REVIEW OF EVIDENCE OF INTERACTIONS BETWEEN BEAVERS AND FISH AND FISHERIES IN ENGLAND AND WALES

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Summary

In recent years, beavers have been reintroduced into the UK, mostly in enclosed (fenced) environments. Several 'wild' populations have also established, including one in the River Otter in Devon, which is being used as a trial to assess the likely impacts (positive and negative) on riverine ecosystem functioning and biodiversity. There are concerns, however, that the River Otter trial is too narrow in scope to provide robust evidence to inform decisions on further reintroductions, especially into the wild. The aims of this review are to:

- re-examine the evidence base on the scale and intensity of impacts from beaver reintroductions on river ecosystems, and specifically on fish and fisheries;
- review evidence from the River Otter Beaver Trial and associated studies to understand the impact of beavers on fisheries under 'wild' conditions;
- provide conclusions and recommendations about the potential impact of beavers on fish and fisheries with particular reference to UK rivers.

A review of the literature and other materials related to beaver reintroductions, with specific reference to fish and fisheries, was carried out. There is considerable emphasis in the literature and media on the positive benefits that beavers can bring to aquatic ecosystems and biodiversity, but the reintroduction of beavers can also cause a number of potential problems, such as disruption to fish migration and fish recruitment, damage to trees, loss of agricultural production, and damage to banks and other infrastructure, with concomitant impacts on biodiversity, stakeholder conflicts and management costs. The fish and fisheries problems mainly occur because of construction of dams that impede fish migration and flood spawning and nursery habitats. It also appears that most of the costs associated with dealing with the impacts of beavers are borne by the stakeholder, including land/riparian owners, fishery owners and river conservation bodies.

The River Otter Beaver Trial [ROBT] studies, which ran for 5 years, provided considerable information on changes in the distribution of beavers in the catchment over the study period and into the future, and illustrated the benefits, in terms of nature-based solutions to flooding and to biodiversity, arising from construction of dams. Emphasis was put on benefits from beavers to the rural economy and ecotourism and less on the impacts of beaver activities on agriculture, fisheries and property. Unfortunately, the **5 year timeframe of the study was insufficient to understand the full implications of reintroducing beavers into open catchments.**

In particular, the evidence collected on the interaction between beavers and fish and fisheries was limited, and lacked the rigour expected of a robust impact assessment, and in some cases was only based on observation data, especially movements of fish past dams. The fisheries surveys focussed on a single dam structure on the River Tale over a four-year period and only one survey on the main River Otter in 2015, despite considerable beaver activity in this latter zone of the river. The findings of the fisheries surveys were largely inconclusive. The ROBT fisheries studies should have, at minimum, examined the fish population/community dynamics above and below a range of dams in different locations and used control reaches to account for variability in the impact of dams between different river types. **It is also important that future studies on the impact of beavers on fish and fisheries cover areas where beavers are active not just where dams have been constructed**, i.e. in the main river channels and lower reaches of larger tributaries.

Studies on fish migration were also inconclusive and based on videos of five adult sea trout passing one structure under what appear to be optimal hydraulic conditions. To address the conjecture surrounding fish migration past beaver dams, which must include both up and downstream movements, **there is a clear need for more robust studies on the barrier effects and otherwise of**

beaver dams on fish migration and recruitment processes. Further, the coarse resolution rapid barrier assessment tool developed within the project is limited in scope and needs to be field tested for validity with a range of dams in different water courses, and with a range of migratory species, before any confidence can be placed in its application. Thus, **before any definitive conclusions can be drawn about passability of beaver dams, fully funded research, including telemetry studies, on a range dam types, including cascades of dams, and for a full range of species, must be undertaken.**

Although studies were carried out to assess the ecosystem services provided by beavers, the cost-benefit analysis was not fully balanced against the impacts on other services delivered by water courses, the economic losses encountered by these services; nor have the values of disservices or costs of remediation and mitigation measures been fully discounted. **Robust impact assessments and risk analyses across a range of rural and urban catchments are needed before further beaver reintroductions are considered, especially into open systems. Further, a risk-based framework to support decisions on whether beavers should be reintroduced into target catchments is required. The outputs should be reviewed by an independent panel with a balanced membership representing all sectors of society and expertise.**

A number of mitigation and management measures were found in the literature and proposed and tested in the ROBT Science and Evidence study to address problems arising from beaver activity. Most of the potential negative effects of beavers on fish are related to dam construction, but these dams may be difficult to modify or destroy because of the beavers' inherent response to rebuild them. Other measures related to flow management ('beaver deceivers') require rethinking as they could potentially exacerbate problems with fish migration.

A hierarchical framework was developed within ROBT to enable decisions on when and how to control beaver activities in line with legislation. Unfortunately, there appears to be no quantitative criteria on which to base decisions to upscale the actions from mitigating beaver activity to reducing their numbers, should they become a nuisance. **This is a fundamental weakness in the derogation process and needs to be resolved before further introductions into open systems are permitted. There is a fundamental requirement for a multi-sectoral review of the issues and an impact/resolution matrix needs to be prepared to support management decisions** on the reintroduction of beavers under different scenarios, to account for variability in catchment topography and ecosystem functioning, as well as fish community structure and dynamics.

Further issues that need consideration are supporting the costs of compensation for physical damage and costs of mitigation or control, which can be substantial. Currently these costs tend to fall on the landowner, farmer or stakeholder impacted. As beaver populations grow and disperse widely, mitigation and control costs are likely to rise and the issue of who pays will increase. **One possible solution may be to internalise costs from those benefiting from the presence of beaver to support a funding mechanism. Evidence from elsewhere suggests these costs can be and must be formalised at the onset of any derogation to reintroduce beavers. One possibility to ease this potential bottleneck is to devolve responsibility to landowners or authorised persons to control and manage beaver populations similar to the strategy used to control deer in the UK.**

In conclusion, based on the review of potential interactions between beavers and fish and fisheries, and on the current science and evidence available, further reintroductions of beavers into the wild should not take place until the recommendations made herein have been fulfilled. Once these knowledge gaps have been filled and management issues resolved, it may be possible to find solutions that would allow further controlled introductions of beaver, where their location, activities and numbers can be managed to curtail any damage to fish and fisheries or other economic or social sectors.

1 Introduction

1.1 Context

The EC Habitats Directive requires the UK to consider the re-introduction of beaver to England where it was last recorded as being present in the 16th Century. There have been a number of trial introductions and escapes of Eurasian Beaver, *Castor fiber,* in the UK. Many of the trials are in relatively small, enclosed areas, especially in England, and there has been an extensive colonisation event in the River Tay catchment in Scotland. In England, there is one unenclosed catchment trial on the River Otter in Devon managed by Devon Wildlife Trust (DWT) and part-funded by Defra. The Otter population is the result of an unlicensed introduction to the catchment around 2014 and further licensed introductions in 2016. It was anticipated that the results of this trial, due to end in March 2020 but granted a six-month extension until the end of August, would be an important factor influencing Defra policy on future regulation of beaver management. But on 6 August 2020, Rebecca Pow, the Environment Minister, announced that beavers on the River Otter can remain[1].

The decision to allow the reintroduction of beavers was based on a Science and Evidence Report from the River Otter Beaver Trial (Brazier et al. 2020) submitted to the Minister with a covering letter from DWT and an earlier proposed Management Strategy Framework, amongst other evidence. Defra indicated the five-year project by DWT to study the role of the beavers on the River Otter – which concluded in August 2020 – found that "beavers can help reduce flooding through dam-building, improve water quality, create habitat for other wildlife, and boost the local economy through eco-tourism[1]".

Notwithstanding, Natural England is currently analysing the results of the River Otter Beaver Trial along with a range of other experiences with beavers across the UK and in other countries, to help inform decisions on the status of beaver in England, including potential management and licensing approaches.

Six organisations - Salmon & Trout Conservation, Game and Wildlife Conservation Trust, Angling Trust, South West Rivers Association, River Otter Fisheries Association and Atlantic Salmon Trust - are concerned the decision was "too narrow and flawed in a number of aspects[2]" and wish to ensure that future decisions on beaver management are informed by the best available evidence on the potential impact of climax beaver populations on freshwater and salmonid fisheries, the importance of which is reflected in the Environment Agency's statutory duty to '*...maintain, improve and develop salmon, trout, eel and freshwater fisheries'*. This need to understand the impact of beavers on aquatic ecosystems is crucial because migratory salmonid stocks (Atlantic salmon and sea trout) in the UK have declined markedly since the late 1990s and populations are under considerable threat of local extirpation (NSACO 2019; ICES 2020). To this end, the six organisations have funded this independent review of beaver-fish-fisheries interactions and the River Otter Beaver Trial Science and Evidence Report. In this context 'fish and fisheries' includes all fish populations

[1] https://www.gov.uk/government/news/five-year-beaver-reintroduction-trial-successfully-completed
[2] https://anglingtrust.net/2020/08/06/whats-the-rush-minister-decision-that-beavers-can-stay-on-river-otter-taken-too-early/

and communities, and the socio-economically valuable angling they support.

