as survival of fish eggs, whether deposited in gravel or on vegetation, may be negatively impacted by suspended sediments. The overall consequence of the potential loss versus potential gain will be site specific and may depend on the importance of an individual stretch of river or lake basin in supporting the reproductive potential of the local population.

Digging of burrows along with potential burrow collapse, may also release sediment into the river or lake with subsequent negative impacts to sediment delivery. Bank erosion caused by water rerouting around beaver dams has the potential to act as an additional sediment source, although the scale of the impact may be small and temporary compared to input from other known pollution sources (e.g. agriculture and urban landscapes) in some catchments. In addition, the increased channel complexity and flow diversity associated with rerouting is likely to offer additional low energy areas for sediment deposition. The potential impacts of these aspects of beaver behaviour have received much less attention in the published literature to date. They are being assessed informally at present in the Netherlands, the River Otter and Scotland.

**Potential conflict 3: Predation**

The potential for changes in predation pressures is relevant to all fish species and mainly associated with piscivorous birds, but may also be a consideration in terms of predatory fish species (e.g. pike) and mammals (e.g. otter (*Lutra lutra*) and American mink (*Neovison vison*). Otters and piscivorous birds have been found to be more prevalent in beaver managed habitat (Collen and Gibson 2001, Johnson-Bice *et al*. 2018). Kesminas *et al*. (2013) reported increased numbers of pike and perch in beaver ponds and concluded that this resulted in low survival of juvenile salmonids in those beaver ponds. Increased predation is likely to create greater conflict where natural fish populations are part of an active fishery, although the extent of impacts on fish populations is unknown. Predation of salmonid smolts due to migration delays could be a potential risk associated with beaver dams, especially during periods of low flow. The increased habitat complexity created by beavers with the addition of woody debris may, however, provide refuge for fish from predators (Kemp *et al*. 2012).

**Potential conflict 4: Water temperature and climate change**

There is potential for conflict due to the presence of beaver and tree planting initiatives, such as the Keeping Rivers Cool initiative[13], as a climate change adaptation measure to manage rising water temperatures. Beavers are patchy feeders acting to coppice, rather than remove, tree cover. However, tree canopy cover may change where beavers are present (Jones *et al*. 2009; Lason *et al*. 2014), which in turn may provide benefits for fish in some situations (Riley *et al*. 2009). Tree canopy cover reduces warming by solar radiation and, when tree canopy is reduced, water temperature increases. Beaver dams have been reported to also increase travel time of water along a reach and surface area increasing the actions of solar radiation (Majerova *et al*. 2015). The focus for tree planting in relation to climate change adaption is generally focussed in headwaters and small streams where planting is most likely to be effective in reducing temperatures and target species benefitting from cooler waters (i.e. salmon and trout) are more prevalent. Parker and Rønning (2007) reported that reduction of shade due to tree felling occurred over much longer reaches than were affected by beaver dams. Consequently, there is the potential for the presence of beavers to conflict with climate management objectives in salmonid streams. Any potential for conflict would depend on when beaver presence occurred in relation to tree planting, the maturity of cover, density of beaver population and where beavers forage in that location. River and lake typology will also play a part in whether or not temperature may be an issue related to beavers or wider environmental factors associated with variations of water body type. For example, variation in non-porous catchments is often high, conversely the variation in groundwater fed water bodies may be ameliorated by the ingress of ground waters with a stable thermal regime.

### 4.4.7 Potential future implications of wider reintroductions in England

The following factors are relevant when considering the potential impacts on fish and fish populations of a wider reintroduction of beavers in England.

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[13] https://catchmentbasedapproach.org/learn/keeping-rivers-cool/ [accessed 11/06/2021]

- Published literature is limited regarding the impacts of beaver activity on the movement of freshwater fish within catchments, and on the habitats on which they depend to complete their life cycles and stages. This reflects the complex interactions of the impacts of beavers on freshwater habitats, dynamic process of dam construction and abandonment, river type, variety of fish species and life stages requirements; all of which are subject to variables across time and space and environmental influences.
- Beavers can generally have an overall positive effect for fish through their impacts on channel morphology and floodplain connectivity, sediment storage and delivery, hydrology, temperature regimes, and aquatic biodiversity. It is likely that some fish species will benefit more than others from their presence.
- The high number of modified catchments may provide opportunities for restoration with associated benefits for fish, but there are also likely to be risks and challenges. For example, localised changes in temperature may create risk or benefit, and fish populations may benefit from stabilised flows by mitigating for extreme rainfall events or holding water back and creating refuges during low flows.
- For salmonids, where much focus of study has been directed, there are potential positive impacts associated with the above factors and potential adverse impacts to migration (upstream adults and downstream smolts) particularly in low flow situations, and from loss of spawning habitat. The balance of benefit and risk is likely to vary geographically and temporally, with less advantage from the presence of beavers for salmonids in warmer systems with lower altitude/gradient.
- Anadromous brown (Sea) trout spawning and passage may be disproportionately at risk from the presence of beavers due to their use of smaller tributaries which may be more likely to be dammed by beavers. The resultant change in habitat may have potential to affect spawning habitat and access to that habitat. Alternatively, it may offer a more conducive habitat to brown trout that do not migrate to the sea. Both scenarios represent the potential for genetic effects on brown trout populations.
- For other European and nationally protected fish species there are limited data on which to determine likely impacts. Potential adverse impacts on movement are reported for lamprey species and bullhead, together with changes in habitat with resultant positive and negative potential. There is a low likelihood of interaction with shad species. Impacts for spined loach are unknown and may require additional consideration in catchments where they are present. There is the potential for reduced siltation of lake spawning gravels for Coregonid and charr species due to beaver activity within the upstream catchment.
- For other freshwater fish species there are limited data on which to determine likely impacts. However, their distribution within catchments may mean that they are less likely to be present in areas where dam frequency is greatest. No negative impacts have been reported for European eel and they are thought to be able to negotiate beaver dams. Potential wider catchment benefits may occur for other fish species through increased habitat heterogeneity, water quality improvements and flow regulation. Though beaver dams have the potential to limit fish movements, fish may also benefit from newly created beaver habitat.

# 4.5 What are the effects of beavers on the biodiversity of bryophytes in potential beaver habitat?

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## 4.5.1 Summary of main findings and recommendations

Medium evidence from the Scottish Review found that an increase in habitat heterogeneity and deadwood may benefit a range of bryophytes, but a subsequent reduction in the extent of older growth trees may be a negative impact for bryophytes if the affected habitat type is rare, and a large proportion of the habitat is impacted (Stringer *et al*. 2015). Local negative impacts of favoured plant species were generally compensated for at the wider landscape scale.

There is limited direct evidence in England on the effects of beavers on bryophytes. Medium evidence from published studies elsewhere indicate that the nature of the impact of beavers on bryophytes will vary according to the species present. Overall impacts are likely to be positive, but there may be a need to protect specific groups of trees with bryophytes at certain sites.

## 4.5.2 Introduction

Bryophytes comprise the non-vascular plants, mosses, liverworts and hornworts. They play a vital role in carbon and nutrient recycling, regulate water availability, may promote soil formation, and stabilise soils against wind and water erosion. They contribute to a substantial proportion of the global plant biomass in a range of ecosystems (Porley 2013). Bryophytes prefer moist environments, hence are likely to be affected by beaver activity affecting trees on which they grow in wet and riparian habitats.

## 4.5.3 A summary of findings from the Scottish Review

- An increase in habitat heterogeneity may benefit a range of bryophytes.
- Increases in deadwood produced by beaver activity may benefit a range of bryophytes.
- Beavers may reduce the extent of older growth riparian woodland by felling trees. This can be a negative impact for bryophytes if the affected habitat type is rare, and a large proportion of the habitat is impacted.
- The effects of felling trees can be particularly pronounced if high browsing pressure by species such as deer hinders or prevents coppice regrowth after felling.
- Monitoring of vulnerable habitats and species that have the potential to be adversely affected by beavers would be needed in some areas in the event of their reintroduction. Management of beavers may also be needed in order to limit negative effects and promote positive effects.

## 4.5.4 Further research since the Scottish Review

The importance of deadwood as a habitat for bryophytes was shown by Muller *et al.* (2015) in a study of bryophyte communities on deadwood related to forest management. They observed that a high number of bryophyte taxa depend on deadwood. The size of deadwood items affected species richness, with larger items having greater diversity of bryophytes due to more varied microsites and habitat niches, and enabling more humid conditions. Larger deadwood items also take longer to decay, which gives uncommon bryophytes with low dispersal abilities time to colonise. Beaver activity may increase the amounts of deadwood, both by direct felling of trees and also the drowning of trees due to raised water levels caused by beaver dams, and this deadwood may benefit a range of bryophyte species.

Elliott *et al*. (2017) summarised the initial findings from the Devon beaver projects. After beavers had been introduced to a fenced enclosure in 2011, it was observed between 2012 and 2015 that some areas dominated by bog-moss (*Sphagnum* spp.) were outcompeted by grass and pondweeds. A species first recorded in the enclosure in 2015 was fingered cowlwort (*Colura calyptrifolia*), a small epiphytic liverwort that had rarely been recorded in North Devon, although this is a species that has shown increases at a national level (Blockeel *et al.* 2014).

## 4.5.5 English context

**Possible effects on bryophytes caused by beavers felling trees**

Epiphytic bryophytes in England of conservation significance that could be affected by beavers felling trees in riparian and other wet habitats include: the Nationally Rare multi-fruited cryphaea (*Dendrocryphaea lamyana*) that grows on alder (*Alnus* spp.), ash (*Fraxinus excelsior*), sycamore (*Acer pseudoplatanus*), willow (*Salix* spp.) and other trees in the flood-zone of large rivers (Blockeel *et al.* 2014), and the Nationally Scarce flood-moss (*Myrinia pulvinate*), showy bristle-moss (*Orthotrichum speciosum*), balding pincushion (*Ulota calvescens*) and club pincushion *(Ulota coarcta*), which grow on a range of trees and shrubs, including on sallows and willows in wet and marshy situations. Iason *et al.* (2014) recorded a consistently strong selection by beavers in Scotland for sallows and willows in relation to their availability.

In addition to the direct effects of beavers felling trees upon which notable bryophytes are growing, there may be also an indirect effect of such felling by removing or reducing the shade and humidity required by the bryophytes growing beneath them. A similar effect caused by the coppicing and pollarding management of trees by human activity is described by Latham *et al.* (2018). Monitoring plots studied by Iason *et al*. (2014) showed an increase in grasses following the reintroduction of beavers, which was considered to be due to an increase in light at ground level following a reduction in tree canopy cover caused by beaver tree felling activity. Similarly, Elliott *et al.* (2017) recorded that some areas dominated by bog-moss were outcompeted by purple moor-grass (*Molinia caerulea*) and pondweed (*Potamogeton* spp.) which grew more vigorously following the felling of trees by beavers, probably due to increased light levels.

Certain bryophyte-rich sites such as Atlantic woods found in the Lake District or trees known to be individually important for bryophytes, such as an ash tree in Weardale in northern England that supports two Nationally Rare *Orthotrichum* species, might need protecting, for example by fencing, if they were at risk of felling activity by beavers.

**Possible effects of damming of watercourses by beavers on bryophytes occurring on the banks and within the channel of watercourses**

Notable mosses that occur on the banks of streams and in ravines in England include the Nationally Rare large Atlantic pocket-moss (*Fissidens serrulatus*) and the Nationally Scarce many-leaved pocket-moss (*Fissidens polyphyllus*) (Figure 9). Although these species occur in the flood zones of watercourses they habitually occur above the normal water level, thus it is likely they would be adversely affected if water levels were raised by beavers damming watercourses to a level where these mosses were permanently submerged. Beck pocket-moss (*Fissidens rufulus*) is a Nationally Scarce species that occurs on rocks at or below normal water level in fast-flowing streams and rivers, and could be disadvantaged if beaver damming reduced water flows where it occurs.

**Figure 9** *Fissidens polyphyllus* a Nationally Scarce moss of stream banks and ravines

**Possible effects of damming of watercourses by beavers on bryophytes occurring in the draw-down zone of standing water bodies**

Specialised bryophytes that occur on mud in the draw-down zone of ponds, meres and reservoirs in England include: the Nationally Rare and Schedule 8 millimetre moss (*Micromitrium tenerum*)*;* Nationally Rare Norfolk bladder-moss (*Physcomitrium eurystomum*)*;* clustered earth-moss (*Ephemerum cohaerens*)*;* channelled crystalwort (*Riccia canaliculate*); and the Nationally Scarce dwarf bladder-moss (*Physcomitrium sphaericum*)*;* sessile earth-moss (*Ephemerum sessile*)*;* violet crystalwort (*Riccia huebeneriana*)*;* and beaked beardless-moss (*Weissia rostellata*)*.* These bryophytes, several of them very small ephemeral species, remain dormant in the mud as spores when water levels are high, and only grow when water levels have receded sufficiently to expose bare mud in the area known as the draw-down zone (Porley and Hodgetts 2005). Such bryophytes could be adversely affected if damming by beavers of watercourses linked to these water bodies prevented the seasonal formation of draw-down zones. It is considered unlikely that the larger water bodies such as reservoirs supporting these rare species would be affected by beaver activity, but ponds and smaller water bodies could be more vulnerable, and this would need to be assessed on a site by site basis. Conversely, beaver damming of streams might possibly increase draw-down mud if the mud that accumulates behind such dams was exposed by receding water levels.

### 4.5.6 Identification of areas of potential conflict in England

As mentioned above, there is the potential for localised conflict should beavers impact on habitats where rare or locally scarce bryophytes are present.

### 4.5.7 Potential future implications of wider reintroductions in England

Increases in habitat heterogeneity through the activities of beavers are likely to be positive for bryophytes overall, but may need to be assessed on a case by case basis in locations where rare or scarce bryophytes are present.

# 4.6 What are the effects of beavers on the biodiversity of fungi and lichens in potential beaver habitat?

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## 4.6.1 Summary of main findings and recommendations

Medium evidence from Scotland showed a risk to internationally important lichen communities of Atlantic hazelwoods and rich assemblages on other host trees in beaver-occupied areas (Genney 2015; Acton and Griffith 2018). However, longer-term impacts at a landscape scale are not yet known. There is no direct evidence in England of the effects of beavers on lichens or fungi. Medium evidence from two published studies indicate pinhead lichens and microfungi can benefit from beaver activity due to their strong association with standing deadwood and damaged bark (Rikkinen 2003; Vehkaoja *et al*. 2017).

The impacts on lichen species across England are likely to vary and the specifics of this, especially if beavers are allowed to establish in the wider countryside, will not be known for many years. However, it is likely that populations of generalist, ephemeral and deadwood species will benefit, whilst those of specialist epiphytic lichens, especially those associated with old trees of types preferred by beavers, will gradually decline in beaver occupied areas.

Fungi are considered highly sensitive to woodland structural change. Both mycorrhizal and deadwood fungal species richness have been shown to increase with tree and woodland age and tree species diversity. In addition, ectomycorrhizal fungal diversity is positively related to canopy cover, whilst saprotrophic fungi of fine woody debris benefit from canopy gaps. Beavers have the potential to influence all of these at local scales. Whether species extirpations at such scales are compensated by increased habitat heterogeneity at a landscape scale is uncertain.

Further research is required to understand the influence of beavers on key species and assemblages of fungus and lichen in England. If beavers are to deliver a net gain for lichens and fungi, the conservation value of losses to existing assemblages will need to be more than offset by the conservation value of incoming species and assemblages. In this respect, species diversity should not be seen as the sole metric of success.

## 4.6.2 Introduction

Riparian woodland and trees can be an important habitat for lichens and fungi in England, supporting species and assemblages significant at national and European scales. Old riverside trees provide a refugium in unmanaged woodland and are more buffered against the impacts of climate change. However, occupation rates of specialist lichens, many of which are threatened or rare species, are naturally low so whether beaver will negatively impact their populations is debatable.

### 4.6.3 Summary of findings from the Scottish Review

- The direct impacts of beavers on trees and therefore woodland structure, continuity and composition are key to how lichens are affected.
- Beavers have the potential to negatively impact nationally and internationally important epiphyte populations by reducing areas of climax riparian woodland, breaking the continuity of specialist microhabitats, and altering water flows/sedimentation.
- The risk varies greatly between habitat types, largely due to the degree of overlap between potential beaver habitat and certain types of woodland. Atlantic hazelwoods, woodlands with aspen (*Populus tremula*), and ravine woodlands are highlighted as of highest conservation value for lichens and the most likely to be adversely affected.
- A relatively high impact on Atlantic hazel lichen habitat was observed in the Scottish Beaver Trial at Knapdale; most felled stems supported oceanic lichen communities, including species of national and/or international conservation concern.
- Localised loss of species associated with old trees will be compounded by the low recovery potential of such species. Furthermore, a shift in riparian woodland composition would result in the loss of epiphytes associated with certain tree species.
- The effects of felling trees can be particularly pronounced if high browsing pressure by species such as deer (family *Cervidae*) hinders or prevents coppice regrowth. This would prevent the re-establishment of epiphytes.
- Epiphytes of trees intolerant of waterlogging would be lost in flooded areas but resultant deadwood (standing and fallen) was a valuable habitat for specialist lichens and fungi. In addition, wet woodland mycorrhizal fungi were expected to benefit.
- Conservation action to expand riparian woodland for beavers could result in an overall increase in epiphytic and fungal woodland habitat, although it was unclear to what degree old-growth woodland would be a component.
- Research is needed to assess the impact of beaver control fencing on woodland lichen habitat quality. A risk was identified from exclosure fencing increasing understorey vegetation that reduced light levels, thus negatively impacting on lichens.
- Questions remained over impacts from: i) a longer-term shift in tree age structure to younger cohorts, ii) longer-term changes in deadwood amounts and variety according to beaver colonisation patterns, and iii) insufficient replacement trees establishing in riparian areas because of beaver and deer browsing.
- It was recommended that catchment-level assessments are made to predict and plan for the impact that beavers may have on rare or threatened riparian tree-dependent species.

### 4.6.4 Further research since the Scottish Review

Studies relating specifically between the interactions of beavers and fungi or lichens are limited.

Vehkaoja *et al.* (2017) found that, beaver-created snags (standing deadwood) supported a higher diversity of pinhead lichens and fungi (Caliciales) in a boreal landscape in Finland compared to sites without beaver activity, especially where snags occurred in water. Calicioid lichens/fungi are widely accepted as indicators of old forest habitats but have benefited here from beaver activity producing a moist deadwood substrate. Dispersal may also have been enhanced by the continuum of deadwood habitat created by beavers and their movements across the landscape, along with the activities of deadwood-dependent animals.

Stringer and Gaywood (2016) carried out a meta-analysis of beavers' interactions with biodiversity. Overall beavers were found to benefit biodiversity, however old woodland biodiversity (including lichens) was highlighted as a concern because the degree to which beavers alter the age structure of occupied woodland was not known. A shift towards younger growth could have a detrimental effect on overall biodiversity. In addition, beavers coppiced numerous tree species which, in combination with high deer densities, would limit woodland regeneration. The authors concluded that a management strategy for both beaver and deer would be needed in such areas.

### 4.6.5 English context

Across taxonomic groups, tree-dwelling lichens and fungi (and bryophytes – considered in section 4.5) collectively dominate the Section 41 list of species of principal importance to biodiversity in England[14] (NERC Act 2006) for woodland habitats, representing over 40% of those listed (Webb *et al*. 2010, based on Woodland Biodiversity Integration Group). The majority of these species are lichens and fungi, but evidence relating to the potential influence on these groups by beavers is limited.

At a European scale, British assemblages of woodland lichens are of great significance, particularly woodlands along the Atlantic fringe (temperate rainforest), southern oceanic woodland (especially south west England), old-growth woodland in general, and post-mature trees outside of woodland - including ancient pasture woodland and parkland (Alexander *et al.* 2003; Farjon 2017; Sanderson *et al*. 2018).

British assemblages of fungi (non-lichen) are no less important in an international context, particularly deadwood species associated with beech (*Fagus sylvatica*) and oak (*Quercus* spp.) (Ainsworth 2005; Ainsworth 2017). In England, it is these saprotrophic (wood rotting) species, but also certain mycorrhizal (root colonising) fungi associated with native oak (*Quercus* robur and Q. petraea*)*, beech and sweet chestnut (*Castanea sativa*), that are of high conservation value (Bosanquet *et al*. 2018). In addition, alder (*Alnus* glutinosa) and willow (*Salix* spp.) woods are known to support nationally important fungal assemblages.

Importantly not one of the above is restricted to watercourse habitats but where trees supporting such assemblages or species do occur within beaver habitat, there is a risk of negative impacts from felling, 'coppicing' (Latham *et al*. 2018) and pond creation (Genney 2015). Old-growth riverine woodland is a scarce and species-rich habitat in England that can be of outstanding importance for its lichens (N. Sanderson, pers. comm.). The potential for conflict here with beavers is considered to be at its greatest.

[14] Biodiversity 2020 - Terrestrial Biodiversity Group. (2014) Section 41 Species - Priority Actions Needed (B2020-008). Priority Actions Spreadsheet. Natural England.

## Lichens

As well as lichens, lichenicolous fungi are covered here. Specialist lichens have narrow ecological tolerances, with low occupation rates across wide areas of superficially suitable habitat (Sanderson 2012; Orange 2017). Riparian habitat is important for lichens, markedly contributing to landscape-scale species diversity, including a relatively high proportion of species of conservation concern, and providing a refugium to environmental change (e.g. McCune *et al*. 2002; Ellis 2020). Stability and continuity of ecological niches, including host and substrate, are key to the survival of these species and could easily be disrupted by beaver activity. However, aquatic lichens may benefit from beaver activity in the longer term through attenuated flows, reduced diffuse pollutants and silt loads downstream of beaver dams (Puttock *et al*. 2017). Furthermore, by keeping stretches of riparian habitat open, lichens of riverside rock stand to benefit; an assemblage of high conservation value in England and Wales (Bosanquet and Wilkins 2013; Orange 2013, Orange 2017; Sanderson *et al*. 2018).

The lichen assemblages of Scotland and England are on the whole strikingly different, so at the species and community levels differential effects would be expected. In Scotland the two most important lichen habitats damaged by beavers, namely Atlantic hazelwood and aspen, feature markedly less in England. Atlantic hazelwood is a rare habitat in England, with key sites only remaining in SW England and Cumbria, while aspen, although widespread in England, generally lacks the high conservation value of the assemblage in the central Highlands (Genney 2015; N. Sanderson pers. comm.). Nevertheless, where these habitats do occur in England, it appears they would be as susceptible to beaver activity as those in Scotland.

A key determinant of lichen diversity is an open habitat structure, providing higher and more varied light levels than closed-canopy woodland (Sanderson and Wolseley 2001; Paltto *et al.* 2011; Sanderson 2012). Consequently, beaver activity may benefit some species by creating this habitat. A reduction in shade, particularly of riparian rocks and siliceous rock within woods, may benefit rock-dwelling species, such as the Section 41 chalice lichen (*Endocarpon adscendens*). Canopy gap creation by beavers resulting in understorey regeneration was well evidenced in the River Otter Beaver Trial (Brazier *et al*. 2020). Although this should benefit some lichens, there is clearly a trade-off for epiphytic species if their host is felled or they are shaded out by subsequent understorey growth. At catchment scales, patches of open wet woodland created by beavers can be expected to increase habitat heterogeneity and may lead to an overall increase in species diversity. However shrubby regrowth and tree regeneration in abandoned territories could have the reverse effect, shading out newly established lichens.

In woodland settings, riparian trees tend to receive higher light and humidly levels than those in forest interiors, making them important for more light-demanding ‘old woodland’ leafy lichens such as tree lungwort (*Lobaria pulmonaria*) (Figures 10 and 11) (Acton and Coppins 2012; Orange 2019) and providing continuity of conditions should the woodland fall into neglect, or acting as climate change refugia (Lidén and Hilmo 2005; Ellis 2020). Such trees may need to be subject to protection from beaver herbivory in a way that conserves the lichen interest.

**Figure 10** Ash (*Fraxinus excelsior*) beside the River Barle supporting a colony of tree lungwort *(Lobaria pulmonaria)*



**Figure 11** Tree lungwort (*Lobaria pulmonaria)*



Lichen assemblages are strongly influenced by bark characteristics and thus the species of tree (e.g. Barkman 1958; Ellis *et al*. 2015). Therefore, where beaver and lichen tree preferences coincide, the effects on lichens are likely to be most severe. Shifts in riparian tree species composition or diversity will therefore have a substantial impact on epiphytic lichen assemblages.

Deadwood is a primary lichen habitat yet often overlooked (Spribille *et al*. 2008). In particular, standing deadwood is vital for lignicolous lichens (Humphrey *et al*. 2002; Sanderson *et al*. 2018). Specialist wound-track (resinicolous) lichens are confined to sap runs and may increase as a result of beaver activity (Rikkinen 2003). Lignicolous lichens and fungi are also expected to increase where beavers have flooded forests creating areas of standing deadwood. However, the longer-term dynamics of deadwood availability is less clear (Genney 2015); as dead trees fall and decay, such specialists may decline unless further deadwood stands are created.

Where beavers dam waterways, causing inundation of wooded areas, new wetlands are formed which in time will support willow/alder carrs. However, once a territory is abandoned, it is unclear whether these trees will reach a suitable age for specialist lichens to establish before beavers return. Notably, the Lobarion lichen community can develop relatively rapidly in this habitat, unlike its occurrence on post-mature and ancient canopy trees (Sanderson 2018).

Great Britain's assemblage of pinhead (calicioid) lichens and microfungi are considered of high conservation value and are strongly associated with standing deadwood and dry bark (Sanderson *et al*. 2018). Various studies outside of Great Britain have shown positive beaver impacts on this group (e.g. Rikkinen 2003; Vehkaoja *et al*. 2017). Pinhead lichens/fungi are widely considered indicators of old forest habitats but in boreal wetlands have benefited from beaver activity producing moist deadwood substrates and potentially enhancing dispersal (Vehkaoja *et al*. 2017).

Generally, trees become markedly richer in lichens after about 200 years (e.g. Fritz *et al*. 2008); most niche specialists do not establish until that time or much later. Veteran tree features provide key microhabitats, for example lignicolous lichens which specialise on decorticated areas or standing deadwood (Spribille *et al*. 2008). Although beavers show a preference for younger tree age classes, large/very large riverside trees are occasionally felled (Rosell *et al*. 2005; Iason *et al*. 2014; Brazier *et al*. 2020). Differences in the felling pattern of larger trees according to distance from the water can also be expected (Haarberg and Rosell 2006), with likely associated impacts on epiphytic lichen communities. At landscape scales the magnitude of these losses will depend on beaver abundance and range, as well as mitigation measures.

Specialist epiphytic lichens can be slow to respond to woodland structural change (Ellis and Coppins 2007). Once lost, such species are typically slow to recolonise, showing a recovery lag. The slowest lichens to re-establish are species of the Ancient Dry Bark community (*Lecanactidetum premneae*), a community requiring very long continuity of old oaks and of conservation importance in England and internationally (Coppins *et al*. 2001; Sanderson 2012). A shift towards a younger tree demographic such as found in secondary oak woodland would result in a loss of rare species (Paltto *et al*. 2011). Dispersal and/or establishment are seen as key constraints for some species (Dettki *et al*. 2000; Sillett *et al*. 2000; Werth *et al*. 2006; Kiebacher *et al*. 2017). Setting aside small areas of woodland to protect scarce sexually dispersed epiphytic lichens is unlikely to help, leading to an extinction debt and local losses of species in the longer term (Fedrowitz *et al*. 2012). Moreover, achieving this through the creation of fenced exclosures, or beaver-free zones, brings its own set of problems (Moore and Crawley 2014; Campbell-Palmer *et al.* 2015); more successful would be the individual protection of host trees.

### Fungi

In this section, fungi other than lichens and lichenicolous fungi are considered; the focus here is on wood-decay fungi (saprotrophs) and those which occur symbiotically on the roots of living trees - ectomycorrhizal fungi. As with lichens, little is known of the direct impacts of beavers on these groups and it is less clear whether the freshwater aquatic and riparian environments are special habitats for fungi in England as they clearly are for lichens. Fungi fundamentally differ from lichens in that they are hidden from view most of the time, occurring as mycelium within substrates, making scientific study inherently difficult.

Rarity patterns in fungi appear fundamentally different to other organisms; the great majority of fungus species are rare, while only a few can be considered common, also species that are rare/common locally appear to be the same nationally (Gange *et al*. 2019). This is important as it suggests local losses of fungi may equate to national extinctions. Fungal communities are highly heterogeneous even within the same site or habitat (Peay *et al*. 2016).

Changes in tree species composition that can result from beaver activity (Nolet *et al*. 1994; Rosell *et al*. 2005) are likely to alter associated fungal communities. Studies of the diversity of ectomycorrhizal and saprotrophic fungi in relation to tree species and host specificity show a high proportion of specialist species can be affected by changes in woodland composition (Newton and Haigh 1998; Abrego and Salcedo 2013; van der Linde *et al*. 2018).

### Saprotrophic fungi

The importance of deadwood for biodiversity is recognised at a European level and has been proposed as one of a suite of biodiversity indicators by the European Environmental Agency (Humphrey *et al*. 2004; Müller and Bütler 2010). Deadwood amounts, sizes (diameter) and types (tree species, part of the tree, decay stage) are key determinants of dependent wood-inhabiting fungal diversity (Heilmann-Clausen and Christensen 2003; Junninen *et al*. 2006; Ódor *et al*. 2006; Abrego and Salcedo 2013; Arnstadt *et al*. 2016). Moreover, these fungi are directly responsible for the generation of new habitats and food resources for other wood-dependent organisms (Boddy 2001).

In Great Britain, beech and oak wood-decay fungi are of conservation importance (Ainsworth 2005; Farjon 2017; Bosanquet *et al*. 2018). Some species occur as latent propagules in the sapwood of living trees and appear to develop when the tree becomes physiologically stressed or damaged (Boddy 2001; Parfitt *et al*. 2010). The premature felling or drowning of host trees by beavers is likely to alter these natural decay pathways. Wood moisture levels fundamentally affect the fungal assemblage. Within highly moist wood, soft rot fungi (ascomycetes and deuteromycetes) predominate while the activity of white and brown rot fungi (basidiomycetes) is strongly suppressed (Kim and Singh 2000; Thompson *et al*. 2016). Some species may be particularly associated with temporarily submerged wood.

Beavers are known to increase deadwood volumes and deadwood heterogeneity (Thompson *et al*. 2016), although whether the supply is sustainable is uncertain. For example, Fustec and Cormier (2007) concluded that in relation to lodge construction, repeated use of deadwood by beavers created shrubby re-growth that was too small to use for lodge construction. Dependent biodiversity may also be limited by the types of deadwood left behind (Iason *et al*. 2014; Genney 2015; Misiukiewicz *et al*. 2018). The outcome may vary across habitat types and regions, and warrants further investigation in an English context.

Nevertheless, a heterogeneous woodland structure, with enhanced amounts of standing and fallen deadwood, mimicking late successional woodland characteristics, has been shown to increase fungal species richness (Dove and Keeton 2015). Although this study focussed on forestry practices, the effects on woodland structure appear not dissimilar to those created by beavers. Similarly, Brazee *et al*. (2014) found that canopy gap creation in combination with the addition of coarse woody debris resulted in increased abundance and diversity of wood-inhabiting fungi (polypores and corticoid fungi). However, the species richness of fine woody debris (FWD) appears mainly controlled by microclimate as determined by canopy cover (Bässler *et al*. 2010). This implies that where beavers open up the canopy, so increasing exposure to sunlight, FWD fungal richness would be reduced.

Logs in intermediate to late stages of decay have been shown to be most rich in fungi (Heilmann-Clausen and Christensen 2003; Arnstadt *et al*. 2016). This not only depends on the retention of logs through natural decay, but the future supply of logs facilitating habitat continuity of the fungal community (Heilmann-Clausen and Christensen 2003; Ódor *et al*. 2006). Alterations in environmental or substrate conditions are likely to affect fungal community development and decomposition rates (Heilmann-Clausen and Christensen 2003; Přívětivý *et al*. 2016; Boddy and Hiscox 2017). The mode of tree death may be a further driver e.g. Heilmann-Clausen and Christensen 2003 showed beech logs broken at the stem base (root neck) were especially valuable for threatened (red-listed) species. Beavers have the capacity to affect all of the above and therefore influence fungal community composition and diversity. For example, by felling trees and flooding wooded areas, beavers create a pulse of deadwood but the temporal pattern in the longer term is unclear (Genney 2015).

Some saprotrophic fungi can survive felling and continue to produce fruitbodies for several years, or even decades, where a trunk has been left in situ (e.g. Roberts 2002) but, generally, felling marks a major change in fungal succession as timber is rapidly colonised by a range of primary wood-rotting species (Boddy 2001).

### Ectomycorrhizal fungi

No studies were found that specifically looked at beaver impacts on mycorrhizal species. However, it is possible to make some inferences based largely on recent studies. Woodland characteristics which show a positive relationship with ectomycorrhizal fungal community composition/diversity include host tree age, forest age, and canopy cover (Tomao *et al*. 2020). In addition, ectomycorrhizal species richness is strongly associated with tree species diversity (Spake *et al*. 2016).

In all these respects beavers may have negative impacts due to a shift towards early successional woodland with younger trees predominating, reduced canopy cover, and potentially a reduction in tree species diversity. At a landscape scale these can be seen as local effects that add to overall habitat heterogeneity although this is dependent on beaver population sizes and the extent of beaver-occupied habitat.

Various studies relating to forest management practices have shown that retention of some trees or woodland patches can act as a 'lifeboat' for ectomycorrhizal fungi demonstrating a degree of resilience to surrounding felling (Tomao *et al*. 2020). This could enable former fungal communities to recover once beavers abandon territories although where wetlands have been created, ectomycorrhizal fungi may be killed (Terwilliger and Pastor 1999).

Beaver meadows show a paucity of ectomycorrhizal fungi because of past ponding. This may constrain recolonisation by obligate ectomycorrhizal trees and therefore delay woodland recovery (Terwilliger and Pastor 1999). The effect on ectomycorrhizal fungi is localised but meadows may persist as damp grassland for decades, often 70 years or so (Moore 1999).

### 4.6.6 Identification of areas of potential conflict in England

Orange (2019) carried out a riverside lichen survey in the Barle Valley SSSI. This survey showed the importance of riparian trees (within 4 m of the water's edge) and those in well-lit areas. Consequently, this is an example of a site that, should beavers be introduced or colonise, lichens would be adversely affected through felling, unless host trees were protected.

At Arlington SSSI (North Devon), the swampy sallow woodland supports a nationally important *Lobarion* assemblage (Sanderson 2018) (Figure 12). The occurrence of beavers here would very likely be damaging; although good light levels are essential for the *Lobarion*. Beaver felling, coppicing and browsing in combination with an existing red deer (*Cervus elaphus*) population in a five hectare woodland would likely have a profound effect on host trees and dependent epiphytes. Moreover, this type of lichen-rich woodland is considered quite rare and has developed over around 150 years at Arlington (Sanderson 2018).

**Figure 12** A sallow stem with luxuriant growth of leafy lichens characteristic of the Lobarion at Arlington SSSI. Species pictured include *Sticta sylvatica*, *Sticta fuliginosa s.s.* and *Peltigera collina*

An example of a lichen that could theoretically be threatened by beaver activity is the Section 41 species brown shingle lichen (*Fuscopannaria sampaiana, syn. Nevesia sampaiana*) which occurs in Dartmoor woodland on just two riverside oaks (Sanderson 2017) (Figure 13). Although beavers do not currently occur in this area, and the oaks are large, its loss here would represent an England-wide extinction, thus such trees should be protected should beavers become active in the area. In Scotland the impacts of beavers on this lichen are being monitored (Acton and Griffith 2018).

**Figure 13** The Section 41 lichen *Fuscopannaria sampaiana* (*Nevesia sampaiana*) on a bankside oak on the River Webburn, Dartmoor

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Important trees were protected with a sandy-textured anti-beaver paint during the River Otter Beaver Trial (Brazier *et al*. 2020). At present it is not clear whether deterrent paint used on key lichen trees is harmless to lichens. Lichens tend to be highly sensitive to their chemical environment, and some, e.g. crustose and pinhead lichens, can be very easily overlooked, although it is acknowledged only a small proportion of the overall surface area of the bark would be painted. Similarly, the use of galvanised weld mesh in contact with tree boles would be toxic to lichens below due to zinc runoff (Seaward 1974; Brown and Beckett 1983), so alternative non-zinc meshes should be considered.

Fencing off areas of woodland from beavers, or installing fenced exclosures around special trees, may have a negative outcome for tree- and rock-dwelling lichens within the exclosures, due to increased shading (Orange 2009; Sanderson 2012; Moore and Crawley 2014). If this is unavoidable, it is essential that vegetation inside the exclosure is kept in check through grass or understorey cutting, bramble (*Rubus fruticosus* agg.) and ivy (*Hedera helix*) control, keeping lower trunks open and unshaded (N. Sanderson pers. comm.).

### 4.6.7 Potential future implications of wider reintroductions in England

Beavers are known to coppice a wide variety of trees and shrubs. The SSSI selection guidelines for woodlands, wood pasture and parkland, and veteran trees (Latham *et al*. 2018) cites the risk of coppicing (and pollarding) to lichens (and bryophytes), stating that it can be very damaging, and that recovery is likely to take many years or decades, and in some cases, especially where very rare species are present, the interest may never fully recover.

Although beavers are central-place foragers with a localised impact at any one point in time, they are known to relocate their lodges and, moreover, as their populations grow, to colonise new areas (e.g. Brown *et al*. 2018). In this event, sites supporting rich assemblages or populations of lichens and/or fungi, such as river valley woodlands and wet or swampy woods, including some protected sites, could be at risk. Quantifying this risk spatially and temporally, and evaluating mitigation options at a national scale, e.g. as Campbell-Palmer *et al.* (2015) have done for Scotland, may be important in planning a way forward.

Where high deer numbers and beaver coincide, they may restrict tree/shrub regrowth and regeneration (Stringer and Gaywood 2016). Overgrazing by deer and the associated slow recovery of vegetation has been previously highlighted as a concern in England (Tanentzap *et al*. 2012; Perry *et al*. 2018). A reduction in the availability of older bark trees would markedly limit epiphytic lichen diversity.

In relation to Ash dieback (*Hymenoscyphus fraxineus*), the tree species most suitable as alternative hosts for ash lichens, such as sycamore (*Acer pseudoplatanus*), willows and poplars (*Populus* spp.), are also preferentially selected by beavers for food or construction (Nolet *et al.* 1994; Stringer *et al.* 2015; Sanderson and Lamacraft in press). In this case conservation conflicts are likely to arise in areas where beaver habitat overlaps with lichen-rich ash woods.

## 4.7 What are the effects of beavers on the biodiversity of vascular plants?

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### 4.7.1 A summary of main findings and recommendations

Strong evidence from Scotland found that overall impacts from beaver foraging was positive, resulting in increased plant diversity. Local negative impacts of favoured plant species were generally compensated for at the wider landscape scale. The presence of other large herbivores, both livestock and deer, had the potential to negatively impact on the recovery of exploited species (Gaywood 2015; Stringer *et al*. 2015).

No evidence is available for the preferential or differential effects of beaver activity and exploitation levels for almost all of the threatened English vascular flora species. Strong evidence suggests that increased habitat heterogeneity and dynamism is likely to benefit vascular plants at the landscape scale (Bergman and Bump 2015; Rentch *et al.* 2015; Law *et al*. 2016; Bergman *et al*. 2018; Willby *et al*. 2018). However, further work is required to investigate the impacts on locally occurring rare or threatened species, particularly those whose habitats are likely to be directly impacted or whose morphologies are known to be favoured for food, render them particularly vulnerable to exploitation.

### 4.7.2 Introduction

Beavers exploit both terrestrial and aquatic vascular plant species for food and gather mainly terrestrial woody species for the construction of their dams and lodges (Stringer *et al.* 2015). Their ‘engineering’ activities result in enhanced habitat heterogeneity which generally increases vascular plant species diversity at the landscape scale (Wright *et al.* 2002; Willby *et al.* 2018).

It is generally acknowledged that most feeding and gathering activity lies usually within 30 m and especially within 10 m of water bodies or watercourses (Pinto *et al.* 2009). This has a significant impact in reducing the number of English native vascular plant species likely to be directly affected by grazing and collecting activity. However, the presence of other large herbivores, both livestock and deer (family *Cervidae*), has a considerable impact on the recovery of exploited species (Baker 2003). This can cause localised declines especially of willows (*Salix* spp.), aspen (*Populus tremula*), ash (*Fraxinus excelsior*) (already compromised in many parts of England by ash dieback (*Hymenoscyphus fraxineus)*) and hazel (*Corylus avellana*).

### 4.7.3 A summary of the findings from the Scottish Review

- Impacts were found to be restricted to freshwaters and riparian habitats with broadleaved woodland or scrub. No significant impacts were detected beyond 50 m and very little beyond 20 m from the water margin.

- Overall impacts on vegetation (hence most vascular plants) was found to be very positive with diverse new habitats formed, including coppiced woodland and beaver meadows, and a greater heterogeneity and connectivity of habitats created. Enhanced structural diversity is well known to increase vascular plant diversity.
- Local dis-benefits for certain vascular plants (such as favoured food species) are generally compensated for at the wider landscape scale (by, for example, extension of suitable habitat outside the favoured foraging range of beavers).
- There is a critical interplay of the impacts of beavers and other large herbivores, e.g. livestock and grazing deer such that riparian willow, alder (*Alnus glutinosa*) and aspen may locally fail to recover following exploitation by beavers.
- Favoured tree species for food included aspen, willow, ash, rowan *(Sorbus aucuparia),* sycamore *(Acer pseudoplatanus)* and hazel. Other locally common tree species were taken in proportion to their abundance, mainly for construction.
- Four plant species were particularly affected in Knapdale. Great fen-sedge (*Cladium mariscus*) was grazed heavily, white waterlily (*Nymphaea alba*) also declined with beavers particularly preferring large leaves near the shore, common club rush (*Schoenoplectus lacustris*) was heavily grazed together with water horsetail (*Esquisetum fluviatile*).
- Sedge (*Carex* spp.) and pondweed (*Potamogeton* spp.) were generally avoided with the exception of bottle sedge (*Carex rostrata*).
- Beavers switched to less-preferred species for food rather than travelling further away from the lodge or water's edge.
- Parrot's-feather (*Myriophyllum aquaticum*) and waterweeds (*Elodea* spp.), which are invasive non-native vascular plant species, were preferentially grazed.
- In Scotland a species of European importance, the slender naiad (*Najas flexilis*), was thought to have high interaction potential with beavers although the risk was considered low. The plant is abundant in lakes in North America where beavers are present.
- Uprooting of isoetids (short tufted species with stiff, linear, basal leaves growing on the bed of shallow water bodies) occurred but the impact was regarded as trivial.
- Rhizomatous aquatic vascular plants were generally preferred over non-rhizomatous species with great fen-sedge and common club-rush (*Schoenoplectus lacustris*) very heavily impacted by foraging - their cover being disproportionately reduced over time. White water-lily, water horsetail and bogbean (*Menyanthes trifoliata*) were, however, also negatively impacted and yellow water-lily (*Nuphar lutea*) was preferentially taken.
- Feeding and collecting was not found to occur in brackish situations, which is a relevant finding in respect of triangular club-rush (*Schoenoplectus triqueter*) – a species of tidal river margins which is Critically Endangered. It is closely related and morphologically similar to common club-rush (a strongly favoured food) and occurs in Devon.

### 4.7.4 Further research since the Scottish Review

Most recent studies since the Scottish Review have focussed on aquatic plants. However, Willby *et al.* (2018) studied the impacts of beavers on vascular plant species diversity at α, β and γ scales (where α is the level of diversity in a sample, β the level of diversity between samples, and γ the total diversity across all samples) in southern Sweden. The study found 15% more vascular plant species per plot in beaver ponds than in other wetlands (α-diversity) and 33% more at the site scale (γ-diversity) (reflecting the experience of Wright *et al.* 2002 in

North America). Plant β-diversity (the difference between plots within sites) was also up significantly ($p = 0.013$) by 17%.

Rentch *et al.* (2015) concluded from a study of plant communities in a wetland in West Virginia that in areas impacted by North American beavers, the broken overstory created a variable light regime which resulted in a high diversity of herbaceous plants. They also noted that sedge beds and scrub increased in area in beaver affected areas.

### 4.7.5 English context

Stroh *et al.* (2014) found 21.8% of the English vascular flora to be threatened, comparable to the figure of 22.3% for Great Britain as a whole (Cheffings *et al.* 2005) but, unfortunately, no direct evidence is available in the literature for the preferential or differential effects of beaver activity and exploitation levels for almost all of these threatened species. The majority of studies which are available have focussed on trees which are used both as food and for construction (See woodland section 4.3 for further information).

The assessment of the impacts of reintroduced beavers in Scotland covered two very different situations, Knapdale and Tayside. The Knapdale context, with frequent lochs and coniferous trees abundant in the landscape, is different from the predominantly lowland, farmed English landscape where much of the freshwater available for beaver exploitation exists in the form of small streams in an agricultural context. There will clearly be greater parallels with Knapdale should beavers reach the more upland areas of south west England or should further reintroductions take place in the north of the country. However, there may be more parallels overall with beaver impacts in the Tayside landscape. There are lessons to learn in particular from findings related to an enclosed beaver population on the Bamff Estate in Perthshire in which they were found to focus on yellow iris (*Iris pseudacorus)* and bogbean – the latter species not having been targeted to any significant extent in Knapdale. This demonstrates that different beavers may have individual or family group food preferences and that direct extrapolations from particular geographies will not always be reliable.

Given the fact, however, that beavers self-located into areas of native broadleaved woodland with similar vegetational composition and patterning to equivalent ecosystems in England, the Scottish experience is likely to be relevant to England. It is perhaps worth emphasising that England generally has more intensive land use over a larger proportion of its land area resulting in more fragmented vascular plant populations, many of which are locally threatened as a result.

All of the taxa highlighted as impacted in the Scottish report occur in England and the majority are widespread and 'Least Concern' (Stroh *et al.* 2014). Willow species are generally referred to only at the genus level in the Scottish report and, in England, two species of willow are 'Threatened' or 'Near Threatened' (NT). Downy willow (*Salix lapponum*) is a 'Critically Endangered' montane, Lake District species which is very unlikely to be impacted due to its habitat being unsuitable for beavers. Creeping willow (*Salix repens*) is widespread and NT; it grows in seasonally damp ground and may be impacted in some situations, although its NT status is primarily due to habitat loss and the effect of beavers is likely to increase habitat availability. No references could be found specifically identifying significant impacts on creeping willow.

It is also noteworthy that a large proportion of the diet of beavers consists of herbaceous and aquatic species, particularly species with extensive rhizomes such as yellow iris, great fen-sedge*,* common club-rush and bulrush. Floating aquatic plants such as white water-lily and yellow water-lily are also preferentially consumed (Milligan and Humphries 2010). Estimates suggest that 50% to 80% of a beaver's diet may be made up of non-woody species but recovery in exploited populations of these species is usually very good (Bergman and Bump 2015). Studies of the impacts of beavers on vascular plant species diversity at α, β and γ scales all suggest increases in diversity of between 15 and 33% (Willby *et al.* 2018). Attention, therefore, must be focussed on individual taxa which may be adversely affected, and mitigation considered where necessary. For most species of conservation concern, targeted *ad hoc* assessments and monitoring will be required as few such species have been subjected to scientific studies in this regard.

The Scottish report gave particular attention to two aquatic plant species, slender naiad and floating water plantain (*Luronium natans*); both are on Annex II of the European Habitats Directive. Floating water plantain has such a restricted distribution in Scotland little could be said about the impacts. There are more lake and pond sites which contain this species in England, and it will therefore need to be considered. Slender naiad is extinct at its only previous English location, but its seeds are present in the sediment and it is hoped it can re-establish should conditions improve sufficiently. The Scottish report found that whilst there was overlap between beaver and slender naiad habitat, the risk to slender naiad was thought to be low. It is, however, of note that several of the Tayside lochs have recently lost their slender naiad populations, although this is thought to be due to nutrient enrichment and waterweed growth (Bishop 2018).

In addition to the European Protected Species (EPS) assessed in the Scottish report the following EPS occur in England:

- Creeping marshwort *(Helosciadium repens)* - also known as *Apium repens* – a small umbellifer, now restricted to periodically flooding grazed commons alongside the Thames in Oxfordshire and a recently created wet wildflower meadow in Thetford, Norfolk. Given the waterside nature of its locations, this species may be impacted by changing hydrological conditions should beavers be reintroduced to these areas. Consequently, specific assesments should be undertaken should beavers be reintroduced to these areas.
- Fen orchid (*Liparis loeselii*) is now restricted in England to a few sites in East Anglia. As with creeping marshwort, its regularly inundated habitats would be highly likely to be impacted should beaver reintroductions take place locally. Also, as with creeping marshwort, it is likely that additional suitable habitat could be created by beavers. Specific assessments would be required if such proposals were to be made in the relevant parts of East Anglia.
- Lady's-slipper orchid (*Cypripedium calceolus*), shore dock (*Rumex rupestris*) and early gentian (*Gentianella anglica*) are all extremely unlikely to be impacted due to no or negligible overlap in habitat requirements with beavers. However, one lady's-slipper

orchid reintroduction site immediately adjacent to a lake could potentially be adversely affected should beavers be reintroduced in the area and cause the lake level to rise.

There are many other rare and threatened vascular plant species in England which could possibly be impacted due to similarities in habitat requirements to beavers but there appears to be very little evidence in the literature at the species level for the majority of taxa. However, given the attention drawn to some of the most favoured food species in Scotland, two threatened species might be predicted to be especially at risk if their distributions were to overlap with beavers – these are triangular clubrush and least water-lily (*Nuphar pumila)*, both of which are Critically Endangered in England. The restriction of triangular club-rush to the tidal Tamar, and evidence that beavers avoid feeding in the lower reaches of large tidal rivers (Stringer *et al.* 2015) suggests that negative impacts on this species are very unlikely. Least water-lily, on the other hand, is likely to be preferentially selected if beavers were to co-occur at its single English locality in Shropshire, given their documented dietary preference for its more widespread congener: yellow water-lily (Milligan and Humphries 2010). Any proposed reintroduction in Shropshire would need to take special account of this highly threatened species, including undertaking additional positive conservation action for the water-lily.

In relation to non-native plant species, beavers are known to preferentially forage on Himalayan balsam (*Impatiens glandulifera*) (Nolet *et al.* 1995) and have been recorded feeding on this species on the River Otter in Devon as part of the River Otter Beaver Trial, but not enough to be likely to reduce its abundance (Brazier *et al.* 2020). The method of dispersal is through seed projection and it is unlikely that beavers would affect its distribution. Himalayan balsam appears to prefer very open seed beds, such as scoured river banks or under winter flooded trees. The creation of more permanently inundated land by beavers is not ideally suited to Himalayan balsam. However, if lots of Himalayan balsam were present initially this could prevent the establishment of other vegetation and lead to winter-bare areas which would repeatedly recolonise with Himalayan balsam each spring.

Beavers may also feed on Japanese knotweed (*Reynoutria japonica*) and *R. x bohemica* - a hybrid between Japanese and giant knotweed (*R. sachalinensis*) – has been recorded growing within a beaver dam in the River Otter catchment (Brazier *et al*. 2020). It is unclear whether it had been used as a construction material by the beavers or had been washed into the dam. As these three knotweed taxa will grow from the nodes of pieces of green stem, the actions of beavers feeding and depositing sections close to the water in feeding stations, or incorporating into dams, could aid the spread of this invasive species. Therefore, should these species be present within catchments where beavers may become established, monitoring, or ideally eradication efforts, should be undertaken.

Beavers were also recorded feeding on rhododendron (*Rhododendron ponticum)* and cherry laurel (*Prunus laurocerasus)* using it as lodge and dam building material on the River Otter (Brazier *et al*. 2020). Cherry laurel is spread by birds, through the seeds in their droppings, or through layering and suckering. Rhododendron spreads by seed or layers where branches touch the ground. It is unlikely therefore that beavers will promote the distribution of these invasive species. Foraging may, however, reduce viability of the plant, and cherry laurel in particular is not suited to permanently wet ground. Therefore, beavers may have a negative effect on their abundance.

### 4.7.6 Identification of potential areas of conflict in England

The main threats to vascular plant diversity are: localised loss of preferred species through a combination of beaver feeding or felling for construction, the inhibition of recovery due to livestock or deer browsing, and significant losses which might occur to vulnerable threatened species should beavers come into contact with them. The evidence is that generally beavers enhance vascular plant diversity in the landscape. Attention needs be prioritised to those taxa not already specifically studied; especially those known to be favoured for food which are also rare, threatened or for which England has international obligations. Such assessments can only realistically be undertaken as and when reintroductions of beavers are proposed in areas in which they occur or if existing reintroduced populations are predicted to spread into those areas.

Interactions of beaver activity with high levels of browsing or grazing by other herbivores are very significant. Baker (2003) emphasises that both beavers and willows decline where vegetation is heavily browsed by livestock and/or deer.

### 4.7.7 Potential future implications of wider reintroductions in England

One group of species that particularly stands to benefit from beaver activity is that associated with open shallow water and emergent wetlands which, certainly for vascular plants, is one of the most threatened groups in England (Stroh *et al*. 2014). Species that are likely to benefit include lesser water plantain (*Baldellia ranunculoides*), lesser marshwort (*Apium inundatum*), and water violet (*Hottonia palustris*), which are all listed as Vulnerable in the England Red List of Plants (Stroh *et al*. 2014) due to widespread loss from much of the country.

With direct reference to vascular plants the most significant impacts are likely to come from the interactions between beavers and browsing deer and livestock causing willow carr to decline locally, although as discussed above no English willow species which are likely to be impacted are threatened. More significantly, the lack of knowledge at the individual species level is of concern, particularly for those species with characteristics known to be favoured by beavers in their diet. The implication is that any threatened vascular plant species with populations in areas of proposed reintroductions (or subsequent predicted expansion) is likely to require specific assessment. In many cases there will be significant niche segregation between the species of concern and beavers such that assessments should be relatively straightforward. However, for those threatened vascular plant species with significant habitat overlap with beavers, and particularly some of the EPS, in-depth assessments will be needed. Many other threatened vascular plant taxa which are aquatic, marginal or simply have populations adjacent to watercourses or water bodies will also require targeted assessment, particularly when morphological characteristics suggest they are likely to be strongly favoured as food items.

# 4.8 What are the effects of beavers on the biodiversity of invertebrates?

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## 4.8.1 Summary of main findings and recommendations

Studies on the impacts of beaver on two species of Odonata from the Scottish Beaver Trial were limited but highlighted that changes in habitats brought about by beavers were likely to benefit invertebrates overall (Gaywood 2015).

Medium evidence from elsewhere demonstrates that the high variation in microhabitat diversity caused by beaver benefits riparian invertebrate species overall (Bush *et al*. 2019; Ramey and Richardson 2017; Robinson *et al.* 2020), but may result in localised changes in abundance of some species due to the change from lotic to lentic habitat favouring certain species (Robinson *et al.* 2020; Strzelec *et al*. 2018; Washko *et al*. 2019). The development and presence of beaver dams, which alter physical and chemical characteristics of streams, will therefore have consequences for the types and functional characteristics of macroinvertebrates that can colonise streams where beavers are present.

Impacts from beaver activities on freshwater pearl mussels and white-clawed crayfish in England are expected to be complex, with variation in the positive and negative impacts for different sites and at different times. Subsequent monitoring would be required to determine the overall influence of beaver activity on populations.

Overall, the activities of beavers are likely to have differing effects on different invertebrate groups at different times and locations. Such changes are expected in the process of restoring natural function to freshwater and associated ecosystems, restoring lost diversity, dynamism and ecological resilience in the face of climate change. Local assessments should be undertaken to identify potential risks to those species of conservation concern and/or restricted distribution.

## 4.8.2 Introduction

Invertebrates represent a large proportion of the animal diversity within riparian and wetland areas. The impact on invertebrates by beavers is likely to be from two main sources: direct impacts on modification of specific niches and more generalised habitat shift as a result of beaver activity over time. Invertebrates perform various ecological functions, consequently their abundance and distribution are likely to affect other vertebrate species.

## 4.8.3 A summary of the findings from the Scottish Review

The Scottish beaver report highlighted the following main themes:

- A general and beneficial improvement in structural heterogeneity, to the benefit of invertebrates.
- Increases in coarse woody debris in watercourses, to the general advantage to invertebrates.
- Hydraulic and structural changes to watercourses, leading to increased variation in the habitats to the general advantage to invertebrates.
- Changes to downstream ecological parameters, which differentially impact different invertebrate families.
- Majority of invertebrates found in newly inundated areas were non-biting midge (*Chironomidae* spp.) and water boatman (*Corixidae* spp.) larvae. Water beetle diversity increased with predatory beetles and diving beetles becoming more dominant.
- Alteration to the localised treescape, through felling and alteration of riparian woodland through flooding, with variable impacts, especially on aspen *(Populus tremula*) woodlands.
- 92% of freshwater pearl mussels were in locations less likely to be dammed by beavers, therefore were largely unaffected.

### 4.8.4 Further research since the Scottish Review

There are limited studies related to the influences on invertebrates from beaver activity since the Scottish review.

Robinson *et al*. (2020), working in Switzerland, looked at how beaver impacts can vary according to topography. They compared a highland area characterised by streams running though ravine-like basin with a lower altitude open basin area. Beavers had a significant influence on fluvial dynamics and invertebrate communities in both areas, this was more pronounced in the lowland ‘open basin’ area, indicating that topography can influence the impacts of beavers on fluvial dynamics and invertebrate diversity and communities.

Malison and Halley (2020) compared the number of benthic, terrestrial and aquatic invertebrates between beaver-influenced and control sites in Norway to aid their study of salmonids. No differences in ecological response was detected, but data only represented a single year of study which may have been too short to detect any effect.

Bush *et al*. (2019), working in Georgia, USA, looked at how the natural successional gradient created by beavers affects invertebrate β-diversity and its components (where α is the level of diversity in a sample, β the level of diversity between samples, and γ the total diversity across all samples). The natural successional stages were natural stream channels, forested wetlands created by newly formed beaver dams, mature open wetland marshes, and abandoned wetland meadows. They found that invertebrate diversity was nearly twice as high for the overall study system than for any of the individual successional stages, which all had similar diversity. This strengthens the idea that beaver activity can be an important conservation tool by contributing substantially to diversity in areas where they are present. Beaver wetlands have the potential to help stabilise invertebrate diversity in the face of wetland loss from climate change and other human impacts.

Washko *et al*. (2019) studied macroinvertebrate communities in Utah, USA, where beavers were present and focussed on the difference between unaltered stream areas and beaver ponds. They found that beaver ponds were less diverse with 25% fewer species and that, on average, beaver ponds had 75% fewer individuals and 90% lower total macroinvertebrate biomass compared to areas of unaltered stream. It was not made clear though, whether this represented an overall increase in biodiversity over the area as a whole (i.e. beaver ponds adding to the overall biodiversity).

Strzelec *et al.* (2018) studied benthos composition in a beaver modified small river and beaver pond in Poland. They found that the diversity of Trichoptera and Coleoptera was greater below the beaver dam, while Diptera were more abundant in the beaver pond. Betidae (Ephemeroptera) were a constant component in the benthos assemblages and were most abundant in the beaver pond. Overall fewer genera/families of macroinvertebrates in beaver ponds were observed compared to streams. The degree of habitat differentiation caused by beaver activities in fluvial networks ultimately caused differences in biotic assemblages along the spatial dimension.

Ramey and Richardson (2017) undertook a synthesis of invertebrate ecology in riparian zones and further cite evidence of increases in invertebrate diversity, noting that: 'High variation in microhabitat diversity, usually created by recurrent disturbance, therefore helps support an array of riparian invertebrate species.'

McCaffery and Eby (2016) found a more than 200% higher emergence of aquatic invertebrates by total number in North American beaver modified catchments in North America relative to non-beaver sites, confirming increased aquatic invertebrate prey abundance.

Thompson *et al*. (2016) studied deadwood generation/dynamics in boreal wetlands and riparian forests. They found beaver-induced flooding created abundant volumes of deadwood in areas rarely experiencing other disturbance types. Compared to other disturbance types, different invertebrate saproxylic community diversity resulted.

### 4.8.5 English context

From an English context, the themes are generally much the same, though the importance of aspen within England for invertebrates might be slightly lower than in Scotland. This mostly stems from the work that the Malloch Society (MacGowan 1997) has undertaken, and from the geographical restriction of a number of key species in Scotland. A species of particular note here is the aspen hoverfly (*Hammerschmidtia ferruginea*) which is only known from Scottish aspen woods. Stubbs (2015) noted 139 invertebrates with some affiliation to aspen in the UK, and eight Priority Species (Section 41 of the NERC Act 2006) associated with the tree. The widespread distribution of aspen away from watercourses in England that could be occupied by beavers suggests that any impacts are likely to be very local.

Ramey and Richardson (2017) present five characteristics of riparian zones that may support specialist riparian invertebrates: high rates of disturbance; elevated nutrient and water availability; increased vegetation and microhabitat diversity; strong microclimate gradients and unique food resources. All these characteristics can be brought about by the activities of beavers.

In particular thermal changes to aquatic habitats brought about from dam impoundment, and the noted subsequent warming of the downstream waters, and localised reductions in water shading from beaver felling of riparian trees may have an effect on invertebrates, particularly the larvae of families like caddisflies (*Trichoptera* spp.) and potentially freshwater pearl mussels (*Margaritifera margaritifera*). Moulton *et al.* (1993) noted the Critical Thermal Maxima (CTM) for four caddis species in North America and observed that more northerly populations had lower CTM values. In the face of summer warming, potentially reduced summer rainfall leading to lowered river levels, beaver dam effects, and shading reduction, one could envisage the retreat of some taxa. How much influence any one of these factors has on its own is unclear. However, Knight (2017) considers CTM a rather blunt tool and that 'environmentally relevant thermal regimes' may be more relevant in the question of what kills mayflies (*Ephemeroptera* spp.) at higher temperatures.

Jackson and Funk (2019) found 'acute responses' from the larvae of four mayfly species to temperature in the face of elevated salinity, although in their study this was from sodium chloride (NaCl) rather than from other ions. However, the observed reductions in nitrates, phosphates and suspended sediments recorded on the River Otter Beaver Trial (Brazier *et al.* 2020) suggests that this driver may be ameliorated by beaver presence, and so becomes neutral. There are likely to be some impacts on the aquatic fauna, although this will be a complex matrix of distribution versus resource availability, versus impacted resource, and will vary by stream and river type and stream order.

Odonata eggs and larvae also show significant responses to temperature changes. Hassall and Thompson (2008) suggest that increased temperature could result in localised reduction in fish numbers which could result in odonatan larvae assuming the role of top predator in such water bodies. Also, although odonatan larvae grow more rapidly with increased water temperature, survival is reduced (Chavez *et al.* 2015).

**Potential impacts on invertebrates listed in Annexes II and V of the Habitats Directive**

*Lesser whorled rams-horn snail*

The lesser whorled rams-horn snail (*Anisus vorticulu*) is found in grazing marsh ditches in England, often in the range width of 2 to 4 m. In central Europe it is found in natural wetlands, but these habitats have been largely lost from England. In that respect, beavers may re-create habitat for this species. Grazing marsh offers suboptimal habitat for beavers due to the lack of tree species but could be occupied should population pressure build. It is unclear how the rams-horn snail would respond to dams, though as a species which seems to respond to disturbance patterns within its habitat, it may well benefit, at least in the short term. If wider natural processes arise from dam construction and the adjacent land is allowed to become proper wetland, then conditions would be expected to become more favourable for the species.

*Freshwater pearl mussel*

The freshwater pearl mussel (FPM) is endangered and of conservation importance. Population declines have been caused by factors such as pearl-fishing, pollution, acidification, organic enrichment, siltation, river engineering, and declining salmonid stocks. Most populations in England are now found in very low numbers, with some populations facing extinction. They require clean, oligotrophic, flowing water with stable river beds of rocks, cobbles and sands. Channel structures should not be altered that will impede water flow, increase erosion/scouring, or alter the distribution of substrates. Severe flooding or very low summer flows have a detrimental impact on populations, as can high sediment and nutrient loads (Skinner *et al*. 2003). Even slight hydrological changes in flow may result in serious degradation of habitat for mussels due to the very specific requirements of juvenile mussels (Buddensiek 1995; BSI 2017).

The impact on FPMs by beaver activity would seem to be from three main sources:

1. Hydraulic (flows) and structural changes to watercourses from beaver impoundments.
2. A more generalised habitat shift and increased habitat heterogeneity through beaver activity (e.g. tree felling, increased woody debris, alteration of riparian woodland).
3. Indirect effect on salmonid fish host through impeding migration and access to spawning areas.

Impacts from beaver activities on FPMs are expected to be complex, with variation in the positive and negative for different sites and at different times. The likely patchiness of beaver territories suggests only localised impacts on FPM populations. Beaver activity will only affect a proportion of stream length, ranging from <1% to 50%, the latter being recorded in the North American beaver (Rosell *et al*. 2005). This means that habitat can be available for FPMs between beaver ponds. That said, the majority of populations in England are now very restricted and in low numbers.

Although the total impacts of beaver activity will depend on the physical characteristics of each site, it would appear that beaver dams might actually benefit mussel populations, downstream at least, owing to reduced water sediment load and the regulation of water flow. On the reverse side, siltation immediately upstream of dams would be detrimental to mussels in those river sections, particularly juveniles, if dams were allowed to persist. Sedimentation can clog the interstitial spaces within the bed substrate, which can result in reduced water circulation and insufficient oxygen for juvenile mussel survival. FPM are less abundant where gravels, sands or silts dominate the sediment matrix (Hastie *et al*. 2000; Geist and Auerswald 2007). In addition, the potential increase in water temperature, whether in a beaver pond due to low flow rates or downstream due to a broader shallower stream may also be detrimental to FPM.

By restricting flows, beaver dams may lead to localised changes in erosion and sediment deposition and, in turn, changes to the cross-section and planform of rivers and streams. The significance of this will depend upon the setting; for example, it might result in changes in the quality of salmon spawning or juvenile mussel habitat.

Trees play a critical role in providing bank/bed stability, cover for fish hosts, shade and thus reducing water temperatures and ameliorating the impacts of nutrients, and plant and algal growth (Mainstone 2010). Felling of trees may increase the amount of light reaching watercourses, that can lead to changes in river bed habitat in situations of nutrient enrichment due to increased presence of aquatic plants and filamentous algae growth which can bind sediment and trap finer sediments (Mainstone 2010). This may result in poor substrate conditions for FPM and fish (spawning areas) (Laughton *et al*. 2008; Skinner 2003).

Freshwater fish are an important element of the ecology of FPMs which are wholly dependent on the presence of salmonids (Atlantic salmon (*Salmo salar*) or brown trout (*Salmo trutta*)) to complete their life cycle (Skinner 2003). Beavers could therefore have an indirect effect should they affect the species' fish host. Dam-building downstream of FPM sites may have an impact if the dams affect the migration of salmonid hosts and access to tributaries and spawning areas. A reduction in the number or distribution of host fish may negatively affect FPMs, although it is possible that negative impacts will be offset by potential improvements in water quality or the creation of habitats that may benefit fish and therefore FPMs.

The potential increase in water temperature may also be detrimental to FPMs which require cool, well-oxygenated waters (<25°C max) (Skinner 2003). High water temperature can have a negative impact on the survival of juvenile mussels (Buddensiek 1995) and free glochidia (larvae) live much longer at low water temperatures (<15°C) (Akiyama and Kawamura 2007).

*White-clawed crayfish (Austropotamobius pallipes)*

White-clawed crayfish are widespread throughout England and occur in areas with relatively hard, mineral-rich waters on calcareous and rapidly weathering rocks. The species is found in a wide variety of environments, including canals, streams, rivers, lakes, reservoirs and water-filled quarries (Holdich 2003). Although once widespread in England, disease, habitat modification and pollution have resulted in its now restricted distribution and protected status.

Research into the effects of beavers on crayfish are limited. Adams (2013) noted that responses of a complex crayfish community in Mississipi to beaver dams were variable and changed seasonally. In the absence of specific research on white-clawed crayfish, the effects of beaver activity would be expected to benefit the species through increases in refuge opportunities, stability of water levels and improved water quality. Increases in sediment from dams and burrowing may pose a negative impact as their gills may become clogged and white-clawed crayfish are not usually found inhabiting substrates covered in mud or silt (Holdich 2003). Beaver dams could also potentially partially isolate populations, although the effects of this are unclear. The activities of beavers would also be expected to benefit the non-native North American signal crayfish (*Pacifastacus leniusculus*) which can outcompete white-clawed crayfish for food and shelter and also spread crayfish plague (caused by the fungus (*Aphanomyces astaci*) to the white-clawed crayfish. Research is recommended to study potential interactions between beavers and white-clawed and North American signal crayfish.

### 4.8.6 Identification of potential areas of conflict in England

Although invertebrate diversity is likely to increase with increased water temperature, not all invertebrate groups benefit from this, with Odonata in particular, showing some negative responses. In any beaver reintroductions in England however, such effects will be very localised due to the fact that only small areas of water are likely to be affected and there are relatively few Odonata species specialising in watercourses within or adjacent to woodlands; an exception to this is the common clubtail (*Gomphus vulgatissimus*).

Due to the very restricted distribution and vulnerable nature of FPM populations in England appropriate management planning and action would be required in the event that beavers colonised rivers where FPMs occur.

### 4.8.7 Potential future implications of wider reintroductions in England

The increase in dynamic processes and habitat heterogeneity from the activity of beavers is likely to have a positive influence on invertebrate assemblages overall, although local assessments should be undertaken to identify potential risks to those species of conservation concern and/or restricted distribution.

# 4.9 What are the effects of beavers on the biodiversity of amphibians and reptiles?

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## 4.9.1 Summary of main findings and recommendations

There was no evidence from the Scottish Review on negative impacts of beavers on amphibians and reptiles, but any effects were predicted to be positive (Gaywood 2015). Medium evidence from England (Elliot *et al*. 2017) is consistent with strong evidence from Europe and North America demonstrating that effects on amphibians are positive and reptiles neutral to positive (Bashinskiy and Osipov 2016; Bashinskiy 2020; Dalbeck *et al.* 2020; Hossack *et al.* 2015; Osipov *et al*. 2018; Vehkaoja and Nummi 2015; Zero *et al.* 2016).

Overall, the effects of beavers on amphibian species in England is generally positive due to the creation of new ponds and wetland areas which provide habitat for breeding, foraging and dispersal. The grass snake is also expected to benefit from the habitat created. Adders prefer drier soils so may be detrimentally affected at a local scale, particularly if hibernacula sites are flooded.

## 4.9.2 Introduction

Beavers may affect reptile and amphibian distribution, diversity and numbers by modifying both aquatic and terrestrial habitats, although this influence is likely to be higher for amphibians. The impact on amphibians will mainly come from two sources: the creation of beaver ponds and foraging canals which will provide habitat and function as movement corridors for emigrating young.

Reptiles will benefit from tree felling providing increased opportunities for thermoregulation. Grass snake (*Natrix helvetica*) is most likely to benefit from beaver activity, as it feeds largely on fish and amphibians. The species could also benefit from beaver lodge structures in which to lay eggs.

## 4.9.3 A summary of the findings from the Scottish Review

- Beaver activity will result in the creation of ponds, slow-moving water and the development of wetlands habitats. This is likely to influence and have a positive effect on amphibian species as it will provide more standing water for breeding.
- The clearing of trees through beaver activity would increase sunlight and raise the temperatures of standing water which would be beneficial to amphibian larval development.
- Creation of ponds should increase aquatic invertebrate numbers which will also be beneficial to amphibians as prey.

- During their terrestrial phase, amphibians use damp rather than wet habitats and many of these areas would become unsuitable due to waterlogging, however it is likely that amphibian species would locate to other areas as they become available. Similarly, hibernation sites lost to waterlogging would be found as the landscape adapts to beaver activity. The main negative impact could be the presence of fish within beaver ponds. Fish feed on the larval stages of most amphibians (although probably not the common toad (*Bufo bufo*)) and this can have a serious effect, particularly with great crested newt (*Triturus cristatus*), which are particularly vulnerable as they are pelagic in habit. As great crested newts do not favour lotic habitats, beaver activity could provide considerable opportunities for this species by creating slow moving or still water (lentic) habitats. Of the three species native to Scotland - common lizard (*Zootoca vivipara*), slow-worm (*Anguis fragilis*) and adder (*Vipera berus*), effects are likely to be neutral. Beaver activity, such as the felling of trees, will open the canopy in woodland, providing increased opportunities for thermoregulation (basking and feeding). As with amphibians, hibernation sites may become lost to waterlogging, but other suitable sites are likely to become available.
- It is unclear whether the grass snake is native to Scotland, although there is evidence that populations are present. This species is the most likely to benefit from beaver activity, as it largely feeds on fish and amphibians. It could also benefit from laying eggs in suitable conditions created by detritus in beaver lodge structures, which would also benefit other amphibian and reptile species as shelter.
- Beaver impoundments and structures may provide suitable habitats for non-native species including freshwater terrapin such as red-eared terrapin *(Trachemys scripta elegans*) and European pond tortoise *(Emys orbicularis*) and 'water frogs' (marsh frog *(Pelophylax ridibundus),* pool frog *(P. lessonae*) and edible frog *(P. esculentus*).

### 4.9.4 Further research since the Scottish Review

Since 2011 studies on beaver reintroductions have been carried out in England at two sites in Devon – an enclosed (fenced) project on the River Tamar and free-living beaver population on the River Otter (Elliot *et al*. 2017). Monitoring included counts of common frog (*Rana temporaria*) spawn clumps, which increased significantly from 10 in 2011, when the site was first surveyed, to 580 in 2016 (an increase in predators such as grass snakes was also noted). This large increase is in part no doubt to the increase in breeding habitat created by beavers, but short-term studies need to be treated with some caution since amphibian and reptile populations naturally fluctuate.

Dalbeck *et al.* (2020) undertook a literature review to compare the available data addressing the effects of beaver dams on amphibians in streams of central temperate and boreal Europe. Despite having differing habitat requirements, all 19 species of amphibian that occurred in the study region were found in beaver ponds. Beaver ponds in headwater streams contained greater species diversity compared to beaver ponds in the floodplains of large rivers. The authors propose that beavers and their habitat creating activities are pivotal determinants of amphibian species richness in headwater streams, which account for 60–80% of the water bodies in catchment areas in temperate Europe and are important in contributing to the long term conservation of amphibians.

Bashinskiy (2020) reviewed the literature of beaver impacts on lakes and ponds. It was found that beaver activity can positively affect amphibians in these freshwater habitats through the creation of channel systems and shallow water in the littoral zone, which increases the number of spawning areas. The occurence of reptiles in burrows may be higher on lakes than river systems and food supply may be significantly increased for reptiles living in lakes as a result of beaver activity.

Downie *et al.* (2019) reviewed the distributions and conservation status of the six native amphibian species in Scotland and mentions that the beaver reintroduction programme may benefit amphibians in the longer term, with longer term research required.

Pollock *et al*. (2017) noted that the ability of beavers to diversify the landscape with different sizes and ages of lakes, ponds and modified streams can also significantly increase the biodiversity of amphibians and reptiles.

Zero *et al.* (2016) studied wetland use of the northern leopard frog (*Lithobates pipiens*), in southeastern Wyoming and found that the main drivers of breeding distribution were the degree of beaver activity at wetlands and the ability of a site to retain water throughout the summer. Active beaver ponds were preferentially used for breeding by this species.

Bashinskiy and Osipov (2016) and Osipov *et al*. (2018) studied the impact of Eurasian beaver on forest-steppe river ecosystems from damming and the creation of beaver ponds. Amphibian abundance increased with the presence of beaver ponds including old ponds and decreased where ponds were drained due to increased water flow.

Anderson *et al.* (2015) and Grudzinski *et al.* (2019) examined the role that beaver canals can play as movement corridors for various species, including amphibians and concluded that this is predominantly positive.

Hossack *et al.* (2015) studied trends for five wetland-breeding amphibian species in the Rocky Mountains, USA, alongside the role of beavers. Although beavers were uncommon, occupancy by amphibians increased 34% in beaver-influenced wetlands compared to wetlands without beaver influence.

Vehkaoja and Nummi (2015) studied the effects of Canadian beaver on the common frog, moor frog (*Rana arvalis*) and the common toad in the Finnish landscape where 100% of forests have been drained. Anuran species richness was found to be higher in beaver ponds compared to non-beaver and temporary ponds.

### 4.9.5 English context

There are 13 species of amphibian and reptile native to England. The potential for breeding and terrestrial habitats to be affected by beaver activities is high for all amphibian species except northern pool frog and natterjack toad *(Epidalea calamita*), which are found on sites that beavers are unlikely to use. Reptiles are likely to be less affected, apart from the grass snake (Figure 14) which extensively uses aquatic habitats for foraging. Common lizards and slow worms will forage in wetland areas to some extent.

**Figure 14** Grass snakes (*Natrix Helvetica)* use aquatic habitat for foraging

© Tim Bernhard, Natural England

One of the most important aspects of beaver engineering is the continual creation, abandonment and further creation of new waterbodies over time. This can provide many varied water bodies, of different sizes and depths and at various successional stages, where beavers are active. This will benefit amphibians as it greatly increases the chances of breeding ponds that provide the right conditions being available in the landscape for most species.

The frequent presence of fish in beaver ponds is not necessarily detrimental if sufficient aquatic vegetation is present to provide shelter for the larvae of newts and frogs. Even the more fish-sensitive great crested newt, whose larvae prefer open water and are highly vulnerable to fish predation, can still forage in and benefit from these ponds as juveniles and adults. Common toads can breed with or without the presence of fish, the tadpoles being distasteful to most predators, so are most likely to benefit from the widest range of beaver ponds.

The absence of a high density of suitable, high quality breeding ponds is the major limiting factor for amphibians in many parts of England, as a result of losses from agricultural activity since the 1950's (Robinson and Sutherland 2002). The creation of new water bodies and changes to existing water bodies by potentially increasing temperatures, stabilising water levels and improving water quality are all expected to benefit amphibians and reptiles by providing new opportunities for breeding, foraging, dispersal and shelter. Common frogs often breed in ephemeral ponds and these may be negatively impacted by raised water levels following beaver activity, however, they are able to use a variety of other water bodies and are unlikely to be detrimentally affected overall.

Although native amphibians prefer still (lentic) freshwater habitats, some species such as common toads (Figure 15) and common frogs can breed in the slower sections of flowing (lotic) water bodies such as small streams and rivers. The more the activities of beavers slow the flow of streams (Bashinskiy 2012; Bashinskiy 2014; Puttock *et al.* 2017) the more that amphibian species are likely to benefit.

**Figure 15** Male common toads (*Bufo bufo*) can breed in the slower sections of flowing (lotic) water bodies such as small streams and rivers

© Tim Bernhard, Natural England

Terrestrial habitat should also be improved for amphibians and reptiles. Although woodland can support high densities of amphibians, and beavers may locally reduce tree cover, all species occur in a variety of other terrestrial habitats and would benefit from improved connectivity and structural diversity overall. An increase in the amount of small branches and deadwood would provide valuable cover and basking opportunities for both amphibians and reptiles (Edgar *et al.* 2010; Baker *et al*. 2011).

Amphibians and reptiles have limited mobility compared to many birds and flying invertebrates, and even mammals, so habitat connectivity is of crucial importance to amphibians and reptiles for dispersal and the maintenance of healthy metapopulations (Marsh and Trenham 2001; Semlitsch 2002; Dalbeck *et al*. 2014; Cayuela *et al.* 2020). Therefore, beaver activity would be expected to improve connectivity for populations.

### 4.9.6 Identification of areas of potential conflict in England

Short-term impacts on existing water bodies by beavers may have some negative implications such as the potential spread of predatory fish which can detrimentally affect breeding success of smooth (*Lissotriton vulgaris*), palmate (*Lissotriton helveticus*) and great crested newts (Hecnar and M'Closkey 1997; Indermaur *et al.* 2010). However, given that the number of small waterbodies in England has declined hugely in recent decades anything that increases their number will be important for freshwater conservation, even in areas where ponds already exist in the landscape (Biggs *et al.* 2017; Magnus and Rannap 2019), so long-term benefits are likely to outweigh any initial short-term negative effects.

Adders prefer drier soils so flooding caused by beavers may be problematic to this species at a local scale, but limited habitat overlap between these species would be expected to occur more generally. The main risks to any native reptile species from beaver activity is the potential winter flooding of hibernacula and the loss of formerly dry reptile habitats due to water level rise.

### 4.9.7 Potential future implications of wider reintroductions in England

The common toad and the grass snake are both likely to benefit significantly from the activities of beavers, both of which (but especially the common toad) have suffered recent declines in England. Among the other amphibians the common frog, followed by the two more widespread newt species (smooth and palmate newts) should all benefit. The great crested newt is likely to take advantage of the increase in the number and variety of new ponds that would be created, although this might be tempered somewhat by the frequent association of fish with beaver ponds and canals. Currently, due to their extreme scarcity, northern pool frogs are very unlikely to encounter beavers, however with further reintroductions on a wider scale, they would undoubtedly benefit from beaver activity.

## 4.10 What are the effects of beavers on the biodiversity of birds?

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### 4.10.1 Summary of main findings and recommendations

Evidence from the Scottish Beaver Trial was limited in relation to determining whether the biodiversity of birds was affected by beavers, which was attributed primarily down to a lack of study in this area. It was concluded that the overall effect of beavers on bird diversity was likely to be neutral to beneficial (Gaywood 2015). There is strong evidence that wetland areas created by beavers can positively increase bird biodiversity and numbers overall (reviewed in Stringer and Gaywood 2016).

There is no evidence to suggest the activity of beavers through the modification of habitats will be detrimental to the biodiversity of birds within England, although their presence in areas where deer browsing is already a land management challenge could be an issue for woodland regeneration and would need to be addressed.

Limited evidence from England on the River Otter showed no significant difference in species diversity or in the numbers of territories of individual species before and during beaver presence, but it is acknowledged that surveys may have been undertaken too soon after the beavers were established here to see any significant differences (Brazier *et al*. 2020).

There is no evidence that bird biodiversity is likely to be negatively affected by the activities of beavers. The available evidence demonstrates that overall, birds are likely to benefit.

### 4.10.2 Introduction

It is well documented that the activities of beavers are of benefit to a range of avian species, by creating wetland systems and increasing the available habitat for feeding and nesting (Gurnell *et al.* 2009; Stringer and Gaywood 2016). Wetland areas created by beavers can significantly increase bird biodiversity and are quick to take effect, with numbers much higher in comparison to surrounding areas (Nummi and Pöysä 1997). It has also been shown that beavers act as a whole-community facilitator for waterbirds and that favouring beavers is a worthwhile tool in restoring wetlands to promote waterbird communities (Nummi and Holopainen 2014).

Ecological variability and habitat heterogeneity are important for birds at both spatial and temporal scales. The presence of beavers generates heterogeneity at local and landscape scales creating structurally complex aquatic habitats. The diversity of habitats at beaver ponds reduces predation pressure and increases food availability.

### 4.10.3 A summary of the findings from the Scottish Review

- Increase in wetland areas is a key determinant of avian biodiversity.
- Aquatic characteristics of beaver ponds are important for waterfowl.
- Structural complexity improves nest concealment, reduces predation and increases food production.
- Ponds created by flooding kills trees in the riparian zone thus attracting woodpeckers (family *Picidae*) and nuthatches (*Sitta europaea)*, for which standing deadwood is an important nesting and feeding habitat.
- Aquatic habitats created by beavers provide a more abundant food supply in the form of macroinvertebrates and fish (beneficial for ducks (family *Anatidae*), herons (family *Ardeidae*) and kingfishers (*Alcedo atthis*)).
- Beaver meadows support diverse vegetation which promotes grassland bird diversity.
- Where ponds are covered by ice and snow, beaver activity causes earlier ice melt and therefore access to habitat by wildlife for an extended period.

### 4.10.4 Further research since the Scottish Review

Since the Scottish literature review and report there has been limited further relevant research. Where studies have been undertaken, they support the existing body of evidence demonstrating the positive benefits of beavers for birds.

Nummi *et al.* (2019) found that where waterfowl require high quality habitats beavers can be considered as a restoration tool. This study also showed that beaver flooding was a crucial factor positively affecting teal (*Anas crecca)* productivity.

Brazier *et al.* (2020) noted that bird surveys at a County Wildlife Site (Clyst William Cross) within the River Otter trial area showed no significant difference in species diversity of the site or in the numbers of territories of individual species between surveys (before and during beaver presence). Several additional species were, however, recorded in the 2019 survey. The authors conclude that surveys may have been undertaken too soon after beavers were established to note any significant differences in bird assemblages. Marshy grasslands that were created periodically by the beavers on the River Otter attracted snipe (*Gallinago gallinago*) and dipper (*Cinclus cinclus*). Teal and other wetland birds were observed on the open water created in the floodplain during the winter months. One beaver created wetland supported passage migrants such as common sandpiper (*Actitis hypoleucos*) and green sandpiper (*Tringa ochropus*). Although breeding evidence for some was inconclusive, it gives an indication that if there is any beaver-mediated influence on the site's breeding bird assemblage then it is most likely to be positive.

### 4.10.5 English context

It would be expected that the benefits set out in the Scottish report would also apply to the English situation.

Birds with British breeding populations predominantly in England that could benefit from beaver activity are lesser spotted woodpecker (*Dendrocopos minor*), crane (*Grus grus*), willow tit (*Poecile montanus*), little egret (*Egretta garzetta*) (Figure 16), cattle egret (*Bubulcus ibis*) and kingfisher.

**Figure 16** Little egret (*Egretta garzetta)* could benefit from beaver activity



Birds with British wintering populations predominantly in England that could benefit from beaver activity are green sandpiper, common sandpiper, kingfisher, crane, willow tit, lesser spotted woodpecker, little egret, cattle egret, great white egret (*Ardea alba*) and shoveler (*Anas clypeata)*.

Overall, the main species that could benefit are waterfowl (e.g. teal, gadwall (*Anas strepera*) and mallard (*Anas platyrhynchos*)), herons and kingfishers. Woodcock (*Scolopax rusticola*) could also benefit. They breed in damp woodland and one possible cause of the decline in their population could be due to woodland drying out. Beaver ponds adjacent to woodland could be of benefit to this species.

Studies at Knapdale show that beavers create woodland with a more open canopy and more diverse field layer. This mimics the benefits of woodland management through traditional coppicing techniques. Clearly this would be of significant benefit in England where such positive management of woodland has largely been neglected or discontinued. Provided deer (family *Cervidae*) numbers are controlled, and appropriate management put in place, the benefits from increased structural diversity within woodlands is clear. It will open up additional ecological niches for a range of species. There will be benefits to insectivorous birds such as warblers (family *Sylviidae*), as well as positive effects for dead-wood feeders such as woodpeckers and nuthatches.

It could also be the case for England that wetlands created by beavers may assist the spread of non-native species, e.g. Mandarin duck (*Aix galericulata*) and red crested pochard (*Netta rufina*). This is, however, unlikely to have any negative impacts for native species.

Overall, the effect on bird diversity is likely to be positive and to result in greater avian diversity. If it is found there are negative effects on individual species then this can be looked at on a case by case basis. In any land management situation bespoke management measures may be necessary for some species.

### 4.10.6 Identification of areas of potential conflict in England

Birds dependent on a diverse age structure of woodland could be detrimentally affected, but this would be at a local, not landscape scale so it is likely that any negative effects could be ameliorated. This could, however, be exacerbated if tree regeneration is limited by deer browsing in areas where this is not controlled. If the positive effects of beavers are to be facilitated then reintroductions should be combined with deer control to improve tree regeneration.

Monitoring of non-native species should be carried out to identify potential issues at an early stage.

### 4.10.7 Potential future implications of wider reintroductions in England

Application of the principles of Lawton (Lawton 2010) and a focus on Nature Recovery Networks should be used as a guide to the locations for reintroductions which may benefit birds the most. Existing wetland habitat re-creation strategies should be consulted and table 3.17 in Brown and Grice (2005) provides a useful summary of potential areas for wetland restoration for birds in England.

The presence of beavers in areas where deer browsing is already a land management challenge could be an issue for woodland regeneration and would need to be addressed.

# 4.11 What are the effects of beavers on the biodiversity of mammals?

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## 4.11.1 Summary of main findings and recommendations

There was strong evidence from the Scottish Beaver Trial that negative impacts from beavers on native mammals were considered unlikely and that overall beaver activity would have a positive effect on mammal diversity and abundance (Gaywood 2015; Stringer and Gaywood 2016).