The aims of this review are to:

- re-examine the evidence base from the UK and elsewhere in Europe and North America to determine the scale and intensity of impacts from beaver reintroductions on river ecosystems (structure and functioning), and specifically on fish and fisheries supported by them;
- review the evidence from the River Otter Beaver Trial and associated studies, together with supplementary information gathered for the River Otter, in terms of understanding the impact of beavers on fish and fisheries under uncontrolled, 'wild' conditions;
- provide conclusions about the information reviewed and the potential impact of beavers on fish and fisheries with particular reference to UK river systems to inform decisions on the potential management and licencing of beaver introductions in England.

This review specifically examines the interactions between beavers and fish and fisheries, and not other biological elements of the ecosystem, such as birds, mammals, invertebrates, although information is drawn from studies on these species groups where appropriate.

1.2 About the author

Professor Ian G. Cowx received his BSc Hons in Zoology specialising in Freshwater Fisheries from the University of Liverpool and PhD on Management and Ecology of Fish in the River Exe from the University of Exeter. He was subsequently employed as a Fisheries Biologist with Severn Trent Water and Senior Lecture in Fisheries studies at Humberside College of Higher Education before moving to the University of Hull in 1989. Professor Cowx is Director of the University of Hull International Fisheries Institute, Hull UK and Adjunct Professor at Michigan State University, USA.

He has extensive experience in management strategies for freshwater ecosystems in both developed (UK and mainland Europe) and developing (Africa and Asia) countries and considerable consultancy and research experience in rehabilitation techniques for freshwater fisheries, impact of invasive aquatic species, impact of water resource management and droughts on UK rivers and integrated aquatic resource management planning and environmental impact assessment, particularly associated with water resources development schemes. He has carried out reviews on the impact and management of non-native species for the European Union and GB non-native assessment group, as well as the impact of cormorants on fisheries for Defra and the European Parliament. He is currently working on the impact of climate change and hydropower dam development on freshwater fisheries both in Europe and the lower Mekong Basin. In addition, Professor Cowx has taught undergraduate and postgraduate courses on Fisheries Ecology, Inland Fisheries Management, Fisheries Resources, and Aquatic Ecology.

He has worked for a wide range of clients including the European Commission DG Fish and DG Environment, The European Parliament, UK Department of the Environment and Rural Affairs, World Bank, GEF, United Nations Food and Agriculture Organization [FAO], UNDP, DANIDA, Mekong River Commission, UK Department for International Development (DFID), Environment Agency, UK water companies and numerous national governments and consultancy companies.

He is the Editor in Chief of Fisheries Management and Ecology, a fellow of the Institute of Fisheries Management and a Chartered Environmentalist. In 2012 he was recipient of the International Fisheries Science Prize in honour of life time contribution to fisheries science and conservation (an awarded endowed only once every 4 years by World Council of Fisheries Societies) and was awarded an Honorary PhD from Michigan State University (USA) for services to Inland Fisheries. In 2008 he won the American Fisheries Society award for outstanding contribution to international inland fisheries management, and in 2015 the Fisheries Society of the British Isles Beverton Medal for contributions to fisheries science.

2 Review of beaver-fish interactions

2.1 Methodology

A comprehensive review of the peer-reviewed literature and other materials related to beaver introductions, with specific reference to fish and fisheries, was carried out to update the reviews of Collen and Gibson (2001), Rosell et al. (2005), Kemp et al. (2012), Jones et al. (2012), Campbell-Parker et al. (2016), Stringer & Gaywood (2016) and Ecke et al. (2017). The review used the following methods to obtain information:

- Electronic search engines such as Web of Science (WoS), Google Scholar and Scopus. These provided a comprehensive list of available material since 1950, with JStore providing access to literature prior to 1989.
- Requests for information, particularly in the grey literature, were made through an extensive network of experts involved in inland fisheries in Europe and N. America, and specifically through the EIFAAC and INFish networks.
- Identification of local operational investigations and national projects undertaken by conservation agencies and other programmes that are pertinent to delivering the outputs of this review.

The electronic literature searches used keywords (or Boolean derivatives) that are found under the extended keyword list available in WoS, including: *angling; beaver; Castor fiber; freshwater OR inland fish*; environmental impact; recreational fish*; "fisheries management"; mortality; migrat*; dam*; barrier**. The searches then used the snowballing strategy to pick up non-indexed sources of literature, especially grey literature. The closely related North American species, *Castor canadensis*, has also been studied extensively and relevant information on its impact on fisheries was explored for commonalities.

The information has been consolidated into a review that summarises relevant information and comprises two components: i) Review of beaver-fish-fisheries interactions; and ii) Assessment of potential mitigation and management options and further R&D. The intention is not to review all aspects of beaver ecology and impacts, and repeat previous comprehensive reviews, but to focus on specific issues related to the potential interactions of reintroducing beavers into UK water bodies on fish and fisheries, including their habitats.

2.2 Review of beaver fisheries interactions

As of 10 November 2020, there were 796 publications reported in WoS with the basic search term "fish* AND beaver*", notably from the North America, and eastern and northern Europe. This is supported by numerous reports in the grey literature and reports in relation to proposals to introduce beavers into Scotland[3] and Wales[4]. Further, the web site of the Beaver Advisory Committee for England (BACE)[5] provides a comprehensive list of relevant literature. Whilst many of the references were not directly relevant they were

[3] https://www.nature.scot/professional-advice/safeguarding-protected-areas-and-species/protected-species/protected-species-z-guide/protected-species-beaver/beavers-scotland
[4] https://www.welshbeaverproject.org/home/
[5] https://beaversinengland.com/bibliography/

scanned and the most pertinent were read for primary information. This information was consolidated into a number of topics related to beaver fisheries interactions that are illustrated in the bowtie analysis in Figure 2-1 and summarised in

Table 2-1. This analysis shows the main issues arising from the reintroduction of beavers in terms of impact on the ecosystem and fisheries (cause) highlighted in the lower part of the bowtie, and the possible responses on the ecosystem and fisheries (effect) in the upper part of the bowtie (Figure 2-1). These issues are subsequently explored in more detail in the following sections.

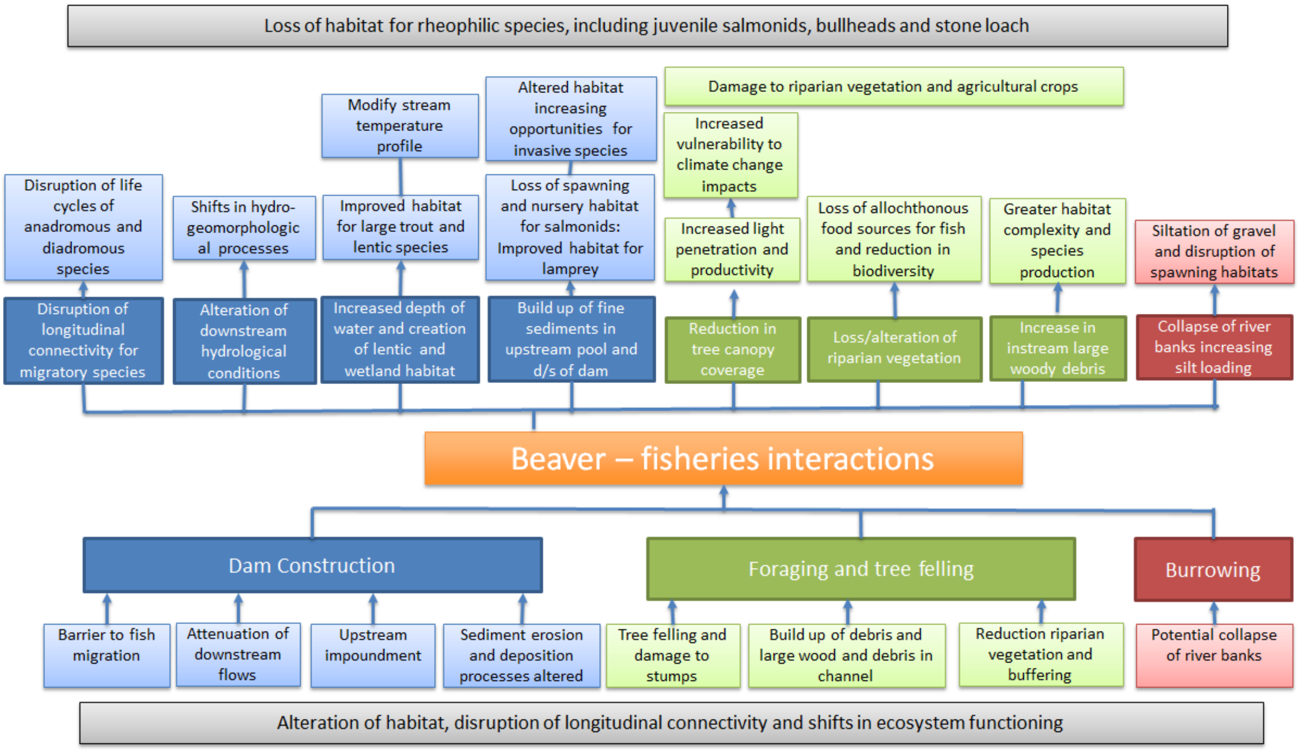

Figure 2-1. Main issues arising from the reintroduction of beavers in terms of impact on the ecosystem and fisheries (cause) highlighted in the lower part, and possible responses (effect) in the upper part. Lower and upper grey bars give the overall cause-effect.