There is medium evidence in England that the effects of beavers through modification of habitat benefited native mammal species such as otters, water voles and water shrews through increases in the provision of habitat, prey and shelter. There is also medium evidence that non-native invasive mammal species such as mink can also benefit, subsequently posing risks to water voles and other small mammals. (Blythe *et al*. 2016; Brazier *et al*. 2020).

There is medium evidence from elsewhere in Europe that beaver activity can positively affect mammal species richness and occurrence (Samas and Ulevičius 2015; Nummi *et al*. 2019).

Overall, it is concluded that beavers are likely to positively influence native mammal fauna in England. The activity of beavers may however also positively influence the distribution of non-native American mink through improved habitat and prey provision. The significance of this for the native water vole is uncertain and requires further investigation.

## 4.11.2 Introduction

The activities of beavers may affect mammal species through changes in habitat, abundance and distribution of food sources, increased structural complexity of habitat and direct provision of resting and breeding places. Mammal species of particular note are the water-dependent mammal species: the native European otter (*Lutra lutra*), water vole (*Arvicola amphibious*), water shrew (*Neomys fodiens*) and Daubenton's bat (*Myotis daubentonii*). Non-native American mink (*Neovison vison*), which is a significant predator on water voles, could also be affected.

Interspecific behavioural interactions may also occur, such as predator/prey relationships between beavers and predators such as foxes (*Vulpes vulpes*), otter and potentially American mink which may take young beaver kits. Indirectly, there will be impacts on these mammalian predators through changes to their other prey sources due to beaver induced changes to the habitat.

### 4.11.3 A summary of the findings from the Scottish Review

The Scottish Review concluded that negative impacts from beavers on native mammals was considered unlikely. This followed a review of 35 studies which found no negative impact of beavers on mammal diversity or abundance, and a positive impact in half of the studies that involved a direct comparison between beaver occupied and non-occupied areas (Stringer *et al.* 2015). The ways in which beaver activity can influence the local distribution and abundance of other mammal species were summarised in the Scottish report as follows:

- By creating new areas of open water and associated wetland rich in aquatic plants, fish, amphibians and invertebrates, beavers can increase the availability of food for other mammal species. There are subtle and localised effects of selective grazing by beavers on plant species composition but overall, there is an increase in food sources and habitat for water voles.
- Through the construction of lodges, dams and the creation of burrow systems in river banks, beavers can create additional secure dens and resting places for other mammal species, such as otters.
- By creating coppiced riparian woodland, the resultant semi-continuous cover is likely to benefit some bat species, provided it remains at relatively small scale. The consequential creation of more permanent open areas may affect foraging patterns of certain bat species.
- In Knapdale there was no evidence of an impact of beavers on otter presence. Beavers are likely to have a positive impact on otters through the creation of new wetland habitat, provision of more amphibian and possibly fish prey, and resting sites.
- The tree species preferred by beavers (willow (*Salix* spp.) and ash (*Fraxinus excelsior*) at Knapdale) gave vigorous regrowth. These species were also heavily browsed by deer (family *Cervidae*) which could be considered a benefit to local deer populations, but is likely to have implications for woodland ecology. Whilst woodland regeneration is possible at low to medium deer densities, at the high deer concentrations currently experienced in much of Scotland, regeneration could be significantly affected without appropriate deer management measures.

### 4.11.4 Further research since the Scottish Review

Brazier *et al.* (2020) undertook a survey of water voles along the River Tale for the River Otter Beaver Trial (ROBT) in 2016 and 2017. Resurveys in 2019 for water voles showed they had expanded their range into new wetland habitat created by beavers. American mink were present in the catchment, but at a low density.

Brazier *et al.* (2020) recorded numerous sightings, observations and camera trap footage of interactions with other mammals in the ROBT, but no other formal survey data:

- Several mammals were observed using a beaver dam to cross a brook, including American mink, brown rat (*Rattus norvegicus)*, badger (*Meles meles*) and stoat (*Mustela erminea*). A fox, a potential predator, was filmed approaching a beaver dam, possibly just to cross the brook but retreated when a beaver approached it. On another occasion an adult male beaver was seen attacking a badger which had fallen into the water, biting it before swimming away.

- Otters were observed regularly near to beaver natal burrows and there was speculation that otters were actively hunting for beaver kit as prey. An adult beaver was filmed acting aggressively towards an otter in July, when beaver kits would have been emerging. On two occasions, otter spraints were found in old beaver burrows indicating that otters were using the burrows, perhaps as shelter.
- Roe deer (*Capreolus capreolus*) and rabbit (*Oryctolagus cuniculus*) were reported feeding in the drier areas of the Danes croft site in the ROBT, but there were no signs that this was significantly inhibiting the regeneration of vegetation. Brown hare (*Lepus europaeus*) could benefit in a similar way as it is known to utilise woodland cover, but no literature was found pertaining to this species and overlap with beaver areas.

At a fenced beaver project in Essex, four months after beaver were released into the enclosure, water shrews were detected in eDNA samples taken a few hundred metres downstream from a pond created by the beavers. A few weeks later water shrews were observed on a camera trap in the beaver pond, where eDNA of water shrew had previously not been detected (A. McDevitt pers. comm.).

McCaffery and Eby (2016) found an increased number of deer mice (*Peromyscus maniculatus*) and increased aquatic invertebrate prey abundance in beaver modified catchments in North America relative to non-beaver sites.

Samas and Ulevičius (2015) found that small forest mammals were significantly more numerous and diverse near beaver lodges than elsewhere in the forest, especially in summer, autumn and winter in Eastern Lithuania.

Nummi *et al.* (2019) found a significantly greater number of terrestrial and semi-aquatic mammal species were observed in beaver patches than control patches in a boreal setting in southern Finland. Otter, pine marten (*Martes martes*) and weasel (*Mustela nivalis*) made more use of beaver sites in winter, possibly due to the ice-free areas maintained by beavers which facilitate foraging.

The facilitation of American mink by increased availability of suitable prey was confirmed in a study from the southern end of the Americas (Crego *et al*. 2016). The prey in this case was muskrat (*Ondatra zibethicus*), which has similar habitat requirements to the native water vole in England, although the muskrat had also been introduced in this location alongside beaver and American mink so results may be of limited relevance to England.

### 4.11.5 English context

Common dormouse (*Muscardinus avellanarius*) was not considered in the Scottish Review as the species does not occur in Scotland. The Scottish Review did report a greater use of hazel (*Corylus avellana*) by beaver in the two latter years of the study, and suggested that hazel may ultimately become less abundant, particularly if also impacted by deer browsing the regrowth. Growth stage of hazel is also a key factor for dormice, as hazel greater than seven years old produces more nuts, which are important for fattening for winter hibernation. Common dormice prefer habitats with a high degree of species diversity, a mosaic of age classes and a fully three-dimensional physical structure, with plenty of links between woody vegetation between all levels (Bright *et al.* 2006). Therefore, provided deer browsing of regrowth can be controlled, beaver activity could be expected to benefit dormouse populations.

Pine marten is rare and restricted in England but has been subject to recent reintroduction attempts, e.g. in Gloucestershire, and therefore might increase in range. If there was overlap with beavers, it is likely to benefit from the increase in standing deadwood and hole nesting opportunities from inundated trees. Other small mammals are also likely to utilise holes in trees, such as: squirrels (family *Sciuridae*), yellow-necked mouse (*Apodemus flavicollis*), and wood mouse (*A. sylvaticus*), as well as variety of birds. All could be prey to pine marten and other mustelids such as stoats, which can hunt in trees (though are not as well adapted to arboreal hunting as pine marten).

Different bat species have subtly different habitat requirements, enabling them to occupy different niches and therefore impacts will be species and site dependent. Overall, it would be expected that the increase in habitat complexity and invertebrate prey abundance would benefit most bat species, although there may be localised changes in distribution as woodland canopy cover is affected. Given the restricted nature of the activity of beavers, any changes in woodland is not thought likely to negatively affect bats on a landscape scale.

### 4.11.6 Identification of areas of potential conflict in England

The combined effects of beavers and deer browsing could have implications for dormouse populations if hazel regeneration is negatively affected in close proximity to potential beaver wetlands.

Beavers are likely to benefit water voles by creating new habitat and creating channels through dense emergent vegetation (reed beds, etc) to potentially increase the permeability of these habitats. The impact of American mink on water voles is considered to be exacerbated by habitat loss and fragmentation (Macdonald *et al*. 2002) so additional habitat may provide a refuge area for water voles from mink predation. For example, there is evidence from England that water voles and American mink, which rarely coexist, can do so in dense reed beds (Carter and Bright 2003) as the mink tend to occupy the main water channels while the water voles inhabit the more densely vegetated areas. However, American mink may also benefit through using beaver lodges as den sites and beaver ponds for foraging and, possibly, predating young beaver kits. Any benefit to water voles would be unlikely to occur should American mink also utilise these areas. However, there is evidence from Patagonia and Russia (Kiseleva 2008) of American mink avoiding beavers, and plausible evidence of competition with otters in the UK (Bonesi *et al*. 2006). The assumed habitat benefits to mink may, therefore, potentially be cancelled. Further research is required in this area specific to the English landscape.

### 4.11.7 Potential future implications of wider reintroductions in England

The activities of beavers are expected to benefit native mammal species overall. American mink and deer populations should be monitored in areas of reintroduction to identify potential conflict with water voles and coppice re-growth respectively.

# 5 Social feasibility – beavers and their interaction with the human environment

## 5.1 What are the public attitude and perceptions towards a potential beaver reintroduction?

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### 5.1.1 Summary of main findings and recommendations

Evidence from the Scottish Beaver Report and wider research suggests that stakeholders and the public are generally supportive of beaver reintroductions, however the evidence is limited as there is very little research with representative samples (Gaywood 2015; Hamilton and Moran 2015). There is medium evidence relating to the social science evidence base relevant to beaver reintroduction in England (Auster *et al.* 2019; Auster *et al*. 2020.a; Auster *et al*. submitted; Brazier *et al*. 2020; Crowley *et al*. 2018; Inman In press). The evidence suggests some exceptions to stakeholder support, notable because they are typically from those that could be directly negatively affected by beaver re-introduction. In general, evidence suggests that this is linked to the fact that the impacts of beaver reintroduction are not distributed evenly and the costs are borne by a smaller number of individuals while the benefits accrue to society.

The context for beaver reintroduction in England is one of a densely populated and heavily man-made landscape used by humans. The introduction of a keystone species is likely to have social and cultural implications. Social research methods, qualitative and quantitative, can be used to better understand attitudes and experiences, underlying values, resultant behaviour and the social, cultural political and historical contexts under which these are formed and enacted. It can identify best practice approaches to engagement and inform development of management options.

Wildlife conflict can occur when 'parties with strongly held opinions clash over conservation objectives and when one party is perceived to assert its interests at the expense of another' (Redpath *et al.* 2013). The evidence suggests potential conflict related to beaver reintroduction amongst certain groups including landowners and farmers, anglers and commercial fisheries and specific ad-hoc communities living close to beaver areas.

Attitudes towards beavers (and their advocates) and perceived disbenefits vary depending on whether the introduction was planned or 'unplanned'. Conflicts can be heightened when linked to perceived legitimacy or 'threat' of illegal releases, mis-trust between parties and in management processes, power imbalances (including feelings of not being listened too), differences in value sets and identities, and where scientific information is partial or uncertain, or perceived differently. There is evidence that dialogue improves trust and can help reduce conflict and that engagement can support attitudinal change (though further research is needed to understand how this is sustained).

There are concerns among land owners and anglers about lack of agency to address negative impacts of beavers quickly. Agency is defined as 'the ability to act (and achieve) on the basis of what one values and has reason to value' (Hicks *et al*. 2016). This is one reason why culling is supported by some stakeholders. There is widespread support that getting the management right is important. There is potential that lack of management or mis-management generates a significant trust deficit and further polarisation.

Better integration between the social and natural sciences is needed to understand the social context of beaver reintroduction and to inform effective management that takes account of people's concerns and experience of disbenefits. Further research should use a wider range of methods, including deliberative processes, both with the general public and those potentially directly affected, to inform management options. Social research methods should be incorporated into monitoring and evaluation in the long term to understand 'what works' in reducing conflict and supporting co-habitation of people and beavers.

### 5.1.2 Introduction

Social science research approaches and methods (qualitative, quantitative and mixed) can be used to better understand individual and community attitudes and experience of benefits and disbenefits of beaver reintroduction. Social science can also be used to explore the underlying values and behaviours of those involved, and the social, cultural, political and historical contexts under which these are formed and enacted. It can also help to identify best practice approaches to stakeholder engagement. All of which can be employed to develop better approaches to reintroduction and management options.

Traditionally, conservation science has been dominated by biological and quantitative approaches. There is, however, a much needed and developing role which uses approaches developed within the various social science disciplines to understand individuals' and communities' attitudes, values and behaviour and take account of tacit or indigenous and local knowledge that may be key to solving conservation challenges (Sutherland *et al.* 2018). Social science can also situate these attitudes, values and behaviours in wider social and cultural contexts. This section draws on the social science evidence to explore people's perceptions, views and experiences of beavers, as well as exploring the wider evidence related to public attitudes towards beavers and the management of beaver reintroduction. Note that the social science evidence is relatively small (but growing). As the report to the Scottish Government states: *'overall, there is far less published information on these [social] topics from Europe and North America than there is on ecological topics. However, for certain topics some very useful studies have been carried out in Scotland in recent years'* (Gaywood 2015).

This section focuses on new social science evidence available since the publication of the Scottish Review. The aim is to highlight key evidence that is relevant to decisions on further beaver releases in England. Therefore this section in particular focuses on areas of potential tension and conflict, and the attitudes and experiences of those who may be most likely to have concerns or worries or directly experience dis-benefits of beaver reintroductions. This review began with a literature search looking for social science evidence specifically related to beavers published since 2015. In drafting this review, the authors have augmented it with references to papers from the wider social sciences literature relating to wildlife conflict, land management and stakeholder engagement, for example, that do not specifically relate to beavers, but findings are relevant to species reintroductions generally. A literature review on these wider evidence sources has been out of scope for this review but is recommended as a future next step for developing reintroduction management plans.

Historically, humanity's relationship with beavers has been socially complex (Campbell-Palmer *et al*. 2016; Auster *et al*. 2019). In North America, with its vast landscape, human interactions with beavers are less frequent. Management relies on lethal control in the context of hunting and shooting being, historically, a 'deeply cherished' part of the American cultural identity (Manfredoa *et al.* 2017). However in Western Europe, where the human-beaver interactions are more frequent, beaver reintroduction and management techniques are more contested, resulting in conflict (Schwab and Schmidbauer 2003; Campbell-Palmer *et al*. 2016).

Conflict, both human-wildlife and human-human, can arise when misinformation or ineffective management are combined with strong personal values (Campbell-Palmer *et al*. 2016). The importance of understanding social attitudes and perceptions is therefore paramount when reintroducing the Eurasian beaver to England to reduce conflict and ultimately enhance the natural environment for both humans and nature.

### 5.1.3 Summary of the findings from the Scottish Review

- A number of public consultation exercises were conducted in Scotland between 1998 and 2015, exploring attitudes to beaver reintroduction in general (i.e. across Scotland) and to a trial in Knapdale. The consultation showed significant support for reintroduction amongst stakeholders in general and for the trial in particular, but with notable exceptions and concerns. Concerns were raised by some land use sectors and by people living close to Knapdale. A comparison of consultation exercises conducted in 2007 and 2014 suggested that support increased over time.
- An independently coordinated Citizen's Panel in Argyll and Bute (thought to be representative of the local population to the Knapdale trial) found that 46% residents supported beaver reintroduction, 21% opposed and 33% neither.
- A stakeholder event held by Scottish Natural Heritage in November 2014, discussed future scenarios for beavers in Scotland. Common feedback suggested that all reintroduction scenarios needed an associated and detailed management strategy. It noted that the marginal benefits from cultural ecosystem services (e.g. relating to recreation and education) were likely to decrease as the beaver population increases (presumably on the assumption that beavers/sites would lose their novelty value), although evidence to support this was not presented.
- The Beavers in Scotland report compared evidence from Knapdale and Tayside and concluded that there was a significant difference in the socio-economic situation between a planned trial and reacting to an 'unplanned' release.

**Scottish Beaver Trial (Knapdale): socio-economic monitoring report for the planned trial:**

- Between 2008 and 2014, over 32,000 members of the general public were involved in various activities held by the Scottish Beaver Trial staff (including volunteering and guided walks).
- Formal consultation exercises showed that the majority of participants were supportive although there were notable exceptions from those with concerns.
- The Scottish Beaver trial generated a high level of media interest that was viewed to be instrumental in forming wider public opinion (albeit noting that the level of trial coverage may be unlikely to be replicated elsewhere).
- A small number of qualitative stakeholder interviews found evidence of concerns about the consultation process and independence of the Scottish Beaver Trial.
- An online survey of 32 local businesses in the tourism/accommodation sector noted low impact on their business, yet the majority were favourable or neutral towards reintroduction.

**The Tayside beaver socio-economic impact study ('unplanned' releases):**

- In Tayside a survey was sent to all land-managers in the catchment (response rate of 29%). Of those respondents who had seen, or suspected beavers were on their land, the large majority reported perceiving no benefits of beavers and no financial benefit to them personally. A minority had incurred quantifiable costs ranging from £300 to £10,000 with the higher costs incurred for damaged flood defences and large trees being felled in the arable part of the catchment. In less arable parts of the catchment, land managers perceived limited benefits from current or future beaver presence, but seemed willing to tolerate them pending appropriate control and potential compensation. Local control (i.e. culling) was the most favoured management option, along with compensation and dam removal.
- Responses from 31 local tourism businesses (representing a 4% response rate) indicated a significant level of awareness of the beaver presence and a largely positive attitude.
- A stakeholder consultation reported in the Tayside beaver socio-economic study concluded:
    - *'Organisations representing land managers expressed concern about the legality of the beaver presence, as well as noting current costs incurred and concern about the magnitude of future [negative] impacts.*
    - *Conservation organisations emphasised the possible benefits, although realising that management options need to be developed.*
    - *Tourism bodies thought that beaver presence would benefit local businesses*
    - *Some organisations noticed that clarification of the legal position of beavers is needed and the need for impact monitoring systems.'*
- The study noted: *'perceptions of beavers can change as impacts change (Siemer et al. 2013), as may be expected in an area such as Tayside with a dynamic population [of beavers].'*

The three Scottish reports show the difference between a managed process of reintroduction and 'unplanned' release, with significant differences in the size of the beaver populations and the land management context into which releases occurred. This resulted in a in a differential extent of potential human-beaver interaction and conflict. This manifests in terms of degrees of stakeholder engagement and support. Broadly speaking, there was majority stakeholder support, but the issue was to some degree polarised between those who are strongly supportive and those who have strong concerns.

Sedee (2016) summarised the Knapdale and Tayside studies: '*The results from the Scottish Beaver Trial and Tayside studies show that benefits outweigh the costs of the presence of beavers. However, there is an imbalance between those who experience the benefits of beavers (e.g. tourism industry, wider public) and those who bear the costs (e.g. agriculture and forestry)'.*

It remains to be seen how the social dimensions of beaver conservation in Scotland is to be monitored and evaluated and how further learnings on managing conflict can be obtained using scientific methods. Since the protection of beavers by law in Scotland (in May 2019), NatureScot have committed to a Survey, Monitoring and Research Strategy[15].

### 5.1.4 Further research since the Scottish Review

Most of the social research reviewed here used quantitative methods, e.g. surveying a sample of the population and subsequent quantitative analysis to measure responses to stakeholder consultations. In certain situations and for certain research questions, particularly when the subject is sensitive, qualitative methods can be a more realistic way to generate valid data, allowing researchers to identify the issues of importance to respondents, rather than impose those of the research team (Drury *et al.* 2011).

**General public attitudes**

A quantitative survey was conducted in 2017 (n = 2,759) by Auster *et al*. (2019). Due to the snowball sampling method, and recruitment mainly via invitation to organisations / representatives with a stake in beaver reintroduction, the sample was not designed to be nationally representative. Auster *et al*. (2019) used an online questionnaire to explore social factors: key stakeholder perceptions; engagement methods; attitudes towards legal protection and management responsibilities; and support for management techniques. The survey aimed to provide a wider understanding of the stakeholder and public perceptions, which looks beyond opinions of beaver impacts alone. The survey found that 86% supported beaver reintroduction, a similar response to that found in the River Tay catchment (Hamilton and Moran 2015) and 7.44% were not supportive ($n$ = 2741). A follow up survey in 2019 (to original respondents, n=386), showed attitudes towards the reintroductions had not changed (Brazier *et al*. 2020; Auster *et al*. 2019).

Analysis of survey results by Auster *et al*. (2019) by occupation found that occupations within the 'Farming and Agriculture' and 'Fisheries and Aquaculture' sectors were significantly less likely to have a positive view of beaver impacts, as were those who were 'Retired,' and those respondents whose property extends up to/includes a watercourse. In contrast, those in the

[15] https://www.nature.scot/management-framework-beavers-scotland-monitoring-survey-and-research-2019-2024 [accessed 11/06/2021]
Scottish Natural Heritage became NatureScot in August 2020.

‘Environment, Nature and Wildlife’ or ‘Arts, Sport and Media’ were significantly likely to have a positive view. Polarised opinions between these groups is noteworthy in the English context and further understanding of *why* these groups hold these opinions is imperative to conflict avoidance. Respondent level of knowledge about beavers was correlated with levels of support for reintroduction. Support for reintroduction was also positively associated with perceptions of need for strong levels of protection for the beaver. Auster *et al*. (2019), found that:

> *‘Among respondents who felt there should be ‘Strong’ or ‘Limited’ protection, the dominant view was that management practice was the responsibility of an environmental charity/organisation, followed by a government body. For respondents who felt there should be no legal protection, the dominant view was that responsibility should be with individuals/landowners, followed by a government body. ‘No Management Will Be Necessary’ was least supported in all groups.’*

A YouGov study (2019) conducted in December 2019, (with a sample of 2083 adults designed to be representative of the Great British population), asked ‘In general, to what extent would you support or oppose reintroducing species to the UK?’ This found that the majority of the public were positive about species reintroductions in general (36% adults strongly supported and 46% tended to support, with only 7% either strongly or tend to oppose). Of those that supported reintroductions, three quarters (76%) supported beaver reintroduction (for comparison, 83% supported reintroductions of locally extinct birds of prey, 57% Elks, 44% wolves and 30% brown bear). Taken together, this single survey, with just two simple questions, would suggest that around two thirds of the general public across Great Britain would support beaver reintroduction. Surveys such as this, while representative, are limited due to low levels of understanding and awareness of the issues and even the animals involved. For example, ‘respondents are not presented with a full appreciation of the complexities of the topic’ (Inman In press).

**The River Otter Beaver Trial in Devon – social science evidence**

The River Otter Beaver Trial: Science and Evidence Report (Brazier *et al.* 2020) included social research. As part of this, Crowley *et al*. (2018) conducted interviews and documentary analysis (including consultation responses) to examine the ‘story’ of the River Otter Beaver Trial (ROBT), looking at the evolution of the project, how and why the people responded and the environmental politics that ran along side. The research identified that the beavers were initially *‘framed as both unnatural and illegitimate, and the government planned to secure the situation by capturing them. This decision was strongly opposed by a diverse collective of British citizens who were united and made powerful by a common goal: protecting the beavers.’* This initial framing, and a perception that in effect the trial legitimised an illegal reintroduction may have helped to polarise ‘pro-beaver’ and not so ‘pro-beaver’ voices and contribute to tensions between stakeholders. Crowley *et al*. (2018) states that Devon’s beavers: *‘became fully abstracted from their corporeal selves, emerging in discourses of protection as ‘The Beaver’… ‘Rather than patrolling rivers, or encouraging compassion for individuals, protecting ‘The Beaver’ involves contesting legal classifications and ‘educating’ people about the species and its value’*.

A notable finding of the research from the ROBT and reiterated by Inman (In press), is the role that trust, or lack of it, plays in conflict resolution. Auster *et al.* (2019) showed that the majority of respondents (60%) felt unable to express their views or influence the decision making process, which was more acute for those who did not support beaver reintroduction or were undecided, than for those who did. This may reflect the initially unplanned genesis of the ROBT (as noted by Crowley *et al.* 2018).

Some disengagement by some landowners and fishery interests was also found by Inman (In press). A small number of interviewees reported considerable frustration towards beaver reintroduction management processes. The ROBT study also showed that knowledge and ability to express opinion can help to build support. For example, analysis of pre- and post-stakeholder event surveys indicated a change of views following evidence-based engagement activities (further research is needed to understand whether this supports sustained attitude and behaviour change) (Brazier *et al*. 2020).

Auster *et al.* (2020.a) explored the perceived benefits of beavers to communities, using a quantitative survey of properties in a village in the trial area (n=66) and qualitative interviews with local businesses (n=3). This found that 41.8% of residents reported that the beavers had influenced their use of the river, both positively (e.g. increasing time by the river and enhanced enjoyment) and negatively (e.g. avoiding certain stretches, being more careful with dogs). Those residents who had seen beavers commented positively of the experience (Figure 17). The three local businesses reported perceived economic benefit (which was greatest where businesses took steps to maximise the opportunity, though there was uncertainty about attribution to beavers.


**Figure 17** Reproduced from Auster *et al.* (2020.a). Word frequency analysis of how local residents felt upon seeing beavers or signs of their activity.

## Research outside of Great Britain

In South America, social research on beaver management primarily focuses on the potential *eradication* of the non-native North American beaver (*Castor canadensis)* (e.g. Anderson *et al. 2017;* Santo *et al.* 2017) and was not therefore considered relevant to this report.

In the USA a study based on interviews with 19 Owyhee County (Idaho) landowners, ranchers, and key stakeholders found an overall positive perception of beaver presence. However, much like Great Britain and Europe, concerns surrounding regulations, management and liability were highlighted (Abrams *et al.* 2019). A study by Pilliod *et al.* (2018) that examined 97 projects implemented by 32 organisations in the Western USA over the last ten years noted that *'beaver-related restoration has outpaced research on its efficacy and best practices'* and that human dimensions were rarely considered. The socio-ecological context of the United States and Great Britain are vastly different: the landscape of North America is that of vast areas of separated protected national parks and production land, whereas the landscape in Great Britain is considerably smaller with natural and production land being intertwined and interconnected. There is also a deeply embedded and popular culture related to shooting and hunting in the USA, which remains a basis of wildlife governance in many places (Manfredoa *et al.* 2017).

In Bavaria, Germany, education is a key factor in their management framework to increase knowledge and decrease conflict (Schwab and Schmidbauer 2003). Government advisers, NGO beaver managers and volunteers manage and monitor the beaver populations and disseminate information, guidance and advice to local landowners (Schwab and Schmidbauer 2003; Scottish Wild Beavers Group 2020). This level of support and guidance is attributed to creating trust and confidence and acceptance of beavers in Bavaria (Scottish Wild Beavers Group 2020).

### 5.1.5 English context

The Scottish Beaver Trial at Knapdale was a result of many years of planning, investigation and discussion resulting in a planned reintroduction. In Tayside, beaver populations spread due to 'unplanned' releases. In some ways, the ROBT was a hybrid of these, with illegal or unplanned release of beavers forming the basis of a trial which was then legitimised, considerably planned, monitored and discussed.

These three case studies highlight a number of key socio-cultural considerations for any future release and for the management of any current reintroduction programme. They include:

- The current human uses of the land and rivers systems.
- Population density of the beavers (and humans).
- Trust and confidence in management processes (and institutions/professionals).
- Trust and dialogue between stakeholders.
- Awareness of the beavers, the trial and management processes.
- Provenance and legality of the beaver population.
- Decision making processes and governance.
- Efficacy of management response to any problems or issues arising.

The social and cultural context of any reintroduction is an important factor to consider when reviewing studies that express general Britain wide perceptions of beaver reintroduction (i.e. Auster *et al.* 2019).

How these considerations change over time is also important and there is some evidence that support for beavers (as measured by stakeholder consultation and surveys) has increased over time in both the Scottish and English beaver trials and also in continental states such as Bavaria (Scottish Wild Beavers Group 2020).

There is some evidence from the ROBT (Brazier *et al*. 2020) that farmers demonstrate attitudinal changes over time in response to scientific input and localised site specific action research. This reflects finding from wider evidence related to land management changes as part of agri-environment schemes (e.g. Wheeler *et al*. 2018). This suggests that over time, conflict can change, fears and concerns can be allayed, new cultural norms develop, and stakeholders learn together how to manage for new land management objectives (e.g. Carolan 2006). Further evidence is needed to understand how to maintain and sustain attitudinal and behavioural changes. Some evidence exists from the wider environmental land management literature, but little specifically on beaver reintroductions.

**Wildlife conflicts**

Coz and Young (2020) show that, while species reintroductions have become more common, they can be controversial and may generate social conflicts.

There is a broad literature on wildlife conflict, which Redpath *et al.* (2013) defines as: '*situations that occur when two or more parties with strongly held opinions clash over conservation objectives and when one party is perceived to assert its interests at the expense of another'*. This literature on wildlife conflict more generally has not been systematically reviewed for the purposes of this report. Future work should explore this literature specifically to understand and inform beaver reintroduction.

Conflicts can emerge when the objectives of conservation are imposed on others (Redpath *et al.* 2013). Human-wildlife conflict arising from social factors is likely to play a key part in determining the future of beaver reintroductions (Auster *et al*. 2019).

Evidence from the ROBT, Scotland and the wider literature identifies that there are three societal groups where human-beaver conflict (or human-human conflict over beavers) is likely to be greatest related to reintroduction in England. These are: landowners/farmers in specific geographies, salmonid fisheries and specific local communities.

In the ROBT, those working in fisheries and aquiculture were identified as a group where there may be potential conflict (Auster *et al.* 2019; Auster *et al.* 2020.b; Auster *et al.* Submitted). In a quantitative survey, respondents in the 'Farming and agriculture' occupations were statistically less likely to have a more positive view about the impacts of beavers than other respondents, and opinions within this group were mixed (Brazier *et al*. 2020). Auster *et al.* (2020.b) examined this further using qualitative methods and found that respondents from farming backgrounds raised concerns about the potential inflexibility of management methods and management responsibilities. Lack of agency, defined as the 'the ability to act (and achieve) on the basis of what one values and has reason to value' (Hicks *et al.* 2016), appears to be a concern among land owners and anglers who may wish to address any perceived negative impacts of beavers quickly.

An online questionnaire lead by Plymouth City Council aimed to gain insight into the perceptions of people in the urban environment to a proposed reintroduction of beavers in the city (Brazier *et al.* 2020). Benefits identified by respondents included: improved human mental health, increased urban biodiversity, educational opportunity, increased opportunities for nature connection and aesthetic improvements. Some of the concerns raised by respondents included risk to the beavers from humans/the urban environment; damage from beavers felling trees and the associated costs and management considerations. The majority of the urban communities were indirectly affected by the presence of beavers unless any individual's business or home was situated in a high risk area.

Conflicts can arise when parties have different beliefs and values (Redpath *et al.* 2015). Inman (In press) found that differences in perceptions about which human activities should be allowed, particularly shooting and culling. These findings, while from a small qualitative study looking at beavers, are consistent with a larger quantitative study on hen harriers: St John *et al.* (2019) found that those affiliated with field sports reported more utilitarian values (e.g. 'wildlife exists for human use and enjoyment'), and those linked to conservation holding more mutualistic values (e.g. 'wildlife has as much right to life as humans').

The level of conflict for beaver reintroduction is associated with the reintroduction process (perceived lack of management and lack of legal guidance, as well as illegal or escapee provenence), relationships between stakeholders, perceptions of nature and landscape and concerns about lack of control and uncertainty around future reintroductions (Coz and Young 2020). Analysis of stakeholder interviews (n=25) by Coz and Young (2020) revealed disparity in the perception of conflict across Scotland, with perceived conflict in Tayside (related to the accidental or illegal releases), with no conflict in Knapdale and the Highlands; however, across Scotland, there were tensions and concerns related to long-term management.

Beaver population management techniques vary throughout Europe and have varying degrees of acceptance (Gaywood 2015). Culling has been a particularly contested topic in Europe and Scotland and is thus likely to provoke conflict in England. A wider social interest in non-lethal management solutions seen in areas of high human-beaver interactions could provide an alternative to culling (Gaywood. 2015). However, for those who might bare the worst burden of beaver presence, the option to cull connotes higher agency and immediacy of addressing problems.

Conflicts can arise linked to differences in opinion over the validity of scientific information (Redpath *et al.* 2015). Inman (In press) and Auster *et al.* (Submitted) found that the beaver-salmonid research was a particularly contested or viewed by some as partial or uncertain. Inman (In press) found some mistrust and perceptions of bias about science and scientists related to beaver amongst land-managers and anglers. This is reflected in the evidence around wildlife conflict in general, where scientists can be perceived as biased if they are seen as 'pro' conservation (Redpath *et al.* 2013). Auster *et al.* (Submitted) recommends *'open, cross sectorial dialogue about research into beaver-fish relationships and management'.*

To better understand potential conflicts associated with beaver reintroduction, Natural England commissioned an independent pilot qualitative research study into social dimensions for this document by Professor Alex Inman (Inman In press).  This pilot study directly explored potential conflicts, using qualitative research with a small sample of people (n = 7) including members of the farming community; members of the angling community; and, professionals from the conservation community who had been actively involved in the ROBT and the reintroductions in Scotland. As with all qualitative research, it is not intended to be representative of the population, but to help aid understanding of the depth of feeling from stakeholders who had experienced conflict, perceived conflict or were involved in efforts in conflict resolution related to beaver. Analysis of interviews suggested three main potential areas of conflict:

(1) Landowners/farmers in specific geographical contexts

Respondents suggested that not all landowners and farmers were potentially in conflict. Rather, this was limited to specific geographical contexts. Respondents percieved these to include: those with particularly flat or very gently sloping high productivity land; ground adjacent to watercourses which might be inundated by embankment breaches or drainage failures; those with high value deciduous trees near to watercourses and; those with crops in the vicinity of watercourses which are a favoured food source for beavers (e.g. maize).

(2) Salmonid fisheries

Angling stakeholders reported concerns related to restrictions to the migration of salmonids within a river system as a result of dam-building. Impacts on coarse fisheries (e.g. pike, roach etc) were deemed by respondents to be less controversial as these species were considered less susceptible to migration barriers. Respondents concerns were linked to the Atlantic salmon population in England being in a very fragile condition. Respondents regarded what was perceived to be voluntarily introducing an additional negative pressure as illogical. Introduction of beaver was viewed as directly conflicting with conservation objectives for designated Special Area of Conservation habitats such as chalk streams in southern England. Respondents reported uncertainty in the science surrounding positive salmon/beaver symbiosis and concerns related to changes to fishery aesthetics.

(3) Specific communities in downstream areas

Respondents suggested that there may be negative impacts on flood defence and drainage networks which may create risks (e.g. blocked culverts from beaver activity can cause localised flood risk). Respondents reported concerns about damage to ornamental gardens and other speciality resources that might be incurred by beaver tree felling, boring activity etc.

The Inman (In press) study highlighted that those fisheries and farming interests are not against beaver reintroductions *per se*. As one respondent put it, ‘they may work in some areas’; what they fear is a loss of agency over their own land related to how the animals are controlled and who controls this process. That resistance is likely to be reduced if landowners have agency to address problems quickly (e.g. using culling - with ‘light touch’ permission process - as a management tool). There were similar findings in Scotland (Coz and Young 2020), who found that ‘Those who were concerned about beaver reintroduction did not necessarily dislike beavers’ but they wanted control on beaver numbers, expansion and impacts.

The Inman (In press) study did suggest a potential trust deficit, with respondents reporting mis-trust related to legality of reintroductions, emotive communications and some mis-trust in the science and evidence, on the grounds that it is uncertain or partial. Some respondents also reported perceptions of bias. This was a pilot qualitative study and the author concluded that further work is needed to understand how widespread such views are across the farming and fishing communities.

Lack of trust can erode willingness to engage (Redpath *et al.* 2015). Coz and Young (2020) showed that a lack of trust (e.g. between conservationists and landowners in Scotland) impacted on the perceptions of the reintroduction and fuelled tensions between stakeholders. Inman (In press) also found that historic and contemporary experiences with management bodies and processes on other issues can contribute to a trust deficit.

Processes that help build trust are likely to encourage engagement (Redpath *et al.* 2013). Increased trust can contribute to conflict resolution and support improved understanding and a change in attitudes (Young *et al.* 2016). Auster *et al.* (2020.b) noted the importance of a rapid response from conservationists; effective and honest information helped build engagement in the ROBT.

### 5.1.6 Identification of potential areas of conflict in England

The summary of further research outlines the evidence base underpinning the likely areas of potential conflict in England, notably land owners and farmers in specific geographies, salmonid fisheries and specific communities (i.e. those that co-habit alongside beavers or those where beaver activity, such as tunnelling, could increase risk of flooding).

In the long term, achieving a level of population control in line with natural ecosystems is an important issue for achieving biodiversity objectives, and would go some way towards addressing stakeholder concerns (although would not address site-specific issues).

### 5.1.7 Potential future implications of wider reintroductions in England

There are a number of factors to be considered in relation to a reintroduction strategy for beavers across England. These include:

- The social and cultural context for reintroductions including the diversity of values, attitudes, impacts and agency amongst the people involved. For some, the subject is highly emotive. There are also perceived (and actual) differences in power and control and potential trust deficit. This indicates that there is potential for conflict related to beaver reintroduction.
- There is also the potential for those conflicts to be mitigated if addressed proactively and those affected have agency in managing impacts (Auster *et al*. 2019; Inman In press). The evidence suggests that all parties are supportive of proactive management.
- While there seems to be generally broad support for reintroduction, further public research is needed to understand wider public perceptions (e.g. potential concern about lethal control methods) and be undertaken in partnership with stakeholders.

- Co-design (e.g. as defined by Tsouvalis and Little 2019[16]) and implementation of management between policy makers, management bodies, scientists and stakeholders would potentially reduce conflict and gain trust.
- Consideration and action to address the trust deficit indicated by qualitative studies (Inman In press; Auster *et al*. 2020.b) is vital to address to build confidence in management systems and bodies and to allay fears.
- Managing beaver conflict (particularly beaver removal), is important to address as a priority. Low levels of trust in non-lethal management methods should be addressed by inviting scrutiny, an ‘honest broker’ and, where possible, collaboration in trials.The need for management to include proactive engagement (particularly with those likely to be negatively or directly affected) and include fast responses to emergent problems, to facilitate open dialogue between parties. A multi-stakeholder dialogue process could build confidence in management and would also hopefully build much needed social capital between interest groups (Inman In press).

[16] Co-design is a novel method for creatively engaging citizens and stakeholders to find solutions to complex problems. If planned and executed well, a co-design process can: lead to the generation of more innovative ideas; ensure that policies and services match the needs of users; achieve economic efficiencies by improving responsiveness; foster cooperation and trust between different groups and between different groups and government; engage the ‘hard to reach’; achieve support for change; and lead to successful implementation. Involving citizens and stakeholders in the co-design of policy can also help pre-empt future problems, ‘especially by overcoming the common problem of policy interventions being based on flawed assumptions’.

## 5.2 What are the discernible economic benefits and costs associated with a reintroduction of beavers to England?

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### 5.2.1 Summary of main findings and recommendations

Reintroducing beavers can generate a range of both benefits and negative aspects for society, the enviroscottishnment and the economy. This includes: allowing people to enjoy wildlife experiences, re-naturalising degraded habitats and reducing the risk of impacts from extreme weather events, but also potential damage to infrastructure, agriculture and forestry.

Comparing monetary benefits to costs is useful for understanding whether reintroducing beavers will leave society better off. This is one aspect to consider when assessing whether beavers should be reintroduced further in England.

Limited evidence exists on the monetary benefits and costs of wild and reintroduced beavers across a wide range of contexts. This evidence is insufficient to assess the benefits and costs of a full reintroduction of beavers into England. There are three reasons for this; i) evidence on costs and benefits is location-specific and reintroducing beavers to different locations may not result in the same type and/or magnitude of benefits and costs. These contextual factors need to be understood better, ii) evidence on benefits and costs is captured for a short period in time only. How benefits and costs evolve with time and beaver population densities needs to be understood better and iii) appropriate management and mitigation strategies need to be identified as part of a reintroduction to maximise the benefits and minimise the costs of beaver activity and to address any distributional issues (those who benefit from a beaver reintroduction may not be those who bear the costs).

Recommendations for future cost benefit work to allow this analysis are provided.

### 5.2.2 Introduction

Reintroducing beavers can generate a range of benefits for society and the economy. For example, beaver activity can reduce the risk of flooding, allow people to enjoy wildlife experiences, create volunteering opportunities and provide ecosystem services for humans (Gaywood 2015; Brazier *et al*. 2020; Thompson *et al.* 2020). From an ecological perspective, beavers do not damage or negatively influence their surroundings (except in areas in the Southern Hemisphere where the North American beaver is invasive), but from an ecosystem services viewpoint, damage (i.e. disservices) to humans does occur (Thompson *et al.* 2020). This section summarises the available evidence on the impacts of beaver reintroductions that have been valued in existing studies, i.e. monetary costs and benefits.

Cost-Benefit Analysis (CBA) is a systematic process for assessing the anticipated benefits and costs of a policy or project. It is useful for understanding whether a reintroduction project leaves society better off and for comparing different reintroduction scenarios. Recommendations for future CBA work are presented at the end of this section.

Due to the nature of the information and assessment undertaken for this section, it deviates from the structure outlined in other sections of this report in order to describe the findings in the most useful way. All relevant studies since 2000 have been analysed, including the results from the Scottish Review.

**Evidence on the socio-economic benefits and costs of reintroducing beavers**

This section reviews existing evidence on the costs and benefits of reintroducing beavers. It only includes evidence on the impacts of beaver reintroductions that have been valued in existing studies, i.e. monetary costs and benefits. Impacts that have been captured qualitatively or quantitatively, but are not valued, are excluded. Only references that generated insights for beaver reintroductions to Great Britain were included. As such, evidence had to be sufficiently rigorous, sufficiently transferable to the British context and sufficiently recent (evidence from before 2000 has not been considered). As a result, this section only presents some of the impacts of reintroducing beavers. To get a more complete understanding it is important to consider the monetary evidence in the context of the impacts that are identified in other sections of this report.

Gaywood (2015), Hamilton and Moran (2015) and Moran and Lewis (2014) are associated with trial reintroduction projects in Scotland, namely the Scottish beaver trial in Knapdale forest and the Tayside beaver study group in the River Tay catchment, alongside evidence from the Scottish Beaver Mitigation Scheme (SBMS)[17] which reports costs from the Scottish Beaver Mitigation Scheme.

Brazier *et al.* (2020) is associated with the trial reintroduction on the River Otter in Devon, England.

Sjöberg and Belova (2019), Shwiff *et al.* (2011), Hood *et al.* (2018) and Thompson *et al.* (2020) report evidence on the benefits and costs of beaver activity in Sweden, Poland, Canada and the United States. This evidence is not from reintroduction projects (beavers occur in the wild in these countries) and may only be transferrable to the British context to a limited extent.

It is important to keep the following in mind when interpreting the evidence:

- **Location-specific evidence.** The evidence is mainly from beaver reintroduction projects in different parts of Great Britain, specifically England and Scotland. Impacts are likely to be dependent on location-specific factors, such as land and water-use in the area or accessibility. As a result, the identified impacts may not occur in other locations and/or with a different magnitude. One can thus not readily assume that reintroducing beavers to different locations will result in the same type and/or magnitude of benefits and costs.

[17] Evidence from the Scottish Beaver Mitigation Scheme. https://www.nature.scot/professional-advice/protected-areas-and-species/protected-species/protected-species-z-guide/beaver/beaver-mitigation-scheme [accessed 11/06/2021] and personal communication with a wildlife ecologist from Nature Scot

- **Trial versus reintroduction.** The evidence captures benefits and costs of a trial reintroduction. This implies that benefits and costs are only captured for the length of the trial. Post-trial benefits and costs are not included. Under a reintroduction, benefits and costs may occur for a longer period of time. Moreover, some costs may occur only in the beginning of a reintroduction and may be less important at later stages. Similarly, some benefits (particularly environmental) will only be realised fully over a longer time period. Another aspect to consider is that reintroductions can learn from the experience made in trials. This can, potentially, result in lower costs and greater benefits. For example, the majority of the scheme cost of the Scottish Beaver Trial in Knapdale has been generated through importation of the animals and a very detailed level of monitoring (first mammal project of this kind). Scheme level costs of this extent are unlikely to be repeated in future projects.
- **Distribution of costs and benefits.** Benefits do not need to occur in the same location as costs. This implies that those who benefit from a beaver reintroduction may not be those who bear the costs. Conflict may, for instance, arise between landowners/managers where beaver activity may result in damage to their land. Local residents may, however, benefit from reduced flood risk to their property. These conflicts may be addressed, to some extent, through appropriate management and mitigation strategies.