Table 2-1. Summary of potential beaver-fish interactions relating to specific activities (adapted and updated from WTT and Collen & Gibson, 2001)

Beaver activity and outcome	Positive effects on fish and fisheries	Negative effects on fish and fisheries
Felling of trees and shrubs		
Changes to riparian woodland and bankside cover, shifting of riparian tree species composition, opening up the canopy and increasing canopy patchiness	• Increased light penetration may lead to increased primary production within rivers and ponds. Increased primary productivity and temperature may increase production of macroinvertebrate prey items for fish, potentially leading to greater fish productivity rates. • Increased light may lead to the establishment of instream macrophyte communities creating complex habitats that offer shelter to some fish species (e.g. pike, perch, roach & sticklebacks) but also colonization by non-native species. • Penetration of light to the riparian zone may result in the development of plant communities that will stabilise banks, reduce erosion and provide increased opportunities for greater terrestrial input of food items for fish.	• Reduction in shading has the potential to increase water temperature and result in increased thermal stress on some fish species, particularly salmonids – this is particularly relevant in the face of climate change scenarios. • Change in riparian canopy can result in reduction in quantity and/or quality of terrestrial material (principally leaf litter) may lead to a reduction in macroinvertebrate diversity, and reduction in quantity of terrestrial (invertebrate) prey items (that are a major food source of salmonids) that enter the aquatic environment. • Shift in fish species composition towards non-salmonid species which have a higher tolerance to lower dissolved oxygen concentrations (such as cyprinids and sticklebacks) • Increased instream plant growth may block rivers and cause upstream flooding and loss of connectivity for fish during the summer months (Note: increased plant growth may require intervention to control). • Elevated temperatures can contribute to reduced dissolved oxygen in some circumstances. This may be unfavourable for some fish species (such as salmonids). NOTE: Tree-felling may impact on tree-planting restoration activities that are being undertaken, particularly where little natural tree cover remains.
Changes in the amount/ diversity of woody material in watercourses	• Greater quantities of large wood in rivers and ponds can increase habitat diversity, availability of prey items, and fish cover. • Possible increase in terrestrial invertebrate prey entering the aquatic environment.	• Possible reduction in the size and quantity of large woody material entering the watercourse in the longer term may affect in-stream habitat structure, and this may adversely affect some fish species. • The establishment of large log jams could temporarily hinder the movement of some fish species if they act as barriers. • Large quantities of large and small wood items may result in blockages that effect the transport of coarser sediments.

Feeding on specific terrestrial herbaceous & aquatic plant species.	• Changes to aquatic macrophyte community structure may favour some species of non-salmonid fish and their prey.	• Decrease in macrophyte species in may have a negative impact on species that depend on them for food or shelter, e.g. pike use emergent macrophytes as cover during feeding and cyprinids use macrophytes as refugia from predation or during high flow events. Recruitment of some species, e.g. perch, which lay eggs on aquatic macrophytes may be impaired. Salmonids are rarely associated with macrophytes. • Altered riparian vegetation may allow invasive plant species to proliferate. • Loss of trees and large shrubs may all scrub plant material to proliferate and change may result in reduction in quantity and/or quality of terrestrial material into the river. • Change in riparian vegetation may reduce capacity to regulate sediment and nutrient run-off into river.
Construction of dams		
Change of upstream habitat from flowing to stillwater system.	• Increase in habitat diversity, which may favour some fish species or fish life- stages. In some situations this may also result in an increase in species richness of both fish and invertebrate prey items, particularly lentic species such as minnow. • Increased temperatures, changes in habitat availability and feeding opportunities in stillwater habitats may result in increased individual growth rates, fish condition and overall production. • Pond offers depth water habitat that is occupied by larger trout and proliferation of lentic species such as minnow or roach and predatory species such as pike.	• Increase in habitat diversity for fish may favour some species over others, especially non-native species, or benefit only some life stages (e.g. juvenile or adult fish). • Depending on location, the creation of lentic habitats may result in habitat loss for species that favour flowing water habitats. • Loss of spawning habitat for rheophilic species. • Accumulation and smothering of substrate upstream of dams, reducing habitat quality and preventing spawning for some species (principally salmonids). • Reduction in flow may occur upstream of dams, resulting in a reduction in dissolved oxygen and increase in water temperature. • Possibility of increased opportunities for fish predators (e.g. goosander, cormorant, otter, mink) and poachers. • Increased opportunity of invasive species to colonise altered habitat.
Change in hydrological processes on riparian & downstream habitat	• Reduction in the transport of fine material may improve the quality of spawning and rearing habitats downstream of any impoundment. • Impoundments may create low- and high-flow refuges for fish. • Flooding of riparian and wetland	• Changes in flow may result in starvation of gravel for downstream spawning areas. This can affect both salmonids and spawning lamprey. • Reduction in flow downstream of the structure may result in a reduced wetted width and a loss of juvenile

	habitats can provide spawning opportunities for species such as pike and additional habitat for species such as eel and lamprey ammocetes.	fish habitat. • Attenuation of flows may reduce capacity of flow to clean gravels downstream of dam.
Creation of barrier	Moderates upstream movement of invasive species.	• Prevention of the free movement of fish to all habitats required during their life cycle. This is particularly relevant during key migration periods (such as spawning migrations), but also at other times. • The scale of impact may be greater for species that have a limited ability to overcome in-stream obstacles, such as lamprey and cyprinids.
Changes in water quality downstream	• Reduction in the amount of fine material deposited on the stream or riverbed downstream of the impoundment. This may result in an improvement in the quality of gravel spawning areas (downstream) for salmonids and lamprey. • Trapping finer sediment and associated nutrients and contaminants improving water quality downstream, although the relatively temporary nature of beaver dams would suggest this retention of contaminants is also temporary. • Accumulation of fine sediments may increase the volume of available habitat for lamprey ammocetes.	• Breaching of dam may deposit high volumes of fine sediments and contaminated materials downstream. • Potential warming of water in impounded area may raise downstream water temperature which could affect fish survival, especially of salmonids.
Other constructions - creation of lodges, burrows, canals	• Indirect habitat creation/ restoration initiatives as result of beaver presence. • Beaver used to promote opportunities for riparian and freshwater habitat creation/ restoration. • Presence of beaver may act as an incentive for greater investment, management and monitoring. This could include those related to the restoration and management of riparian woodland.	• Beaver habitats (impoundments and flooded wetlands) may benefit Invasive Non-Native Species such as skunk cabbage or signal crayfish, if these are present within the catchment. • Beaver tunnelling causing collapse of river banks and increased sediment loading. • Beaver presence may impact on fish-related riparian woodland restoration activities.
Direct beaver-human interactions		
Beaver attacks	•	• People and pets attacked by aggressive beavers defending their territories • More prominent during night fishing
Disease transmission	•	• Beavers transmit *Echinococcus multilocularis*, which can have serious human health implications.

2.2.1 Distribution of beaver in Europe

At the beginning of the 20th Century, the number of beavers found across Europe was at an all-time low of about 1000 individuals. In recent years, the EU Habitats Directive has encouraged the reestablishment of extirpated species "where feasible". Eurasian beaver is currently listed as an Annex IV species and an Annex III species of the Bern Convention, and thus would contribute towards fulfilling this policy.

Beavers have been reintroduced to many countries on mainland Europe since the 1970s (Halley & Rosell, 2002), and are now found in 24 countries (Figure 2-2) where they were formerly extirpated (Wróbel 2020; Halley et al. 2020). Their numbers are estimated to be around 639,000 individuals.

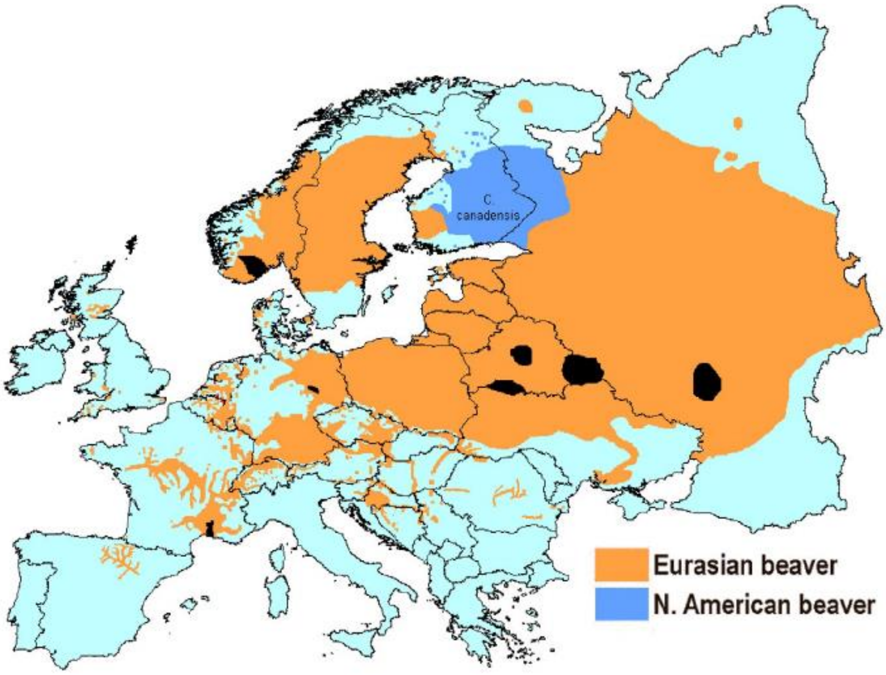

Figure 2-2. Beaver distribution in Europe in 2020 (source: Halley et al., 2020). Relic populations are marked in black: 1 *Castor fiber*; 2 *Castor fiber albicus*; 3 *Castor fiber galliae*; 4 *Castor fiber belarusicus*. Red shading represents the present range of Castor fiber. Blue shading represents the range of *Castor canadensis*.

2.2.2 Distribution of beaver in the UK

There are two distinct beaver populations in Scotland: one in Knapdale in Argyll, and a second in Tayside and Forth (Gaywood et al. 2015; Halley et al., 2020). Beavers were first introduced into Knapdale under licence as part of the Scottish Beaver Trial in 2009. They were introduced as a time-limited, naturally contained trial population for scientific monitoring, rather than a founder population for a long-term reintroduction (Gaywood et al. 2015). The population has been reinforced in subsequent years and there are currently four family groups. The Tayside beavers were first recorded around 2006 and thought to have originated by either escape from captive collections or unauthorised releases (Gaywood et al. 2015; Gaywood 2018).

Beavers have been reintroduced into enclosed areas across England and Wales since 2002 (**Figure 2-3**), including the River Tamar in Devon, Spains Hall Estate, Finchingfield Essex, Ham Fen near Sandwich, Kent, Wild Ken Hill, Norfolk, the Forest of Dean, Gloucestershire, Holnicote in Somerset and Cropton Forest on the North York Moors, Yorkshire (Halley et al. 2020). Several of the beavers introduced into these locations have been transferred under licence from the Tayside population. The aims are to improve biodiversity and help to reduce local flood risk as part of a new approach to flood prevention. A wild population of unknown origin (although the genetic analysis suggests they are Bavarian or Baden-Württemberg stock: Campbell-Palmer et al. 2020) has been living on the River Otter in Devon, south-west England, since at least 2008 and other populations have been reported living wild on the Tamar River, the Kent Stour, the Wye on the Welsh border, and in the Somerset levels (Swaile et al. 2018). Breeding has been confirmed in the River Otter beaver population from 2014. Critically, the location of beaver reintroductions to date and those proposed mostly overlap with fish habitats dominated by salmonids (see **Figure 2-3** right panel).

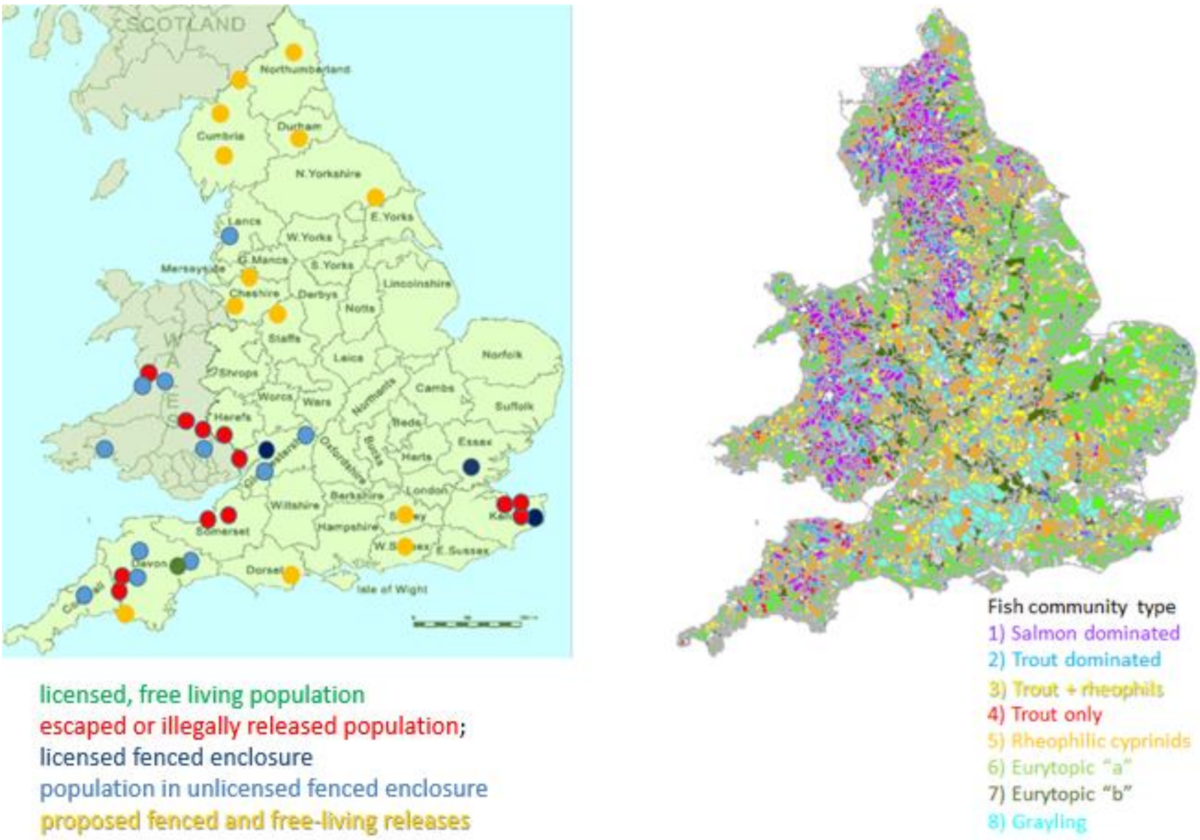

Figure 2-3. Left: Distribution of beaver populations in England and Wales: colour coding indicates release strategy (Source: Swaile et al. 2018). Right: Predicted fish community types in England and Wales: colour coding represents fish community type (after Noble & Cowx 2007)

This overlap in distribution of beavers and salmonid communities is of concern because Atlantic salmon populations are in severe decline across the UK and Europe (NASCO 2019). The latest estimates indicate UK spawning population sizes (ICES 2000) are about 50% down on the ten-year average. Many rivers across the UK are failing to meet their salmon spawning targets to sustain populations, and there is considerable effort to reverse this current situation. The populations are under pressure from an array of marine and freshwater environmental and habitat changes, as well as, but to a much less extent nowadays, exploitation, but obstructions to migration are a key impediment (ICES 2020). This issue is slowly being addressed across Europe and North America through fish passage easement projects at major artificial barriers (NASCO 2010; see EU AMBER project[6]). The addition of new barriers to migration created by beaver dams is the antithesis of this initiative to open rivers to free movement for migratory salmonids.

Currently there are proposals to reintroduce beavers to other parts of England, including Cumbria[7] and the western parts of Wales[8], again mostly overlapping with migratory salmonid fish communities. Natural England is reviewing evidence from the River Otter Beaver Trial and elsewhere, and will make a recommendation on the desirability of further reintroductions in the future, but in the meantime illegal introductions are being made, for example in the River Dyfi, in Wales.

2.2.3 Ecology of beavers

Beavers are large, semi-aquatic rodents that can weight up to 35 kg. Beavers are highly territorial and form family groups of 3 to 5 individuals, typically comprising the adult pair, kits under one year of age and sub-adult siblings before they disperse to form new territories (Rosell & Thomsen 2006). Beavers are found equally in riverine watercourses and lakes of various types (Bashinskiy 2020). Territories can occupy stretches of river or lake bank up to 13 km long, but are usually considerably less in high quality habitat. For example, mean territory length in Norway is about 4 km of water bank (Campbell et al. 2005), 1.8 to 4.7 km in Knapdale (Scottish Beaver Trial; Harrington et al. 2015) and, somewhat less at 2.9±1.5 km in the open population on Tayside (Campbell et al. 2012). Counting these beaver territories is the standard method for reporting beaver population size, rather than attempting what is considered a difficult task of counting the actual number of individual animals.

Beavers are largely restricted to freshwater and associated riparian habitats, including mainstem and tributaries of rivers, agricultural ditches and lakes, the latter of which are often overlooked (Campbell-Palmer et al. 2016). They prefer areas where broadleaf woodland and scrub are present. Beavers fell trees (estimated up to 200 per annum per beaver), including many with large diameter trunks, sometimes away from the associated water body (Reynolds 2000, Rosell et al. 2005; Jones et al. 2012). They can also damage the bark on much larger trees, e.g. oak and beech, eventually killing the tree. They build lodges from piled logs and tree branches or burrow into river banks. Where the streams and rivers are shallow and narrower, they construct dams mainly across the channel with tree trunks, branches, mud and stones, although they will also build dams across wetlands and construct channels into the riparian zone (see Section 2.2.4). The dams are constructed to raise and maintain the water levels above the entrances of their lodges or burrows, afford protection from predators, but also assist the movement of large tree branches and vegetation for overwinter food. European beaver (*Castor fiber*) do not construct dams to the same extent and scale as the North American species (*Castor canadensis*), largely because of the different landscapes

[6] https://amber.international/deliverables-2/
[7] https://www.bbc.co.uk/news/uk-england-cumbria-51111811
[8] https://www.welshbeaverproject.org/downloads/

and river topography.