**Benefits**

Table 4 summarises the monetary benefits of reintroducing beavers. Benefits include: increased business turnover; opportunities for recreation and volunteering; educational benefits; alleviation of flood and drought risk; water supply; water purification; greenhouse gas sequestration; habitat and biodiversity provision and non-use value[18].

As mentioned previously, the evidence in this section is partial. It only presents the positive impacts of beaver reintroduction that have been valued in existing studies. Some of the monetary benefits of beaver activity are understood better than others. Recreational opportunities, for instance, are estimated in most studies, whereas environmental benefits are often excluded due to analytical difficulties.

Not all values in this section are expressed in a ‘cost-benefit analysis format’, meaning as the present value of benefits over the lifetime of the project.[19] Some values are yearly benefits, others capture benefits only for a few years of the reintroduction project (although benefits are likely to have occurred throughout the trial). Some values are case study evidence only but are not extrapolated for the entirety of the trial. The figures below thus need to be interpreted with care. They cannot be readily used to communicate the benefits of reintroducing beavers.

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[18] In the given context, non-use values are associated with knowing that beavers exist, for current and future generations.

[19] Benefits (and costs) may occur at different points in time throughout the lifetime of a project. Discounting is used to compare costs and benefits that occur at different points in time. Discounting expresses costs and benefits at different points in time in a common metric, the so-called present value.

**Table 4** Summary of benefits

| Category | Reference | | Value | Marginal value | Method | Comments |
|---|---|---|---|---|---|---|
| **Business** | Hamilton and Moran (2015) | Tayside Beaver Study Group | £5,080 (per year) (*) | Not available | Increased turnover per year, based on survey responses from businesses. | It is questionable whether these benefits should be included. There is a risk of double-counting if value estimates of recreation benefits include visitor expenditure. |
| **Recreation** | Gaywood (2015); Moran and Lewis (2014) | Scottish Beaver Trial | £355,000 - £520,000 (May 2008 to May 2014) | £54 - £79 (per visit) | Based on the number of guided and unguided visits over the period of the trial and daily visitor expenditure data. | Good value estimates are available (even though they are likely to be an under-estimate). The main challenge is expected to be assessing the uplift in visitor numbers through the reintroduction of beavers (i.e. additional visits). |
| | Hamilton and Moran (2015) | Tayside Beaver Study Group | £16,200 (per year) | £54 (per visit) | Based on estimated visitor data and daily visitor expenditure data. | See above. |
| | Brazier *et al.* (2020) | River Otter Beaver Trial | £0 - £801,580.84 (June 2017 to February 2019) (**) | £5.78 - £9.70 (per visit) | Based on residents' willingness to pay values for beaver-watching experiences and different estimates of the number of beaver related uses of a riverside footpath. | Residents' willingness to pay may not be a representative estimate of visitors' willingness to pay. |
| | Sjöberg and Belova (2019) | Sweden | €308 million (per year) | Not available | Annual sales of nature-based tourism in Sweden. | Not exclusive to beavers. |

| Category | Reference | | Value | Marginal value | Method | Comments |
|---|---|---|---|---|---|---|
| | Sjöberg and Belova (2019) | Sweden | Not available | €130 – €180 (per visitor) | Cost of one/two-day beaver safaris in Sweden. | Safaris are advertised as an opportunity to spot beavers, next to other animals. |
| | Thompson *et al.* (2020) | Northern Hemisphere | $1.6 million (USD) (per year) | $6.1 (USD) (per hectare) | Aggregate values are based on estimates for per-hectare values and beaver pond area in the Northern Hemisphere. Per-hectare values are estimated using a meta-analytic regression model. | |
| | Thompson *et al.* (2020) | Northern Hemisphere | $43 million (USD) (per year) | $167 (USD) (per hectare) | See above. | |
| **Educational value** | Gaywood (2015); Moran and Lewis (2014) | Scottish Beaver Trial | £56,000 (May 2008 to May 2014) | £5.30 and £6.50 (per primary and secondary school student per hour) | Based on educational activities provided to primary and secondary school students and the Scottish Government's estimates of costs of students in primary and secondary education. | The investment cost approach provides a good lower bound estimate of the value of educational activities. It should be extended to all those who benefit from educational activities through the reintroduction of beavers. |
| **Volunteering** | Gaywood (2015); Moran and Lewis (2014) | Scottish Beaver Trial | £84,000 (May 2008 to May 2014) | £6.50 (per hour) | Replacement cost based on volunteer hours and minimum wage. | The replacement cost approach provides a good lower bound estimate of the value of volunteering. Wages other than minimum wage should be considered for 'skilled' volunteering activities. Not all |

| Category | Reference | | Value | Marginal value | Method | Comments |
|---|---|---|---|---|---|---|
| | | | | | | recorded volunteering hours may be additional. |
| **Flood alleviation** | Brazier *et al.* (2020) | River Otter Beaver Trial | £163 - £18,588 (per year) (*) | £150, £450 and £750 (per moderate, significant and very significant risk property downgraded by one category; pre-inflation values) | Annual damage cost avoided by the reduction of flooding through beavers. | Good value estimates are available, we expect the main challenge to be the estimation of a change in flood risk through beaver activity. |
| **Moderation of extreme events** | Thompson *et al.* (2020) | Northern Hemisphere | $32 million (USD) (per year) | $124 (USD) (per hectare) | See above (Recreation). | |
| **Water supply** | Thompson *et al.* (2020) | Northern Hemisphere | $20 million (USD) (per year) | $77 (USD) (per hectare) | See above (Recreation). | |
| **Water purification** | Thompson *et al.* (2020) | Northern Hemisphere | $28 million (USD) (per year) | $108 (USD) (per hectare) | See above (Recreation). | |
| **Greenhouse gas sequestration** | Thompson *et al.* (2020) | Northern Hemisphere | $75 million (USD) (per year) | $75 (USD) (per hectare) | See above (Recreation). | |
| **Habitat and biodiversity provision** | Thompson *et al.* (2020) | Northern Hemisphere | $133 million (USD) (per year) | $133 (USD) (per hectare) | See above (Recreation). | |

| Category | Reference | | Value | Marginal value | Method | Comments |
| --- | --- | --- | --- | --- | --- | --- |
| **Non-use value** | Gaywood (2015); Moran and Lewis (2014) | Scottish Beaver Trial | £564,000 - £6,038,000 (May 2008 to May 2014) | £5.60 - £30 (per household) | Based on different willingness to pay estimates for reintroducing beavers to 50% of the national territory and different population scenarios. | It is questionable whether non-use value estimates should be included in the overall benefits as there are large uncertainties in their estimation and estimates are likely to inflate overall benefits.<br>The willingness to pay estimates are likely to also include use values and have been estimated for a different reintroduction scenario. It is not clear to which population the estimate should be applied to. |
| | Gaywood (2015); Hamilton and Moran (2015) | Tayside Beaver Study Group | £182,000 - £2,000,000 (per year) | £5.60 - £56 (per household) | | |

(*) This value should not be included in the overall CBA if recreation has been valued using visitor expenditure due to a risk of double-counting. (**) Case study evidence only. Values have not been discounted and have not been calculated for the entire period of the trial. October and November 2018 are excluded. (***) Case study evidence only.

**Business**

Only one report, the Tayside Beaver Study, includes increased business turnover as a benefit from reintroducing beavers. Even though reintroducing beavers may lead to an increase in business turnover (e.g. visitor expenditures – restaurants, shops, accommodation, other attractions) we would caution against including it as a separate benefit. There is likely to be double counting with recreational benefits as explained below.

**Tayside Beaver Study** (Hamilton and Moran 2015): A survey was sent to wildlife tourism and general tourism providers. Five out of the 31 respondents cited increased turnover amounts through the reintroduction of beavers with a total of £5,080 per year. These benefits should not be included in the CBA if recreational benefits are valued using visitor expenditure as this is likely to result in double-counting.

**Recreation**

Recreational opportunities through the reintroduction of beavers have been assessed in all trial reintroduction projects covered in this evidence review. Nevertheless, there is a big difference in recreational visits and their value across the different reintroduction trials. Understanding what drives this variation in visitor numbers and values across sites is important for transferring these values to new sites (e.g. for the CBA of a new reintroduction project). Factors that can drive these differences include: remoteness; ease of access; availability of other attractions nearby and media coverage of beaver reintroduction.

**Scottish Beaver Trial in Knapdale Forest** (Gaywood 2015; Moran and Lewis 2014): Recreational visits were captured as guided and unguided walks due to the reintroduction of beavers. There was a total of 6,582 walks – 2,194 guided walks and an estimated 4,388 unguided walks (assuming two unguided walks for every guided walk). It is not clear whether all walks are additional. Recreational visits were valued using daily visitor expenditure. Two estimates were used: £54 (daily visitor expenditure, including travel costs, for tourism to the region originating from the UK)[20] and £79 (daily visitor expenditure, including travel costs, for wildlife tourism) (Scottish Government 2010). This yields a total of £355,000 to £520,000 in benefits from recreation due to the reintroduction of beavers to Knapdale Forest. This is a lower bound estimate for recreational benefits as visitors' willingness to pay (WTP) may exceed their expenditures.

**Tayside Beaver Study** (Hamilton and Moran 2015): Recreational benefits were estimated similar to the Scottish Beaver Trial in Knapdale Forest. There were an estimated 300 visitors a year with assumed expenditures of £54 per day (including travel costs). It is not clear whether all visits are additional. This suggests £16,200 in visitor expenditures per year. This is a lower bound estimate for recreational benefits as visitors' WTP may exceed their expenditures.

**River Otter Beaver Trial (**Brazier *et al.* 2020): Recreational visits were estimated via three different methods. Data from two footpath counters that capture visits to the riverside footpath was used (benefits from recreational visits are estimated separately for the two footpath

[20] Based on data from Visit Scotland.

counters to avoid double-counting). Footpath count data is not available for the entire period of the trial. The first method estimates recreational visits as 19.17% of footpath counts (19.17 has been identified via a questionnaire as the percentage of residents that use the river for viewing wildlife). The second method uses 0 – 40% of footpath counts. The third method uses the difference in footpath counts between summer 2017 and 2019 (a family of beavers moved away from the area). Recreational visits were valued using WTP values from a questionnaire. Residents were asked what they would be willing to pay for a typical beaver watching experience near their village. The average value was £7.74 (with a range of £5.78 to £9.70). Table 5 summarises the results. The values have not been discounted and thus cannot be readily compared to the results from the Scottish Beaver Trial in Knapdale Forest. Moreover, they are not calculated for the entire period of the trial and present only case study evidence (values have not been extrapolated for the entirety of the trial).

**Table 5** Value estimates of recreational benefits in the River Otter Beaver Trial, June 2017 – February 2019 (with exception of October and November 2018) by willingness to pay values (WTP) (Brazier et al. 2020)

| Method | Footpath Counter | Visitor numbers (*) | Average WTP estimate (£7.74) | Lower WTP estimate (£5.78) | Higher WTP estimate (£9.70) |
|---|---|---|---|---|---|
| **1** | North | 17,669 | £136,758 | £102,126.80 | £171,389.20 |
| | South | 39,604 | £306,534 | £228,910.40 | £384,157.60 |
| **2** | North | 0 – 33,380 | £0 - £285,358.32 | £0 - £213,097.04 | £0 - £357,619.60 |
| | South | 0 – 82,637 | £0 - £639,611.93 | £0 - £477,643.02 | £0 - £801,580.84 |
| **3** | North | 10,925 | £84,559.50 | £63,146.50 | £105,972.50 |
| | South | 15,506 | £120,016.44 | £89,624.68 | £150,408.20 |

(*) Based on own calculations for Method 1 and 2.

**Evidence from Sweden** (Sjöberg and Belova 2019)**:** In Sweden, nature-based tourism realises approximately €308,000,000 in annual sales. Nature-based tourism is not however exclusive to beavers. One day beaver safaris cost €130 (€180 for two day safaris). Providers advertise these safaris as an opportunity to spot beavers, next to other animals. This has to be taken into account when using these figures as a proxy for people's willingness-to-pay for beaver wildlife experiences. Note that beavers are present throughout Sweden (with the exception of the South). In 2016 the Swedish beaver population counted more than 130,000 individuals (Wróbel 2020).

**Estimation for the Northern Hemisphere** (Thompson *et al.* 2020)**:** The study estimates recreational benefits, distinguishing between consumptive (hunting and fishing) and non-consumptive recreation. Recreational hunting and fishing in beaver wetlands is estimated to be worth $1.6 (USD) million per year in the Northern Hemisphere (based on $6.1 (USD) per hectare per year). Non-consumptive recreation is estimated at $43 million (USD) per year (based on $167 (USD) per hectare per year). Annual per-hectare values are estimated based on existing ecosystem services valuation studies, using a meta-analytic regression model. The model accounts for differences in study characteristics (valuation method) and wetland type. Only studies focusing on wetlands in beaver habitats in the Northern Hemisphere are included and prices from various years and countries are standardised into comparable values (values are for 2017). Aggregate values for the Northern Hemisphere are calculated based on: the estimated annual per-hectare values for each service; an estimated beaver pond area of 1 million hectares in the Northern Hemisphere (considering differences in pond-building frequencies and dam numbers between different beaver species) and density coefficients that account for the fact that some services are dependent on sufficient human population densities whereas others function on a global scale.

**Educational value**

Only the Scottish Beaver Trial covers the educational benefits from the reintroduction of beavers. Their approach provides a good lower bound estimate of the value of educational activities. It should however be extended to all those who benefit from educational activities through the reintroduction of beavers.

**Scottish Beaver Trial in Knapdale Forest** (Gaywood 2015, Moran and Lewis 2014): The value of educational activities (visits to 135 schools across Scotland and events at various sites) is estimated at £56,000. The estimate is based on the resource investment cost of the equivalent time spent on educational activities by primary and secondary schools. This implicitly assumes that the knowledge gained must be at least equivalent to this value. The estimate does not capture the longer term benefits of ecological knowledge and excludes the educational value for adults. Resource investment may not be fully additional and may have displaced other educational activities. The estimate of £56,000 is based on educational activities provided to 5,308 primary and secondary school students. It uses the Scottish Government’s estimates of costs of students in primary and secondary education (£5.30 and £6.50 per primary and secondary school student per hour).

**Volunteering**

Only the Scottish Beaver Trial provides an assessment of the value of volunteering activities. Their approach provides a good lower bound estimate. However, wages other than the minimum wage should be considered to value ‘skilled’ volunteering activities. Moreover, not all recorded volunteering hours may be additional. Most (beaver) reintroduction projects include volunteers and should thus value the contribution of their efforts.

**Scottish Beaver Trial in Knapdale Forest** (Gaywood 2015; Moran and Lewis 2014): Between July 2012 and December 2013 at least 42 individuals provided a total of 3,882 volunteer hours to assist with beaver tracking and monitoring and to support public events. Volunteer time is valued using the replacement cost method, meaning by the number of volunteer hours multiplied by the average hourly wage. Assuming minimum wage (£6.50), this suggests a value of £84,000 for the period of the trial (assuming volunteering data from

July 2012 to December 2013 was replicated during the other years of the trial). Minimum wage is likely to underestimate the value of volunteering for skilled volunteers.

### Flood alleviation

Only the River Otter Beaver Trial provides evidence on the benefits of beaver activity on flood alleviation (annual damage cost avoided through the reduction of flooding through beavers). All in all, good value estimates are available. The main challenge is expected to be the estimation of a change in flood risk through beaver activity.

**River Otter Beaver Trial (**Brazier *et al.* 2020): The trial provides case study evidence of the positive impacts of beaver activity on flood risk. Values have not been extrapolated for the entirety of the trial and have not been discounted. Beavers established habitat 300 m upstream of a flood-prone village. They created a large water storage area within the floodplain above the village, routing water via complex flow-paths and increasing the roughness of the flow surface. The resulting benefits in form of a reduction in flood risk have been estimated using the Environment Agency's Partnership Funding calculator for flood and coastal erosion risk management. The valuation approach is based on hypothetical scenarios that differ in how beavers impact the flood risk to properties in the village. Table 6 summarises the reduction in damages to residential properties from a change in flood risk band for the different scenarios. The calculations assume seven properties at moderate risk of flooding, 38 at significant risk and five at very significant risk prior to the reintroduction of beavers to the area.

**Table 6** Reduction in damage to residential properties from a change in flood risk band to a flood-prone village in the River Otter catchment

| Scenario | Benefit per year | Five-year benefit (*) | Ten-year benefit (*) |
|---|---|---|---|
| **One moderate risk property downgraded to low risk.** | £163 | £815 | £1,631 |
| **One significant risk property downgraded to moderate risk.** | £489 | £2,446 | £4,892 |
| **One very significant risk property downgraded to significant risk.** | £815 | £4,076 | £8,153 |
| **All moderate risk properties downgraded to low risk.** | £1,141 | £5,707 | £11,414 |
| **All significant risk properties downgraded to moderate risk.** | £18,588 | £92,939 | £185,877 |

| Scenario | Benefit per year | Five-year benefit (*) | Ten-year benefit (*) |
|---|---|---|---|
| **All very significant risk properties downgraded to significant risk.** | £4,076 | £20,381 | £40,763 |

(*) Values have not been discounted.

Ideally, flood risk alleviation benefits would be valued based on an assessment of how beavers impact the probability of flooding. This could be done using the methodologies presented in the Flood Hazard Research Centre's Multi-Coloured Manual combined with hydrological models of beaver impacts on watercourses.[21]

### Moderation of extreme events

**Estimation for the Northern Hemisphere** (Thompson *et al.* 2020)**:** Beaver created wetlands can moderate extreme events. For instance, by retaining rainwater and slowly releasing it through dams, flood peaks and drought conditions can be mitigated. This is estimated to result in benefits of $32 million (USD) per year in the Northern Hemisphere ($124 (USD) per hectare per year). For details on the estimation method, please see above (Recreation).

### Water supply

**Estimation for the Northern Hemisphere** (Thompson *et al.* 2020)**:** Beaver dams raise groundwater levels both upstream and downstream of the dam. Water supply services are estimated at $20 (USD) million per year in the Northern Hemisphere ($77 (USD) per hectare per year). For details on the estimation method, please see above (Recreation).

### Water purification

**Estimation for the Northern Hemisphere** (Thompson *et al.* 2020)**:** Beaver dams improve water quality by filtering compounds and human-caused pollutants. By this they lessen the costs of downstream wastewater treatment. These water filtration services are estimated at $28 million (USD) per year for the Northern Hemisphere ($108 (USD) per hectare per year). For details on the estimation method, please see above (Recreation).

### Greenhouse gas sequestration

**Estimation for the Northern Hemisphere** (Thompson *et al.* 2020)**:** Beaver wetlands both sequester and emit greenhouse gases which will depend on factors such as beaver occupancy, dam, flood and pond age and water table level. Beaver wetlands are estimated to sequester approximately $75 million (USD) of greenhouse gases ($75 per hectare per year). For details on the estimation method, please see above (Recreation).

### Habitat and biodiversity provision

**Estimation for the Northern Hemisphere** (Thompson *et al.* 2020)**:** By creating wetlands, beavers may facilitate the rehabilitation and restoration of freshwater habitats. These habitats

[21] Based on communication with an economist from the Environment Agency.

are important for species diversity but are becoming increasingly rare. Beaver wetlands contribute an estimated $133 million (USD) per year in form of habitat and biodiversity provision in the Northern Hemisphere ($133 per hectare per year). For details on the estimation method, please see above (Recreation).

### Non-use value[22]

Non-use values are included in the Scottish Beaver Trial and the Tayside Beaver Study. It is questionable whether non-use value estimates should be included in the overall benefits as there are large uncertainties in their estimation and estimates are likely to inflate overall benefits.

**Scottish Beaver Trial in Knapdale Forest** (Gaywood 2015; Moran and Lewis 2014): Non-use values are estimated based on a Scottish Natural Heritage funded PhD project. The project suggests a WTP of £56 per household for reintroducing beavers to 50% of the national territory. This value is applied to all Scottish households, all households in Argyll and Bute and half of the households in Argyll and Bute. Table 7 summarises the annual estimates for the different approaches. These values should be interpreted with caution. The WTP value of £56 may include values other than non-use values and may thus be an overestimate. Moreover, it is not clear how to adjust the value for use in the context of the trial and/or to which population it should be applied.

**Table 7** Annual estimates of non-use values in the Scottish Beaver Trial in Knapdale Forest

| Willingness to pay value | All Scottish households | Households in Argyll and Bute | Half of households in Argyll and Bute |
|---|---|---|---|
| £5.60 | £13,362,759 | £225,417 | £112,706 |
| £30 | £71,586,210 | £1,207,590 | £603,780 |
| £56 | £133,627,592 | £2,254,168 | £1,127,056 |

**Tayside Beaver Study** (Gaywood 2015; Hamilton and Moran 2015): Benefits are estimated in the same way as for the Scottish Beaver Trial in Knapdale. Non-use values are estimated based on a Scottish Natural Heritage funded PhD project. The project suggests a WTP of £56 per household for reintroducing beavers to 50% of the national territory. This value is applied to all Scottish households and all households in Perth and Kinross. Table 8 summarises the annual estimates for the different approaches. As mentioned above, these values should be interpreted with caution. The WTP value of £56 may include values other than non-use values and may thus be an overestimate. Moreover, it is not clear how to adjust the value for use in the context of the trial and/or to which population it should be applied.

**Table 8** Annual estimates of non-use values in the Tayside Beaver Study[23]

[22] In the given context, non-use values are associated with knowing that beavers exist, for current and future generations.
[23] Estimates for a WTP of £5.60 and for half of the households in Perth and Kinross are own calculations.

| Willingness to pay value | All Scottish households | Households in Perth and Kinross | Half of households in Perth and Kinross |
|---|---|---|---|
| £5.60 | £13,362,759.20 | £345,683.20 | £182,341.60 |
| £10 | £23,862,070 | £651,220 | £325,610 |
| £30 | £71,586,210 | £1,953,669 | £976,830 |
| £56 | £133,627,592 | £3,646,832 | £1,823,416 |

**Costs**

Table 9 summarises the costs of reintroducing beavers. Costs include direct reintroduction scheme costs and negative impacts of beaver activity on agriculture, forestry and infrastructure. Details are provided below. As mentioned previously, the evidence in this section is partial. It only includes the negative impacts of beaver reintroduction that could be valued.

Not all values are expressed in a 'CBA format', meaning as the present value of costs over the lifetime of the project. Some values are yearly costs. Others are case study evidence only but are not extrapolated for the entirety of the trial. The figures below thus need to be interpreted with care and cannot be readily used to communicate the costs of reintroducing beavers further to England.

**Table 9** Summary of costs

| Category | References | | Values | Details |
|---|---|---|---|---|
| **Scheme costs** | Gaywood (2015); Moran and Lewis (2014) | Scottish Beaver Trial | £2,080,000 (2008 – 2015) | Includes: costs of beaver capture, quarantine and transport; staff, equipment and premises; scientific monitoring; management overheads; interpretation and communication. Excludes some staff costs and elements of scientific monitoring. |
| | SBMS | Scottish Beaver Mitigation Scheme | £180,000 (2017/18 – 2018/19) | Costs of the Scottish Beaver Mitigation Scheme. |
| **Agriculture** | Gaywood (2015); Hamilton and Moran (2015) | Tayside Beaver Study Group | £179,900 (per year) | Based on estimates from land managers in the Tay catchment. |
| | Brazier *et al.* (2020) | River Otter Beaver Trial | £3,422 (*) | Based on a gross margin loss of £1,722 from two cash crops in a waterlogged field and an |

| Category | References | | Values | Details |
|---|---|---|---|---|
| | | | | additional £1,700 in one-off costs. |
| | Brazier *et al.* (2020) | River Otter Beaver Trial | £95 (per year) plus £500 (one-off) (**) | Based on gross margin loss from 0.054 hectares of flooded farmland and management intervention to reduce flooded area. |
| | Sjöberg and Belova (2019) | Poland | €4 million (per year) | Compensation for beaver damage claimed by landowners. |
| **Woodland and timber** | Gaywood (2015); Moran and Lewis (2014) | Scottish Beaver Trial | £603 - £6,279 (May 2008 to May 2014) | Based on 1.59 hectares of flooded land now unavailable to forest operations. |
| | Sjöberg and Belova (2019) | Sweden | €200 - €20,000 (per hectare) | |
| | Shwiff *et al.* (2011) | United States | $2,050,465 (USD) - $6,967,384 (USD) (per year) | |
| **Infrastructure** | Gaywood (2015); Moran and Lewis (2014) | Scottish Beaver Trial | £35,000 - £38,000 (one-off) | One-off costs to repair road damage caused by flooding (£22,000 – £25,000) and to mitigate future risk of flooding (£13,000). |
| | Hood *et al.* (2018) | Canada | $100,926 (CAD) (2011-2013) | Costs of repairing damage to a 170km long trail network through flooding. |

(*) Case study evidence only. It is not clear whether values have been discounted and whether gross margin loss has been calculated in perpetuity. (**) Case study evidence only.

### Reintroduction scheme costs

Only the Scottish Beaver Trial in Knapdale Forest provides evidence on the direct scheme costs of the reintroduction project (Table 10). This trial was the first mammal reintroduction project of this kind. Beavers were imported for the reintroduction, rather than translocated within Great Britain or based on an existing/newly discovered beaver population in Knapdale Forest, and the level of monitoring was highly detailed. It is unlikely that scheme costs at this level would need to be repeated in future beaver reintroductions (R Campbell-Palmer pers. comm.).

**Scottish Beaver Trial in Knapdale Forest** (Gaywood 2015; Moran and Lewis 2014): Direct scheme costs include: beaver importation and capture, quarantine and transport; staff, equipment and premises; scientific monitoring; management overheads; interpretation and communication. Staff costs of Scottish National Heritage and Forestry Commission Scotland are not included. The costs of four scientific monitoring projects are excluded.

**Table 10** Details on reintroduction scheme costs for the Scottish beaver trial in Knapdale forest

| Item | Costs 2008 – 2015 |
|---|---|
| **Beaver capture, quarantine and transport** | £375,000 |
| **Staff, equipment and premises** | £640,000 |
| **Scientific monitoring** | £631,000 |
| **Management overheads** | £245,000 |
| **Interpretation and communication** | £85,000 |
| **Education ranger** | £56,000 (*) |
| **Total** | £2,080,000 |

(*) For 2012 – 2014 only.

**The Scottish Beaver Mitigation Scheme** (SBMS)**:** In 2019, the Scottish Government gave beavers European protected species status. Beavers can expand their populations across the country from their existing locations in Tayside and Knapdale Forest. A management framework was developed to minimise negative impacts (and maximise benefits). The SBMS is part of this. The scheme provides free advice on how to manage beaver activity, provides and installs equipment, monitors the effectiveness of mitigation measures and trials innovative solutions and technology. Any landowners/managers whose land is affected by beaver activity are eligible for support. In 2017/18 to 2018/19 costs were around £180,000. About £120,000 covered consultancy advice, monitoring and survey work, fencing and boundary work, field equipment and research contracts. Another £60,000 was used to cover staff costs, travel and other expenses and the hosting of training events.

### Negative impacts

Next to direct scheme costs, reintroduction projects can also involve indirect costs such as negative impacts of beaver activity on agriculture, forestry and infrastructure. These can be mitigated through appropriate management and mitigation strategies.

### Agriculture

**Tayside Beaver Study** (Gaywood 2015; Hamilton and Moran 2015): A survey of land managers in the Tay catchment identified the following cost categories: damage to trees; damage to banks and drains; damage to crops; flooded fields/trees/crops. Thirteen respondents provided monetary estimates of the annual costs. Based on this, an estimation for the whole Tay catchment (ca. 5000 km$^2$) was attempted. Annual costs for the whole catchment were estimated to be £179,900. The estimate needs to be interpreted with caution as it relies on several key assumptions, for instance, that those land managers who reported costs are representative of the whole population of land managers, which is unlikely as most landowners reported losses in the lower Tay, where arable (high value) farming dominates.

**River Otter Beaver Trial (**Brazier *et al.* 2020): The trial provides case study evidence of the negative impacts on agriculture through the reintroduction of beavers. Values have not been extrapolated for the entirety of the trial and it is not clear whether values have been discounted. Beavers established habitat next to a mixed organic farm. The site supports six dams, creating 0.1 hectares of standing water and a further 0.08 hectares of complex multi-thread channels. Due to this additional water storage, 0.4 hectares of a Grade 1 organic potato field had to be removed from agriculture for one year. Moreover, part of a pasture field and ford became submerged and impassable to machinery and livestock. Beavers also felled five trees, one of which fell onto the farmer's fence. Total economic costs (profit foregone, unplanted seeds, ford relocation, removal of felled trees) are estimated to be £3,422. Profit foregone has not been calculated in perpetuity but only for the first two years after the field became submerged, as the area of the field that was waterlogged has now been taken out of agriculture. Damming activity also flooded 0.89 hectares of grazing land for a spring-calving dairy herd upstream of a beaver dam before management interventions were initiated. Management interventions reduced the flooded area to 0.054 hectares, reducing the estimated gross margin loss from £1565 to £95 per year. The management intervention involved costs of £500 (installation of flow device to manage water levels).

**Evidence from Poland** (SBMS): In Poland, landowners can claim compensation for beaver damage. In 2016, these claims amounted to around €4,000,000. Note that beavers are present throughout the country. In 2018, the Polish beaver population was estimated as 125,000 individuals (Wróbel 2020).

**Woodland and Timber**

**Scottish Beaver Trial in Knapdale Forest** (Gaywood 2015; Moran and Lewis 2014): Forestry Commission Scotland estimates that 1.59 hectares of flooded land is not utilisable for forest operations and reports inconvenience to tree felling and thinning operations within the trial site. The value of the lost area is estimated by the value of the most likely foregone revenue stream via two different approaches: (1) based on a value of £68/hectare for softwood production suggested by the UK National Ecosystem Assessment (suggesting a value of £603 for the period of the trial); (2) based on the Office for National Statistics data which suggests a one-off lost output value of £6,270. This amounts respectively to a value of £3,604 and £8,200 (assuming the land is not available for forest operations at any point in the future).

**Evidence from Sweden** (Sjöberg and Belova 2019): A study in a reforestation area near an artificially created wetland area found that beaver activity can cause damage of between 2000€ to 20,000€ per hectare to forests (based on economic gross value). Note that beavers are present throughout Sweden (except for the South). In 2016 the Swedish beaver population counted more than 130,000 individuals (Wróbel 2020).

**Evidence from the United States** (Shwiff *et al.* 2011): The annual timber damage from beavers in Mississippi is estimated to range from $2,050,465 to $6,967,384 (expressed in 2009 prices). Information is recorded in relation to damage and value estimates of the cost. Any type of damage is included in the estimations, so this may be from direct damage by foraging and/or felling as well as losses from inundation from dam building. Note that beavers are present throughout Mississippi.

**Infrastructure**

**Scottish Beaver Trial in Knapdale Forest** (Gaywood 2015; Moran and Lewis 2014): Forestry Commission Scotland estimates one-off costs of £38,000 attributable to beaver damages: replacement cost of £22,000 – £25,000 after 400 m of road flooding and road improvement costs of £13,000 to avoid future flooding.

**Evidence from Canada** (Hood *et al.* 2018): Evidence from the Cooking Lake/Blackfoot Provincial Recreation Area in Canada reports management costs of $100,926 (CAD) over a three-year period (2011-2013) (mainly to repair damage to the 170 km long trail network through flooding). The installation of pond levellers mitigated trail repair expenses by an average of $2,803 (CAD) per site per year.

**Benefits versus Costs**

Comparing benefits and costs over the lifetime of a reintroduction project is useful for understanding whether the project leaves society better off. This is one aspect to consider when assessing whether the beaver is a suitable candidate to reintroduce in England.

Unfortunately, the reintroduction projects covered in this evidence review capture costs and benefits in different formats. Some are recorded as the present value over the lifetime of the project. Others are yearly values. Some capture benefits only for a few years of the reintroduction project (although benefits are likely to have occurred throughout the trial). Other values are case study evidence only but are not extrapolated for the entirety of the trial. Not all values are discounted or adjusted for inflation. That is why this evidence review can only compare benefits and costs within one and the same reintroduction project.

We focus on the Scottish Beaver Trial in Knapdale as it provides the most evidence on costs and benefits of reintroducing beavers (in terms of the negative and positive impacts that could be valued). The estimates below are partial as many costs and benefits could not be valued. To inform decision-making, the figures should thus only be used together with the qualitative and quantitative evidence.

**Table 11** Benefits versus Costs for the Scottish Beaver Trial in Knapdale (Moran and Lewis 2014)

| | Low estimate | High estimate |
|---|---|---|
| **Benefits**[24] | £1,059,000 | £6,698,000 |
| **Costs** | £2,116,000 | £2,124,000 |
| **Benefits – Costs** | -£1,057,000 | £4,574,000 |

Table 11 shows that benefits outweigh costs over the lifetime of the Scottish Beaver Trial only for the high estimate scenario. However, it is important to realise that costs are mainly driven by the direct scheme costs (and not by the negative impacts of beaver activity). As

[24] Non-use value is not included.

such, scheme costs are responsible for around 98% of total costs. As explained previously, the Scottish Beaver Trial in Knapdale was the first mammal reintroduction project of this kind. Beavers were imported for the reintroduction, rather than translocated from within Great Britain or based on an existing/newly discovered beaver population in Knapdale Forest, and the level of monitoring was highly detailed. It is unlikely that scheme costs at this level are repeated in future beaver reintroductions. Indeed, evidence from the SBMS shows greatly reduced scheme level costs (SBMS). In 2018 – 2019, £180,000 were needed to cover the costs of advice on how to manage beaver activity, the provision and installation of equipment and mitigation measures, monitoring work and surveys (including staff costs). Updating scheme costs in the Scottish Beaver Trial with the more recent figures from the Scottish Beaver Mitigation Scheme yields greatly reduced overall costs. In this scenario, the benefits of reintroducing beavers outweigh the costs also in the low estimate case. This seems to suggest that reintroducing beavers leaves society better off (especially when considering that, as mentioned previously, most estimates of benefits are partial and underestimates).

It is important to mention that the reported costs and benefits are for a trial reintroduction. To obtain an understanding of the monetary impact of a full reintroduction more work is needed. Among other things, an understanding is needed of how benefits and costs evolve with time and beaver population densities and what management and mitigation strategies should be part of a reintroduction to maximise the benefits and minimise the costs of beaver activity.

### 5.2.3 Recommendations for future Cost-Benefit Analysis work

This section sets out high-level recommendations for assessing the costs and benefits of reintroducing beavers. It is not intended to be a ‘how-to’ guide and assumes an understanding of Cost-Benefit Analysis (CBA) and economics.

- **HM Treasury’s Green Book.** The guidance for appraisal and evaluation set out in HM Treasury’s Green Book should be followed.
- **Long-list and short-list of options.** The studies included in this evidence review assess trial reintroductions *ex-post* by comparing the pre- and post-trial situation. This provides an indication of whether the trial reintroduction increased social welfare. Doing a CBA prior to a reintroduction not only helps to determine whether the project is likely to increase social welfare but also what ‘reintroduction design’ is likely to be the best way forward. This includes, for example, the scope of the reintroduction (partial vs full vs no reintroduction) and/or the intensity of beaver management interventions. This is done by appraising a short-list of options that has been created from a long list of potential options. The Green Book provides guidance on how to create the long-list and filter it down to a short-list of suitable options.
- **Proportionality of efforts.** Efforts should be proportionate. The level of detail required in the CBA will depend on several factors. These include the costs of the reintroduction, who bears them and/or how contentious the reintroduction is. This will impact, for instance, whether primary valuation studies should be undertaken or whether existing valuation evidence is used.
- **Involving experts from different specialisms.** Identifying, quantifying and valuing the impacts of reintroducing beavers, will require the collaborative effort of various specialists. This includes species experts, economists, social scientists and natural capital specialists.

- **Non-monetisable impacts.** Impacts should be identified qualitatively first and then quantified and valued. To value impacts, one needs an estimate of the quantitative impact as well as a value estimate. Moreover, to transfer values from one study to another it is potentially crucial to understand quantitative impacts. For instance, if one understands the change in flood risk to properties due to beaver activity, one can transfer a more accurate flooding benefit. Non-monetisable impacts should be presented in any results. This is especially important as what can be valued is limited (values only provide a partial estimate of the true impact).
- **Natural capital approach.** It can be helpful to adopt a natural capital approach. Natural capital are the aspects of the natural environment that provide benefits to people. Using the natural capital concept involves identifying influences of beaver activity on ecosystem assets, services and benefits (qualitatively and quantitatively) and then valuing these influences. Natural England has developed indicators for defining and measuring change in ecosystem assets and links these to changes in ecosystem services/benefits through logic chains (Natural England 2018).
- **Caveats**. The analysis should make clear what assumptions were made. Estimates should be discussed, particularly regarding what they tell us and what they do not tell us.
- **Value transfer.** Value transfer refers to the transfer of (valuation) evidence to a different context. Care needs to be taken when transferring values from this report. There are several reasons for this. First, the evidence is location specific. The identified impacts may thus not occur in other locations and/or with a different magnitude. Second, not all evidence on costs and benefits is expressed in the same format. Some values are in a 'CBA format', meaning the present value of costs and benefits over the lifetime of the project. Others are annual values. Some values capture costs and benefits only for a few years of the reintroduction project. Others are case study evidence only and are not extrapolated for the entirety of the trial. Third, the estimates rely on several key assumptions which might not be met in a different context. These factors can be addressed, for instance, by comparing the characteristics of the original study site to the new study site (e.g. the type of land-use near beaver habitat will influence any negative impacts of beaver activity on agriculture and forestry). Moreover, it should be possible to convert figures into comparable formats. Economics for the environment (Eftec) provides practical guidelines for the use of value transfer (Eftec 2010). There is a further issue of how quantitative impacts and value estimates will change as the number of reintroductions across Great Britain increases. For instance, the first reintroductions might see the greatest recreational benefits. Costs may reduce as learning is shared across reintroduction projects or may increase as the 'cheapest' sites are chosen first. Costs related to damage may however increase as beaver populations increase.
- **Reintroduction of other species.** It might be worth considering whether there is anything that can be learnt from other species reintroduction studies. For instance, in terms of valuation methods, how data limitations were addressed, etc. Of course, being aware that there will be fundamental differences between the reintroduction of beavers and the reintroduction of other species.
- **Distributional analysis.** As explained previously, benefits do not need to occur in the same location as costs. This implies that those who benefit from reintroducing beavers may not be those who bear the costs. The analysis should comment on these imbalances.

- **Time horizon.** The studies referenced in the evidence review assess costs and benefits either on a yearly basis or for the duration of the trial. It needs to be determined what time horizon would be appropriate for appraising the potential future costs and benefits of reintroducing beavers. The government's Green Book states that costs and benefits should be calculated over the lifetime of an intervention and suggests that a time horizon of ten years should be suitable for many interventions. Interventions and assets with a longer lifetime, including environmental projects, are best appraised over longer time horizons. As beaver activity is likely to cause changes in flood risk, we recommend a longer time horizon of at least 20 years following on from when the population is considered stable.

# 5.3 How may beavers affect human-orientated water management issues?

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## 5.3.1 Summary of main findings and recommendations

Medium evidence was available from the Scottish Review to understand the influence of beavers on water management processes (Gaywood 2015). Strong evidence from England and Europe since the Scottish Review strengthens our understanding that beavers can have a wide range of positive effects on water-related ecosystem services associated with restoring natural hydrological, sedimentological and geomorphological processes (Law *et al*. 2016; Puttock *et al.* 2017; Puttock *et al*. 2018; Smith *et al.* 2020). The scope for benefits varies with the scale of influence of beaver activity in different environmental conditions.

Whilst beavers can play a positive role in restoring the natural processes upon which water management depends, it is important not to over-estimate this role in ways that might undermine strategies for addressing impacts on natural processes at source. Impacts on natural processes (abstraction and water diversion, diffuse and point source pollution, drainage, physical modifications to rivers, streams and lakes) are many and varied and need to be tackled through concerted and strategic restoration plans, providing beavers with a foundation upon which to add their beneficial contribution.

Continued understanding of catchment-scale effects of beavers is needed, together with continued development of tools that help to increase benefits and identify when management is needed to address conflict.

## 5.3.2 Introduction

The creation of dams, with their associated wetting and flooding of adjacent land, can help restore natural hydrological and related sediment processes and improve water quality through water attenuation and sediment storage. This creates decreased peak flows and extension of lag times by increasing storage capacity (e.g. Puttock *et al*. 2017; Gaywood 2017), channel complexity (John and Klein 2004) and surface roughness (e.g. Nyssen *et al*. 2011; Puttock *et al.* 2017).

Dams can contribute to drought resilience by maintaining base flow, storing water during dry periods and raising ground water tables (Brazier *et al*. In Press; Gibson and Olden 2014; Janzen and Westbrook 2011; Puttock *et al.* 2017; Smith *et al*. 2020); in addition, dams capture fine sediment (Visscher *et al*. 2014; Puttock *et al*. 2018), so helping to in-fill artificially deepened channels (Pollock *et al*. 2014) and improve water quality downstream by filtering out pollutants (Butler and Malanson 2005; Puttock *et al.* 2017; Brazier *et al*. 2020).

These reported benefits of dams may accrue in the same location as where costs manifest, but more often they will be in different locations (e.g. downstream flood reduction as a result of floodplain inundation upstream) (Brazier *et al.* 2020).

Beaver canals may increase channel-floodplain connectivity including through the connection of previously discrete floodplain water bodies within a stream or river (Grudzinski *et al*. 2019). Beaver wetlands and dam sequences can affect sediment regimes and biogeochemical cycling. By slowing the flow of water in some locations, suspended sediment and associated nutrients are deposited with ponds shown to be large sediment and nutrient stores. Increased water availability, raised water tables and increased interaction with aquatic and riparian vegetation have all been shown to impact upon biogeochemical cycling and nutrient fluxes. (Brazier *et al.* In Press).

Some of these processes are very rapid and some take decades to develop. Beaver dams are only created in certain conditions, which provides a natural limit on the extent of benefits to water-related ecosystem services.

### 5.3.3 A summary of the findings from the Scottish Review

- Beavers only had limited influence on the fluvial geomorphology and river habitat during the trial period at Knapdale, despite appearing to have explored much of the stream network. Due to the location of the trial study site, it offered limited data on human-orientated water management isues.
- Habitat change brought about by beaver activity might contribute to restoring natural processes within catchments. The slowing of flow and storage of water resulting from beaver dams could have local, perhaps wider, flood risk management benefits and would accord with natural flood management aspirations discussed in Scotland. Strategic and local flood risk management planning will need to take account of potential beaver activity in managing flood risk sustainably.
- Beaver dams will have some effect on sediment transport processes and are likely to lead to localised changes in both the upstream and downstream composition of bed sediment.

### 5.3.4 Further research since the Scottish Review

Law *et al*. (2016) demonstrated that the local restoration of ecosystem processes may also offer wider scale benefits, including greater nutrient retention and flood attenuation. These benefits should be evaluated against evidence of any negative effects on land use or fisheries.

Puttock *et al.* (2017) showed that the activity of Eurasian beavers in an enclosed site in north Devon, England increased water storage, attenuated flow and mitigated diffuse pollution from intensively managed surrounding grasslands. Beaver activity, primarily via the creation of 13 dams, increased water storage within the site (holding ca. 1000 $m^3$ in beaver ponds). A significant flow attenuation impact was also observed, determined from peak discharges (mean 30 ± 19% reduction), total discharges (mean 34 ± 9% reduction) and peak rainfall to peak discharge lag times (mean 29 ± 21% increase) during storm events. In addition to water storage behind beaver dams, the added channel complexity created additional resistance to flow, whilst flooded areas provided additional water storage. Each litre of surface water leaving the enclosure site had three times less sediment than water entering the site, and nitrogen was reduced two-fold and phosphate four-fold.

Puttock *et al.* (2018) also found from researching sediment and nutrient storage in the same beaver enclosure sute in north Devon as Puttock *et al*. (2017) that beaver ponds may help to mitigate the negative off-site impacts of accelerated soil erosion and diffuse pollution from agriculturally dominated landscapes such as intensively managed grassland. The 13 beaver ponds subsequently created from the beaver dams held a total of 101.53 ± 16.24 t of sediment, equating to a normalised average of 71.40 ± 39.65 $kgm^2$. The ponds also held 15.90 ± 2.50 t of carbon and 0.91 ± 0.15 t of nitrogen within the accumulated pond sediment.

Swinnen *et al*. (2019) studied the locations of beaver dams and provides a simple tool for planners to assess the probability of floodplain inundation by beaver dam building, as part of multifunctional riverine landscape management. This work is reflected in Graham *et al*. (2020) for England.

Graham *et al*. (2020) describes the development and uses of modelling Eurasian beaver foraging habitat and dam suitability, for predicting the location and number of dams throughout catchments in Great Britain. The authors provide information describing the distribution of beaver foraging habitat, where dams may be constructed and how many may occur which will be important in identifying risks and opportunities for beaver reintroductions.

On the River Otter, England, Brazier *et al.* (2020) report a number of beaver dams built upstream of a reservoir storing water and trapping sediment; collection and collation of data to further understand this effect is ongoing at the time of writing.

Smith *et al.* (2020) studied hydrological processes and water quality in a lowland agricultural catchment over a 30 year period in northern Germany. Wetland rehabilitation started in 2000, facilitated by beaver colonisation in 2007, and resulted in longer water transit times in the stream network, less linear storage-discharge relationship and a loss of daily stream variability, increased dissolved organic carbon concentrations, isotopic evaporative enrichment downstream and moderated stream temperatures. Groundwater levels increased and became more stable over the study period, suggesting that beaver dams may have resulted in increased surface water leakage to groundwater fluxes. There was limited long-term water quality improvements from wetland rehabilitation which likely reflected the long-term legacy of fertilizer use on nutrient reservoirs in the catchment's soils, aquifers, and stream network.

### 5.3.5 English context

The scale of environmental degradation of freshwater and wetland systems in England is much greater than in Scotland. The implications of releasing beavers into heavily degraded systems in England therefore needs particular thought. Research has shown that beavers can be part of a program of efforts to improve environmental resilience to flooding, soil erosion and diffuse pollution (amongst other things) (e.g. Elliot *et al*. 2017; Law *et al*. 2017; Puttock *et al*. 2017). It is therefore in combination with other landscape or habitat restoration approaches, that the most success via beaver reintroduction will be delivered. It is further interesting to note that the research demonstrating benefits (and costs) of beaver reintroduction has highlighted that a great deal of the landscape is in a degraded state and thus will feed flood water, eroded soil and diffuse pollutants into new beaver sites (Law *et al.* 2017; Puttock *et al*. 2017; Smith *et al*. 2020). Beaver dams, in particular, may then mitigate those environmental problems, but they will not solve them at source and, where soil erosion and diffuse pollution is severe, beaver ponds may suffer from sedimentation and eutrophication as any receiving surface water might do.

The scope for beaver activity to potentially provide sustainable flood alleviation is receiving increasing attention, as part of strategic shifts towards flood risk management that works with natural processes[25]. Further work is required in order to understand how dynamic water storage in beaver ponds can be, which is critical to understanding when and where beaver dams may aid flood water retention (Westbrook *et al*. 2020). However, in light of climate change, any increased resilience for catchments has the potential to deliver wide reaching benefits.

The English context highlights the need for an overview assessment of standing water body types and socioeconomic vulnerability and opportunities from beaver activity. Particular consideration should be given to sites with water management function (e.g. water supply reservoirs). At some sites appropriate management strategies may be needed to counteract negative effects and promote positive effects (See Campbell-Palmer *et al.* 2016). Where water bodies (still and running) have recreational uses, there will be a need to consider where the presence of beavers and their activity is likely to interact with these other uses.

Along with a range of strategic measures to restore natural function to freshwater and wetland ecosystems for biodiversity, natural capital and climate change objectives, the widespread presence of beavers in England has the potential to bring substantial benefit to water-related socioeconomic objectives. Improvements in catchment water storage, flood regulation and water purification as a result of beaver activity all contribute to increasing resilience to climate change for water management (Puttock *et al*. 2017; Brazier *et al.* In Press).

Beaver activity is not however a substitute for tackling impacts on catchments and water quality issues at source (see Smith *et al*. 2020), but can enhance water-related ecosystem services where suitable measures have already been taken to restore natural ecosystem function to freshwater and wetland ecosystems. Suitable measures include: tackling critical pollution source areas, minimising abstraction, minimising engineered structures on the river and stream network, and targeted removal of drainage and water level management infrastructure. Particular care is needed in heavily degraded systems to avoid unintended consequences of beaver presence, such as poor water and sediment quality in and around beaver ponds due to the accumulation of excessive fine sediments and associated nutrients.

[25] https://www.gov.uk/government/publications/working-with-natural-processes-to-reduce-flood-risk [accessed 11/06/2021]

### 5.3.6 Identification of areas of potential conflict in England

Whilst, from nature conservation and ecological perspectives, the reintroduction of the beaver is seen as restoring a missing component of freshwater and wetland ecosystems, an over-emphasis on the ability of the beaver to deliver water-related ecosystem services could create conflict with some biodiversity and ecological objectives. Renaturalising hydrological, sediment and water quality regimes to restore stream and associated wetland systems requires concerted action in headwater areas to change land use/land management and reduce abstraction and artificial water transfers. Portraying beaver reintroduction as a means of dealing with pollution and hydrological regulation *within the stream and river habitat resource rather than at source,* can potentially detract from land-based strategies that address upstream impacts in ways that deliver ecological and ecosystem service benefits to and from catchment headwater areas. There is no such problem where beavers are reintroduced to headwater areas that are already exclusively under natural and semi-natural vegetation to address such impacts at source, and in these situations beavers can play a central role in critical conservation action to naturalise mire-stream transitions as well as habitats further downstream (Mainstone *et al*. 2016).

The dynamic activity of beaver's means there will be interactions linked to flood risk assets (see section 5.7 on infrastructure and general land use), but there are known methods of responding appropriately to each situation (See Campbell-Palmer *et al*. 2016).

Dam capacity modelling using map layers to identify risk and opportunity is successfully used in other countries in a 'zoning' system. These are used to effectively identify likely areas of risk and enable forward planning for activities or identify future potential management needs. Knowledge of dispersal, habitat preference and dam building has led to a variety of modelling hypotheses to create predictive tools (Stringer *et al.* 2015; Macfarlane *et al.* 2017; Swinnen *et al*. 2019). Most recently, Graham *et al.* (2020) derived a model with a suite of parameters including: stream power, bank width, habitats to predict the likely location, and number of dams throughout catchments in Great Britain. This will be valuable in planning and reacting to beavers in catchments.

### 5.3.7 Potential future implications of wider introductions in England

Beaver presence will generally be positive for water management objectives, but is not a substitute for catchment-based water management actions to deal with impacts on water and the water environment at source. There will also be broader socio-economic issues arising on riparian and floodplain land, associated with localised flooding, impacts on assets and infrastructure, land drainage and site-specific (often time-limited) restrictions on fish passage. Catchment-scale ecological and water benefits do not offset site-level impacts on land and water use for the individuals affected. Managing these risks will require a funded management framework strategy with a spectrum of appropriate management options and a clear governance structure. This will need to take into account any legislation, permitting regimes and policy that have relevance to running waters and beaver-influenced landscapes such as ecological status objectives under the Water Environment Regulations and flood risk management legislation.

## 5.4 What are the effects of beavers on freshwater fisheries?

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### 5.4.1 Summary of main findings and recommendations

There is limited evidence from the Scottish Review demonstrating how beavers may affect fisheries, with no negative impacts to fisheries noted (Gaywood 2015). Evidence from England on how beavers influenced fishery interests is equivocal (Brazier *et al*. 2020) which is comparable to studies elsewhere (Johnson-Bice *et al*. 2018).

The limited understanding of the potential impacts of beaver activity on some fish populations and lack of published data considering the potential impacts on fisheries, make it difficult to fully determine the effects, positive and negative, of beavers on fisheries. The human, socio-economic element introduced by the consideration of the potential interaction between beavers and fisheries adds an additional layer of complexity to an already intricate mix of variables which may influence the impacts of beaver-fish interactions either positively or negatively, with may in turn impact the fishery.

Greater understanding around the overall balance of potential benefits and risks to migratory fish populations is needed to understand the potential wider implications for fisheries for these species in England. The interactions between beavers and migratory salmonids is of concern given the status of sea trout and salmon stocks in England and the potential consequences for these fisheries and their management.

The potential effects of beavers on the types of small stillwater fisheries common across England are not widely considered in the available literature, though are likely to be dependent on their proximity to watercourses.

### 5.4.2 Introduction

The potential interactions between beavers and fish (reviewed in section 4.4 Fish assemblages) also represent the principal interactions between beavers and fisheries, both recreational and commercial. In this context, ‘fisheries’ are considered to represent the exploitation of the ‘fish’ resource, i.e. the activity of fishing. Fisheries are known to deliver a variety of socio-economic and health and wellbeing benefits (Brown *et al*. 2012). Exploitation does not imply that fish are killed or removed from the system; most coarse and salmonid fisheries in England operate catch and release with a small associated percentage mortality rate or a small proportion of wild Atlantic salmon (*Salmo salar*) (~10%) and anadromous brown (sea) trout (*Salmo trutta*) (~13%) now retained. Commercial exploitation of fish such as eel (*Anguilla* spp.) and river lamprey (*Lampetra fluviatilis*) is regulated via authorised quota limits. Not all fish populations support a fishery and not all fish species are of fisheries interest, and the fish species of interest may vary by location and individual angler or fisherman. This human socio-economic element distinguishes the interactions between beavers and fisheries from the interactions between beavers and fish, though many aspects are intrinsically linked.

In addition to the potential interaction between beavers and fish populations, beavers may affect fisheries through their effects on vegetation, bank structure and stability, creation of wetland habitat and disturbance associated with eco-tourism.

### 5.4.3 A summary of the findings from the Scottish Review

- From a fisheries perspective, it is likely that the two species which will be most influenced by the presence of beavers are Atlantic salmon and trout. Although little is known about the actual impact of beaver activity on fish in Scotland, the potential for fishery impacts within the River Tay is considered high.
- The potential for interactions between beavers and fish have been reviewed extensively. Whilst these reviews focused on the potential impact of beavers on 'fish' rather than 'fisheries', it is clear that any impacts on fish of commercial or sporting value may also have direct impacts on associated fisheries. There is limited published data on the direct impact of beavers on freshwater fisheries outside Scotland.
- The report of the beaver salmonid working group (BSWG) critically reviewed the potential impact on Atlantic salmon and, to a lesser extent, trout, within Scotland. These species were covered in greater detail because salmonids comprise the highest-profile freshwater fisheries in Scotland, but they are not the only fisheries sector that may be affected by the reintroduction of beavers.
- The BSWG report suggests that whilst tributaries can be important spawning and rearing areas for Atlantic salmon throughout catchments, the upper tributaries which are commonly used to produce the spring Atlantic salmon stock component are currently under the most threat, and hence are the most vulnerable to any obstructions from beaver dams. The resilience of migratory salmonid populations to new pressures is an issue that must be considered in respect of how beaver–salmonid interactions are managed.
- Models suggest that within SACs classified for Atlantic salmon, the lengths of the rivers predicted as less likely to be dammed range from 84.5% for the River Spey up to 100% for the Little Gruinard River and River Thurso. This approach can help identify areas where effective management may be required and available resources usefully deployed. Prioritising areas where the Atlantic salmon spring stock component are known to spawn, for example, may be a useful starting point if that element of the fishery resource is to be protected.
- Beaver activity on small streams may have a disproportionate impact for trout production as a function of their widespread distribution within small watercourses. It is possible that the potential overlap between beaver activity and trout may be more significant than has been estimated for Atlantic salmon. It is therefore not yet possible to predict what impact reintroduced beavers might have on trout fisheries within the River Tay catchment.
- An assessment of the impact of beavers on the grayling *(Thymallus thymallus)* fishery is difficult as limited information is available relating to the population status and local ecology of grayling within the River Tay system, and few data are publicly available on the numbers of grayling caught and its value to the local economy.

- The impact of beaver activity on other native species for which recreational fisheries exist in Scotland, such as pike (*Esox lucius)*, roach (*Rutilus rutilus)* and perch (*Perca fluviatilis)*, may be less controversial. These are species which utilise a wide range of habitats and can establish in both rivers and standing waters. Whilst these species do undertake spawning migrations, or spawning movements, they are possibly less likely to be found in situations where they are affected by beaver dams.
- There was no indication during the trial period that beavers, which utilised the lochs extensively, negatively affected the operation of Loch Barnluasgan and Loch Coillie-Bharr as a recreational fishery.
- Past and recent reviews, as well as the report of the BSWG, acknowledge that beavers can have overall positive effects on the production of some species of fish. This is largely because of the ability of beavers to modify river habitats and, as a consequence, influence hydrological characteristics and water chemistry within the watercourse. This must, however, be balanced against possible negative impacts of dam-building on the movement of fish within river systems and their effect on critical in-stream habitats.
- The development of a management strategy is key to the successful coexistence of beavers and fisheries. This strategy should provide guidance on the type(s) of interventions which can be made, the evidence base required and resourcing. The strategy should be developed in full consultation with stakeholders from the fisheries management sector. Effective management is also dependent on a good understanding of the actual, rather than perceived, impacts of beaver on aquatic ecosystems, and fish in particular.

### 5.4.4 Further research since publication of the Scottish Review

Studies since the Scottish Review relating specifically to the influence of beavers on fisheries are limited.

In their review of beaver-salmonid relationships and the history of management actions in the western Great Lakes (USA), Johnson-Bice *et al*. (2018) consider past beaver management actions and provide recommendations to guide fisheries resource managers when designing management strategies to address current and future beaver-salmonid conflicts. The authors note that the management of the fisheries resources in the presence of beavers continues to be a contentious issue in the study location, reflecting the difficulty in balancing the management priorities of salmonids, beavers and forestry, given competing human desires and complex interactions. Historically, complaints resulted in significant numbers of dams and beavers being removed. An example is given whereby 617 beavers and 482 beaver dams were removed from a low gradient river over a two-year period following reports of poor fishing conditions by anglers, resulting in ‘noticeably larger salmonid populations’, but potentially to the detriment of the beaver population. The current beaver adaptive management program has evolved to be based on two primary principles: (1) beavers, salmonids and their habitats are managed for human needs and wants; and (2) the less common natural resource (i.e. coldwater streams) must be protected while still providing opportunities for beavers to exist. High-quality salmonid streams are identified and local managers are responsible for responding to complaints and determining nuisance beaver presence on salmonid streams. The ‘*ecological and ethical dilemma*’ faced by resource managers of whether to prioritise the management of coldwater streams for the benefit of healthy and robust salmonid populations or seek to replicate 'natural' ecological processes with the knowledge that this could be to the potential detriment of salmonids is presented. Recognising the temporal component of the beaver-salmonid relationship in North America, whereby maximum benefit occurs in the first 2-4 years post dam construction, they proposed that beaver management could be undertaken on a 3-5 year basis, rather than an annual basis, to mitigate long-term negative effects on salmonid populations, while preserving the short-term benefits and reducing management costs. The authors advocate a need for science-based management plans, but note that there is a lack of empirical data on beaver-salmonid interactions on which to base management decisions.

Fishery aspects were considered in the report of the River Otter Beaver trial (ROBT: Brazier *et al*. 2020). The study reported difficulty in assessing the economic value of the existing fishery for reasons including incomplete or absent effort returns by anglers, incomplete records and challenges in identifying and engaging with all anglers. There were reports of occasional negative impacts on anglers associated with disturbance of a fishing session by the presence of 'beaver-watchers', some of which were perceived as confrontational towards anglers and *vice versa*, and a beaver-felled tree which prevented wading through the river. Disturbance to fishing was reported to have led to a syndicate reporting to the owner of fishing rights that fishing had been affected in 40% of their stretch of river; the owner subsequently reduced the rent in that year. Negative economic impacts of angling activity on other recreational users, such as 'beaver watchers' and opportunities lost by local businesses were not considered. Potential benefits were proposed for the brown trout fishery as beaver ponds were found to have a slightly greater number of larger fish. Further scientific assessment of fish data being collected as part of the ROBT will help further evaluate the potential fisheries and beaver interactions.

### 5.4.5 English Context

Defra is the Government department responsible for fisheries in England. The main legislation covering freshwater and migratory fisheries is The Salmon and Freshwater Fisheries Act 1975 which was created to protect salmon and trout from commercial poaching, to protect migration routes, to prevent wilful vandalism and neglect of fisheries, and to ensure correct licensing of all fisheries. The Environment Agency has a statutory duty to maintain, improve and develop salmon, trout, eel, lamprey, smelt (*Osmeridae* spp.) and freshwater fisheries in England, as set out in the Environment Act 1995, and also has powers in the Water Resources Act 1991 and the Eel Regulations 2009. This fisheries remit is carried out in parallel with specific and overarching duties and powers including those regarding biodiversity, flora and fauna in the Acts listed above and also the Environment Act 1995, Countryside and Rights of Way Act 2000, Wildlife and Countryside Act 1981, Natural Environment and Rural Communities Act 2006 as well as the Water Environment (Water Framework Directive) (England and Wales) Regulations 2017 and Environmental Permitting Regulations 2016.

Inshore fisheries, which have relevance to migratory fish are primarily protected and assessed by the Inshore Fisheries Conservation Authorities, set up by the Marine and Coastal Access Act 2009. Natural England has a role in the protection of fish, which are also utilised as fisheries, through the protection of species which may be a feature, or supporting feature, for the designation of a protected area.

In England, commercial net or fixed engine fisheries exist for salmon (though currently severely restricted by the Salmon and Sea Trout Protection Byelaws 2018 due to declines in stock abundance), sea trout, eel and lamprey. There are no commercial rod fisheries for salmon or sea trout since the introduction of a national byelaw in 2009 banning of sale of rod caught salmon and sea trout. A large number of recreational fisheries exist in the rivers, canals, lakes and other stillwaters across England. A study in 2015 estimated that freshwater angling in England contributed £1.46 billion to the economy and supported 27,000 full-time equivalent jobs (Environment Agency 2018).

Assessment of the potential risks and benefits associated with the presence of beavers in relation to fisheries is necessary to ensure these statutory duties are met and that the socio-economic and health and wellbeing benefits of the fishery are maintained.

**Diversity of fisheries**

The range of fish species, and therefore types of fisheries, present in England is far greater than in Scotland. There is little information within the literature on many high value angling species. Literature reviews agree that beavers can have overall positive effects for fish across Europe and North America due to their influence on the hydrological characteristics, water chemistry and morphology (Kemp *et al*. 2010; BSWG 2015; Gaywood 2015). In England, some species of coarse fish are known to thrive in situations where water quality is affected by nutrient enrichment. Water quality improvements should primarily be delivered by addressing polluting inputs at source, however, improvements to natural biological processes as a result of beaver activity have the potential to moderate water quality impacts and these water quality changes may alter the fish community structure. As organic input declines, the trophic status of a water body can reduce, lowering overall productivity (Ecke *et al*. 2018), potentially changing fish community structure and numbers of fish (Nash *et al*. 2003; and reference therein). Water quality improvements, which are positive in terms of environmental benefit, can therefore result in declines in some coarse fish species which may be of high angling interest, such as roach (Beardsley and Britton 2012), and a restructuring of the overall fish assemblage which may require a change in both angling methods and expectations. Ponds directly associated with dams can offer greater rearing habitat availability within streams for certain species (Kemp *et al*. 2010; Johnson-Bice *et al*. 2018). In parallel spawning habitat for gravel spawning species (including dace *(Leuciscus leuciscus*), grayling and barbel (*Barbus* spp.), as well as salmonids typically considered in the literature) can be lost (Collen and Gibson 2001; Virbickas *et al*. 2015) in ponded areas but may be gained downstream of a dam (Kemp *et al.* 2010; Johnson-Bice *et al.* 2018 and references therein, Brazier *et al.* 2020). This highlights the requirement for a mosaic of habitats that can be used by fish species at different life stages. In a naturally functioning, dynamic system these habitats will demonstrate temporal and spatial variability within a catchment (Mainstone *et al*. 2016). It is this temporal and spatial variability that demonstrates the fundamental difference between the temporary changes which may occur at a particular point due to beaver activity and a permanent, fixed structure, such as a weir or dam wall, built by human endeavour.

For brown trout, the reported improvements in habitat and increased food availability could, along with increased migration difficulty due to the presence of multiple beaver dams, influence propensity to migrate and alter the balance of resident brown trout and anadromous brown (sea) trout (CSTP 2016). Such changes are a natural element of brown trout life history, governed by a combination of genetic factors and habitat queues. An increase in numbers of larger brown trout may be beneficial to some fisheries, however, a potential decline in the migratory sea trout component may be detrimental to others and could have a potentially greater impact on socio-economic factors due to the higher value of migratory fisheries.

The opportunities for certain types of fishery due to the creation of deeper pool habitat behind beaver dams would benefit from further assessment for English river catchments. A better understanding of the potential overlap of predicted beaver dam building and burrowing activity, and the distribution of fish species of angling interest in England, across a range of catchments types, would help inform fishery benefits and opportunities and the balance of risk to other fish species. Reported benefits are often cited for minor fish species (e.g. minnow (*Phoxinus phoxinus*) and stone loach (*Barbatula barbatula*), which are typically of no direct fisheries value other than prey for valued species, or for fish species unlikely to be present (due to river zonation or lake type) in areas of English water bodies which could be favoured by beavers for dam construction (e.g. pike and roach). A GIS mapping approach similar to that undertaken in Scotland could identify where the potential interactions for a range of fish species could be expected to deliver fisheries benefits in English catchments, both now and in the future. Although it is recognised that any mapped overlap between fisheries and beaver activity does not infer that the level of overlap equates to the total area over which interactions may occur, neither does it predict the scale or direction of any impact (Gaywood 2015).

The large number of stillwater fisheries across England, with potential positive and negative fisheries impacts, have received less attention in the literature. Evidence from Scottish lochs where beavers are present report little impact on fish populations and no impact on the local fishing club was reported from the Scottish beaver trial (Gaywood 2015). These fisheries are predominantly based on boat fishing in large waterbodies, though bank fishing is also available, and so may not be considered representative of the majority of smaller stillwater fisheries in England. The presence of beavers in a fishery is more likely to affect the site itself than fish population within a stillwater, though there is the potential for beaver herbivory to impact aquatic plants which may have associated impacts on spawning substrates and water quality. The extent of potential impacts is difficult to predict due to the already extremely degraded state of the majority of English lakes and their associated aquatic plant and fish populations. Any attempt to quantify these impacts on a fishery must take into account this deviation from natural conditions. Beaver dams may block entry into feeder streams with potential negative consequences where these provide important spawning habitat for certain fish species (Popkov *et al*. 2018; Rohzkova-Timina *et al*. 2018). Limited data from studies of trout at Knapdale provide some evidence that fish are able to move between the loch and spawning/nursery habitat downstream (Gaywood 2015). Beaver activity upstream of a stillwater fishery may improve water quality and conditions of the fishery (Puttock *et al*. 2017; Brazier *et al*. 2020), including the potential for reduced siltation of spawning gravels for

Coregonid species and charr (*Salvelinus alpinus*). Beavers may burrow into banks which could potentially reduce bank stability and negatively impact access. Beaver dams may be constructed at the outfalls of online fishing ponds requiring management to meet discharge consents and/or manage water levels, however, the ambition to restore a more natural hydrology to water bodies would minimise the need for future management interventions. Tree felling and/or coppicing may be viewed positively or negatively by a fishery owner and, if required, management measures are available to protect trees. The dispersal of beavers into a stillwater fishery is likely to be influenced by the proximity to a river/watercourse due to beavers' tendency to stay in or close to watercourses (Brazier *et al*. 2020). A commercial fishery may be expected to operate within the bounds of the natural environment around it, rather than modifying the natural environment to accommodate it, or it may make a commercial decision to isolate itself from the wider environment allowing it to operate in a more independent manner (e.g. the installation of otter fences). Any potential risk to commercial stillwater fisheries could be considered as part of a wider catchment risk assessment and the potential costs to fisheries owners could be considered in the development of a management strategy.

**Salmonid fisheries**

The potential for beaver activity in small streams to have a greater impact on brown trout, and consequently their anadromous variant 'sea' trout, is of particular relevance to the English situation. Whilst salmon and brown trout, particularly sea trout variants, have broadly similar ecological and habitat needs there are subtle differences which separate the two species, reflecting their specific life history strategies (reviewed in Armstrong *et al.* 2003). Where they co-exist, salmon and sea trout are often spatially segregated with salmon having a preference for the main river stem and lower reaches of larger tributaries (3 to 10 metres wide) compared to sea trout which preferentially spawn in the headwaters, entering very small streams and tributaries (0.5 to 5 metres wide) to take advantage of clean spawning gravels. As identified during the reviews in Scotland and elsewhere, the habitat requirements of salmon and trout directly overlap with those habitats known to be suitable for beavers (Kemp *et al*. 2010; BSWG 2015; Gaywood 2015; Johnson-Bice *et al*. 2018).

**Fisheries management**

The approach to salmon population management in England, whilst broadly similar in its overall objective to that in Scotland, differs in its approach and subsequent management actions in relation to fisheries. In England (and Wales), river specific conservation limits have been set and used for the management of stocks since the 1990s. In line with the North Atlantic Salmon Conservation Organisation (NASCO) guidance (NASCO 1998) conservation limits are based on maximum sustainable yield which links directly to the sustainability of fisheries rather than conservation objectives (though the two are linked and inform Common Standards Monitoring targets for specially protected sites with Atlantic salmon as a feature). Individual stocks are annually assessed against a management objective that requires them to meet or exceed their conservation limit for at least four years out of five (i.e. at least 80% of the time). The probability of meeting the management objective determines the overall status of the stock based on four categories: 'Not At Risk', 'Probably Not At Risk', 'Probably

At Risk' and 'At Risk'. The latest stock assessment[26] indicates 57% of rivers in England are 'At Risk' and 36% 'Probably At Risk'. Continued concerns regarding the declining status of salmon stocks across England led the Environment Agency, supported by Defra, to develop the salmon five point approach[27] for England working in collaboration with key stakeholder organisations with an interest in maintaining and building resilience in salmon stocks. This has seen the implementation of new fisheries management regulations (Salmon and Sea Trout Protection Byelaws 2018) to reduce exploitation by nets and rods. These new byelaws extend protection for 'spring salmon' (previously provided by Spring Salmon Byelaws 1998) whereby all fish caught by rod and line prior to the 16 June must be released. The spring salmon run is a recognised important stock component which was identified for Scotland (Gaywood 2015) as being at potentially greater risk of adverse impacts from beavers due to their preferential spawning in the upper tributaries. The potential contribution of beavers to the delivery of objectives relating to other elements of the five point approach (improved water quality and safeguarding flows) must be balanced against potential for adverse impacts (relating to free passage and habitat) that could further threaten the sustainability of salmonid fisheries.

In England, a fishing licence is required to fish for salmon, trout, freshwater fish, smelt or eel with a rod and line. Licences (or authorisations) are also required to fish with a net or trap for salmon, sea trout, eels, lamprey and smelt. Fishing licence income is spent on delivering a national fisheries management service. This introduces an important customer relationship to the management of fisheries in England. While most fishing rights on rivers are privately owned, that does not include ownership of the fish as they are considered a national asset and therefore owned by society in its totality rather than an individual or corporate body. However, on enclosed still waters the fish are generally deemed to be owned by the owner or occupier of the fishing rights. Riparian legal rights confer ownership of the land and soil that abuts a river and which extends to the middle of the watercourse. As in Scotland, this complex system of licensing, fishing rights and riparian ownership means that reintroducing beavers may affect a wide range of stakeholders, at a variety of scales, with the potential for both positive and negative outcomes.

### 5.4.6 Identification of areas of potential conflict in England

The following areas of potential conflict are considered to be specific to the fisheries aspects of interactions with beavers in England. The potential conflicts identified in the Fish Assemblages section are also relevant and should be considered alongside the aspects reviewed below.

[26]Salmon stocks and fisheries in England and Wales in 2019. Preliminary assessment prepared for ICES, March 2020. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/907284/SalmonReport-2019-summary.pdf [accessed 11/06/2021]

[27] https://www.gov.uk/government/news/new-proposed-measures-announced-ahead-of-salmon-consultation [accessed 11/06/2021]

### Fish passage legislation

The Salmon and Freshwater Fisheries (Consolidation) (Scotland) Act 2003 provides context for potential management of beaver dams to ensure the maintenance of free passage for migratory fish in Scotland. In England, the Salmon and Freshwater Fisheries Act 1975 does not provide any powers for the management for fisheries, in terms of beavers and their dams, or the powers to instruct a third party to carry out management work, unless there is an association with flood risk. Were beavers to be reintroduced further in England, the management strategy should consider how beaver management actions that are associated with an identified risk to fisheries could be implemented, including the required legislation and resources to do so. Guidance would also be required to determine how risk to fisheries would be assessed in relation to deciding whether or not management action is appropriate.

### Salmon and anadromous brown (sea) trout fisheries

As reviewed in the Fish Assemblages section and highlighted in the report to the Scottish Government (Gaywood 2015), from a fisheries perspective, it is likely that the two species which will be most influenced by the presence of beavers are Atlantic salmon and anadromous brown (sea) trout. Uncertainty regarding the overall population level response to the interaction of multiple potential positive and negative impacts of beavers on salmonid populations has obvious consequences for determining the likely effects on these fisheries. It has been suggested that sea trout and spring salmon could be disproportionately impacted due to their greater tendency to spawn in smaller headwater streams (Gaywood 2015), which may be more readily dammed by beavers (Virbickas *et al.* 2015). A key objective for both salmon and sea trout stock and fishery management is to increase the natural resilience of fish populations by restoring, where possible, the natural processes which support high quality freshwater habitats and their associated fauna and flora, with the aim of supporting juvenile rearing capacity and smolt output. The accessibility and quality of spawning/rearing habitat are key factors in achieving this: a reduction in total area of suitable spawning habitat can lead to spawning redds (nests) being overcut and an increase in density dependent mortality of juveniles (Jonsson *et al*. 1998). Conversely, spawning habitat may be improved through a reduction in sedimentation (Puttock *et al*. 2017; Puttock *et al*. 2018) and habitat increased/improved if there is the potential for braided channels to be created around dam sites or greater food availability and cover to support juvenile growth rates and survival. Better understanding of the potential for beavers to change the carrying capacity of salmon and trout in whole catchments may offer a way to assess the likely population level effects of beavers on salmonids. However, given the temporal and spatial variability of beaver activity within a catchment (Kemp *et al*. 2010; Taylor *et al*. 2010), this is likely to require continued assessment. The UK Government is a contracted party to NASCO and as such has signed up to the NASCO principles for salmon stock and fishery management. This requires each contracted member state to apply a precautionary approach to the management of salmon fisheries and those river catchments which support and sustain wild Atlantic salmon stocks in the North Atlantic region (NASCO 1998).

### Fish community structure

The modification of river habitats by beavers has the potential to change the structure of the fish community with potential consequences where there is an existing fishery. Ecologically speaking this change may reflect an overall positive impact by the restoration of natural processes/function, as catchment pressures continue to be addressed at source (e.g. nutrient inputs), but may have a negative impact on some fish populations of high angling interest in some circumstances (Nash *et al*. 2003; Beardsley and Britton 2012). Predicting the direction of impact (positive or negative) may be difficult as this will depend on the nature of the existing fishery and the potentially unknown future interests of local angling clubs and individuals. When considering the potential impacts for fisheries, there is a requirement under Environment Agency fisheries duties to consider the existing socio-economic value of the fishery. An English Management Strategy should consider the need for communication and customer engagement regarding the intended environmental and social outcomes and any potential changes, both positive and negative, to the fishery that might occur as a consequence of the presence of beavers within a catchment.

**Fisheries economics**

Beavers are recognised landscape engineers and the positive impacts of their reintroduction are associated with their modification of water dependent and riparian habitats. In doing so, there is the potential for these habitat changes to have financial implications for landowners, including those with fishing or riparian owner rights and owners of stillwater fisheries. Negative impacts reported to affect agriculture and land management such as burrowing into banks, increased erosion and bank collapse (Gaywood 2015) are also relevant to fisheries. The creation of wetland and ponded habitat may make sections of the river unfishable or difficult to access. Tree felling could block swims or access paths requiring management intervention at the cost of the landowner/fishery manager. Disturbance of fishing activity from other members of the public hoping to see beavers has been reported (Brazier *et al*. 2020), though it should be noted that in this location there was shared public access. As demonstrated in the ROBT, the value of angling can be influenced by perception which may be an important management consideration. Such complex anthropogenic factors blur the line between perceived and actual impact, with potential consequences for the recommendation that effective management is dependent on a good understanding of actual, rather than perceived, impacts of beavers on fish. In this case, impacts (of beavers on anglers) could potentially be perceived, but result in an actual impact in monetary terms (to the fishery owner). Whether the positive benefits offered by beavers will outweigh the potential costs for fisheries is likely to be dependent on individual circumstances and it is acknowledged that there is likely to be a difference, in various scenarios, between who receives potential benefit and who meets potential cost (Brazier *et al*. 2020), which would need to be resolved and potentially managed.

**Angler safety and wellbeing**

Some fisheries interests have raised concerns around the potential impacts to their safety and wellbeing from the presence of beavers, such as: potential disease risks, dam collapse and aggressive behaviour. A recommendation of the BSWG was that effective management is dependent on a good understanding of the actual, rather than perceived, impacts of beaver on aquatic ecosystems, and fish in particular. This principle should also be extended to include the potential impacts on anglers. It is therefore important to review if the concerns raised are substantiated and should be considered in the development of a management strategy for beavers in England.

**Beaver dam longevity**

The longevity of beaver dams varies widely depending on a suite of factors. These include environmental conditions, time of year and the reason for the dam's presence, for example maintenance of a dam before breeding season or construction by a dispersing animal setting up a territory and foraging. The greatest potential for a negative interaction comes where dams are constructed at a time when fish need to migrate past them to complete their lifecycle, such as reaching spawning grounds. Where these dams are found to present a barrier to free movement, either through timing, location, local conditions or longevity, the greatest impacts, and therefore potential conflicts, are likely to occur.

### 5.4.7 Potential implications of wider reintroductions in England

The following factors are relevant when considering the potential impacts on fisheries of a wider reintroduction of beavers in England:

- It is likely that some fish species in some locations will benefit from the presence of beavers while at other locations certain species may be negatively impacted. The impact that this may have on a fishery will depend not only on the impacts for the fish populations, but on the character of the existing fisheries and individual anglers.
- The limited understanding of the potential impacts of beaver activity on some fish populations (identified in the Fish Assemblages section) and lack of published data considering the potential impacts on fisheries, make it difficult to fully determine the effects, positive and negative, of beavers on fisheries, although the knowledge of beaver and fish ecology provide information to infer potential effects. Direct and indirect impacts on fisheries for a wider range of species would benefit from more assessment with agreed assumptions for cost-benefit on a strategic scale.
- It is unlikely that effects can be quantified for fisheries in England, but this would not preclude an approach that seeks to further understand economic and social factors alongside potential environmental impacts and effectiveness of management.
- Salmon and sea trout fisheries have the most potential to be adversely impacted by the presence of beavers, whilst recognising there may also be benefits to fisheries, due to predicted overlap of habitat and the potential for both positive and negative impacts associated with dams. Greater understanding and, where needed, certainty around the overall balance of potential benefits and risks to migratory fish populations should inform future decisions and the development of a management strategy for England. This should include the need for salmonid fisheries to continue to be managed with consideration of NASCO objectives.
- For coarse and other fisheries there is a lower likelihood of impact from beavers due to being less likely to overlap with preferred beaver habitat and, where they do, they may be more likely to benefit from the creation of beaver pool habitat. Aspects of environmental improvements delivered by beavers, such as changes to sediment and nutrient transport, may lead to a restructuring of coarse fish assemblages and their associated fisheries.

- The potential effects of beavers on the types of small stillwater fisheries common across England are not widely considered in the available literature, though are likely to be dependent on their proximity to watercourses. The impacts for these fisheries may be more likely to be related to beaver interacting with land management rather than fish stocks.
- Fisheries regulations that apply in England regarding fish and fisheries differ from Scotland. Licensing requirements for fisheries activities (nets and rods) benefit from a partnership approach and any management strategy should seek to engage fully with the fisheries community and other stakeholders to ensure concerns are listened to and addressed.

# 5.5 What are the potential effects of beavers on commercial forests?

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## 5.5.1 Summary of main findings and recommendations

The Scottish Review provided limited evidence that the presence of beavers would have a high impact on commercial timber production. The greatest impacts were considered to be related to infrastructure, such as the loss of forest track due to flooding (Gaywood 2015).

Medium evidence from elsewhere in Europe and in North America has shown that there can be significant issues with impacts on infrastructure due to flooding, but damage to trees is less common. The majority of herbivory occurred within 10 m of the watercourse, but methods of protection have found to be effective (Wróbel and Krysztofiak-Kaniewska 2020; Janiszewski and Hermanowska 2019; Varju and Jánoska 2015; Kamczyc *et al*. 2016; Reeves *et al.* 2016).

There is no direct evidence in England of the effects of beavers on forestry, but there is a larger proportion of broadleaf woodland cover than in Scotland, including areas of highly preferred species such as willow and aspen. There is also likely to be a greater proportion of forestry on lower gradient sites, which may have the potential to result in greater impacts from flooding. However, ensuring sites adhere to the UK Forestry Standard (Forestry Commission 2017), will help mitigate impacts due to the need to provide a buffer zone along watercourses.

## 5.5.2 Introduction

Beavers are likely to interact with commercial forestry through tree-felling, flooding and impacts on forest infrastructure. Small-scale farm woodlands are also potentially likely to be subject to high impacts if a water course is present and if they are of a species which beavers prefer. Forestry operations that may be impacted, depending on the level of protection given to beavers in the future, include: felling operations along river corridors; restocking or new planting in riparian zones; and infrastructure (road, ride and culvert) creation and maintenance.

## 5.5.3 A summary of the findings from the Scottish Review

- The impact on productive forestry (trees) was very limited at Knapdale (estimated at £108/year).
- The greatest impact was through the loss of 400 m of forest track due to flooding (cost of replacement estimated £22-25K).
- In the Tay catchment, two cases of damage to commercial trees were reported as a result of damage and flooding.

- Impacts to infrastructure associated with forestry were considered greater than impacts on the trees themselves.

### 5.5.4 Further research since the Scottish Review

A review from Poland, which included beaver interactions with commercial forestry, showed the main issues from beavers were with forest infrastructure, such as culverts with damage to forests themselves very rare (Wróbel and Krysztofiak-Kaniewska 2020).

The key human-wildlife conflict associated with beavers and land use in Poland was flooding of grasslands. Flooding of tree stands was viewed as a less prevalent but still important conflict. Flooding and felling occurred during spring and summer months, and this is when the authors recommended management of beavers and their structures should be targeted (Janiszewski and Hermanowska 2019).

In a study of forested areas affected by beavers in Hungary, 75% of herbivory was within 10 m of the watercourse (Varju and Jánoska 2015).

A 1 m high chain-link steel fence with 6 cm mesh size and buried to 50 cm, built parallel to the river and laterally to 40 m, was effective at protecting tree stands from herbivory in Poland (Kamczyc *et al*. 2016).

Reeves *et al.* (2016) studied planted oak seedling mortality at two sites in southern Mississippi. They found that 22% mortality of seedlings was caused by beavers uprooting and consuming roots at a time when when other food sources were scarce. More significant causes of mortality were freezing and flooding (non-beaver).

### 5.5.5 English context

The English situation differs in key ways from Scotland, with a much larger proportion of broadleaf woodland cover. There may also be more plantations of species which beavers prefer, in particular cricket bat willow (*Salix alba var. caerulea*), and aspen/poplars (*Populus* spp.).

It is estimated that 75% of woodland cover in England is broadleaf, while 3% of woodland cover is of highly preferred species such as willow and aspen (Forestry Commission 2014). For highly preferred species it is likely that impacts will be concentrated within 20 m (possibly extending to 50 m) of a watercourse. Beavers will utilise less favoured resources that are closer to the water in preference to travelling further from the water to utilise preferred resources (Iason *et al.* 2014).

Compared to Scotland, there is also likely to be a greater proportion of forestry on lower gradient sites, potentially resulting in greater impacts from flooding due to stream impoundment.

### 5.5.6 Identification of areas of potential conflict in England

The UK Forestry Standard (Forestry Commission 2017) has a minimum buffer width of 10 m along all permanent watercourses, including a 20 m buffer along all watercourses >2 m in width, and this will mitigate most tree-felling conflicts. However, if beavers dam a watercourse and cause it to expand, this may cause higher levels of conflict (e.g. inundation and death of trees). In these cases, pond-levelling devices (also known as beaver-deceivers which manage water levels down to acceptable heights) may be necessary to reduce intrusion into valuable crops. Specialised plantations of willow and aspen near to watercourses may be particularly vulnerable. Standard techniques to reduce beaver impacts on specific trees, such as painted sand, fencing, and tree guards, are well understood and likely to be effective in certain situations (Campbell-Palmer *et al.* 2016). Increased costs will come from implementation of these management techniques and monitoring (Brazier *et al*. 2020; Campbell-Palmer *et al.* 2016).

The impacts on forest infrastructure may be an area of conflict. Forestry operations, and in particular timber extraction, rely on a robust network of forest infrastructure such as forest roads, bridges and culverts. This is potentially a key source of conflict as beavers view pinch points along rivers, such as culverts, as preferred places for dam building. Levelling devices and culvert designs to ensure impacts can be prevented or mitigated are well understood and may need implementation.

### 5.5.7 Potential future implications of wider reintroductions in England

The majority of the English forestry sector will see minimal influence from beavers. The UK Forestry Standard requires buffer zones along watercourses, as well as dedicated areas for the protection and enhancement of biodiversity, which will go a long way to mitigating any adverse impacts caused by beavers.

However, impacts on forest infrastructure may be a source of conflict, and forest owners will need to understand potential impacts and mitigation options. Also, some forest owners with landholdings predominantly specialising in willow or aspen, and concentrated near to watercourses, may be disproportionately negatively affected. Specific advice within the next iteration of the UK Forestry Standard would be useful.

## 5.6 What are the effects of beavers on agricultural land?

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### 5.6.1 Summary of main findings and recommendations

There is strong evidence from Scotland that beavers can have a negative impact on production and productivity of intensively farmed low lying agricultural land (Gaywood 2015). This is supported by strong evidence elsewhere in Europe and North America, although the impacts will vary according to land use and topography (Small *et al.* 2016; Janiszewski and Hermanowska 2019).

There is medium evidence so far in England that beavers can negatively affect production and productivity on agricultural land (Brazier *et al.* 2020). However, given the evidence from Scotland and Europe alongside the similarities in landscape affected to the English agricultural landscape, there is strong evidence that beavers may negatively affect productivity of agricultural land in England in certain situations, particularly lowland arable agricultural land on floodplains.

There is medium evidence that beavers may have a positive influence on agricultural land through flood attenuation (Puttock *et al*. 2018). These benefits are at a catchment scale, so not necessarily directly beneficial to individual farmers who bear the costs, but whose land may be the source of erosion or pollution. A range of variables must therefore be considered collectively for any reintroduction project. These should include the propensity for population growth and dispersal of beavers, the local topography, soil structure and hydrology, the proximity of agriculture to watercourses and the long-term plans for the recovery of nature along watercourses.

The economic cost from conflicts is most likely to be higher on low-lying, intensively farmed, high value, arable land. In England it is likely to be regions dominated by lowland arable agricultural land where most management of beaver impacts is likely to be required. In particular, areas with high proportions of Agricultural Land Classification Grades 1 and 2 land, such as Cambridgeshire, East Riding of Yorkshire and Lincolnshire, are likely to be affected the most by beaver activity.

In addition to land use, proximity to watercourses and topography are important factors which influence the impact beaver activity will have on agriculture. Further analysis using mapping software such as that demonstrated by Graham *et al*. (2020) could pinpoint key areas where conflict and/or opportunity is most likely to occur.