It is widely acknowledged that beavers are herbivorous and feed on a wide diversity of aquatic plants and terrestrial herbaceous and broadleaved woody vegetation (Haarberg & Rosell 2006; Nolet et al., 1995; Severud et al., 2013), but see commentary below. During the autumn and winter they mostly consume tree bark, twigs and leaves, with a preference for willow (*Salix* spp.), ash (*Fraxinus excelsior*), rowan (*Sorbus aucuparia*) and hazel (*Corylus avellana*), and woody stems <0.1 m in diameter (Reynolds, 2000; Elmeros et al., 2003). These trees are well adapted to the coppicing effect of beaver foraging and will potentially rapidly regenerate (Jones et al. 2009). There are some potential benefits of this activity in opening out the riparian zone and creating diversity of habitat, but once coppiced the tender shoots are vulnerable to other wildlife such as deer that graze them and ultimately kill the trees. Other trees are less tolerant to beaver foraging, such as black poplar and oak, which are slower growing and do not regenerate quickly, if at all. This felling of, and damage to, trees also conflicts with agri-environment schemes to plant trees[9] and Defra's recommendations on buffer zones along rivers (Stutter et al. 2020[10]). They suggest 3-dimensional (3D) buffer zones working above and below the ground will tackle pollution pathways more effectively, including surface run-off, subsurface flow and gaseous exchanges with the atmosphere. This requires buffer zones up to 10 m wide that are planted with trees to enhance the root structure. This will probably not be practical where beavers are resident.

During the summer, a high proportion of the diet consists of herbaceous vegetation, such as grasses, sedges, and aquatic and semi-aquatic plants, such as saw sedge (*Cladium mariscus*) and common club-rush (*Scoenolpectus lacustris*). Beavers are known to establish territories close to agricultural crops such as maize to benefit from this abundant food source.

Although beavers have a preference for foraging on soft wood trees and shrubs, one aspect that has not been well studied, which is especially relevant to wild, open populations, is what vegetation beavers feed on if their preferred vegetation species are not abundant or depleted. This can have significant effects of the landscape if the trees regenerate slowly and potentially change the river form and function, and possibly lead to increased erosion of fine sediments where riparian vegetation buffer zones are depleted. Further the change in the riparian vegetation community structure can leave the opportunity for invasive plant species, such Japanese knotweed and Himalayan balsam to colonise and dominate, causing a different array of problems (Jones et al. 2012).

Another issue that that is critical when introducing or reintroducing animals and plants is transmission of diseases and parasites or other species piggy-backing on the target species. There is a risk of one such parasite, the tapeworm *Echinococcus multilocularis*, being introduced into the UK with beavers (Campbell-Palmer et al. 2015). The life cycle of *Echinococcus multilocularis* involves a carnivore such as a fox (or a domestic dog) as the definitive host and usually a rodent, such as a vole or a beaver, as a secondary host. Other animals and humans can be infected by ingesting eggs of the parasite, thus it potentially represents a serious threat to human health. Care must therefore be taken to avoid

[9] https://www.gov.uk/government/news/government-launches-new-scheme-to-boost-tree-planting
[10] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/928121/3D_buffer_strips___designed_to_deliver_more_for_the_environment_-_report.pdf

introduction of diseases and in particular *Echinococcus multilocularis,* because of the serious consequences of infection, Although Girling et al. (2019) considered the risk of introduction low because all beavers should be certified clear of *E. multilocularis* on reintroduction, there is the possibility they can become infected post-introduction, as seem to have occurred in Switzerland where free-ranging beavers were found to be infected for the first time in 2002, well after their reestablishment (Janovsky et al. 2002).

Beavers have also been found to harbour *Leptospirosis*, which causes the potentially fatal Weil's disease in humans. Leptospirosis has wiped out whole families of beavers in Switzerland and have been suggested as a possible cause of human infection. Beavers may also harbour other diseases, including: *Tuberculosis, Salmonellosis, Pasteurellosis, Coocidiosis* and *Toxoplasmosis*, but these are of 'less concern' because they are either: rarer, less problematic to humans, or beavers are just one source amongst many (Girling et al. 2019).

It should also be noted that a species of beetle *Platypsyllus castoris,* known as the beaver beetle, was found on a wild-born female beaver kit trapped at the Knapdale reintroduction site in Scotland (Duff et al. 2013). This non-native beetle species must have been introduced with beavers brought to Scotland from, probably, Norway in 2009-2010, but was not detected in health checks prior to release (Goodman undated). It appears the infestation caused distress to the infected beaver.

Footnote:

Having acknowledged that beavers are herbivorous, there is some misconception with the various actors in the beaver debate that beavers do eat fish. ROBT (Brazier et al. 2020) examined the source of this confusion and asked a range of stakeholders (n = 2338) what they thought were the main items making up the diet of beavers. The averaged response was that ≈ 80% of the diet was contributed by vegetation and the remainder was made up mostly of fish with minor contributions of invertebrates, small mammals and birds. Interesting, the fisheries stakeholder group was amongst the lowest that thought fish were part of the diet (contributing less than 10% of the diet). Reasons why this misconception arises were not explored but the confusion may arise because people assume that the diet is similar to that of other larger aquatic mammals like otter and mink that certainly do eat fish (Almeida et al. 2012; Britton et al. 2006). In addition, videos on social media (*https://www.youtube.com/watch?v=ES0YQyqv4O0*) provide some evidence that beavers are not wholly vegetarian and gives some credence to the 'myth' and they may feed opportunistically on probably dead fish. It is clear, however, they do not catch or hunt fish. As a consequence, there is perhaps a need to use modern biochemical methods for determining diet to address this confusion. Regardless, predation on fish is not the fundamental issue regarding the impact of beavers on fish and fisheries.

Figure 2-4. Image of beaver eating a fish (source: *https://www.youtube.com/watch?v=ES0YQyqv4O0*)

2.2.4 Beaver dams

Beavers are termed "ecosystem engineers". They modify habitats by building dams and lodges and creating networks of ponds and wetlands, which can influence water quality, water storage, flood risk and biodiversity (Figure 2-1). The provision of ecosystem services by beavers, and the potential positive and negative impacts of re-establishing the species have been explored in detail throughout the literature (see Pollock et al., 2015; Kemp et al., 2012 for reviews), and impacts with particular reference to fish and fisheries are summarised in Table 2-1.

One of the defining features of beavers is the presence of dams (Kemp et al. 2012). These can be constructed across the river channel to isolate wetland areas and provide an upstream pool or wetland. Structures can measure over 100 m in length and over 2 m in height, but most are much smaller (Johnston & Naiman 1990). This provides safety from predators and stabilises water level fluctuations to protect lodge and burrow entrances. The pool also allows the beavers to explore their territories and exploit nearby food resources (Halley et al. 2009). To expand their foraging range, beavers create networks of ponds and construct connecting canals. This changes the hydromorphological features of rivers to form long, continuous, deep and slow flowing reaches.

A variety of physical attributes that determine where beavers construct dams has been described for both North American and European species, and include stream gradient, stream order, stream power, depth, width and valley shape (e.g. Pollock *et al*., 2003, 2004; Green & Westbrook, 2009). For Eurasian beavers, the criteria that define whether beavers construct and maintain dams can be explored using a classification tree (Figure 2-5), and such a simple model can be used to determine the potential number of dams that could be constructed within a catchment. Indeed the concept has been used to determine the likelihood of beaver activity in catchments and where beavers could potentially build dams. This type of model can provide planners the opportunity to understand and evaluate the likely impact of dams and potential inundation of the river channel, (MacFarlane et al. 2016; Swinnen et al. 2019). Such an analysis was carried out for the River Otter (), and it was predicted that anything between 262 and 814 dams could be constructed on the river (Brazier et al. 2020).

The threshold criteria for whether a dam is constructed are based on studies in Sweden and Germany (Hartman and Törnlöv, 2006) and more recently in the UK (Graham et al. 2020). Dams are typically built in streams < 70 cm depth, < 6-10 m width and with a gradient < 7 % but typical in gradients of 1 to 2.5% (Hartmann & Törnlöv, 2006). Atlantic salmon and trout spawn in areas with gradients of 3% or less (Hendry & Cragg-Hine, 2000).

The number of dams can vary depending on the depth and area of the ponds created. Three to six dams in a cascade are often found, but in excess of 20 have been reported. The density of dams in streams has also been found to vary considerably, with the density of functional dams in a river landscape driven by season and flow regime (Gurnell, 1998). Parker & Ronning (2007) recorded one dam for every 14.3 km of stream in a Norwegian study, while Zurowski, (1989) reported 24 dams in a 1.3-km reach of a Polish mountain stream. Beaver dams are ephemeral structures and generally last 2-3 years, although dams can exist for up to 10 years depending on duration and intensity of high flows (Taylor *et al*. 2010).