### 5.6.2 Introduction

Agriculture is a vital part of the English economy and covers 9.6 million hectares[28]. Only a very small proportion of this land is ever likely to be affected by the presence of beavers, but it is important to consider the implications of beaver reintroduction for agriculture in the English context.

Beaver reintroduction programmes and other studies have identified multiple influences that beaver activity can have on agriculture. The significance of these influences depends upon variables such as proximity to water and vegetation available (Swinnen *et al.* 2017), as well as local topography, soil structure, hydrology and the vulnerability of the agricultural activity itself (Gaywood 2015). Given the propensity of English farmland to extend right up to stream or river banks with very narrow riparian buffers, agricultural land in low-lying areas, particularly on floodplains, is likely to be the most significantly impacted by any beaver activity.

### 5.6.3 A summary of the findings from the Scottish Review

- In Tayside, 28 of the 56 beaver sites reported negative impacts, the majority of these being recorded in the more intensively farmed lowland areas at sites adjacent to watercourses. Of those experiencing negative impacts, 70% reported a financial cost.
- Direct impacts to agriculture included:
    - Burrowing leading to increased erosion and bank collapse. Burrowing may be particularly problematic where it occurs in earth embankments which provide protection to intensive agriculture situated on low-lying floodplains.
    - Dam-building resulting in flooding of productive land behind the dam; where dams cause water to be pushed sideways this can also result in erosion and flooding of crops.
    - Feeding on crops close to watercourses; although in most cases the scale of the loss was not commercially significant.
    - Felling causing obstructions to farm roads, damage to fences and blocking of drainage ditches.
- Dam-building activity on intensive arable land on fertile floodplains is likely to have a significant impact, and farmers' organisations have indicated that the presence of beavers would not be appropriate on this type of farmland.
- Beaver colonisation of Scotland will result in increased conflict with riparian landowners, in turn increasing the requirement for management activity. The significance of conflicts would vary greatly across Scotland depending on the vulnerability of the land and the intensity and value of the crops.

### 5.6.4 Further research since the Scottish Review

Brazier *et al*. (2020) from the River Otter Beaver Trial (ROBT) identified that beaver burrows may affect a farmer's ability to carry out agricultural operations very close to stream or river

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28 https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/868945/structure-jun19-eng-28feb20.pdf [accessed 11/06/2021]

banks, as there could be a significant risk of machinery breaking into hidden chambers. This could affect grass and silage cuts, harvesting of other forage crops as well as arable and horticultural operations. Apart from damage to the machinery and a potential health and safety risk to the operator, this could make some land unusable and reduce the area of a field on which crops can be grown or requiring some areas to be left unharvested along streams or riverbacks. Part of the problem is that it is not always possible to detect where burrows might be, and a precautionary approach might lead to a farmer having to avoid machinery movements within a certain distance of any watercourse.

Brazier *et al*. (2020) found that feeding on agricultural crops and fruit trees by beavers had a negligible effect on agriculture overall during the ROBT. A 15 $m^2$ area of maize crop was destroyed by beaver feeding, resulting in an estimated gross margin loss of £1.33 for one harvest. Beavers were found to travel 30 m across a woody buffer strip, farm track and under a fence to access maize in this instance. Aside from five maize fields that were impacted by crop-feeding, this study found evidence that beavers had accessed a small area of root crop, but left no significant damage and fed on fruit trees (taking apples and coppicing a few trees) in three privately owned riverside orchards.

Smith *et al.* (2020) studied hydrological processes and water quality in a lowland agricultural catchment over a 30 year period in northern Germany. Wetland rehabilitation started in 2000, facilitated by beaver colonisation in 2007, and resulted in longer water transit times in the stream network, less linear storage-discharge relationship and a loss of daily stream variability, increased dissolved organic carbon concentrations, isotopic evaporative enrichment downstream and moderated stream temperatures. Groundwater levels increased and became more stable over the study period, suggesting that beaver dams may have resulted in increased surface water leakage to groundwater fluxes. There was limited long-term water quality improvements from wetland rehabilitation which likely reflected the long-term legacy of fertilizer use on nutrient reservoirs in the catchment's soils, aquifers and stream network.

Janiszewski and Hermanowska (2019), identified flooding of grasslands resulting from beaver activity as the most significant cause of damage to private farms in two Polish regions. Results from the ROBT estimated that at one site, the backlog of water behind a beaver dam prevented the sowing of 0.4 ha of organic potato seed and resulted in a gross margin loss of approximately £2,055 (approximately £5,137 per hectare). At another site, flooding of 0.89 ha of grazing land for a spring-calving dairy herd would have resulted in a gross margin loss of approximately £1,566 (approximately £1,759 per hectare) over a year without management intervention (Brazier *et al*. 2020). According to Czarnecka (2015), waterlogging caused by beavers immediately inhibits the development of plants which are already present at a site. In addition, it can prevent machinery access to crops meaning that they cannot be harvested, as was observed during the ROBT.

A study by Bełżecki *et al.* (2018) on the contents of beavers' digestive tracts found that during the winter their diet primarily consisted of woody material, whereas in the summer it was predominantly herbs, grass and leaves. The impact of crop-feeding by beavers may therefore vary according to the season. In addition, whether the agricultural land is used for grazing or not may also be a factor affecting the distribution of beavers. Small *et al.* (2016) found that

North American beavers were present mainly on sites in New Mexico which were not grazed or where there was some form of alternative grazing management.

In addition to the previously mentioned impacts, the ROBT report identifies impacts on farm variable costs that may be associated with beaver reintroduction:

> *'The Trial has recognised other potential variable costs which may result from the impacts of beavers, including: variations in financial support for farmers; staff time costs (such as those resulting from increased time to move cattle if an access route is waterlogged); costs of machinery repair (caused for example by a tractor driving over a beaver burrow); losses for landowners from reduced farm rents; wear and tear to farm tracks (if for example beaver damming increases the route required to a milking parlour on a dairy farm); fence repairs from felled trees, etc. Due to the context-dependent nature of these secondary costs, they will need to be assessed on a case-by-case basis.'* *(*Brazier *et al.* 2020, p.33*).*

Other studies have highlighted potential benefits that the presence of beavers can bring to agriculture. A study by Puttock *et al*. (2017) on the effects of beavers in an enclosure to an intensively farmed lowland agricultural landscape in south west England, found that the creation of beaver dams can help to attenuate flooding downstream. They also found that water leaving the enclosure site had lower concentrations of suspended sediment, nitrogen and phosphate (sourced from farmland upstream). They concluded that beaver reintroduction programs can act as nature-based solutions to the catchment-scale water resource management issues faced within agricultural landscapes. This is further supported by Puttock *et al*. (2018) who found that ponds created by beavers in south west England may help to mitigate the accelerated soil erosion and diffuse pollution that occur within agriculturally dominated landscapes such as intensively managed grasslands. Individual farmers are, however, unlikely to benefit from sediment acculmulating in beaver ponds as it has already been lost from fields. Capture of diffuse pollution again is unlikely to benefit the farmer directly, but will improve water quality downstream. Such issues do therefore need to be addressed at source.

### 5.6.5 English Context

Farming systems in England are similar to those in Scotland, albeit with less upland grazing. Where agricultural land borders the riparian zones of streams and rivers, if it is farmed close to the water, then there will be a risk of beavers impacting on that type of agriculture. Where that type of agriculture is high-value arable land, costs would be highest.

The ROBT identified negative impacts on agriculture caused both directly and indirectly by beavers (Brazier *et al*. 2020). All were localised and in most cases intervention by ROBT staff or landowners mitigated conflict situations and avoided significant economic losses. Of the six established beaver territories where dams were built, four of the landowners welcomed the presence of beavers with ongoing management mitigating any negative effects. On the remaining two sites, the dams caused impacts on drainage in the floodplain which were unacceptable to the landowner. Further research reveals a more mixed picture regarding the costs and benefits to agriculture resulting from beaver reintroduction. Factors influencing impacts to agriculture include the proximity to watercourses, willow (*Salix* spp.) stands, wetland vegetation and poplar (*Populus* spp.) trees (Swinnen *et al*. 2017) as well as the vulnerability of the agricultural activity itself, local topography, climate, hydrology and soil structure and texture which will determine how well soil drains (Davies 1972).

Whilst beaver activity may have localised negative impacts on agricultural land close to watercourses, it can also have positive impacts on agricultural land downstream and at a catchment scale, not only through the moderation of water flow and improvements in water quality described above but also through opportunities for diversification such as ecotourism and recreational shooting on flooded land. These impacts will therefore need to be considered collectively in decision making processes.

### 5.6.6 Identification of areas of potential conflict in England

The severity or cost of any impacts to agriculture from beaver activity will be higher where the land is intensively farmed, high value, arable land. However, flooding to poorer quality land may still have significant impacts at the farm scale. Agricultural land classifications (ALC) can be useful in identifying areas where greatest financial impact from beaver activity on agriculture may arise in future. This grading system assesses the potential for land to support agricultural uses, with grades 1 to 3a being considered the Best and Most Versatile (BMV) agricultural land. Grades 1 and 2 land support higher value cropping systems and have an inherently higher sale/rental value which could be undermined by beaver conflicts in riparian corridors. Additionally, grades 1 to 3a have the highest potential for yields, versatility of use, yield consistency and lower input. Therefore, beaver activity which impacts negatively upon BMV land is likely to cause conflict, although measures such as reducing the intensity of farming up to the riparian edge would help mitigate any conflict and deliver other societal benefits.

Where beavers are present on grazed pasture, their burrowing activities could pose a risk of damage to farm machinery and injury or death to livestock, especially to larger animals such as cattle, although such occurences have not been recorded in Great Britain to date. In addition, the raised water levels on grazed pasture that may result from dams and blocked culverts may also pose a disease risk to livestock, unless pragmatic management to create riparian buffer strips is implemented which exclude livestock. Specifically, wet pasture may increase sheep and cattle’s susceptibility to liver fluke (Faciolosis, caused by the parasite *Fasciola hepatica*). Liver fluke causes poor health and production losses in cattle and sheep and can occasionally be fatal (Mitchell 2002). The snail *Galba truncatula* is the most important intermediate host of *F. hepatica*, although other snail species may be used occasionally (Caron *et al*. 2007; Relf *et al.* 2009; Caron *et al*. 2014). *Galba truncatula* favours small water bodies such as ditches and ponds, and is commonly present in patches which are only seasonally wet or have fluctuating water levels (Hourdin *et al*. 2006; De Roeck *et al*. 2014). Livestock would therefore be more at risk if they are allowed access into the watercourse (or beaver pond). Wetter ground can also increase the risks to cattle of other diseases such as blackleg (*Clostridium chauvoei*), a fatal disease which mostly occurs in young stock between ten months and two years of age (The Cattle Site 2020). However, no known incidents of such disease risk manifesting have been recorded in any peer-reviewed literature to date.

The requirement for increased management and potential conflict between beavers and agricultural land use is more likely to occur in flat or gently sloping, intensively farmed, lowland areas at sites adjacent to watercourses. Studies investigating the impact of beaver activity on agriculture have identified that beavers will usually only come into contact with agricultural land when it is within approximately 20 m of watercourses such as streams, rivers, drainage ditches, wetlands, lakes or ponds (Gaywood 2015). Conflict is also more likely to occur where beaver activity takes place in close proximity to irrigation infrastructure (Abrams *et al*. 2019) and in landscapes dominated by canalised watercourses to support intensive agricultural production (Campbell-Palmer *et al.* 2016). Table 12 identifies the amount of agricultural land that falls within a 20 m buffer of a riparian corridor within each county in England. The counties are listed in order with the counties with the greatest area of grade 1 and 2 agricultural land occurring within the 20 m riparian buffer compared to the total grade 1 and 2 in county first. This does not however take into account topography which will also influence the severity of any impacts caused by beavers.

Beaver reintroduction projects and other studies have documented the mechanisms that have been trialled to address conflict between beavers and agriculture (Gaywood 2015; Campbell-Palmer *et al*. 2016). During the ROBT, structural management interventions included: flow devices to reduce water levels, management of dam heights or locations, removal of dams, infilling of burrows, and cordoning off areas with burrows. Although generally, the capital cost of mitigating negative impacts was relatively low, in many cases ongoing monitoring is necessary which can be costly. Similarly, the Scottish Review suggests that on agricultural land, '… checking for and managing beaver dams may become a regular activity for land managers, with attendant costs in terms of time and machinery.' (Gaywood 2015).

As the majority of impacts are most likely to occur within 20 m of a watercourse, riparian buffer strips may be an effective method to reduce conflict associated with burrowing, foraging and canal building. Taking a strip of land out of active production alongside water courses will not only have significant benefits for water quality, riparian habitat and biodiversity recovery, but will mean these catchment areas are much more resilient to any 'adverse' impacts resulting form subsequent beaver activity. The reduction in productive land area would however have an impact on gross margins. In the east of England in particular, high value crops are farmed to within 2 m of watercourses in many circumstances. In addition, an opinion cited in the report published by Inman (In press) suggests that '…*the backing up of river levels causing field drains to stop flowing can affect farmland drainage many hundreds of metres from a watercourse (i.e. not just the riparian corridor). This means 10 m 'beaver buffer strips' immediately adjacent to watercourses will not alleviate the problem in these situations*' (Figure 18). Although this should only affect low lying agricultural land where field drains are compromised by beavers, the costs and benefits of buffer strips need to be considered in differing situations.

**Figure 18** Flooding of agricultural land caused by backing up of river levels by beaver dams, causing field drains to stop flowing



Financial assistance has been used in other countries as an approach to reducing conflict. Measures may include:

- Compensation for losses.
- Contribution toward costs of remediation and mitigation.
- Land purchase schemes and/or land exchanges.
- Reward payments e.g. agri-environment schemes.

There is significant variation between countries as to what financial assistance is available to those experiencing beaver problems. In some countries, including Germany and the Netherlands, the riparian buffer zones discussed previously are encouraged through agri-environment schemes. In others, such as Scotland and France, there are no compensatory schemes in place, although both have agri-environment schemes and potentially buffer strip options that could in theory be used, even if they are not encouraged/targeted for this situation. In the USA it has been found that grant and cost-share funding opportunities helped to reconcile beaver related projects with cattle production interests (Abrams *et al*. 2019). Similarly, as the mitigation measures supplied and installed during the ROBT were financed by the project team rather than the landowners, this successfully reduced conflict (Brazier *et al*. 2020; Inman In press). Whilst there is no precedent in England for financial assistance to be provided to compensate for damage caused by a protected or unprotected species, as a reintroduced species there may be an expectation from some landowners of some form of assistance to help resolve conflicts and losses arising from beaver activity. In order to reverse previous interventions, such as land draining and river dredging, and provide the most benefit to nature, incentive schemes may be a more pragmatic approach than reactive compensation schemes.

Finally, a management intervention that can be considered alongside increased monitoring, structural measures and financial assistance is education. A study by Morzillo and Needham (2015) found that education regarding how to coexist with beavers was often the most effective management response, and that incentives help land managers to select appropriate mitigation tactics.

### 5.6.7 Potential future implications of wider reintroductions in England

The impact of beaver activity on agriculture will vary significantly across England. However, beaver activity is likely to have the greatest influence where riparian corridors are farmed in those regions of England which are dominated by lowland arable agricultural land. In particular, conflict with agriculture may be more severe in counties with high proportions of ALC Grade 1 and 2 land (see Table 12). It does however need to be noted that relatively low proportions of these ALC grades fall within the riparian corridor, so impacts will only manifest on very low proportions of the total farmed areas.

To pinpoint those areas where beaver activity will most significantly impact upon agriculture, mapping software can be used to examine the topography and watercourses of each county. Such software could build upon the work of Graham *et al*. (2020), who mapped where dams are most probable to occur. This would highlight lowland areas adjacent to watercourses, which have the potential to be inundated by embankment breaches or drainage failures, and are therefore most susceptible to beaver activity.

Predicting population dispersal and expansion is important when considering the impact that beaver reintroduction would have on English agriculture. In Scotland, those beavers which were translocated to the Knapdale site were found to largely remain at the site, possibly due to local topography and lack of connectivity (Gaywood 2015). However, since the first fenced enclosure projects began in the early 2000s, there has been a growing number of sightings of wild-living beavers in locations across England, including Oxfordshire, Devon and Kent (see Introduction section 1.2; Heydon *et al.* In press). Approximately ten years after many of these projects started, escaped beavers have been found up to 50 km away from their fenced enclosures, so it is important to carefully consider the agriculture surrounding potential release sites. The nature of the release site, barriers to dispersal and surrounding beaver populations can all impact upon population growth and expansion, and in turn the potential for beaver activity to come into conflict with agriculture.

**Table 12** Amount of agricultural land classifications (ALC) area by ALC category within 20 m of a watercourse (OS Mastermap Water Network Layer)

| County | Total area of agricultural land in county ($km^2$) | Total area of ALC 1 & 2 in county ($km^2$) | Amount of agricultural land within 20 m of watercourse (all grades) ($km^2$) | Amount of ALC grade 1 and 2 within 20 m of watercourse in county ($km^2$) | Percentage of ALC grade 1 and 2 within 20 m of watercourse compared to total grade 1 and 2 in county |
|---|---|---|---|---|---|
| **Lincolnshire** | 6590.9 | 3115.5 | 990.9 | 522.7 | 16.8 |
| **Cambridgeshire** | 3157.3 | 2183.4 | 502.0 | 353.5 | 16.2 |
| **Norfolk** | 4791.3 | 1339.1 | 548.6 | 157.2 | 11.7 |
| **Essex** | 3225.2 | 1605.0 | 303.1 | 99.5 | 6.2 |
| **East Riding of Yorkshire** | 2336.2 | 1130.5 | 230.3 | 86.4 | 7.6 |
| **Kent** | 3185.1 | 1094.3 | 297.8 | 83.3 | 7.6 |
| **North Yorkshire** | 8179.8 | 1176.6 | 829.7 | 82.6 | 7.0 |
| **Lancashire** | 2770.2 | 447.7 | 424.1 | 79.5 | 17.8 |
| **Somerset** | 3953.6 | 524.9 | 509.0 | 72.0 | 13.7 |
| **Suffolk** | 3438.3 | 1002.5 | 284.1 | 63.4 | 6.3 |
| **Herefordshire** | 2094.0 | 929.7 | 162.0 | 52.2 | 5.6 |
| **Bedfordshire** | 1039.5 | 444.7 | 101.0 | 38.1 | 8.6 |
| **Nottinghamshire** | 1835.8 | 386.7 | 152.2 | 29.3 | 7.6 |
| **Shropshire** | 3339.2 | 656.8 | 260.8 | 26.3 | 4.0 |
| **Oxfordshire** | 2454.0 | 523.5 | 172.2 | 23.8 | 4.6 |
| **Devon** | 6371.7 | 465.8 | 599.3 | 20.3 | 4.4 |
| **Worcestershire** | 1618.4 | 337.2 | 123.7 | 19.0 | 5.6 |
| **Wiltshire** | 2982.7 | 571.1 | 157.0 | 18.1 | 3.2 |
| **Hertfordshire** | 1326.5 | 313.3 | 83.6 | 17.8 | 5.7 |
| **Merseyside** | 262.5 | 133.5 | 45.1 | 17.7 | 13.2 |
| **West Sussex** | 1644.1 | 202.1 | 161.3 | 16.7 | 8.3 |
| **South Yorkshire** | 1194.6 | 198.0 | 147.3 | 16.2 | 8.2 |
| **Cheshire** | 2099.3 | 293.9 | 184.2 | 14.8 | 5.0 |
| **Gloucestershire** | 2822.3 | 205.8 | 208.0 | 12.1 | 5.9 |

| County | Total area of agricultural land in county (km$^2$) | Total area of ALC 1 & 2 in county (km$^2$) | Amount of agricultural land within 20 m of watercourse (all grades) (km$^2$) | Amount of ALC grade 1 and 2 within 20 m of watercourse in county (km$^2$) | Percentage of ALC grade 1 and 2 within 20 m of watercourse compared to total grade 1 and 2 in county |
|---|---|---|---|---|---|
| **Staffordshire** | 2420.7 | 268.9 | 207.9 | 11.8 | 4.4 |
| **Warwickshire** | 1870.0 | 236.9 | 129.4 | 11.0 | 4.7 |
| **Cornwall** | 3372.4 | 288.7 | 249.2 | 10.5 | 3.6 |
| **Hampshire** | 3043.8 | 194.1 | 209.9 | 10.1 | 5.2 |
| **Leicestershire** | 2008.2 | 232.2 | 138.1 | 9.4 | 4.1 |
| **East Sussex** | 1507.2 | 45.9 | 174.9 | 9.3 | 20.2 |
| **Berkshire** | 980.1 | 227.4 | 85.5 | 8.8 | 3.9 |
| **Northumberland** | 4414.0 | 135.9 | 473.4 | 8.3 | 6.1 |
| **Northamptonshire** | 2206.4 | 199.9 | 147.9 | 7.8 | 3.9 |
| **Greater Manchester** | 692.4 | 49.5 | 119.4 | 7.8 | 15.7 |
| **Cumbria** | 6323.0 | 105.8 | 797.7 | 7.6 | 7.2 |
| **Derbyshire** | 2426.1 | 170.7 | 204.6 | 7.0 | 4.1 |
| **Buckinghamshire** | 1672.9 | 148.2 | 96.1 | 6.4 | 4.3 |
| **Durham** | 2400.5 | 76.4 | 263.7 | 5.1 | 6.6 |
| **West Yorkshire** | 1526.7 | 138.7 | 180.9 | 4.7 | 3.4 |
| **Dorset** | 2372.9 | 113.6 | 168.4 | 4.6 | 4.0 |
| **Greater London** | 227.4 | 38.3 | 72.0 | 2.3 | 6.1 |
| **Surrey** | 968.9 | 24.7 | 124.2 | 2.3 | 9.4 |
| **Rutland** | 370.4 | 36.0 | 21.5 | 1.3 | 3.5 |
| **Isle of Wight** | 335.5 | 11.8 | 28.7 | 0.7 | 6.2 |
| **West Midlands** | 241.5 | 10.7 | 47.9 | 0.4 | 3.5 |
| **Bristol** | 5.3 | 0.3 | 8.2 | 0.1 | 17.4 |
| **Tyne & Wear** | 245.6 | 0.1 | 25.4 | 0.0 | 6.0 |
| **City and County of the City of London** | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |

## 5.7 What are the potential impacts of beavers on infrastructure and general land use?

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### 5.7.1 Summary of main findings and recommendations

There is strong evidence to suggest that beavers can affect human infrastructure within riparian zones (Campbell-Palmer *et al.* 2016; Gaywood 2015) although the scale and significance of impacts will vary on a case by case basis. There is limited evidence from Scotland that beavers negatively affect certain types of infrastructure such as tracks (Gaywood 2015) and there is no evidence to suggest that the situation would be different in England.

Various infrastructure types and networks have a high likelihood of being affected by beaver activity where they lie on floodplains. Whether this is positive or negative and the scale and significance of these resulting effects will vary according to local circumstances and over space and time. The presence of beavers may benefit some infrastructure network and assets, such as wetland designations, drinking water storage assets and flood mitigation.

Monitoring beaver populations and their activities is essential to predict and manage impacts on infrastructure and land. Management options, where required, may be implemented retrospectively or designed into a scheme or activity related to the infrastructure or its function. Any interventions into beaver activity should be carried out in the context of existing legal and policy frameworks. This includes policy and legislation that seeks to enhance natural processes and make space for water. Such policy is likely to reduce the risk of beaver activity having a negative effect on infrastructure networks and assets.

### 5.7.2 Introduction

Infrastructure and land use have the potential to be affected by beaver activity where they are in close proximity, or closely connected, to still or running waters. Beavers readily use natural, semi-natural and artificial water bodies and can tolerate living in close association with humans, including within urban areas and intensively managed landscapes (Campbell-Palmer *et al.* 2016; Swinnen *et al*. 2017). The scale and significance of any risk will vary on a case by case basis.

Potential negative impacts may be both as a direct and indirect result of beaver activity. For example; dam building may result in blockage of culverts and waterlogging of assets, trees may be felled across footpaths and onto infrastructure, burrowing may cause erosion and bank instability which in turn can affect infrastructure.

There are also potential benefits related to the same activities which may result in assets and structures being more resilient to climate change. Maintenance and replacement of flood risk assets may reduce due to increased attenuation further up in the catchment together with reduced bed erosion. Beavers may reduce and slow flood peaks resulting in the need for less infrastructure and potentially decreasing the size of embankment required. There may be less maintenance requirements, increased capacity upstream of sluices, higher bank stability in areas of increased water levels, reducing the need for retaining structures.

Beaver impacts will vary hugely depending on the context. Some effects will be isolated, some may be in areas of low consequence or unlikely to occur regularly and all will vary across space and time. What is important is the significance of beaver induced change to the functioning of infrastructure affected and whether, as a result, action is required.

### 5.7.3 A summary of findings from the Scottish Review

The Scottish Review carried out literature searches and collated information from discussions with North American and western European and Scandinavian counterparts. The report also collected evidence from the Scottish experience, summarised below:

- Flooding of a forestry track due to a dam and flooding of an access track to a small area of residential housing due to beaver dam building.
- Beavers felling trees alongside and onto roads resulting in some gnawed trees being pre-emptively felled, others protected with wire mesh together with increased checking by rangers.
- Dam capacity modelling predicted 78% of culverts, weirs and dams were at sites less likely to be impacted by damming.
- Bank erosion reported at four Tayside sites, with five sites reporting burrows in flood banks.
- Nine records of impacts on ornamental and amenity value trees and a single report of a fishpond being flooded.
- No impacts were recorded on a number of historic sites monitored at Knapdale.
- Based on European experience, cases involving serious infrastructure issues are likely to be rare but they do occasionally happen. Implications were expected to increase as beaver population density increases and range extends, with associated increases in appropriate management and mitigation anticipated.
- There are known methods that can be used to protect infrastructure interests, particularly small scale structures such as culverts and pre-emptive action is recommended.
- For larger scale structures such as flood banks, the costs and scale of mitigation/management could be greater and more challenging in some instances.
- The Scottish report states that the effectiveness of beaver management in Scotland will increase over time as experience is gained and methods are refined.

### 5.7.4 Further research since the Scottish Review

In Flanders, Belgium, Swinnen *et al.* (2017) confirmed that even in a highly human-dominated landscape there is space for beavers to thrive.

A study in Warsaw (Romanowski 2018) recorded 15 beaver families in Warsaw city and other urban aquatic habitats of the Vistula catchment. The animals are thought to have migrated there from reintroduction sites along riparian woodland corridors in the Vistula Valley. The lower density of beavers in the urban section of Vistula (approx. 4.5 families/10 km) in comparison to semi-natural river habitats north of Warsaw was reported to be due to infrastructure development and removal of riparian forest in the city.

In the Czech Republic a study of beaver presence in relation to cycle routes, hiking trails, human settlements and infrastructure showed that beavers preferred undisturbed natural habitats (Mikulka *et al.* 2019).

A study by Puttock *et al*. (2017) on the effects of beavers in an enclosure to an intensively farmed lowland agricultural landscape in south west England, found that the creation of beaver dams can help to attenuate flooding downstream. Puttock *et al*. (2018) studying the same enclosure site, found that beaver ponds stored large amounts of sediment sourced predominantly from intensively managed grassland upstream.

Brazier *et al.* (2020) compiled a database of the dams constructed by beavers during the River Otter Beaver Trial (ROBT), noting location, characteristics, impacts and mitigation methods employed. Circa 80 dams were constructed during the 5-year trial. Fewer than 10% of these dams were reported to have caused any conflict. Different mitigation measures were used on those dams where conflict was observed depending on the impact or risk. These included: removal of beaver sticks, dam lowering, dam removal (where this did not negatively impact maternity sites) and installing flow devices/beaver deceivers to enable water to bypass the dams. There were no negative impacts recorded on Environment Agency infrastructure within the trial period.

Brazier *et al.* (2020) also describe a case study where clearance work by volunteers was carried out to keep spillways/outfall structures clear. The ROBT proposed a Beaver Management Strategy (BMS, Appendix 5a Risk Assessment, Devon Wildlife Trust 2016) which suggests a permanent trash screen can be installed upstream of a culvert and checked regularly, particularly in high risk urban areas. This is already a common standard practice on many culverts in urban and semi-urban areas for health and safety reasons and should not be an additional burden. One small country lane experienced water encroachment which was successfully resolved by occasional reduction of the height of the dam by the landowner. One farm access track (and permissive path) flooded periodically and regular management of the dam was carried out to address this. There were no observed impacts on water treatment plants or telegraph poles.

One beaver burrow was reported as collapsed in an agricultural field during the ROBT but no harm came to farm machinery or livestock. Three burrows collapsed adjacent to public footpaths but overall the risk from burrows was small as they were near to the riverbank which could be avoided and most were within dense vegetation (Brazier *et al*. 2020).

Trees at risk of beaver felling during the ROBT were protected, including two adjacent to power lines. Occasional damage to fencing from tree felling did occur; some fences were repaired and nearby vulnerable trees protected, but in one location the management decision was to not protect trees and allow felling. The BMS recommends that tree safety surveys are carried out by landowners, together with the use of wire netting and deterrent sand paint to proactively protect trees of importance. Tree felling across footpaths did occur, causing minor obstructions, and was resolved by regular inspection and proactive felling or protection of trees where considered necessary (Brazier *et al*. 2020).

### 5.7.5 English context

The scenario in England, in terms of infrastructure types and potential impacts, is similar to Scotland although the density of infrastructure networks and assets is likely to be greater at some locations across England, and the number of properties at risk of flooding will be significantly larger. In landscapes that have been modified and are occupied by people, beaver activity will have to function within limits acceptable to human interests (Campbell-Palmer *et al*. 2016). The majority of the English countryside falls into this category, with some rewilding and wider projects that aim to enhance and recover natural processes. Opportunities, policies and funding sources also exist for making space for water.

In England, flood management is fulfilled by a range of flood risk management authorities such as Environment Agency, Lead Local Flood Authorities and Internal Drainage Boards, who have powers to act where appropriate. Legislation around flood risk is different to Scotland and the legislative framework needs to be fully considered in developing management processes and understanding liabilities in England. Permissions for some mitigating actions, which assess flood and environmental risk, in response to beaver presence may be required. The term infrastructure in the context of this section will include the potential impact on properties.

Infrastructure 'owners' will be different to those in Scotland. Consideration of the full suite of competent authorities and interested parties is needed to inform any guidance or frameworks. In addition, England has a large number of other associations, affiliations and individuals that the activity of beavers may interact with.

Beaver activity in a catchment has the potential to create positive benefits to infrastructure and general land use such as:

- Improvements to wetland designations or features;
- Improvements in water quality to a drinking water storage asset;
- Contribution to a reduction in peak flow and increased lag time for a flood community at risk;
- Reduced maintenance requirements;
- Restored natural processes leading to assets and structures more resilient to climate change;
- Potential need for less infrastructure and potentially decreasing the size of embankment required.

### 5.7.6 Identification of areas of potential conflict in England

The scale and significance of the impacts of beaver activity will vary according to local circumstances. If beaver activity does cause conflict, or require management or mitigating action, then the majority of cases are expected to be minor and quickly resolved. Some however, will be potentially more major and these will vary across space and time and depend on the activity type.

The main mechanisms from beaver activity that may negatively affect infrastructure include:

- Undermining structures causing collapse;
- Blockage of structures causing flooding or blocking passage;
- Increased erosion;
- Direct impacts such as tree felling across roads and footpaths;
- Structure instability as a result of waterlogging;
- Direct physical damage e.g. burrowing.

The main infrastructure assets and the associated potential conflict that could result from these activities include:

- Highways/Rail and their associated infrastructure such as bridges and culverts;
- Utility (gas, water, electricity) structures, intakes and outlets.
- Instream structures;
- Flood risk management riverine and coastal structures, e.g. earth embankments, walls, flap-valves, sluices;
- Reservoirs;
- Abstraction sources for irrigation, drinking water supply, hydro-power etc.;
- Navigation and other canals;
- Recreational assets e.g. kayak passage;
- Ornamental gardens;
- Forestry;
- Sites of historic or environmental value.

Still water fishery assets and running water angling 'assets' are discussed in section 5.4.

Beavers could potentially have an impact on the historic environment, on both designated and non-designated sites should they be close to water. Changing water levels, sediment build up or changes in water chemistry may affect the preservation conditions which can affect the survival of artefacts. Beavers may also affect designed landscapes such as parks and gardens through tree felling. The Strategic Environmental Assessment for the Knapdale and Tayside reintroductions identified a crannog and canal as 'at risk', but further study found this to be low. It will be important to establish what sites could be at risk from beaver activity prior to release in an area and an appropriate management and monitoring strategy undertaken.

The most recent compilation of management techniques is described by Campbell-Palmer *et al.* (2016) and some of these were trialled in England during the ROBT. The management techniques to protect assets from beaver activities employed in Europe and North America were collated and summarised in the Scottish Beaver Trial and it is considered that the majority of these techniques would also work in the English situation.

### 5.7.7 Potential future implications of wider reintroductions in England

Expansion of the beaver population will inevitably increase the potential for impacts, both positive and negative, on infrastructure and land use. Criteria for assessing risk and likelihood of impacts should be fully developed in association with mapping to inform the likelihood of need for the range and scale of available intervention criteria.

Large, operational organisations should be encouraged to work together in order to be effective, efficient and consistent in the design and implementation of common methodologies. These ways of working should be based on existing management practices and developed for the English landscape and objectives, e.g. the Environment Agency has a presumption against the use of culverts.

Should beaver populations expand, the potential benefits related to natural flood management are likely to increase and be more readily assessed. Care will need to be taken to note the differences in structure of beaver induced features and manmade structures in any modelling or assessment work.

Infrastructure assets and networks may create a barrier to beaver dispersal so creating vulnerabilities for the species. Measures would need to be assessed and action taken for new or existing structures or networks that could create a negative impact for the species. For example, beaver ladders have been constructed at hydro-electric dams (Office Nationale de la Chasse 1997; Benn *et al*. 2019).

# 5.8 What are the potential impacts of beavers on public and animal health?

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## 5.8.1 Summary of main findings and recommendations

Beavers, like all wild mammals, are naturally associated with a range of parasites. Some of these parasites are specific to beavers while others can potentially infect other species and humans. Strong evidence from Europe and Great Britain is available to understand the risks posed to public and animal health from beaver translocations and reintroductions (Girling *et al*. 2019; Donald *et al*. In press). These disease risk analyses have identified potential hazards that need to be taken into account for any reintroduction program. The most important for humans is the tapeworm *Echinococcus multilocularis.* At present, there is limited capture and relocation of beavers in Great Britain. Despite this, a great deal of work has already been undertaken to address the risks associated with translocations and the procedures followed in Scotland achieve high health and welfare standards. Overall it is considered that the potential disease risks can be effectively managed, so overall, if beaver reintroductions take appropriate measures, beavers are not considered to pose any increased risk to public health beyond that posed by existing native wildlife populations.

The risk of introducing significant parasites or infectious agents of humans, domestic animals or other wildlife is low if beavers used in reintroduction projects are taken from wild-living populations in Great Britain. These beavers are not considered to pose any increased risk to public health beyond that posed by existing native wildlife populations. However, if reintroduction projects plan to (i) source beavers from zoological or private collections, (ii) house them temporarily in zoological-type or private collections (unless housed in bio-secure facilities designed for beaver translocations), (iii) if it is proposed to release beavers held in enclosures into the wild, or (iv) release beavers from wild populations sourced outside of Great Britain, then further disease risk analysis is required. Pending this additional analysis, it is recommended that beavers sourced from enclosures are only moved to other enclosures within Great Britain.

Any beavers of unknown origin in Great Britain could carry non-native diseases and parasites, subsequently detailed post-mortem examinations should be undertaken of any beavers found dead in England from enclosures or free-living in the wild. Efforts should also be made to use retrospective sample archives to build our understanding of potential hazards.

## 5.8.2 Introduction

Wildlife translocations for conservation purposes (reintroduction, reinforcement, ecological replacement and assisted colonisation) have become a key conservation tool to help restore species and/or ecosystem functions (IUCN/SSC 2013). However, species translocations can facilitate the movement of parasites and risk animals encountering parasites that they normally would not be exposed to. Risks from disease associated with wildlife translocations arise because individual animals moved are a biological package, consisting of the host and all the associated viruses, bacteria, fungi and other parasites that an animal or plant may naturally harbour (Davidson and Nettles 1992). Subsequently, reintroduced beavers may act as a mechanism for the introduction of new or previously eradicated parasites or may establish new transmission routes for the infection of humans, domesticated livestock and existing wildlife. Subsequently, disease risk analysis and the evaluation of mitigation measures is a key requirement if the risks from disease to humans, livestock and wildlife from the translocation are to be understood and controlled.

Although the primary focus of this section is in relation to disease, other potential considerations relating to the influence on beavers on public health, such as through flooding, dam failure and beaver attacks, have also been considered in this section.

### 5.8.3 A summary of the findings from the Scottish Review

A health surveillance programme established for the Scottish Beaver Trial (SBT), in which wild beavers were imported from Norway, addressed IUCN and governmental guidelines as well as public health concerns (Goodman *et al*. 2012). This surveillance programme included pre-release health and parasite screening in quarantine and regular post-release monitoring, including the *post mortem* examination of any beavers found dead. There was also public health monitoring by independent local authority specialists during the trial. Beavers were held for six months on arrival in order to satisfy UK statutory rabies quarantine regulations (the Rabies (Importation of Dogs, Cats and Other Mammals) (England) (Amendment) Order 2004), however the death of six individuals (37.5%) without a consistent cause and the failure of the remaining beavers to thrive under quarantine conditions resulted in the quarantine period being reduced, with agreement from Scottish Government veterinary advisers, for animal welfare purposes. Two host-specific parasites, the beaver fluke *Stichorchis subtriquetrus* and the beaver beetle *Platypsyllus castoris* were reintroduced with the beavers. These are specific to beavers and do not provide a threat to people or other species.

Health screening was also undertaken of the beavers living within the River Tayside catchment from October 2012 to April 2014, given their unknown origin and health status (Campbell Palmer *et al.* 2015). No evidence was found of pathogens that may cause an increased health risk to humans, livestock and other wildlife and individuals displayed good body condition.

### 5.8.4 Further research since the Scottish Review

In compliance with the licence conditions for the River Otter Beaver Trial (ROBT), in February-March 2015, all four known adults present in the River Otter, plus one kit, were trapped and screened prior to their re-release into the river. Five additional animals released during the 5-year trial were also subject to disease screening prior to release. An external visual examination for general health and body condition was also made of all individuals trapped during the trial. As for beavers examined on the River Tay, no evidence was found of pathogens that may cause an increased health risk to humans, livestock and other wildlife and individuals displayed good body condition.

Girling *et al*. (2019) conducted a disease risk analysis based on peer-reviewed publications and results from disease screening during the SBT and surveillance of beaver populations elsewhere in Great Britain to inform health screening and selection of Eurasian beavers prior to release into the wild in Great Britain. The authors used a four step process adapted from the IUCN's 'Guidelines for Disease Risk Analysis' (OIE/IUCN 2014) formulating i) problem description, ii) hazard identification based on literature review, iii) risk assessment, which resulted in categorisation of pathogens into low, medium, and high risk, and iv) risk management: identification of mitigating measures, followed by risk evaluation in light of the reported effectiveness of the mitigation measures. The highest risk pathogens identified in the literature review process included parasites, specifically *Cryptosporidium parvum Emmonsia parva, Echinococcus multilocularis, Eimeria* spp.*, Escherichia coli, Fasciola hepatica, Franciscella tularensis, Giardia* spp.*, Trichinella britovi, Mycobacterium avium, Salmonella* spp.*, Yersinia* spp., and terrestrial rabies virus. The analysis concluded that the risk of introducing significant parasites or infectious agents to humans, domestic animals, or wildlife from releasing into the wild in Great Britain a beaver that was captive bred in Great Britain or taken from the wild-living population in Scotland is low.

The disease risk analysis method used by Girling *et al.* (2019) has been supplemented by a further analysis by the Zoological Society of London (ZSL) (Donald *et al.* In press). This analysis updates results and investigates the translocation pathways specifically relevant to reintroductions in England to inform this review. A step by step evaluation of the likelihood of release, exposure, biological and economic consequences to beavers, wildlife species, domestic animals and humans was undertaken using a qualitative method adapted from the World Organisation for Animal Health (OIE) (Murray *et al.* 2004) and conforming to IUCN guidelines (IUCN/SSC 2013). The method used is transparent and translatable to other situations and therefore allows for ease of future-analysis and risk estimation as new information comes to light.

Given the risk of inadvertently introducing *E. multilocularis*, European countries where *E. multilocularis* is present were not included in the scope of the analysis. Finland is considered to be free of *E. multilocularis*, but as it has widespread populations of *Castor canadensis* and given the difficulty of distinguishing *C. canadensis* from *C. fiber* without genetic testing it was not considered practical at this stage to include Finland as a source of animals.

As the precise origin of some free-living beavers in Great Britain is unknown, and the release of some of them was not subject to disease risk analysis, these animals may harbour parasites novel to Great Britain. As such the risk of disease from these animals was included in the analysis. Since non-native beavers have only recently (within decades) been translocated to Scotland, and other parts of Great Britain, it was assumed that there has been insufficient time for parasites to be transferred to all parts of England, and these free-living, recently reintroduced, beavers in Scotland, and other parts of Great Britain, are assumed to cross ecological and geographical barriers if translocated to England.

Beavers held in zoological-type conditions were not included in the analysis as, in some circumstances, they may have had exposure to exotic rodents and therefore to non-native parasites. Normal ecological barriers can be broken down in zoo-type conditions, unless stringent mitigation methods are adopted. Investigating the potential risks of contact between beavers and exotic rodents in captivity requires a bespoke disease risk assessment that considers the specific risks associated with that site. This was outside the scope of this assessment. It was discovered that some beavers present in enclosures had passed through zoological-type collections previously and, as details were not known, they were also excluded from this assessment.

Hazards were identified through searches of scientific literature, unpublished data and expert opinion. The pathogenesis, geographic distribution, and diseases associated with each were then considered and ascribed each to an appropriate hazard category (see Table 13). Known pathogens were considered alongside apparent commensal parasites since the pathogenicity of many parasites of free-living wild animals is unknown, and parasites can precipitate disease in novel hosts in new environments. Translocation and adaptation to new environments can affect normal host-parasite dynamics through stressors (resulting in disease). Non-infectious agents or events and their association with disease were also considered. Using the method described in Murray *et al.* (2004), the results of the release, exposure, and consequence assessments were combined to qualitatively assess the risk of disease associated with the hazard (negligible, very low, low, medium or high).

Seventy-eight hazards (73 infectious and five non-infectious) were evaluated, with hazard identification highlighting 20 requiring more detailed analysis. Of the latter twenty, 13 were identified as being of high or medium risk of precipitating disease in beavers or sympatric mammals, including people, prior to any form of disease risk management (see Table 13).

**Table 13** Summary of hazards undergone detailed analysis (Donald *et al*. In press)

| Potential Hazard | Hazard category[a] | Risk type | Unmitigated risk level[b] | Stressor related? |
|---|---|---|---|---|
| *Leptospira* spp. | Carrier | Risk to beavers | High | Y |
| *Yersinia enterocolitica* and *Y. pseudotuberculosis* | Carrier | Risk to beavers | High | Y |
| SARS-CoV-2 | Population | Risk to beavers | Medium | |
| Gram-negative enterobacteria | Carrier | Risk to beavers | Medium | Y |
| *Streptococcus castoreus* | Carrier | Risk to beavers | Medium | Y |
| *Stichorchis subtriquetrus* | Carrier | Risk to beavers | Medium | Y |
| *Toxoplasma gondii* | Carrier | Risk to beavers | Medium | Y |
| *Emmonsia crescens* | Carrier | Risk to beavers | Medium | Y |
| Road traffic collisions | Population | Risk to beavers | Medium | |
| Illegal persecution | Population | Risk to beavers | Medium | |
| Captivity during translocation | Population | Risk to beavers | Medium | |
| *Mycobacteria* spp. | Carrier | Risk to beavers | Low | Y |
| | Carrier | Risk to domestic and free-living wild animals | Negligible | |
| *Eimeria* spp. | Carrier | Risk to beavers | Low | Y |

| Potential Hazard | Hazard category[a] | Risk type | Unmitigated risk level[b] | Stressor related? |
|---|---|---|---|---|
| Tatenale-virus (TATV)/Seoul-virus (SEOV) (hantaviruses) | Destination | Risk to beavers | Very Low | |
| *Echinococcus multilocularis* | Source | Zoonotic risk | High | |
| *Trichinella* spp. | Source | Zoonotic risk | Medium | |
| Puumula-virus (PUUV) (hantavirus) | Source | Zoonotic risk | Medium | |
| *Francisella tularensis* (Tularaemia) | Source | Zoonotic risk/ risk to domestic and free-living wild animals | Low | |
| *Giardia duodenalis* | Unclassified | Zoonotic risk/ risk to domestic and free-living wild animals | Very low | |
| *Cryptosporidium parvum* | Unclassified | Zoonotic risk/ risk to domestic and free-living wild animals | Very low | |

[a] **Carrier hazards** are commensal parasites which, when the host is under stress associated with translocation or is subjected to factors that affect parasite dynamics, such as alterations in host density, may cause disease in transit or at the release site; **Population hazards** are non-infectious and infectious agents present at both the source and destination sites which potentially could have a negative impact on population numbers at the destination; **Source hazards** are a hazard present at the source site which would be novel at the destination site; **Destination hazards** are infectious agents present at the destination but not the source; **Unclassified hazards** are those that do not fall into any of the defined categories according to Sainsbury and Vaughan-Higgins (2012).
[b] This equates to the potential risk that exists without taking any steps to mitigate that risk.

### 5.8.5 English Context

Further details of each hazard in Table 13 are provided in Donald *et al*. (In press). The summaries provide a ‘risk estimation’ and a series of ‘risk management options’. The initial risk estimation is the potential risk that exists (i.e. without taking steps to mitigate that risk), while the risk management options give advice on the steps that can be taken to effectively manage the risk.

The disease risk analysis identified, reviewed and evaluated 78 potential hazards and carried out a full disease risk analysis on 21 selected hazards. Translocation pathways from Norway or Great Britain were both identified as to be crossing geographic barriers, consequently a detailed disease risk analysis was undertaken which included source and destination hazards in addition to carrier and population hazards.

*E. multilocularis* is of particular concern as it is one of the most pathogenic parasitic zoonoses in the northern hemisphere. It is a cestode parasite and the causative agent of alveolar echinococcosis disease in humans. The UK is currently considered free of the parasite, and the only known occurrences in beavers have been from animals known to have been imported. Beavers cannot pass the parasite directly to another beaver as transmission is via a secondary canid host such as the fox or dog; consequently, while the UK remains free of *E. multilocularis*, any beavers born in Great Britain will not carry the parasite. A wild-caught (previously captive) beaver imported directly from Bavaria tested positive for *E. multilocularis* in 2011 (Barlow *et al.* 2011), highlighting the risk of inadvertently introducing this non-native parasite. Subsequently a disease risk analysis on *E. multilocularis* in relation to the import of beavers to the UK was carried out (Roberts *et al.* 2012) and Defra published a voluntary code of practice advising that beavers are sourced only from countries free of *E. multilocularis* (Defra 2014). However, imports continued from countries with endemic *E. multilocularis* and in 2017 a single animal in a group of 12 wild-caught beavers imported from Bavaria for use in release projects tested positive for antibodies to *E. multilocularis*. As a result of this incident and following new veterinary advice that testing could not definitely determine absence of *E. multilocularis,* Natural England decided to no longer allow use of wild-sourced beavers from countries with endemic *E. multilocularis* in release projects. It also revised other disease screening requirements. Wild-caught beavers from European countries where *E. multilocularis* is endemic have not been permitted to be used in release projects in England since 2018. The risk of an outbreak of *E. multilocularis* in England from beavers is therefore very low, when compared against the risk of e.g. domestic dogs entering England from abroad which may only have undergone limited or no health screening.

While the parasites and diseases of the Eurasian beaver have been studied to a degree, it remains a realistic possibility that beaver populations in either Great Britain or Norway harbour an unidentified, novel parasite capable of inducing an epidemic in naïve rodent populations in Great Britain. In undertaking the disease risk analysis, Donald *et al.* (In press) have been alert to the need to detect source hazards of greatest risk to translocation and have used the criteria set out by Rideout *et al*. (2017) to scrutinize the potential hazards to assess the likelihood that these parasites would give rise to an epidemic. Recently identified parasites or new virulent strains of known pathogens were searched for, and effort should continue to be made to scrutinise the published literature, grey literature and reports prior to any translocation.

To further build knowledge of unknown parasites which may present a source hazard for translocation of beavers, it is recommended by Donald *et al.* (In press) that retrospective screening of stored beaver sample archives, both from healthy and diseased animals, should be carried out. It would be advantageous to carry out screening programs prior to any future translocation so that disease risk analyses can be reassessed. Donald *et al*. (In press) state that in addition, given the uncertainty relating to the origin of many beavers already present in Great Britain and the risk of parasites yet to be identified and described in beavers, sustained post-release health surveillance of beaver populations and sympatric rodent populations near past and future release sites in England is recommended.

Of the 21 hazards identified for a full disease risk analysis, *E. multilocularis*, *Y. enterocolitica* and *Y. pseudotuberculosis* and *Leptospira* spp. were identified as high-risk for disease as a consequence of translocation and a further eleven hazards were identified as of medium risk (Table 13). The analysis showed that the risk from disease from seven of the 14 high and medium risk hazards was stress associated. Stress may reduce immunocompetence and consequently immunocompromised individuals will be more susceptible to disease if infected, or from commensal organisms that do not ordinarily cause disease in healthy individuals. Stress has been suggested to be an inevitable component of animal translocations, which can occur at multiple stages including capture, transport and captivity (Teixeira *et al.* 2006; Dickens *et al*. 2009; Dickens *et al*. 2010). There is evidence that beavers are prone to disease and even fatalities following minor injuries and, in addition, susceptible to stressors (Campbell-Palmer and Rosell 2015) and therefore there is a high probability of stressor associated diseases in general. It is therefore essential that measures are taken to minimise stress to beavers at all stages of the translocation process. Lessons learned in animal management techniques in Scotland have improved the success of translocating animals throughout Great Britain (Campbell-Palmer and Rosell 2013).

The disease risk analysis identified three zoonotic hazards of high or medium risk of disease in the human population:

- *E. multilocularis* was analysed as of high risk of disease to people. The maintenance of the UK's infection-free status from this cestode hazard is very important due to the severe biological and economic consequences which would result from its incursion. There remains a small possibility (although no evidence exists) that past imports of un-tested beavers from areas with endemic *E. multilocularis* have already introduced this parasite to Great Britain and for this reason we recommend that, should this population be used for translocations to England, robust and comprehensive disease surveillance is used to monitor the population post-release. Given (i) the further spread of *E. multilocularis* through Scandinavia since Roberts *et al.* (2012) carried out their disease risk analysis for the importation of this parasite to the UK with beavers, and (ii) the understanding that *E. multilocularis* could have evaded detection in foxes in Norway due to sampling statistics (Donald *et al*. In press), the estimated risk of *E. multilocularis* incursion is greater from the translocation of free-living Norwegian beavers than those from Great Britain. Further reduction in risk can be achieved by prioritising free-living beavers proven to have been born in Great Britain for translocations to England.
- *Trichinella* spp. were analysed as of medium risk for disease in the human population. Maintaining the UK's infection free status for this nematode parasite is, like for *E. multilocularis,* important given the severity of the disease in people and the high economic costs of disease prevention should *Trichinella* spp. become endemic in the UK. As for *E. multilocularis,* the risk from disease is reduced if beavers used for reintroduction are translocated from Great Britain rather than Norway.
- Puumala-virus (PUUV), a hantavirus, represents a medium risk source hazard if Norway is chosen as the source for beavers, given the associated disease syndromes in people. There is uncertainty in the likelihood that beavers can be infected on release, and pre-translocation screening using stored archive samples would be of value to improve risk estimation.

The risk from these three zoonotic infectious agents is elevated if beavers from Norway are chosen as the source population, even though Norway was chosen initially as a potential source due to its *E. multilocularis* free status. In light of this and given that the stress of translocation from Norway might be higher than from within Great Britain, due to the time and extra handling measures involved, it is recommended that free-living beavers from Great Britain are the best source for translocations in order to minimise risk from disease.

No transport hazards have been identified to date. These are hazards that may be encountered during the transport (between the source and destination sites) which may be novel to the translocated animals and/or the release environment. Translocated animals can be a potential vehicle for introduction of these hazards to the destination site. Transport hazards are also those infectious agents moved with materials such as transport boxes, equipment, food and water. This may need to be reviewed when translocation routes are identified.

The risk from all hazards is reduced if principles of good disease risk management in translocations are followed. These include measures such as maintaining good hygiene practices and high standards of biosecurity. A great deal of work has already been undertaken to build good practice in beaver translocations, building on lessons learnt from previous translocations (Campbell-Palmer and Rosell 2010; Campbell-Palmer and Rosell 2013; Campbell-Palmer and Rosell 2015). Until now, most beavers taken from the wild and relocated in Great Britain have come from the River Tay in Scotland, and there are well-established procedures in place to manage risks to the health and welfare of beavers. Such standards need to be maintained for all future relocations, including relocations within England.

**Other Potential public health risks**

*Dam failures and flooding*

Beaver dam collapses typically follow significant discharge events (Butler 1989) and are most common in alpine environments where seasonal meltwater can dramatically increase river flows (Butler 1991), which is not relevant to England. Butler and Malanson (2005) reviewed dam failures and associated effects in North America and found that dam failures typically occurred after periods of intense and/or extended rainfall, or in association with high spring runoff from a melting snowpack. The significant pulses of water and sediment posed the greatest hazard to transportation corridors, particularly railways. However, Westbrook *et al.* (2020) recorded hydrometric data during an extreme rainfall event at a beaver occupied peatland in the Canadian Rocky Mountains west of Calgary. They found 68% of the beaver dam cascade systems across the region were intact or partially intact after the event. Water storage offered by the beaver ponds, even ones that failed, delayed downstream floodwater transmission. Therefore, beaver dams do not necessarily commonly fail during large flood events.

Without regular maintenance beaver dams will naturally erode and degrade over time (Gurnell 1998). As they decay their capability to hold back water is reduced (Woo and Waddington 1990). Beaver dams are reported to continue to enhance water retention in riparian areas for 5 years after they are abandoned (Grygoruk and Nowak 2014), although, empirical evidence is sparse (Westbrook *et al*. 2020). Therefore, although there is a risk that, in high energy environments, dam failures may cause infrequent but significant pulses of water and sediment which may pose a risk to public health and safety, given the topography in England, such incidences are likely to be very rare.

*Hazards to recreational river users*

The addition of large woody debris and beaver dams in some rivers could pose a risk to recreational river users such as anglers, kayakers, canoeists and wild swimmers (Wohl *et al.* 2019). However rivers, as natural environments, will contain such hazards currently and river users should already be aware of the risks such hazards could pose. Should beavers settle in rivers that are subject to high levels of recreational use, then it would be advisable to place notices at points of river ingress advising caution.

*Beaver attacks on people and animals*

Reports of beaver attacks on humans are rare and largely unsubstantiated. Where they do exist, it appears there are extenuating circumstances such as the beaver being prone to rabies or being provoked. As with all wild animals, the risk of attack significantly decreases if the animals are not approached when encountered and they are given space to withdraw. This may be particularly relevant to people entering the water close to beaver lodges, although the mostly nocturnal activity of beavers may mitigate any potential conflict.

Brazier *et al*. (2020) report an incidence of a dog and badger being attacked by a beaver in separate incidents. On both of these occasions it appears the dog and badger entered the water close to the beaver's lodge at a time when young kits would have been present. It is likely therefore that the beaver behaved defensively towards the perceived threats, as any wild animal would be likely to do so. An awareness-raising campaign on the River Otter resulted from the incident of a dog being bitten by a beaver, simply stressing that dog-walkers follow the country code and keep dogs on leads, especially when livestock or wild animals may have young at large, i.e. in spring/early summer. Dog owners, including the owner of the dog that was bitten, responded positively (R Brazier pers. comm).

### 5.8.6 Potential future implications of wider reintroductions in England

It is important to note that if, in the future, the translocation pathway is altered and, for example, includes (i) beavers from zoological or private collections, (ii) beavers that have been temporarily housed in zoological or private collections (unless housed in bio-secure facilities designed for beaver translocations), (iii) beavers in enclosures, or (iv) beavers from wild populations sourced outside of Great Britain; a revised disease risk analysis would be required. This is not to preclude use of beavers from these sources, but to allow proper consideration of risks outside the scope of the most recent analysis.

Previous work has shown that the risk from disease to a conservation translocation programme is comparatively high if animals are housed in zoological collections (Bobadilla Suarez *et al.* 2017) primarily due to breach of ecological barriers and the potential for contraction of alien parasites from different ecological and geographical zones. Specifically, beavers that have been held captive in collections that have held, or are holding, exotic rodents may be directly or indirectly infected with novel parasites that present a hazard to the beavers themselves or other animals at the destination site(s). Given the high likelihood that beavers from enclosures will soon need to be moved for welfare reasons, as offspring reach dispersal age, these will form a likely choice for reintroduction projects. Therefore, the need to undertake further work to analyse the risks from beavers from enclosures that may have come into contact with exotic rodents through passing through zoological collections, is required with some urgency. Until this work is undertaken, it is recommended that beavers sourced from enclosures are only moved to other enclosures within Great Britain.

# 6 Summary and Conclusions

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## 6.1 Summary

The reintroduction of beavers into England is ecologically feasible. There is enough suitable habitat in England to support the reintroduction of this species at various locations within England, the climate is appropriate and there is an appropriate source of beavers to use initially as founding individuals.

The reintroduction of the beaver, as a formerly native species, promotes opportunities to renaturalise both habitat provision and species assemblages thus providing a nature-based solution to tackle the decline of the natural environment in England. This is in line with building more ecological resilience into the way nature is conserved, restoring the multiple natural capital benefits that flow from naturally functioning ecosystems, and adapting to climate change.

Ensuring river and lake systems have space to react to the habitat modifications brought about by beaver will be crucial in maximising ecological benefits, and will reduce risks to existing biodiversity and socioeconomic objectives. Beaver activity is not a substitute for tackling impacts on catchments (pollution from nutrients and fine sediment, loss of coarse sediment supply, hydrological monifications, artificially enhanced peak rivers flows, hard river engineering etc) at source, but can enhance water-related ecosystem services where suitable measures have already been taken to restore natural ecosystem function to freshwater and wetland ecosystems.

Reintroducing beavers to England can generate a range of costs and benefits for people and the economy which will vary between locations. If managed appropriately the quantifiable benefits of beaver reintroduction in relation to natural capital and societal benefits can be much greater than the financial costs incurred. Societal challenges stem from conflicts over land use and the unpredictable risks to salmonid populations (particularly at the site rather than catchment scale). Adverse effects of beavers on contemporary land use need to be recognised and practical solutions to their management identified and implemented to mitigate, as far as possible, any negative effects. It is important to note that those who benefit from beaver reintroduction may not always be the same people as those who bear the costs and this imbalance does have the potential to cause problems in the future.

## 6.2 Additional information since the Scottish review

A literature search relating to each section subject identified 989 papers. Analysis of these papers and those submitted by stakeholders identified 139 papers of relevance. Although few papers were in relation to England specifically, extrapolation of information from other studies has yielded useful information. Appendix III contains a summary of findings from each section taking account of new evidence since the publication of the Scottish review. This follows the summary table format outlined in Gaywood (2015) for each section and does not repeat information already provided in that report, but does highlight any points of difference or relevance to England.

There are still areas of uncertainty as many studies on beavers are not directly relevant to beavers in English landscapes. Until further reintroductions and research takes place, the precise effects of beavers on other species and habitats in England will include a degree of uncertainty and decisions will be a matter of judgement. Consideration should be given to prioritising further beaver reintroductions in places where study would contribute the most to understanding beaver behaviour and influences on the environment. Chapter 7 outlines priorities for future research relevant to future reintroduction projects that could help address these areas of uncertainty.

## 6.3 Key elements in relation to an assessment against the IUCN reintroduction guidelines

The reintroduction of formerly native species involves many considerations which are outlined in the IUCN guidelines for reintroduction and other conservation translocations (IUCN/SSC 2013). Individual reintroduction projects would be expected to follow these guidelines at an appropriate scale. The purpose of this section, however, is to assess the general feasibility of reintroducing beavers across England using the evidence presented in the previous sections, and to highlight the considerations relevant in any individual reintroduction project.

### 6.3.1 Founders, animal welfare and disease

As outlined in section 3.4 replacing what used to be present from a purely genetic point of view is not possible. Therefore, in line with IUCN guidelines, the focus needs to be on ensuring an English beaver population is healthy, not a disease risk and genetically diverse enough to sustain a robust, long-term future population. The best strategy is to use animals that are adapted to the British habitat and climate, whilst ensuring there is sufficient genetic diversity within the population to allow for future adaptation to events such as climate change and disease. Care needs to be taken that animals are not so widely sourced as to result in outbreeding depression, although the limited genetic diversity in Europe mitigates against this being a significant risk for beavers.

Most beavers already present in Great Britain are of Bavarian origin. There is no evidence that these animals have failed to adapt to the environment present in Great Britain. However, genetic diversity within British populations is lower than source populations. Eighty-two per cent of beavers from Tayside were as closely related as first cousins and beavers on the River Otter in Devon were even more closely related (Brazier *et al*. 2020; Campbell-Palmer *et al*. 2020), demonstrating populations are highly inbred. Genetic augmentation to populations should therefore be considered in future to ensure successful reintroduction of this species. As founding populations are likely to be meta-populations, too far apart to be naturally connected, human intervention will be necessary to manage the genetic diversity in these populations in the early years.

The need to augment genetic variability needs to be carefully weighed-up alongside disease and welfare considerations. Beavers would need to be sourced from European populations, but, as evidenced in section 5.8, this raises concerns over the disease risk to the translocated beavers, sympatric mammals and potentially humans. Further work is required to assess mitigation of these risks. Donald *et al.* (In press) only considered translocation pathways within Great Britain and from Norway to Great Britain as the risks from *E. multilocularis* were considered too great from other European countries where this parasite is endemic. However, Norwegian beavers suffer from limited genetic diversity due to their own historic bottleneck (Rosell and Parker 2011). Further research is therefore needed to clarify what is necessary for British beaver populations from a genetic point of view and, if a source other than Norway is recommended, a revised disease risk analysis will be required.

Donald *et al.* (In press) concluded that free-living beavers sourced from within Great Britain pose the lowest disease risk. There is no evidence at the current time to suggest inbreeding and lack of diversity is affecting the survival of individuals within British populations (Campbell-Palmer *et al*. 2020). So, while the goal should be to augment genetic diversity, there is no evidence to suggest there is an immediate risk from utilising the beavers that we already have in Great Britain to support reintroduction in the short to medium term. Therefore, free-living beavers sourced from within Great Britain should be the initial primary source for reintroduced beavers to England. The principle source of such beavers at the present time is the Tayside population in Scotland. It is recommended that a stud book (or similar record) should be kept ensuring very closely related beavers are not the sole founders of a reintroduced population (as was the case on the River Otter). In line with the IUCN guidelines (IUCN/SSC 2013), we anticipate that authorities in Scotland will ensure the repeated removal of small groups of animals does not negatively affect the genetic diversity in the source population, which itself is still establishing. Beavers from the Tayside population, which are subject to control measures to manage conflicts with farmers, are the obvious choice for reintroductions in England. Disease risks are low and welfare risks by sourcing animals from Tayside, are manageable. These animals would otherwise be killed and this genetic diversity lost from a growing population. However, this source is unlikely to be sufficient or suitable by itself (for genetic reasons) to provide the numbers of founding individuals required to establish a robust and self-sustaining population in England.

### 6.3.2 Biological feasibility

There is a wealth of information available on the biology and ecology of wild populations of beavers. Information on basic biology and biotic and abiotic habitat needs of beavers are well understood.

**Habitats**

Modelling has demonstrated that that there is enough suitable habitat in England to support the reintroduction of this species at various locations within England (Graham *et al.* 2019; Graham *et al*. 2020).

Beavers have been absent from the English landscape for centuries and there remain uncertainties about their future-prospects and their effects on England's intensively modified and managed landscapes. This will need to be closely monitored. Although beavers rarely forage far from the waters edge, the effects of dam building can be more far reaching. Some rivers may be deliberately constrained and thus unable to respond to beaver activity in a natural way for quite some time. These areas are likely to be subject to the highest levels of potential conflict, although they will be less likely to be dammed (Graham *et al.* 2020). Ensuring freshwater habitats have space to react to modified beaver habitat will be crucial in reducing conflict and maximising potential habitat restoration benefits from beavers.

The browsing activity of herbivores such as deer has also been shown to have a negative effect on vegetation regeneration when they are present at high densities, whether beavers are present or not. Additional herbivory by beavers may have a disproportionate affect on vegetation communities which are already struggling to recover from deer browsing. Deer populations are of concern in many woodland management situations where regeneration is being promoted, and adding beavers as an additional variable merits further investigation and monitoring.

**Species**

The consequences of reintroducing beavers back to the English landscape are likely to be positive for most species and have a positive overall effect on biodiversity. Evidence is, however, inconclusive for certain species and this will need to be monitored. Species of concern are rarities inhabiting what are currently relatively stable niches in areas likely to undergo dynamic change as a result of beaver presence. These species may not have the capacity to shift their small-scale distribution to exploit new opportunities provided by a more dynamic habitat template. Again, increasing the space given over to natural and semi-natural habitats needs to be part of the solution, to ensure sufficient diversity of environmental conditions.

**Climate**

The climate is suitable for beavers, as has been demonstrated in Scotland and in free living and enclosure populations in England. Climate change may affect the suitability of some localised areas of England in the future for beavers (e.g. through tidal inundation or increased flood events). Conversely, habitats subject to beaver activity may help mitigate the effects of climate change for some species through helping to naturalise flow regimes (mitigation of artificially high and low flow events), increased habitat heterogeneity and connectivity, woody debris refuges and possible refuge during periods of drought.

### 6.3.3 Social feasibility and socio-economics

Beavers have been absent from the English landscape for long enough to be lost from the collective memory. Although the overall national perception to beaver reintroduction appears positive, this may come with little realisation of how beavers may modify habitats. Public support for beaver reintroduction may therefore be moderated by increased interaction with the realities of their presence over time. Conversely public support may grow as it becomes clear from first-hand observation what beavers can do. Continued engagement with communities is therefore recommended.

The effects of beavers on the environment and society are dependent on the type, location and intensity of beaver activity, and the current land/water-use in that area. Management and mitigation options will also vary in relation to their efficacy and availablity. It is important to note that those who benefit from beaver reintroduction may not always be the same people as those who bear the costs. This imbalance does have the potential to cause problems and will need to be carefully monitored.

The conservation gain from reintroducing beavers does need to be balanced against the obligation to avoid collateral harm to other species, ecosystems or human interests (IUCN/SSC 2013). In the long term, and in the absence of natural predators of beavers in England, it will be important to achieve a level of population control in line with natural ecosystems to ensure biodiversity objectives can be achieved. This would also go some way towards addressing stakeholder concerns (although would not address site-specific issues).

It will be important to understand and monitor the socio-economic circumstances, community attitudes and values, motivations and expectations behaviours and behavioural change and anticipated costs and benefits of future reintroduction projects.

## 6.4 Strategic context for beaver reintroduction

Human modifications to landscapes over many centuries have changed habitat provision in many ways, which benefit some species and disadvantage (or eliminate) others. Our expectations of what the landscape should provide for species has changed as a result. The reintroduction of the beaver is being considered at a time when our landscapes have never been more modified and further away from functioning naturally or indeed been more degraded. Most natural wetlands (including their pools, flushes, seepages and runnels that eventually turn into streams) have been drained, exacerbated by groundwater abstraction, and much of the remaining wetland habitat resource resides as small fragments (often with very nutrient enriched waters) dependent on artificial water level management. This pattern is repeated elsewhere across Europe, so much so that the European Red List of habitats[29] cites wetland habitats as the most threatened of all habitats. Larger running and standing water habitats (streams, rivers and small and large lakes) are also degraded by a wide range of pressures in their catchments, including: abstraction; various types of physical modification (impoundment, river and stream channelisation and bed lowering, flood embankments); intensive land management right up to the edge of river and lake banks; large-scale absence of riparian trees and the woody material they naturally supply to the river; and diffuse and point source pollution with nutrient; excessive fine sediment and a wide range of synthetic chemicals. The absence of the beaver from our landscapes is another modification to add to this list.

[29] https://ec.europa.eu/environment/nature/knowledge/pdf/terrestrial_EU_red_list_report.pdf [accessed 11/06/2021]

Bringing the beaver back into an otherwise naturally functioning catchment is a very different situation to bringing the species back into a highly modified catchment. Wet and dry habitats and their dependent species have altered their spatial distributions according to modified conditions. Restoration of a more natural ecosystem function in such landscapes, with or without the beaver, can change the distribution of existing habitats and species, resulting in both losses and gains in different situations. Individual species that have benefited from modifications at the expense of wider characteristic biological assemblages may decline in population size and distribution, at least at a local level. Restoration of natural function also implies greater dynamism in the patterns of habitats and species, where they move around the landscape more rather than being supported statically in a particular place. A holistic view is required of the biodiversity implications of these ecological changes.

## 6.5 Conclusion

Based on the evidence presented in this report, beavers are a suitable species for further reintroduction in England. Reintroducing beavers will help restore lost natural ecosystem function, thereby contributing to broader ambitions to restore as much biodiversity as possible through the restoration of more naturally functioning habitat mosaics (Natural England 2018). However, if it is done without first restoring key elements of natural function (such as water quality and natural river morphology) the short-term effects of reintroduction can be very different. English catchments have been, and continue to be, subject to a wide range of often intense pressures, which vary in nature and effect in different types of landscape. Reintroducing the beaver cannot remove these pressures, and could exacerbate ecological impacts in degraded habitats where more fundamental impacts on natural ecosystem function (pollution, river channelisation, etc) have not been (or are not being) addressed at source. It is, therefore, in combination with other landscape or habitat restoration approaches, that the best outcomes from beaver reintroduction will be delivered.

A holistic catchment perspective will be needed to fully understand the ecological and biodiversity benefits of beaver, and the socio-economic costs and benefits. Whilst effects at an individual site may disadvantage some native species for a period, the influences of beaver activity will shift around the catchment over time. This dynamism is expected to benefit most species at a large-scale and over longer periods of time as long as sufficient space is provided for nature. Whilst the general ecological effects of beaver will be beneficial, there will also be situations where existing patterns of wildlife and socioeconomic objectives will be affected, and conflicts will need to be managed to optimise benefits and avoid unacceptable risks to particularly rare and endangered species, or unacceptable costs to people.

Ensuring river and lake systems have space to react to the habitat modifications brought about by beaver will be crucial in maximising ecological benefits, and will reduce risks to existing biodiversity and socioeconomic objectives. Relevant policies, legislation and delivery mechanisms need to work in harmony to ensure beaver reintroduction is properly embedded in biodiversity, water and climate change objectives whilst safeguarding socioeconomic activity. The return of the beaver to England will profoundly change riverine and surrounding habitats. How we use evidence will determine whether we succeed in these objectives.

# 7 Priorities for further research

The following research gaps and priorities have been identified by contributors to this review. They have not been ranked in order of priority as this will be influenced by future government policy for beaver reintroductions.

Future reintroduction projects should be encouraged to undertake monitoring and to conduct studies that help to address these areas of uncertainty. The contribution a project makes could be a factor used in deciding which projects to approve.

Considering the likely information needs of a policy for reintroducing beavers there are four key topic areas where research could make a particularly important contribution:

- Information that can inform mapping tools used to identify benefit and conflict zones for beaver reintroduction;
- Improving our understanding of the effects of beavers on fish populations and fisheries;
- Investigating the benefits and costs of beaver vs conventional approaches for flood management over the long-term and
- Using this opportunity to investigate how public and stakeholder attitudes respond to the reintroduction of the beaver and what factors are most effective at securing support and avoiding conflict.

**Running water habitats**

1. Improve understanding of the interaction between beaver and aquatic ecology and habitats.
2. What geomorphic changes occur to river systems as beaver populations expand?
3. What are the catchment scale effects of beavers?
4. Upscale beaver dam capacity and habitat suitability models to estimate landscape scale effects, and to predict where beaver activity may maximise environmental and societal benefits and potential conflict.
5. Extend beaver dam capacity model to assess hydrology and attenuation modelling. This should be undertaken alongside the habitat suitability work (e.g. Gurnell *et al*. 2009; Brazier *et al.* 2020).
6. Can beaver dams mitigate against low flows and increase groundwater infiltration?
7. What are the effects of burrowing activity on running water habitat?
8. Improve understanding of the effects of introducing beaver into more naturally functioning systems vs systems that are degraded in various ways and to various degrees (geomorphologically, nutrient enrichment, enhanced fine sediment delivery).

**Biodiversity, water level and chemistry of standing water habitats and associated wetlands**

9. How do beavers influence water bodies which are already heavily impacted by eutrophication and support few aquatic plants? Are beavers likely to assist or prevent lake recovery or is this type of habitat is simply unsuitable for beavers?

### Fish Assemblages

10. What are the potential impacts, both positive and negative, of beavers on the full range of fish species native to English catchments? What might beaver-associated changes in fish community structure mean for fish populations and the conservation outcomes we seek to achieve? This research should be tailored to local catchments and their native range of fish species.
11. What impact might the presence of beavers have on the site integrity and populations status of European and nationally protected fish species? Specifically, would the reintroduction of beavers in England represent a risk or opportunity for European designated and nationally protected fish species and are there spatial differences?
12. What are the potential impacts, both positive and negative, of beavers on non-native and locally non-native fish species present in English catchments? Do existing risk assessments for known and potential invasive species provide evidence on likely impacts?
13. What are the potential impacts, both positive and negative, of beaver activity on fish populations in unique English habitats such as lowland chalk stream habitats and higher altitude catchments typical of upland habitats?
14. What are the potential impacts of beaver burrowing activity on fish habitat quality?
15. What are the potential impacts of beaver herbivory on fish habitat quality, with reference to lake habitat and aquatic plants?
16. In highly modified catchments where river expansion onto the floodplain or lake hydrosere development may be limited/prevented, are the potential positive and negative impacts for fish the same and how will freshwater habitat restoration programmes change this?
17. For cold-water adapted salmonids – what is the outcome at a catchment scale of risks due to temperature rises associated with the presence of beaver dams versus the opportunities offered by increases in thermal heterogeneity? For warmer water cyprinids and other species - what role does the interaction between temperature and water quality of beaver ponds, of different ages, play in determining the extent of positive and negative impacts of the presence of beavers?
18. What factors impact the passability of beaver dams for salmonids and other fish species (e.g. pool depth, height, porosity, flow, etc)?
19. Do beavers have an overall positive or negative effect on all fish species that utilise a habitat type? What factors (e.g. geographical location, gradient, existing habitat availability and quality, beaver density, anthropogenic pressures, etc) influence the balance of overall affect?
20. What is the effectiveness of the various mitigation and management measures, to reduce the potential effect of beaver activity, in achieving conservation objectives for fish?

### Fungi and lichens

21. What is the effect of beavers on ectomycorrhizal fungi?
22. What is the effect of beavers on non-tree-dwelling lichens?
23. Do rock-dwelling lichens along watercourses, or in riparian habitats, benefit from beaver herbivory due to increased light levels?

24. How does predicted beaver habitat overlap with habitats for vulnerable species of fungi and lichen?
25. A risk assessment of the likely long-term impacts of beaver on oak trees, of particular importance to epiphytic lichens and fungi, near watercourses/bodies at a landscape scale, would aid understanding of the impacts.
26. How do beavers affect the quantity and varieties of deadwood available for saproxylic species?
27. How do habitats and associated species (lichens and fungi) change when beavers relocate their lodges? Which lichens and fungi can recolonise (and which cannot) in the interval before beavers recolonise?
28. What options are available to protect trees at a landscape scale which are harmless to lichens and fungi?

**Invertebrates**

29. Research is recommended to study potential interactions between beavers and white-clawed and signal crayfish.

**Birds**

30. What are the longterm effects of beavers on bird populations and assemblages?

**Mammals**

31. How are water voles affected by the presence of beavers (including changes to the risks of predation by mink)?
32. How are bat species affected by beaver activity?
33. Do deer affect the regeneration of woodland habitats coppiced by beavers?

**Amphibians and reptiles**

34. How do beavers affect amphibian and reptile populations and assemblages? In particular, do beavers have an effect on breeding success (especially use of small waterbodies such as ditches and ephemeral pools), over-winter surivial in hibernacula located in beaver influenced habitats and on connectivity and movement between populations?

**Social Science**

35. Ongoing deliberative research process with landowners, farmers, anglers and others likely to be directly affected by reintroductions is required to develop management options and to evaluate their progress. This should be informed by application of the wider literature on wildlife conflicts.
36. There is also a need for qualitative and quantitative research amongst the general public to explore attitudes and understanding to beaver reintroduction and to management options.
37. Inman (In press) indicates a low level of trust in the science and practice of those advocating beaver reintroduction by a section of the landowning and fishing community who have been close to the issue thus far. There is also a group of ‘beaver advocates’ (including landowners) who have equally strong views. Such a polarisation has the potential to destabilise future collaborative dialogue. Further research is needed to

understand how widespread such views are amongst the general public and across the wider stakeholder community.

38. There is evidence that farmers demonstrate attitudinal changes over time in response to scientific input and localised site-specific action to manage beavers. We know fears and concerns can be allayed and landowners and stakeholders can work together to manage beaver populations within a working landscape and adjust strategies accordingly. Further evidence is, however, needed to understand how to maintain and sustain attitudinal and behavioural changes in the long term.
39. If financial instruments are put in place that compensate land managers for accommodating beaver populations, it is recommended that studies are undertaken to understand the factors that are likely to affect take-up of measures so they can be designed and targeted appropriately.

**Water Management**

40. Continued monitoring of catchment scale effects will be required, together with continued development of tools that help to increase benefits and identify when management is needed to address conflict.

**Fisheries**

*In addition to the evidence needs identified for 'Fish Assemblages' the following are relevant to the management of freshwater fisheries.*

41. What are the impacts of beavers, both positive and negative, on the processes supporting natural fish community structure and how do beaver interact with them?
42. What are the potential impacts, both positive and negative, for the different types of fisheries in England of potential beaver induced changes in fish community structure?
43. Does beaver presence in stillwater fisheries (natural and commercial/non-natural) result in the need for specific management issues not previously considered?
44. Can the costs and benefits of current fishery management be better quantified and assessed against alternative management scenarios, given the limitations of existing data?

**Agriculture**

45. In addition to land use, proximity to watercourses and topography are important factors which influence the effect beaver activity has on agriculture. Analysis using mapping software could pinpoint key areas where conflict is most likely to occur.

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## 4. Biological feasibility – beavers and their interactions with habitats and species

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## 6. Summary and conclusions

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## 7. Priorities for further research

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# Appendix I - Search terms used to identify relevant evidence

| Heading | Search terms |
|---|---|
| What are the important aspects of beaver ecology and biology in relation to reintroductions? | *Caster fiber* **OR** *Castor canadensis* **OR** *Castor* spp. **OR** Eurasian beaver<br>**AND**<br>Ecology OR Habitat OR Colonisation OR Population dynamics OR Dispersal OR Genetics |
| *Biological feasibility - Interactions with habitats and species* | |
| What are the effects of beavers on the biodiversity, water level and chemistry of standing water habitats and associated wetlands? | *Caster fiber* **OR** *Castor canadensis* **OR** *Castor* spp. **OR** Eurasian beaver<br>**AND**<br>ecosystem engineer **OR** wetlands **OR** pond **OR** water quality **OR** biogeochemistry **OR** carbon **OR** lakes **OR** lochs |
| What are the effects of beavers on running water through hydrology and fluvial geomorphology? | *Caster fiber* **OR** *Castor canadensis* **OR** *Castor* spp. **OR** Eurasian beaver<br>**AND**<br>hydrology **OR** fluvial geomorphology **OR** rivers **OR** water quality **OR** beaver dam **OR** floodplain **OR** groundwater **OR** baseflow **OR** attenuation **OR** flood risk |
| What are the effects of beavers on the biodiversity of woodlands? | *Castor fiber* **OR** *Castor canadensis* **OR** *Castor* spp. **OR** Eurasian beaver<br>**AND**<br>broadleaved woodland **OR** riparian woodland **OR** tree felling **OR** regrowth **OR** deer browsing **OR** forestry **OR** Dead wood |
| What are the effects of beavers on the biodiversity of bryophytes? | *Caster fiber* **OR** *Castor canadensis* **OR** *Castor* spp. **OR** Eurasian beaver<br>**AND**<br>bryophytes |
| What are the effects of beavers on the biodiversity of fungi and lichens? | *Caster fiber* **OR** *Castor canadensis* **OR** *Castor* spp. **OR** Eurasian beaver<br>**AND**<br>fungi **OR** lichens |
| What are the effects of beavers on the biodiversity of vascular plants? | *Caster fiber* **OR** *Castor canadensis* **OR** *Castor* spp. **OR** Eurasian beaver<br>**AND**<br>vascular plant **OR** aquatic plant **OR** invasive plant species |

| Heading | Search terms |
|---|---|
| What are the effects of beavers on the biodiversity of invertebrates? | *Caster fiber* **OR** *Castor canadensis* **OR** *Castor* spp. **OR** Eurasian beaver<br>**AND**<br>invertebrates **OR** water beetle **OR** coleopteran **OR** macroinvertebrates **OR** insects |
| What are the effects of beavers on the biodiversity of fish assemblages? | *Caster fiber* **OR** *Castor canadensis* **OR** *Castor* spp. **OR** Eurasian beaver<br>**AND**<br>Fish **OR** spawning **OR** salmon **OR** trout |
| What are the effects of beavers on the biodiversity of amphibians and reptiles? | *Caster fiber* **OR** *Castor canadensis* **OR** *Castor* spp. **OR** Eurasian beaver<br>**AND**<br>amphibian **OR** reptile **OR** toad **OR** frog **OR** newt **OR** lizard **OR** snake **OR** slow worm |
| What are the effects of beavers on the biodiversity of birds? | *Caster fiber* **OR** *Castor canadensis* **OR** *Castor* spp. **OR** Eurasian beaver<br>**AND**<br>wader **OR** waterbirds **OR** duck |
| What are the effects of beavers on the biodiversity of mammals? | *Caster fiber* **OR** *Castor canadensis* **OR** *Castor* spp. **OR** Eurasian beaver<br>**AND**<br>mink **OR** otter **OR** watervole **OR** bats **OR** voles **OR** mice **OR** shrew **OR** deer **OR** pine marten **OR** badger **OR** red fox |
| *Social feasibility – interactions with the human environment* | |
| What are the public attitude and perceptions towards a potential beaver reintroduction? | *Caster fiber* **OR** *Castor canadensis* **OR** *Castor* spp. **OR** Eurasian beaver<br>**AND**<br>human–wildlife conflict **OR** perceptions **OR** reintroduction **OR** survey **OR** socio-economic **OR** behaviour **OR** attitudes **OR** values |
| What are the discernible economic benefits and costs associated with a reintroduction of beavers to England? | *Caster fiber* **OR** *Castor canadensis* **OR** *Castor* spp. **OR** Eurasian beaver<br>**AND**<br>cost-benefit analysis **OR** cost-consequence analysis **OR** cost-effectiveness analysis **OR** cost-utility analysis **OR** environmental economics **OR** invasive species |
| How may beavers affect human-orientated water management issues? | *Caster fiber* **OR** *Castor canadensis* **OR** *Castor* spp. **OR** Eurasian beaver<br>**AND**<br>Flood risk **OR** Flood defence **OR** Flood risk management **OR** Flood attenuation OR Flood flow **OR** Drought **OR** Groundwater **OR** Baseflow **OR** Surface water flow **OR** Filter **OR** Hydrograph |

| Heading | Search terms |
|---|---|
| | **OR** Slow **OR** store **OR** Flood and coastal risk management **OR** Water storage **OR** Water quality **OR** Phosphate **OR** Nitrate **OR** Diffuse pollution **OR** sediment |
| What are the effects of beavers on freshwater fisheries? | *Caster fiber* **OR** *Castor canadensis* **OR** *Castor* spp. **OR** Eurasian beaver<br>**AND**<br>fisheries **OR** coarse fishing **OR** game fishing **OR** angling |
| What are the potential effects of beavers on commercial forests? | *Caster fiber* **OR** *Castor canadensis* **OR** *Castor* spp. **OR** Eurasian beaver<br>**AND**<br>forestry **OR** commercial **AND** tree |
| What are the effects of beavers on agricultural land? | *Caster fiber* **OR** *Castor canadensis* **OR** *Castor* spp. **OR** Eurasian beaver<br>**AND**<br>Agriculture **OR** grassland **OR** grazing **OR** crop |
| What are the potential impacts of beavers on infrastructure and general land use? | *Caster fiber* **OR** *Castor canadensis* **OR** *Castor* spp. **OR** Eurasian beaver<br>**AND**<br>ecosystem engineering **OR** human infrastructure **OR** urbanisation **OR** culverts **OR** flood* |
| What are the potential impacts of beavers on public and animal health? | *Caster fiber* **OR** *Castor canadensis* **OR** *Castor* spp. **OR** Eurasian beaver<br>**AND**<br>disease **OR** parasites **OR** public health |

# Appendix II Strength of evidence and uncertainty

Table evaluating the overall strength of a body of evidence (From DiFD (2013) How to Note: assessing the strength of evidence).

| Categories of evidence | Combination of quality + size + consistency + context | Typical features of the body of evidence | What it means |
|---|---|---|---|
| Very Strong | High quality body of evidence, large in size, consistent, and closely matched to the specific context of the business case. | The body of evidence includes studies based on experimental designs (including impact evaluations), as well as systemic reviews and/or meta-analysis. | We are very confident that the intervention has the effect anticipated or does not have the anticipated impact. The body of evidence has few or no deficiencies. We believe that the findings are convincing and stable. |
| Strong | High quality body of evidence, large or medium in size, generally consistent, and matched to the specific context of the business case. | The body of evidence is likely to include either experimental or quasi-experimental designs (including use of randomised control trials and statistical methods enabling causal identification). Observational research designs (including comparative case study methods) that make attempts at counterfactual analysis are also likely to feature in these bodies of evidence, as are systemic reviews. | We are confident that the intervention has the effect anticipated or does not have the anticipated impact. The body of evidence has few deficiencies. |

| Categories of evidence | Combination of quality + size + consistency + context | Typical features of the body of evidence | What it means |
|---|---|---|---|
| Medium | Moderate quality studies, medium size evidence body, generally consistent, which may or may not be relevant to the specific context of the business case. Also covers limited number of high quality studies. | The body of evidence is likely to include studies from multiple designs (experimental and operational), but which have been assessed as being only of a moderate quality. The findings of the study do not offer robust findings that can be derived and replicated across a range of contexts. | We are moderately confident that the intervention has the effect anticipated or does not have the anticipated impact. The body of evidence has some deficiencies. We believe that the findings are likely to be stable, but some doubt remains. |
| Limited | Moderate or low quality studies, small or medium size evidence body, inconsistent, not matched to the specific context of the business case. | The body of evidence is comprised of studies, based of varied designs and methodologies, which do not meet the minimum standard of research quality. Includes causal interference derived from single case studies in a limited number of contexts, and cross-section analysis performed in the absence of rigorous baseline data. | We have limited confidence that the intervention has/does not have the anticipated effect. Body of evidence has major and/or numerous deficiencies. Additional evidence needed to conclude that the findings are stable or that intervention has the indicated effect. |
| No evidence | No studies or impact evaluations exist. | | We have evidence of need but no evidence that the intervention does or does not have the effect indicated. |

# Appendix III – Summary of potential interactions between beavers and biological and social factors

Summary of potential interactions between beavers and biological and social factors, additional to findings in the Scottish Review.

Tables are not provided for topics where no additional findings were noted, or where the subject was not covered in the Scottish Review.