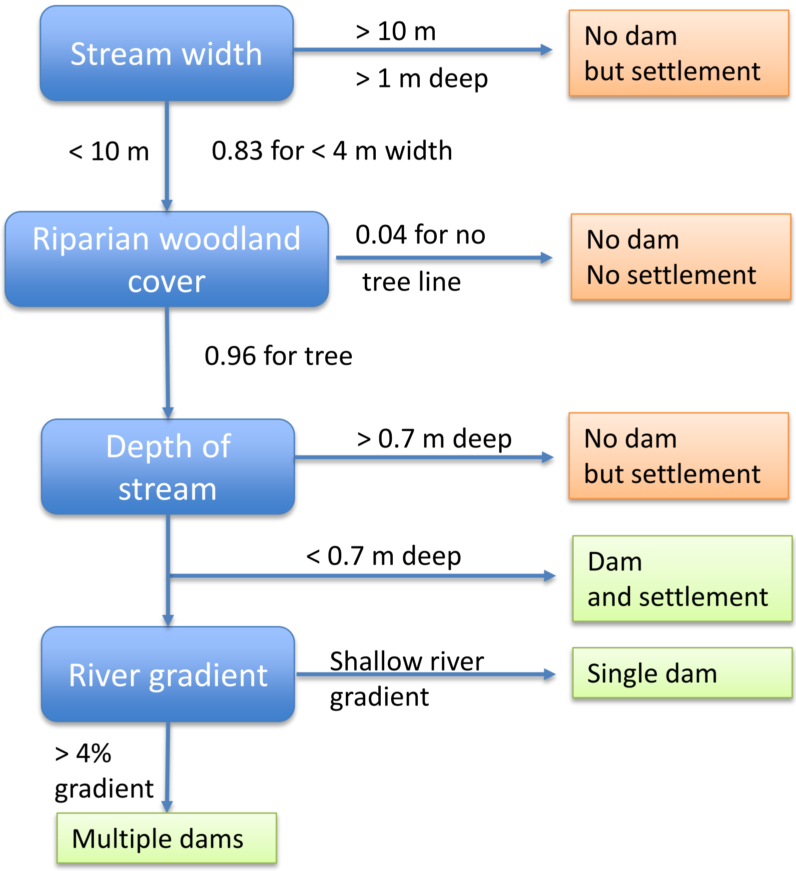

Figure 2-5. Classification tree illustrating the threshold criteria to detremine whether beavers construct dams in river channels.

It should also be recognised that dams are not the only cause of blockages to fish movements in rivers. Beavers can cause secondary blockages by forming debris dams, especially where (a) they have felled trees into water courses (a frequent occurrence) and (b) sticks from their own dams are washed downstream in spates into culverts or constrictions. These debris dams are a further significant block to fish movement.

Beaver colonies can exist, however, without creating dams depending on river topography and hydrology, especially where the gradient and river flow prevent construction of dams. They can burrow into river banks and create lodges on larger, wider river systems where the water depth is adequate to hide the entrance. The burrows can result in the collapsing of river banks and flooding of surrounding land, typically under high flow conditions. This is of particular concern in lower lying areas with flood protection levees, where the flood protection infrastructure can be weakened. Burrowing and collapse of banks can lead to increased erosion and sediment loading, which impacts on other wildlife, such as water voles, that inhabit these areas of the river. Beavers can also create canals for movement throughout wetland areas.

2.2.5 Effects of habitat modification by beaver activity

One of the main benefits that has been attributed to beaver activity is attenuation of flows, and trapping of sediments and contaminants (Gurnell 1998; Puttock et al. 2017, 2018;

Majerova et al. 2020). The value of dams to attenuate flows is without question and potentially could form part of a tool box of nature-based solutions to dissipate peak flooding. However, caution must prevail when considering this option because dams can also increase back flooding and prolong the duration of flooding. This flooding can have considerable effects on riparian vegetation as terrestrial habitat is inundated and turned into an impoundment that can kill trees and change riparian vegetation as they become submerged (Ray et al., 2001, Rosell et al., 2005).

The main impact of attenuating flooding conditions is dissipation of the peak flows and prolongation of the flood cycle, albeit at a moderate discharge (Puttock et al. 2017). What does not appear to have been considered when assessing the benefits of flow attenuation is when extreme rainfall events occur over protracted periods. The dams will be quickly overtopped so their benefits will be lost, and of concern is that the dams will be vulnerable to breaching under high flow conditions, with concomitant impacts (see below).

The slowing down of flows certainly results in deposition of fine sediments in the impounded area that might otherwise silt up river beds downstream, and potentially the accumulation of nutrients and other contaminants in the deposited sediments (Puttock et al. 2018). However, this can have a contrary effect of reducing sediment delivery to the lower catchment and estuarine and coastal water, with associated reduction of nutrients to the lower catchment (Koehnken et al. 2020). The accumulation of sediment in the impounded section, whilst being beneficial for lamprey, has the opposite effect for rheophilic species, such as juvenile salmonids, bullhead and stone loach, which rely on clean gravels. The waterlogging of adjacent land can also potentially cause increased silt erosion during wet periods, especially where the wetted area is trampled or becomes exposed and releases loose soil materials. Reductions in peak flows downstream may also reduce capacity of flows to clean gravels downstream of dams, and reduced flows in general may result in a reduced wetted width and a loss of juvenile fish habitat.

Whilst the dams may trap sediments and contaminants, consideration must be given to the potential impact of release of this material should the dam break. This could be released as a slug of fine, potentially contaminated, material, with concomitant impacts of downstream habitat and biota.

One aspect that has received little attention is the breaching of dams during high flow events and the potential impact of the release of large volumes of sediments, or where such sediment is deposited downstream. Several studies have highlighted that dam failures could lead to infrequent, but significant, pulses of water and sediment, particularly in high energy environments (e.g. Butler & Malanson, 2005; Curran & Cannatelli, 2014; Levine & Meyer 2014). This could potentially smoother downstream spawning and nursery habitat reducing its suitability for fish recruitment. Similarly, should a dam fail, large amounts of woody debris would be moved downstream potentially accumulating at pinch points and causing flooding or other barrier issues. Other studies, however, have suggested that the amount of sediment released following dam collapse would be minimal as the damaged structure will still retain some of its retention capacity and beavers would repair the dam to prevent full washout (Giriat et al. (2010). Alternatively, the sediment would be rapidly colonized by plants thus stabilizing the system (Levine & Meyer, 2014; Curran & Cannatelli, 2014), but, as yet, there does not appear to be any empirical evidence to suggest this is the case. Most of the benefits seem to be related to dams reducing stream power and reducing incision of the downstream channel (e.g. Pollock et al. 2014).

There is some evidence to suggest that beaver impoundments can lead to increased water temperatures, which can also affect downstream water temperatures (Weber et al. 2017, Majerova et al. 2015, 2020). Whilst this may lead to an increase in primary and secondary productivity, particularly in the impoundment, and potentially improved growth of fish, higher water temperatures are of concern to wild fish and fisheries, especially where beaver activity overlaps with salmonid fish communities and species like grayling that are intolerant to water temperatures above 20 °C. It is possible they may be lost to the community if the temperatures remain above this threshold for a few days, as is becoming increasingly likely under prevailing climate change conditions (Orr et al. 2015). The problem of increased water temperatures is exacerbated by the increased solar irradiation of the river surface resulting from beaver activity reducing canopy cover, and ultimately results in a reduction in resilience to climate change in rivers with impaired canopy cover (O'Briain et al. 2017, 2019, 2020).

In addition, apart from barriers to migration, dams and impoundments can cause degradation and loss of key spawning and nursery habitats in headwater and middle reaches of rivers. The impoundments reduce the capacity of salmonids and other lithophilic (gravel spawning) species to breed. Whilst the area of the impoundment and length of river flooded may be small in relation to the total river or steam length, the fact it like overlaps with key spawning and nursery habitat could represent a significant loss to recruitment. In addition the cumulative loses created by cascades of dams can be even more critical. Although some of this loss may be offset by reduced sediment loading downstream improving habitat quality, salmonid populations are driven by density dependent mechanisms so available habitat area is a primary driver of recruitment success (Crisp 2000).

Beaver foraging can have considerable impact on the landscape, altering ecological succession, species composition and plant community structure (Rosell et al. 2005), which may change the hydromorphological processes, perhaps to the detriment of any flood control benefits. In Denmark, beavers were reported to damage forestry and agricultural crops and caused minor problems with flooding of arable fields, gardens, meadows and forest roads (Elmeros et al. 2003). The opening of the canopy, whilst increasing potential productivity of the impounded area, can also raise water temperatures (Weber et al. 2017, Majerova et al. 2020) and lead to increased growth of instream aquatic plants, which may choke the stream and cause flooding it its own right. This problem is likely to be greatest on chalk streams and in the lower reaches of rivers. Given that 85% of global chalk streams are found in the UK and they are highly vulnerable to climate change and human activities, it is important they are protected from further changes to their form and function (Salter & Singleton-White 2019), of which beaver activity could be one.