At some sites appropriate management may be needed to counteract negative effects and promote positive effects. Note that the significance of any individual effect may be far higher or lower than that of other effects.

| **Running water** | | | | |
|---|---|---|---|---|
| **Activity** | **Mechanism** | **Positive effects** | **Negative effects** | **Notes** |
| Change in riparian woodland: Opening of woodland canopy and increased patchiness. | Felling | None identified further to Scottish Review | None identified further to Scottish Review | Recent studies have indicated the thermal stress is reduced or negated due to increased mixing. |
| Change in riparian woodland: Change in relative abundance of different tree species. | Felling | May be of benefit to tree and shrub species and habitat created by them. | None identified further to Scottish Review | |
| Changes in water quality downstream. | Dams/pond creation | None identified further to Scottish Review | • Smothering of bed sediment upstream of dams resulting in change in habitat quality.<br>• Reduction in turbulence upstream of dam, resulting in a decrease in rate of water oxygenation. | |

| Running water | | | | |
|---|---|---|---|---|
| **Activity** | **Mechanism** | **Positive effects** | **Negative effects** | **Notes** |
| Changes in baseflow/ groundwater. | Dams/pond creation | • Buffered baseflows in drought conditions.<br>• Potential for increased groundwater within a catchment. | Localised wetting that may lead to change in surface vegetation. | |

| Standing water and wetlands | | | | |
|---|---|---|---|---|
| **Activity** | **Mechanism** | **Positive effects** | **Negative effects** | **Notes** |
| Change in riparian woodland and riparian zone at lake side. Increased patchiness, different species, and change in age classes. | Felling | • Increased light levels in the shallows.<br>• More emergent vegetation as a result of reduced shading. | • Loss of trees important to recreational users of permanent standing waters.<br>• Additional management required where risk of felling may impact on recreational users. | • Not all recreational users will see loss of trees as negative.<br>• Trees play a functional role around lakes; the presence or absence of trees is not necessarily positive or negative for a lake; a mixture is needed at the landscape scale. |
| Changes in amount/ diversity of woody material. | Felling and dam/lodge construction | • Increased spawning habitat for fish.<br>• Increased habitat and food for invertebrates as a result of increased woody material in lakes. | None identified further to Scottish Review | Other fauna will benefit from increased abundance of invertebrates as a food supply. |
| Removal of specific terrestrial herbaceous and aquatic plant species. | Feeding | Selective consumption of standing water body edge/emergent plants may lead to diversification of vegetation. | Loss of emergent vegetation through herbivory may lead to increased erosion of banks from wave action in lakes and increased nutrient concentrations due to a lack of nutrient uptake by emergents. | • Consumption of species which are common in a local area, such as bogbean (*Menyanthes trifoliate*).<br>• Other commonly consumed English species such as bulrushes (*Typha* spp.) were not included in the Scottish trial. |

| Standing water and wetlands | | | | |
|---|---|---|---|---|
| **Activity** | **Mechanism** | **Positive effects** | **Negative effects** | **Notes** |
| Change from lotic to lentic habitat. | Dams/pond creation | • Creation of more ponds - a priority habitat in England.<br>• Creation of wetland habitat. | None identified further to Scottish Review | |
| Change in hydrological processes on riparian and downstream habitat. | Dam/pond creation | Potential for restoration of hydrosere. | Flooding of existing high-value habitat in modified hydrological landscapes may lead to local losses of species. | |
| Indirect habitat creation/ restoration initiatives as a result of beaver presence. | Beavers used to promote opportunities for riparian and freshwater habitat creation/ restoration. | Riparian zone may become wetter, restoring the hydrosere. | | |

| Fish assemblages | | | | |
|---|---|---|---|---|
| **Activity** | **Mechanism** | **Positive effect** | **Negative effect** | **Notes** |
| Impacts on movement of fish species. | Dam construction | Creation of side channels and complex flow patterns to the side of dams: potential for improving passage for fish species. | • Reduction in accessibility to spawning habitat, particularly for sea trout (*Salmo trutta*) and salmon (*Salmo salar*), decreasing available wetted area, increasing competition, with potential impacts at the population level.<br>• Increased energetic cost of reaching spawning ground with | The impact of dams will be highly dependent on the fish species, location of the dam and dam characteristics (e.g. height, breach status, pool depth, longevity), and flow. |

| Fish assemblages | | | | |
|---|---|---|---|---|
| **Activity** | **Mechanism** | **Positive effect** | **Negative effect** | **Notes** |
| | | | potential consequences for reproduction.<br>• Fish may be stranded above dams during droughts as they are unable to move downstream (or recolonise upstream).<br>• Reduced upstream passage associated with loss of attractant flow or insufficient channel depth around dam. | |
| Conversion of upstream habitat from lotic to lentic. | Dam construction | • Increased habitat diversity, in channel and extended wetland habitats as a result of damming.<br>• Creation of ponded sections of river may benefit certain fish species.<br>• An increase in fish species diversity may be observed due to increased habitat diversity.<br>• An increase in abundance/biomass of certain species may be observed due to increased habitat area and/or productivity. | • Loss of spawning and juvenile rearing habitat for salmonids and other gravel spawning species.<br>• A decrease in species diversity may be observed due to changes in habitat suitability for species present.<br>• A decrease in abundance/biomass of fish may be observed due to deteriorating habitat quality linked to aging of beaver ponds (bullhead (*Cottus gobio*) is of high concern).<br>• Ponded river sections may be favoured by non-native species. | • Findings from published research are variable and depend on individual fish species present within the catchment, location and longevity of the dam.<br>• Increased trout productivity (combined with more barriers to migration) may influence the propensity to migrate with either positive or negative impacts depending on the nature of the fishery and the consequences for population productivity (as larger sea trout produce more eggs). |
| Changes to downstream habitat. | Dam construction | • Increased velocities downstream of dams may improve the habitat quality of downstream gravel | • Dam building may cause bank erosion as side channels are formed releasing additional sediment into the catchment. | • The overall effect will depend of fish species present in the vicinity of dams. |

| Fish assemblages | | | | |
|---|---|---|---|---|
| **Activity** | **Mechanism** | **Positive effect** | **Negative effect** | **Notes** |
| | | which will benefit some fish species.<br>• Creation of wetland habitat and connectivity to the floodplain may potentially provide beneficial opportunities for fish species. | • Increased velocities downstream of dams may reduce the suitability of habitat for some fish species. | • Overall population effects will vary across space and time. |
| Changes to water temperature regime. | Dam construction | • Potential increased stream temperatures associated with increased residence time may be beneficial to non-salmonid species or to salmonids in colder rivers.<br>• Thermal heterogeneity may influence resource partitioning and increase carrying capacity.<br>• Thermal heterogeneity within dam complexes may offer thermal refugia.<br>• Thermal buffering and cooling of downstream water may improve conditions for fish species. | Increased stream temperatures associated with increased residence time may be detrimental to cold-water adapted species in warmer rivers. | Both positive and negative impacts have been reported with no consensus within the literatures and few studies comparable to the English climate. |
| Changes to water quality. | Dam construction/ burrowing | • Beaver dams may act as sediment traps, removing pollutants from the water and improving downstream water quality. | • Dissolved oxygen concentration in beaver ponds may be reduced and decrease over time leading to decreases in fish abundance.<br>• Beaver activity can change the composition of bottom | Impacts will vary depending on individual fish species present within the catchment, and the location and longevity of the dam. |

| Fish assemblages | | | | |
|---|---|---|---|---|
| **Activity** | **Mechanism** | **Positive effect** | **Negative effect** | **Notes** |
| | | | sediment due to burrowing activity, releasing sediment and reducing water quality. | |
| Increased habitat heterogeneity. | Dam construction | • Greater selection of habitats to forage, rest and shelter during different life stages, in-channel and floodplain connection, and wetland habitats.<br>• Creation of pond habitat may provide opportunities for larger brown trout.<br>• Habitat heterogeneity may increase resource partitioning and increase carrying capacity.<br>• Increased woody debris provides shelter and availability of prey items. | | |
| Changes to hydrological processes. | Dam construction | • Beaver dams may stabilise river discharge offering refuge from high flows and storing water during droughts.<br>• Increased variability in flow patterns, creating diverse in-channel and adjacent floodplain wetland connection will benefit some fish species. | • Reduction of flow downstream of beaver dams may reduce wetted area and consequently habitat availability for fish.<br>• Potential sediment starvation for spawning gravels downstream of the dam. | |

| Fish assemblages | | | | |
|---|---|---|---|---|
| **Activity** | **Mechanism** | **Positive effect** | **Negative effect** | **Notes** |
| Predation on fish species. | Dam construction | Habitat complexity may offer increased shelter from predators. | Greater predator abundance associated with pools behind dams may increase predation pressure. | |
| Disease. | Dam construction | | Decreased water quality and increased temperature in ponded areas may increase the prevalence of disease and parasites in salmonids and other fish species. | |
| Adaptation to climate change. | Tree felling | Beavers may beneficially create additional shade through coppicing to create additional tree cover. | Beavers may adversely impact climate change adaptation efforts to reduce temperatures in headwater streams for the benefit of salmon and trout. | Impacts will vary with location, maturity of trees, beaver population density etc. |
| Changes to the invertebrate community. | Tree felling/dam construction | • Changes in the density and composition of the tree canopy may increase invertebrate productivity, providing more food for fish.<br>• Increased woody debris beside and in channel may provide increased invertebrate prey availability. | • Loss of mature woodland may decrease the amount allochthonous material entering waterbodies, decreasing invertebrate productivity, providing less food for fish.<br>• Changes in the structure of the invertebrate community associated with lentic habitat (e.g. sedimentation and reduced flow) may decrease prey abundance for salmonids. | The overall outcomes on invertebrates are complex and subsequent impacts on fish are not well understood. They are also likely to be dependent on fish species. |
| Changes to the aquatic plant community. | Tree felling/dam construction | Changes in the density and composition of the tree canopy may increase light penetration, allowing | Sedimentation within beaver ponds may limit growth of aquatic plants decreasing the availability of shelter for fish. | |

| Fish assemblages | | | | |
|---|---|---|---|---|
| **Activity** | **Mechanism** | **Positive effect** | **Negative effect** | **Notes** |
| | | aquatic plant growth offering shelter to fish species. | | |

| Woodland | | | | |
|---|---|---|---|---|
| **Activity** | **Mechanism** | **Positive effect** | **Negative effect** | **Notes** |
| Felling | Opening of woodland canopy and increased patchiness | Increased habitat heterogeneity across landscape scales. | Possible localised loss of canopy where pressure from other browsers is very high; in landscapes with little wet woodland/riparian woodland the impact may be more severe. | Programmes to increase riparian tree cover and extent of wet woodlands in key areas reduces possible local beaver impacts. |
| Felling | Change in relative abundance of different tree species | Potential increase in diversity through suppression of dominant tree species. | Highly preferred species can be locally extirpated. In specific situations (i.e. near-monocultures), beavers may preferentially select less common species in order to fulfil their need for a diverse diet, reducing species diversity. | |
| Felling | Change in age classes of trees | Natural coppicing, felling trees, and opening of the canopy will allow natural regeneration of woodland and regrowth of felled trees, all leading to increased structural diversity in even-aged woodland. | None identified further to Scottish Review. | A younger age profile is likely to develop over time, with a loss of older trees (and their associated flora and fauna) and of climax riparian woodland communities in specific areas. The younger age profile is beneficial to increase habitat heterogeneity, however if a large proportion of the woodland is affected then ecological continuity |

| Woodland | | | | |
|---|---|---|---|---|
| **Activity** | **Mechanism** | **Positive effect** | **Negative effect** | **Notes** |
| | | | | could be interrupted within the riparian zone. |
| Felling | Amount/diversity of fallen dead wood on woodland floor | Tree-felling by beavers could lead to increased fallen dead wood. | | Unknown impacts on large deadwood dynamics over the longer term due to potential impacts on overall age profile of woodlands. |
| Dams/pond creation | Change in hydrological environment in riparian woodlands | Wet woodland may be restored in previously drained situations or may develop in in previously open drained habitat. | Some loss of tree species typical of drier conditions. | This might be positive, negative, or neutral depending on the area, tree species and regeneration and availability of natural seed sources. |
| Dams/pond creation | Change in standing dead wood resulting from wetter conditions leading to death of some trees | None identified further to Scottish Review | None identified further to Scottish Review | Programmes to increase riparian tree cover and extent of wet woodlands in key areas reduces possible local beaver impacts. |
| Dams/pond creation | Longer term successional changes after dam abandonment, e.g. beaver meadows | None identified further to Scottish Review | None identified further to Scottish Review | Programmes to increase riparian tree cover and extent of wet woodlands in key areas reduces possible local beaver impacts. |

| Bryophytes | | | | |
|---|---|---|---|---|
| **Activity** | **Mechanism** | **Positive effect** | **Negative effect** | **Notes** |
| Increase in habitat structural diversity. | Felling, inundation, hydrological dynamism. | Increased range of habitat niches suitable for bryophytes. | Some bryophytes may be disadvantaged, for example epiphytic species if mature trees are felled. | Considered likely to be positive overall in most cases, but may need to be assessed on a site by site basis. |
| Increase in dead wood. | Tree felling debris, lodge/dam construction and destruction. | Increased range of habitat niches suitable for the many bryophyte species that grow on dead wood. | Potential reduction of habitat areas for bryophytes that grow on open sediments at the edges of waterbodies. | Considered likely to be positive for bryophytes initially in most cases, with uncertainty about long-term impacts. |
| Felling of mature trees. | Beaver feeding activity. | Could benefit bryophytes that prefer less shaded conditions. | • Could potentially affect populations of uncommon epiphytic bryophytes if mature trees are felled, and also ground-dwelling bryophyte species that require the shade and increased humidity beneath mature trees.<br>• Increased light levels following felling of trees could also result in some bryophytes being outcompeted by faster-growing vegetation. | There could be a need to protect specific trees or groups of trees at certain sites. |
| Restricted regrowth of felled trees. | Regrowth of felled trees restricted by, for example, heavy browsing pressure by deer (family *Cervidae*). | Increased light levels could benefit certain bryophytes. | Felled mature trees may not be replaced, causing loss of habitat for uncommon bryophytes. | There could be a need to protect specific trees or groups of trees at certain sites. |
| Increases in wetted margin habitats. | Damming and inundation | Increased range of habitat niches suitable for | Some bryophytes that prefer less wet habitats may be disadvantaged. | Considered likely to be positive in most cases |

| Bryophytes | | | | |
|---|---|---|---|---|
| **Activity** | **Mechanism** | **Positive effect** | **Negative effect** | **Notes** |
| | | bryophytes that favour this habitat. | | |
| Dam impoundment ponding. | Dam construction | Could increase habitat availability for wetland bryophytes. | Could cause localised loss of bryophytes of conservation significance that are adapted to intermittent flooding, but not to prolonged submergence. | Probably not detrimental overall for bryophytes in most cases, but may need to be assessed on a site by site basis. |

| Fungi and lichens | | | | |
|---|---|---|---|---|
| **Activity** | **Mechanism** | **Positive effect** | **Negative effect** | **Notes** |
| Shift in tree species composition of riparian woodland due to pond creation and preferential felling. | Felling and impoundment | An increase in lichen and fungus species associated with wetland trees and shrubs. | • Since beaver select tree species known to support important epiphytic lichen communities, existing lichen interest would be threatened.<br>• A reduction in riparian tree species diversity would lead to a localised decrease in lichen and fungal diversity. | Lasting shifts in tree composition along water courses would have a profound effect on existing lichen and fungal interest. |
| Shift towards early successional woodland where younger trees predominate and older trees decline near water courses. Plus, potential interaction with deer browsing. | Felling and browsing | An increase in fungi and lichens tolerant of higher dynamism, i.e. early successional species (also see entry for structural change). | A loss of epiphytic lichen diversity and ectomycorrhizal fungal diversity can be expected due to reduced numbers of older trees. Beaver in combination with high deer numbers could suppress regrowth and regeneration, limiting the recovery of trees and shrubs and associated epiphytes. | Specialist lichens tend to colonise trees of 200 years or older. The relationship between ectomycorrhizal fungi, tree age and canopy cover has been reviewed by Tomao *et al.* 2020. |

| Fungi and lichens | | | | |
|---|---|---|---|---|
| **Activity** | **Mechanism** | **Positive effect** | **Negative effect** | **Notes** |
| Loss of old trees causing a gradual break in habitat continuity for specialist lichens and fungi | Felling and browsing | An increase in bulky deadwood (coarse woody debris) would provide additional habitat for saproxylic fungi, including crust fungi (corticioids) and pinhead lichens (calicioids). | The steady loss and lack of replacement of mature and post-mature trees would affect old-tree specialists that depend on this habitat. This includes both lichens, ectomycorrhizal fungi and wood-inhabiting fungi. | The impacts are likely to be gradual, a combination of woodland flooding, occasional felling, and natural senescence of trees. |
| Structural change in riparian woodland, increasing sub-canopy light levels but reducing shelter. | Felling and browsing | • Younger trees cast less shade which should benefit lichens occurring on undisturbed substrates, e.g. riverside rocks.<br>• Lichens may gain from reduced habitat competition with bryophytes. | • Epiphytic lichens tend to be intolerant of direct sunlight and drying out. Since they are poikilohydric, some shelter is required.<br>• A less dense canopy is also likely to negatively impact ectomycorrhizal species richness. | Saproxylic fungi are considered highly sensitive to woodland structural change (Parisi *et al.* 2018). The overall impact on the lichen epiphyte assemblage is unlikely to be known for many years due an extinction debt (Ellis and Coppins 2007). |
| Change in the quantity and quality of deadwood | Felling and dam construction | • An increase in bulky deadwood (coarse woody debris) would provide additional habitat for saproxylic fungi, including crust fungi (corticioids) and pinhead lichens (calicioids).<br>• Diversity would be further enhanced if a broader range of deadwood types, e.g. tree species, were available. | Whether increases in deadwood are sustainable is unclear. Deadwood dependent fungi and lichens need habitat continuity in order to persist. Beaver-felled timber is generally either eaten or taken for dam/lodge construction. How much bulky deadwood is left in situ for saproxylic organisms is uncertain. | Increased deadwood dynamism may benefit more ephemeral species, but decay pathways may be altered affecting fungal succession, especially where deadwood has been submerged. The supply of bulky deadwood may to be unsustainable in the longer term. |
| Altered conditions for rock-dwelling | Felling, browsing and | Riparian rock-dwelling lichens benefit through increased light levels and | • Microhabitat changes across the ecotone result in existing lichen community change. | |

| Fungi and lichens | | | | |
|---|---|---|---|---|
| **Activity** | **Mechanism** | **Positive effect** | **Negative effect** | **Notes** |
| lichens across riparian ecotone | creation of dams/ponds | reduced competition from bryophytes. | • Regeneration from coppiced trees/shrubs increases shade levels for rock-dwelling lichens. | |
| Flooding results in groves of standing deadwood. | Dams/pond creation | Lichens and fungi associated with standing or fallen deadwood are likely to increase in abundance and diversity in the short to medium terms. | • Trees die prematurely which curtails the natural succession of epiphytes and specialist lichens, many of which have high conservation value and tend to be restricted to post-mature trees.<br>• In the longer term, flooded woodland generates a pulse of bulky deadwood which eventually falls and decomposes. Habitat continuity for dependent species may become an issue in time. Wet or submerged deadwood is likely to alter saprobic fungal communities and decay pathways. | The longer-term changes in deadwood availability, including dynamics (turnover), size classes and tree species, will be key to determining the outcome for specialist deadwood species. |
| Changes in water flow rates and quality above and below dams. | Dams/pond creation | Below dam flows attenuated and less flashy with reduced silt loads and pollution levels. Although changes in flow rates may alter the occurrence of some aquatic lichens, lower levels of pollution and silt are likely to benefit this group. | • Less seasonal scouring of riverside rock may lead to moss and vascular plant encroachment which would outcompete rock-dwelling lichens.<br>• Creation of ponds alters the aquatic environment (e.g. sedimentation, chemistry and temperature) making it unsuitable for specialists of running-water habitats. Impacts from altered flow may also extend upstream of ponds. | |

| Fungi and lichens | | | | |
|---|---|---|---|---|
| **Activity** | **Mechanism** | **Positive effect** | **Negative effect** | **Notes** |
| Beaver meadow succession to woodland. | Dams/pond creation and abandonment | Beaver meadows can be seen as long-lasting glades that are slow to return to woodland cover. If in England they persist for 70 years or so, tree-/rock-dwelling lichens on the peripheries of old ponds should benefit. | Ectomycorrhizal fungi in beaver meadows can be lost due to past flooding. This is thought to constrain establishment of obligate ectomycorrhizal trees in beaver meadows. The negative effect on ectomycorrhizal fungi is localised. | |
| Abandonment of beaver-influenced habitats. | Lodge relocation: Beavers move to new areas within the same catchment, in time recolonising past territories. | • Aside from a multiplier of local positive effects, the vegetation of abandoned territories is left to regenerate and succeed.<br>• Lichens and fungi associated with lower levels of disturbance should begin to recover. | Aside from a multiplier of local negative effects, the interval before beavers are likely to readopt areas is likely to be too short for lichens and fungi dependent on mature bark and old trees to benefit. | |
| Increased impact of beavers at a landscape scale. | Reproduction: Beaver population expands and disperses into sub-optimal habitat. | A multiplier of local positive effects at a landscape scale. | A multiplier of local negative effects at a landscape scale. An increased risk of beavers colonising sites that are important for specialist lichens or fungi, especially those supporting ancient/veteran trees. Some of these may be protected sites with notified lichen/fungal interest. | On the River Otter, as beaver numbers increased, they moved from the deeper lower reaches into sub-optimal areas such as ditches and headwater streams and started to build dams (Elliott *et al*. 2017). |
| Modification of the climate change refugium potential of riparian woodland. | All beaver activities | Increased structural heterogeneity may enhance the range of microrefugia available. This is only likely to benefit more mobile | Riparian woodland extending up to 500 m or more from watercourses can provide a gradient of microrefugia for epiphytic lichens, increasing resilience to | Beavers tend to remain within 10-20 m of the water body, so direct impacts of beavers would be limited to this area. |

| Fungi and lichens | | | | |
|---|---|---|---|---|
| **Activity** | **Mechanism** | **Positive effect** | **Negative effect** | **Notes** |
| | | species of lichen and fungus. | macroclimatic change. Where beavers modify this habitat, they may disrupt its refugium potential. | |
| Protection of trees. | Individual tree and stand protection measures to prevent beaver damage to important trees. | Dependent lichen/fungus populations are successfully protected (without negative impacts). | • Galvanised weld mesh in contact with bark results in zinc run-off which is toxic to the lichens below. The use of anti-beaver paint on tree boles may/may not have an adverse effect on lichens or fungi but given the high sensitivity of lichens to substrate pH/chemistry, there is a significant risk of harm.<br>• Exclosures around special trees, or stands, adversely impact epiphytic and rock-dwelling lichens due to shading from understorey growth. | Where exclosures are unavoidable, it is essential that vegetation inside the exclosure is maintained through grass or understorey cutting, bramble and ivy control. |

| Vascular plants | | | | |
|---|---|---|---|---|
| **Activity** | **Mechanism** | **Positive effect** | **Negative effect** | **Notes** |
| Felling | Change in riparian woodland: Opening of woodland canopy and increased patchiness | None identified further to Scottish Review | | Very little information regarding species impacts. |
| Felling | Change in riparian woodland: Change in relative abundance of | | Potential localised decrease in or loss of species, particularly in areas with high levels of livestock | |

| Vascular plants | | | | |
|---|---|---|---|---|
| **Activity** | **Mechanism** | **Positive effect** | **Negative effect** | **Notes** |
| | different tree species | | or deer (family *Cervidae*) browsing. | |
| Feeding | Feeding on specific terrestrial herbaceous and aquatic plant species | | None identified further to Scottish Review | Very little information regarding individual species impacts. Some threatened species could be negatively impacted including a number of European Protected Species. |
| Dams/pond creation | Change from lotic to lentic habitat. When pond/lake outflows are dammed there will also be an increase in lentic habitat. | Potential localised increase in or gain of marginal and wetland species through colonisation of new waterside habitats. | Potential localised decrease in or loss of riparian species through loss or displacement of watercourse margins. | Very little information regarding species impacts. |
| Dams/pond creation | Longer term successional changes after dam abandonment e.g. beaver meadows. | None identified further to Scottish Review | Potential loss of drier habitat to wetter habitat | |
| Indirect habitat creation/ restoration initiatives as result of beaver presence. | Beaver used to promote opportunities for riparian and freshwater habitat creation/restoration. | Riparian restoration programmes are likely to benefit vascular plant species in the medium to long term. | | |

| Invertebrates | | | | |
|---|---|---|---|---|
| **Activity** | **Mechanism** | **Positive effect** | **Negative effect** | **Notes** |
| General increase in habitat structural heterogeneity. | Felling, inundation, hydrological dynamism | Increases in heterogeneity are generally considered beneficial for many invertebrates. | There will always be examples of reverse trends for some taxa in the face of niche reduction. | Generally positive for the English riparian landscape, which has suffered from a lack of dynamism. |
| Increase in coarse woody debris. | Lodge/dam construction | More larval habitat for Priority Species of craneflies (*Lipsothrix* spp.) and other wet wood taxa. | • Localised tree felling may reduce the standing decaying wood resource, such as ancient willow (*Salix* spp.) pollards.<br>• Large trees in the river may directly impact mussel beds by changing the hydrodynamics of the river, particularly upstream ponding, which can lead to siltation of the substrate and scouring as water is forced through narrow channels. | 12% of all Priority Species require coarse woody debris. |
| Increases in decaying vegetation. | Lodge/dam construction and destruction, beaver feeding debris, timber felling debris. | Likely to provide significant opportunity for saprophagous beetle and fly larvae (and their predators) feeding on decaying vegetation associated with many aspects of beaver ecology. | Negative impacts are unlikely; the resource of riparian litter has tended to be a relatively scarce resource in modern managed riverine systems. | |
| Increases in wetted margin habitats. | Damming and inundation | Should result in a significant increase in variable wetted margins and complex hydrological gradients, with benefit to many invertebrates. | Will force some taxa out to drier ground, with possible ‘squeeze’ where wetland spread is truncated by less favourable land uses. | Some decrease in the gradient of land adjacent to water may provide additional habitat (‘spreading room’). |

| Invertebrates | | | | |
|---|---|---|---|---|
| **Activity** | **Mechanism** | **Positive effect** | **Negative effect** | **Notes** |
| Changes to exposed riverine sediment (ERS) and soft riparian sediment communities. | Dam induced changes in hydrological flow pattern. | Increases in channel braiding may open up opportunities; variable flow downstream would be beneficial, with the attendant energy changes adding more dynamism. | • Sediment loads may shut down some ERS opportunities.<br>• Impounded flow might locally drown ERS. | 24% of all Priority Species require drawdown and ERS. As both ERS and soft riparian sediments respond to fluvial energy patterns, beavers will reset some of these habitat patches. |
| Localised reduction of large riparian monocot stands. | Differential beaver feeding on sedges (*Cladium* spp.) etc. | Increase in natural hydrological processes may free currently trapped taxa held in 'unnatural' aquatic landforms, such as ditches or very narrow riparian strips. This would reduce localised threat by making more resource potentially available. | Structural dependency on large *Cladium* stands for Priority Species like Desmoulin's whorled snail (*Vertigo moulinsiana*) may be a local issue. | Many of the watercourses used by the snails may be beyond beaver interest. Current declines in snail populations are from reductions in the wetted margin and loss of natural processes. |
| Dam impoundment, ponding.<br>Change from lentic to lotic habitat (flowing to slow/ ponded) | Dam construction | • Increase in habitat diversity.<br>• Likely increase in relatively still/low flow water level areas, which part of the pond fauna could potentially utilise.<br>• Braiding increases the lateral extent of usable habitat.<br>• Increased water temperature would likely benefit overall invertebrate diversity.<br>• Beaver dams retain sediment, pollutants and | • Operates against fast flow species, at least locally. The impact would be greatest on species such as net-spinning caddisflies (*Hydropsychidae*), and stoneflies (*Plecoptera*) which need fast and constant flow.<br>• Increased water temperature could have a localised negative impact on Odonata and freshwater pearl mussel.<br>• Increased sediment upstream of dams can reduce the survival of unionoid mussels' juvenile life stage. | • 53% of all Priority Species are associated with ponds with seasonally fluctuating water levels.<br>• Any local increase in water temperature resulting from these processes is likely to benefit overall invertebrate diversity, but have potential negative impacts on some groups.<br>• A change in the composition of bed material downstream of dams is likely to occur due to sediment being retained behind dams. These changes may also impact habitat diversity. |

| Invertebrates | | | | |
|---|---|---|---|---|
| **Activity** | **Mechanism** | **Positive effect** | **Negative effect** | **Notes** |
| | | nutrients so that water quality downstream is improved for species such as freshwater pearl mussels (*Margaritifera margaritifera*).<br>• Reduction in the amount of fine material deposited on bed sediment downstream of dams helps to maintain spawning redds for salmonids (important for freshwater pearl mussel). | • Reduction in turbulence upstream of dam, can decrease oxygenation of water. | • Fine-textured substrata typically reduce the availability of voids and consequently the abundance and diversity of benthic organisms in the hyporheic zone which can explain the lower abundance and diversity of Plecoptera, Ephemeroptera and Trichoptera at upstream sides of weirs (Mueller *et al*. 2011). |
| Impacts on movement of species | Dam construction | | Possible effect on freshwater pearl mussel if migration of salmonid hosts to spawning areas is prevented/inhibited by the presence of dams. | Freshwater pearl mussels are wholly dependent on the Atlantic salmon or brown trout to complete their life cycle. |
| Change in riparian habitat: opening of bankside tree canopy and increased patchiness | Felling | | Reduction in tree shading may increase thermal stress on freshwater pearl mussels and fish (particularly salmonids) and increase filamentous algae which bind and trap sediments, resulting in poor quality substrate for freshwater pearl mussels and fish. | • Most felling is likely within 10 m of the water's edge.<br>• Effects will depend on the nature of the changes, and the extent to which trees affected by beavers regrow. |

| Amphibians and reptiles | | | | |
|---|---|---|---|---|
| **Activity** | **Mechanism** | **Positive effects** | **Negative effects** | **Notes** |
| Dams/pond creation | Change from lotic to lentic habitat | • Increase in lentic habitat will benefit breeding amphibians, particularly common toad (*Bufo bufo*) (which has suffered recent declines in England).<br>• Potential suitable habitat for re-introduced pool frog (*Pelophylax lessonae*).<br>• Possible increase of aquatic invertebrate biodiversity with benefit amphibians. | None identified further to Scottish Review | |
| Dams/pond creation | Change in hydrological processes on riparian and downstream habitat | None identified further to Scottish Review | • Loss of formerly dry reptile habitats due to water level rise.<br>• Winter flooding mortality of hibernating reptiles, especially on well-established communal adder (*Vipera berus*) hibernacula. | |
| Other constructions | Creation of lodges, burrows, canals, etc. | • Lodge and dam structures will provide some benefit in providing shelter for amphibian and reptiles.<br>• Lodge and dam structures may provide shelter and breeding sites for grass snakes (*Natrix natrix*).<br>• Canals will provide additional habitats and function as movement corridors for emigrating | None identified further to Scottish Review. | |

| Amphibians and reptiles | | | | |
| --- | --- | --- | --- | --- |
| **Activity** | **Mechanism** | **Positive effects** | **Negative effects** | **Notes** |
| | | young with implications for survival to maturity and meta-population dynamics. | | |
| Other | | | Beaver impoundments and structures may provide a haven for invasive non-native species (e.g. freshwater terrapin and water frogs) | |

| Birds | | | | |
| --- | --- | --- | --- | --- |
| **Activity** | **Mechanism** | **Positive effect** | **Negative effect** | **Notes** |
| Felling | Change in riparian woodland: Change in relative abundance of different tree species. | | | Although a more diverse species mix could increase invertebrate diversity and availability thus benefitting insectivorous birds. |
| Dams/pond creation | Change in hydrological processes on riparian and downstream habitat. | The creation of new riparian wetland will boost nesting opportunities for many bird species. | | |
| Dams/pond creation | Changes in water quality downstream. | There may be beneficial impacts on prey species, e.g. freshwater invertebrates. | | |

| Mammals | | | | |
|---|---|---|---|---|
| **Activity** | **Mechanism** | **Positive effect** | **Negative effect** | **Notes** |
| Felling | Change in riparian woodland: opening of canopy and increased patchiness. | • Increase in herbaceous vegetation increases food sources for water voles (*Arvicola amphibious*).<br>• Increased heterogeneity leads to increase in biodiversity through more niche availability with cascading effects through trophic levels. | If openness becomes large scale, perhaps through combined effects of widespread flooding or deer (family *Cervidae*) browsing, then certain bat species preferring more sheltered closed canopy could be negatively affected. | |
| Felling | Change in riparian woodland: change in relative abundance of different tree species. | If neglected hazel (*Corylus avellana*) coppice is targeted by beaver, there could be a positive effect on dormouse (*Muscardinus avellanarius*) by increasing density of understorey and promoting re-coppicing of hazel. | There could be a negative effect on dormouse if hazel woodland is heavily targeted by beaver and deer, causing hazel to decrease in age class and abundance in the long term. | |
| Felling | Change in riparian woodland: change in age class of trees. | Likely to benefit many species of invertebrates, increasing food sources for small mammals and their predators. | Attracting deer and increasing the overall food source for deer could be undesirable if higher deer populations restricts regrowth of important woodland flora. | |
| Felling | Change in riparian woodland: amount/diversity of fallen dead wood. | Beneficial increase in deadwood invertebrates as prey for insectivorous small mammals and habitat structure for cover. Increase in terrestrial small mammals as prey for native | Increase in terrestrial small mammals as alternative prey for non-native mink. | |

| Mammals | | | | |
|---|---|---|---|---|
| **Activity** | **Mechanism** | **Positive effect** | **Negative effect** | **Notes** |
| | | mustelids and foxes (*Vulpes Vulpes*). | | |
| Felling | Changes in amount/diversity of dead wood in water courses | Beneficial for aquatic invertebrates and fish fry, as food sources for water shrew (*Neomys fodiens*), otter (*Lutra lutra*). | Increase in food sources also attractive to mink. | |
| Feeding - herbivory | Selective grazing on specific terrestrial herbaceous and aquatic plant species. | | Where vegetation species diversity is low, water vole could favour similar plant species to beaver. | Beaver and water vole have broad herbivorous diets so interspecific competition is likely to be low. |
| Dams/pond creation | Change from lotic (flowing) to lentic (still) habitat | • Overall positive effects at catchment scale as beaver activity increases heterogeneity.<br>• Creation of pond habitat will boost prey abundance for bat species, otter and potentially water shrew. | There may be localised negative effects on species dependent on faster flowing conditions. | Water shrew occupy lentic and lotic habitats, but beavers lead to overall increase in open water supporting prey for water shrew. |
| Dams/pond creation | Changes in standing deadwood resulting from inundation of trees. | May provide roosting opportunities for bats under dead bark and in holes and nesting opportunities for arboreal mammals e.g. pine marten (*Martes martes*), and nesting birds (prey for pine marten). At lower heights this also will apply to other small mammals e.g. yellow necked mouse (*Apodemus* | Inundation will prevent the growth of very large trees within the wetland, restricting this size class of deadwood. | Pine marten are very rare and restricted in distribution in England, so benefits to this species will be infrequent. |

| Mammals | | | | |
|---|---|---|---|---|
| **Activity** | **Mechanism** | **Positive effect** | **Negative effect** | **Notes** |
| | | *flavicollis*), providing hunting opportunities for stoats (*Mustela erminea*). | | |
| Dams/pond creation | Longer term successional changes after dam abandonment; infill of ponds and creation of beaver meadows. | Grazing opportunities for deer species, also possibly hare (*Lepus* spp.) and rabbit (*Oryctolagus cuniculus*). | Attracting deer and increasing the overall food source for deer could be undesirable if higher deer populations restrict tree regrowth. | |
| Dams/pond creation | Impacts on movements of species. | Beaver dams provide river crossing points for other mammals. | None identified further to Scottish Review | The River Otter Beaver Trial reported that the unevenness of beaver dams can enable fish to pass. |
| Dams/pond creation | Increase in transitional wetland and damp edges. | Damp ground increases soil-living invertebrate food sources earthworm, hoverfly larvae, molluscs, providing food for species such as badger (*Meles meles*), fox and hedgehog (*Erinaceus europaeus*). | Potentially undesirable for crops, farmland and amenity grasslands, and may encourage or increase populations of crop damaging species such as wild boar (*Sus scrofa*) and badger. | |
| Other constructions | Creation of lodges, burrows, canals, dams. | Canals can increase habitat heterogeneity in dense reeds, providing better hiding places for water voles from non-native mink. | None identified further to Scottish Review | |
| Predator/prey interactions | Beavers as prey or carrion. | | Beaver carcasses provide carrion for scavengers such as foxes. This may contribute to | Beavers as prey or carrion are expected to be have a minor effect |

| Mammals | | | | |
|---|---|---|---|---|
| **Activity** | **Mechanism** | **Positive effect** | **Negative effect** | **Notes** |
| | | | disease transmission to other mammal hosts, depending on pathogen. | on predator populations as this food source is already widespread. |

| Water management | | | | |
|---|---|---|---|---|
| **Activity** | **Mechanism** | **Positive effects** | **Negative effects** | **Notes** |
| Change in riparian woodland: Opening of woodland canopy and increased patchiness | Felling | Stabilisation of banks and reduction in erosion due to binding effect of bank and riparian species. | | |
| Change in riparian woodland: Change in age classes of trees | Felling | Possible eventual reduction in the size of wood entering watercourse, and therefore a change in the nature and scale of geomorphological change initiated. | Possible eventual reduction in size of wood entering watercourse, and therefore change in in-stream habitat structure provided, and nature and scale of geomorphological change initiated. | |
| Changes in amount/ diversity of woody material in watercourses | Felling and constructions | Increased number of wood jams, resulting in:<br>i. attenuation of flow and lowering of downstream flood risk;<br>ii. greater geomorphological, hydraulic and habitat diversity;<br>iii. improvement in water quality as fines settle in areas of slower flow. | Increased number of wood jams, increasing the risk of localised floodplain inundation and impacts on land use. | |

| | | | | |
|---|---|---|---|---|
| Change from lotic to lentic habitat | Dams/pond creation | • Increased flood storage, decreasing the risk of downstream flooding.<br>• Improvements in base flow during periods of low precipitation due to increased water storage.<br>• Phosphorous retention and nitrogen reduction. | | |
| Change in hydrological processes on riparian and downstream habitat | Dams/pond creation | Increased habitat and species diversity. | Increased flooding of riparian zone and beyond, with potential impacts on land use. | |
| Changes in water quality downstream | Dams/pond creation | Reduction in the amount of fine material deposited on bed sediment habitat, e.g. spawning redds are maintained, created and improved. | Reduction in turbulence upstream of a dam, decreasing the rate of water oxygenation. | |
| Longer term successional changes after dam abandonment e.g. beaver meadows | Dams/pond creation | • Reconnection of streams and rivers with floodplains, and therefore lateral extension of river corridors.<br>• Improvements in natural flood management. | | |
| Changes in baseflow/ groundwater | Dams/pond creation | Buffered baseflows in drought conditions and potential of increased groundwater within a catchment. | Localised wetting that may lead to change in surface vegetation. | |
| Indirect habitat creation/restoration initiatives as a result of beaver presence | Beavers used to promote opportunities for riparian and | Beavers may be used to promote river restoration projects (as well as contributing | | |

| | | | | |
|---|---|---|---|---|
| | freshwater habitat creation/ restoration | to low-cost restoration through their own activities). | | |

**Fisheries**

| Activity | Mechanism | Positive effect | Negative effect | Notes |
|---|---|---|---|---|
| Change in bankside habitat | Dam construction/tree felling | • Coppicing of bankside vegetation may open up new areas of riverbank for angling.<br>• Potential cost saving of managing bank side vegetation.<br>• Creation of wetland habitat and coppiced trees provide more opportunity for angling locations. | • Wetland creation may impact accessibility of fishing beats.<br>• Fallen trees may affect access to bank swims or block rivers. | |
| Change from lentic to lotic habitat (flowing to slow/ponded) | Dam construction | Potential creation of new fishery opportunities in small streams via the creation of ponds. | • Potential detrimental impact to migratory salmonid fisheries if changes to productivity and difficulty of migration result in fewer sea trout.<br>• Potential detrimental impacts to migratory salmonid fisheries if dams prevent/inhibit access to spawning tributaries and reduce abundance. | |

| Agriculture | | | | |
|---|---|---|---|---|
| **Activity** | **Mechanism** | **Positive effects** | **Negative effects** | **Notes** |
| Felling | Obstructions and damage from felled trees | | • Felled trees can damage farm infrastructure, e.g. blocking tracks, damaging fences, blocking drainage ditches.<br>• Increased operational costs to remedy impacts. | Felling is most likely to be limited to 10–20 m from the water course. |
| Feeding | Foraging on crops | | Beaver foraging (e.g. maize, potatoes, fruit trees) may cause a loss of crops and profit. | Foraging is normally limited to 10–20 m from the watercourse. Research indicates losses directly due to feeding are generally negligible. |
| Burrowing | Collapse of ground above burrows; erosion | | • Access by machinery may be impacted, affecting many agricultural operations. Health and safety risks to machinery operators.<br>• Some land may be made unusable, reducing total productive area.<br>• Risk of injury or death to livestock, if they have access to the riparian zone. | |
| Dams/pond creation | Change in hydrological processes and their impacts on riparian habitat | • Mitigation of diffuse pollution.<br>• Upstream water storage may help with irrigation for crops in dry periods.<br>• Sediment retained locally. Flood attenuation and sediment retention can benefit agricultural land downstream. | • Inundated land can prevent arable crops being sown and livestock from grazing.<br>• Where crops are already present, waterlogging inhibits plant development.<br>• Machinery access to crops may be limited, impacting most agricultural operations. | |

| Agriculture | | | | |
|---|---|---|---|---|
| **Activity** | **Mechanism** | **Positive effects** | **Negative effects** | **Notes** |
| Dams/pond creation | Increased disease risk | | Raised water levels on grazed pasture can pose a disease risk, particularly increasing susceptibility of cattle and sheep to liver fluke. | |

| Infrastructure and land use | | | | |
|---|---|---|---|---|
| **Activity** | **Mechanism** | **Positive effects** | **Negative effects** | **Notes** |
| Foraging | Tree felling | • Reduction of conservation network management.<br>• Improved biological networks.<br>• Increased resilience to drought, flood and climate change.<br>• Improvement of local, national and internationally designated wildlife sites and networks; potentially resulting in reduced investment in flood prevention and defence. | • Impacts on orchards, significant trees or features.<br>• Direct damage to infrastructure or assets e.g. roads, fence lines.<br>• Direct or non-direct impact to archaeological features or networks. | |
| Dam construction and deterioration | Inundation, blockage, increased woody material | • Improved water quality of water supply networks.<br>• Potentially smaller and less flood risk embankments in some locations due to slowing of flow and more attenuation upstream.<br>• Reduction in bed erosion.<br>• Reduction of instream maintenance needs. | • Increased risk of flooding to communities.<br>• Impact on effective functioning or structure of telemetry and gauging infrastructure.<br>• Direct or indirect impacts on assets though inundation, e.g. flooded roads, wetted areas and blocked field drains in low lying areas creating difficulty in water management. | |

| Infrastructure and land use | | | | |
|---|---|---|---|---|
| **Activity** | **Mechanism** | **Positive effects** | **Negative effects** | **Notes** |
| | | • Direct or non-direct benefit to archaeological features or networks. | • Direct impact through blockage of culvert or trash screen though increased debris or lodge or dam construction.<br>• Increased management and mitigation requirements to ensure effective water management.<br>• Direct or non-direct impacts to archaeological features or networks.<br>• Potential to burrow into and undermine embankments and reservoirs. | |
| Burrowing/canals | Erosion, collapse of burrows, earth lodges. | • Improvement of local, national and internationally designated wildlife sites and networks.<br>• Improved 'making space for water' and improved catchment function with consequential improvements for water management. | • Direct impact from burrow collapse undermining infrastructure or assets.<br>• Erosion leading to undermining of infrastructure or asset, or affecting function of an asset through breaching or inundation or undesirable connectivity of areas with controlled water management e.g. Internal Drainage Boards.<br>• Direct or non-direct impact to archaeological features or networks. | |
| Burrowing/canals | Inundation, undermining of infrastructure | • Improvement of local, national and internationally designated wildlife sites and networks.<br>• Potential to improve natural flood management through | • Impact on telemetry and gauging measurements.<br>• Undesired connectivity of water management channels. | |

| Infrastructure and land use | | | | |
|---|---|---|---|---|
| Activity | Mechanism | Positive effects | Negative effects | Notes |
| | | complex wetland habitats slowing flow and attenuating water. | | |

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