The creation of the impoundment upstream of beaver dams has been shown to result in a shift in fish community structure towards a predominance of lentic species, especially cyprinid species such as minnow that have no direct intrinsic value to fisheries (Hägglund & Sjöberg 1999; Smith & Mather 2013). This seems to have been misinterpreted as an enhancement of species diversity. However, in reality, the species composition is only changing to reflect the change in habitat availability, and the lentic species are exploiting their preferred environment. Species diversity is not enhanced per se but maintained, although biomass may increase (Smith & Mather 2013). Worryingly, the modified environment and shifts in fish community dynamics offer an opportunity for non-native species, including plant species, to invade and dominate in the communities. Indeed, Himalayan balsam appears to be benefitting from the altered riparian zone on the River Otter.

The upstream environment can also bring benefits to fish and fisheries in terms of improved growth and production (e.g. Sigourney et al. 2006), but other studies have highlighted changes in species composition towards small fish species of little economic value, such as minnow. Virbrickas et al. (2015) also found salmon abundance declined downstream of beaver dams in Lithuania streams, largely because loss of recruitment from upstream.

If faster water conditions are created below the dams, this could potentially result in an increase in the complexity and quality of habitat, especially if the substrate is composed of coarser materials such as gravels, and ultimately perhaps lead to an increase in the diversity and abundance of rheophilic species. However, beaver dams generally attenuate flows so such conditions are rarely, if ever, forthcoming, and the suggestion that beaver dams may restore downstream habitat needs further study.

Beaver activity also increases the amount of large wood and associated debris in the river channel, providing a complexity of habitats, and promoting productivity and diversity of other species groups, such as amphibians, reptiles and birds, as well as fish. However, large wood can cause serious flooding issues if it moves downstream and accumulates at pinch points, potentially causing impeding fish movements.

2.2.6 Impacts on fish movements

Perhaps one of the most contentious issues regarding beaver dams is disruption to fish migration. The literature is replete with conflicting studies. For example, Parker & Roenning (2007) is a widely quoted example showing that beaver dams pose no problems for spawning salmonids in Norwegian rivers, whilst Kesminas et al. (2006) found the impacts of beaver dams on sea trout populations in the Baltic States highly detrimental to the extent of endangering populations. The problem arises because beaver dams are ephemeral and highly dynamic. They have a limited life, typically between 2-3 year, before they are abandoned or blow out. They vary in shape and size depending on location, and these characteristics together with the hydraulic conditions experienced at each dam determine whether the structure is passable. See, for example Figure 2-6 which shows two beaver dams that potentially block upstream and downstream movement of fish. The presence of a rivulet on the right-hand side of the Danescroft dam does not represent free passage under all conditions and most likely the dam will obstruct upstream movement of salmonids in all but high flow levels. The right-hand photo shows a dam that has no overflowing water or rivulet that would enable fish to bypass the dams so is probably a complete barrier to fish except possibly in high flow conditions. As a consequence, there is considerable conjecture about whether beaver dams are passable by fish, either partially or fully, and whether they are open to free movement. The problem is exacerbated because most studies only seem to be addressing migratory salmonids and eel, yet many riverine fish species are migratory during some stage of their lifecycles and thus need to move up and downstream (Radinger & Wolter 2014); many of these other migratory species have lesser swimming capacities than adult migratory salmonids, which are typically the subject of impact studies (Lucas & Baras 2001).

Figure 2-6. Illustrations of beaver dams: Left Danescroft (Photo – Dylan Roberts); right Photo - Beaver Trust/Nina Constable Media [11]

One aspect of fish migration that is largely overlooked is the downstream movements of post-spawning adults (salmonid kelts or adult cyprinids) or dispersal of juveniles (all species) and salmonid smolts. In the main, beaver dams are considered 'leaky' so do not pose a problem, but this is not proven and the extent to which smolts can pass through or over beaver dams remains unclear. Irrespective, it is highly likely beaver dams will disrupt downstream migration during the critical life stage of fish and lead to delayed departure or even prevent diadromous species from reaching the sea. Delays can also increase predation on migrating fish from avian and terrestrial predators, especially if the fish are held up in the upstream impoundment. Delays and disruption to migration of this nature can cause considerable mortality and affect the status of the fish populations (Gauld 2013).

A number of tools are available to assess barrier passability (see Kemp & O'Hanley, 2010). These fall into site-specific surveying techniques and hydraulic modelling linked to fish swimming capabilities, the latter typically assessed using tagging and tracking methodologies, through to rapid assessments based on direct observations of the barrier and hydraulic features using expert judgement. Most studies on passability of beaver dams to date have declared that fish are able to pass the dams, but most rely on observations of fish bypassing the structures or assume the presence of juvenile fish of migratory species upstream of the dam indicates some fish must have passed the structure. Few studies have assessed beaver dam passability quantitatively.

The few studies that have utilised modern fish tagging and tracking systems to determine the probability of fish being able to bypass a beaver dam present mixed results. Lokteff et al. (2013) used Passive Integrated Tag (PIT) technology to determine if native and non-native trout could bypass beaver dams in Utah streams and considered physical characteristics of the dams, such as height and upstream location, affected passability, although they also found non-native trout species (European brown trout) were less able to pass than native *Oncorhynchus* [salmonid] species. Malison and Halley (2020) also used PIT technology to explore the impacts of beaver dams on movements of juvenile salmon in two Norwegian rivers and concluded that "dams did not block the movement of juvenile salmonids or their ability to use upstream habitats". However, the data presented do not support this interpretation and movements of fish in beaver-free areas were considerably greater than

[11] https://www.bbc.co.uk/news/uk-england-cumbria-54972840

where dams were present. Further the experimental design was not appropriate for exploring the long-distance movements of juvenile salmon as PIT loops (stationary detector arrays), were only set over <100 m of river reach, which approximates the home range of juvenile life stages. Virbrickas et al. (2015), using RFID (short radio frequency identification) tagging, found Atlantic salmon were able to pass some dams in a series of barriers, but they were not able to ascend the full cascade, thus compromising spawning and recruitment processes.

Whilst this is technically an expensive option to assess fish passability at a beaver dam, a full study on a range of dams would remove the controversy regarding passability. Such studies have been successfully carried out to assess the passability of fish pass structures at barriers and hydropower dams (Aarestrup *et al.,* 2003; Knaepkens *et al.,* 2006; Noonan *et al.,* 2012) and should be adapted to assess the passability of beaver dams**. Thus, before any definitive conclusion can be drawn about passability of beaver dams, fully funded telemetry studies on a range dam types, including cascades of dams, should be undertaken.** Such studies should include migratory salmonids, resident brown trout and potamodromous species, such as barbel, chub and dace, to account for the range of fish species and life cycle guilds found in UK rivers.

Coarse Resolution Rapid Barrier assessment methodologies, such as that devised by Kemp and O'Hanley (2010 and Kemp *et al.* (2017) and revised following field trials (SNIFFER, 2012), would be suitable for assessing both up and downstream movements, and are capable of evaluating passability of numerous species and sizes of fish. The assessment method uses rule-based criteria for fish morphology, behaviour, and swimming and leaping ability to estimate barrier passability. The condition of the barrier to impede migration requires visual inspection and in-field measurements. As an example, the criteria used to assign upstream barrier passability for trout are shown in Table 2-2. Barrier passability represents the fraction of fish (in the range 0 [impassable] to 1 [100% passable under all conditions]) that are able to negotiate a given barrier successfully in an upstream or downstream direction. Each barrier is assigned one of four passability levels as follows: 0 is a complete barrier to movement; 0.3 is a high impact partial barrier, passable to a small proportion of fish or passable only for short periods of time; 0.6 is a low impact partial barrier, passable to a high proportion of fish or for long periods of time; and 1 is a fully passable structure. Partial barriers, especially at beaver dams, are often created by fluctuating river discharge, which causes variation in water depth and velocity at the barrier, thereby impeding large fish at low flows or individuals with weaker swimming abilities at high flows.

The methodology described in SNIFFER (2010) can also be used for a variety of other species but has been specifically defined for adult salmon (*Salmo salar*), brown trout (*Salmo trutta*), juvenile salmonids, cyprinids, adult lamprey and juvenile eel (*Anguilla anguilla*). Unfortunately, this methodology has not been field tested explicitly for beaver dams under a range of hydraulic conditions to determine the ability of fish to bypass such structures. This is important because passability likely varies under different discharge levels and a simple model does not fit the complex, diversity of typographical and hydraulic conditions presented at different dams. **There is clear need for further research to assess the barrier effects and otherwise of beaver dams on fish migration and recruitment processes.**

Table 2-2. Barrier assessment criteria for assigning adult brown trout (*S. trutta*) (including potadromous brown or migratory sea trout) upstream passability scores. Additional criteria used for determining passability scores not presented here include the availability of resting locations, level of turbulence, the presence of lips, standing waves or debris, the gap width and the minimum step length

Assessment criteria	**Passability score**			
	1.0	0.6	0.3	0.0
Hydraulic head (m) where gap sizes are greater than 0.2 m in debris dams	≤0.40	0.41–0.60	0.61–0.99	≥1.0
Water depth over barrier (m)	≥0.10	0.075–0.09	0.06–0.074	≤0.05
Gap width For notched weirs, culverts, waterfalls, debris dams and overshot sluices	≥ 0.30 m	0.20 - 0.29 m	0.20 - 0.29 m	≤ 0.10 m
Fish bypass channel characteristics Individual step Maximum step hydraulic head	 ≤ 0.4 m ≥ 1.0 x step	 0.41 – 0.60 m ≥ 0.6 x step	 0.61 -0.69 m ≥ 0.4 - 0.5 x step	 ≥0.7 m ≤ 0.3 x step
Flow velocity(m/s)	≤2	2.1–2.5	2.6–2.9	≥3
Effective pool depth – all structures	Pool depth ≥1.0 hydraulic head	Pool depth ≥ 0.6x hydraulic head	Pool depth ≥ 0.3x hydraulic head	Pool depth <0.3x hydraulic head
Lip and/or standing wave present	May be present but do not restrict fish passage		May be present and may locally restrict fish passage	
Water turbulence associated with structure	Low	Moderate	High	
Debris/sediment blockage For all structures	May be present but does not restrict fish passage		Present and may locally restrict fish passage	

2.2.7 Cumulative effects of beaver activity on water courses and fish

One issue that is often overlooked is the cumulative effect of multiple barriers and impoundments in a cascade or series of cascades in a single river system. Whilst the dams may improve water quality and reduce fine sediment movement, they also act to deprive the downstream region of coarser sediments such as gravels, which are important for the spawning of many fish species, especially salmonids, and attenuation of flows can reduce the capacity of the river discharge to clean/refresh gravels prior to spawning. In addition, multiple dams in a cascade inundate large areas of riverine habitat that are potential spawning and nursery habitats for fish species, and create multiple barriers to fish migration. These issues can be clearly seen in the extent of damming and inundation associated with the Tamar enclosed beaver population (Figure 2-7; Puttock et al. 2017). Here the river is transformed from a flowing system to wetlands with areas of open water. Not only is an extended reach of river lost to salmonid spawning and production, it is unlikely migratory adult salmonids will be able to bypass the 13 dams in the cascade, thus isolating the total upstream reach for

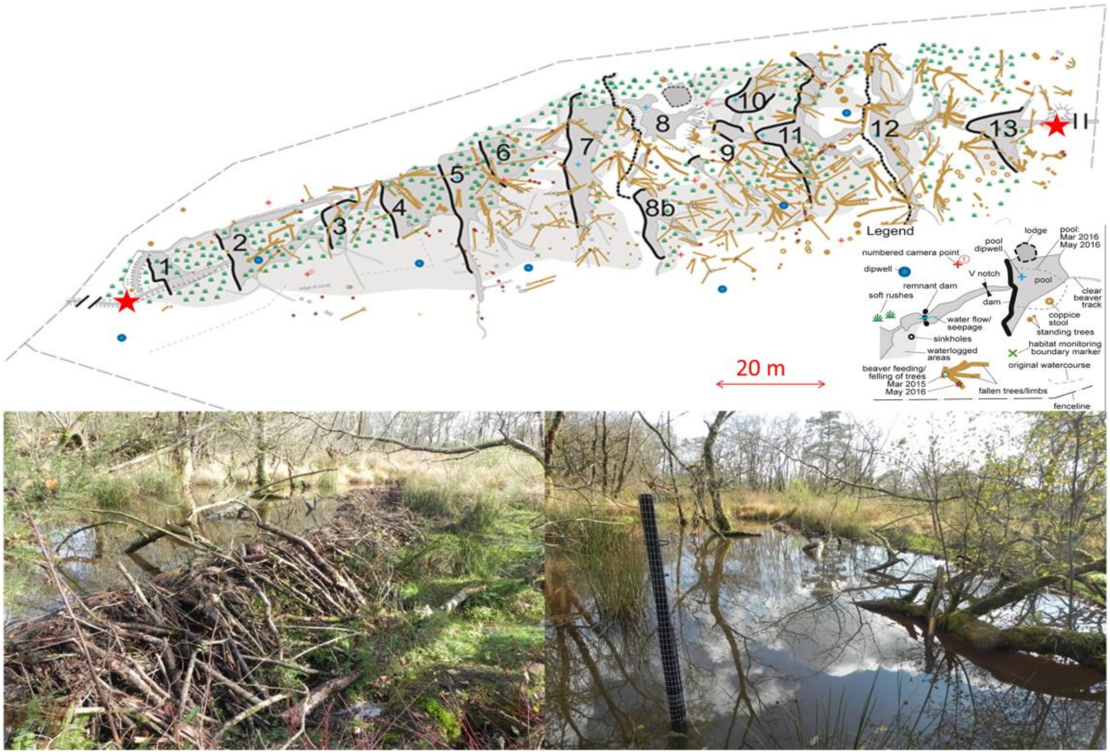

Figure 2-7. Plan of beaver dams and extent of flooding from dams in the River Tamar enclosed beaver study (Source: Puttock et al. 2017)

migratory salmonids. In this case, it is not just the area of river flooded by the impoundments but the habitat from the dams to the headwaters that are lost to recruitment of migratory fishes. Caution must, however, be paid in interpreting the cumulative conditions for the Tamar site because the beavers are enclosed in a limited area so restricted in where they can build dams, and potentially the size and structure of dams. Beavers in open populations may build dams in markedly different locations, potentially causing a different array and scale of impacts. They may also abandon dams after a few years when moving onto new territories, thus expanding the range of impact within catchments from their dam construction activities.

The latter point is particularly pertinent because each dam in a cascade may pose different challenges to migrating fish as they will each have different form and structure, and different hydraulic conditions. The cumulative effect of fish trying to bypass multiple structures will ultimately lead to a decline in total numbers reaching suitable spawning and nursery habitats, upstream of the dam complex, thus impacting recruitment dynamics and stock status. This can have considerable implications for achieving EU Water Framework Directive objectives where species have been excluded from upstream reaches of rivers, thus failing to meet Good Ecological Status.

An example of the cumulative impact of multiple barriers on a system is shown in Figure 2-8. Here the impacts of seven barriers in succession on the population size of an upstream migrating species are compared with different levels of passability. It can be clearly seen that the cumulative effect of compromised passabilities <0.5 at the barriers (i.e. less than 50% of the fish successfully bypassing each dam) results in extirpation of the population in the upstream areas, potentially where the fish spawn. It is thus essential to model the impact of variable passabilities at the various barriers to determine the cumulative impact. Coarse resolution rapid barrier assessment methodologies, such as the one described above (SNIFFER 2012) and adapted by the West Country Rivers Trust for the River Otter Beaver Trial (RAP: West et al. 2019), could be used to determine the cumulative impact of multiple barriers, although it will require considerable development and testing to gain confidence in the tool.

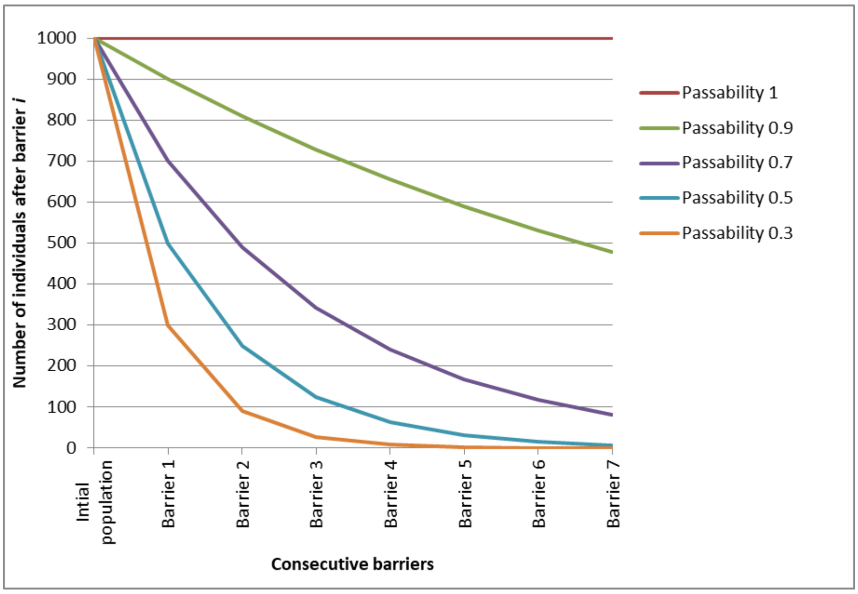

Figure 2-8. Cumulative impact of multiple consecutive barriers of a given passability rate.

The cumulative impacts of multiple dams have also been examined by Bylak and Kukuła (2018) in a western Carpathian river. Here they showed how fish species composition and size structure changed with environmental heterogeneity created by the beaver dams. It appears the fish community structures shift in relation to the changes in habitat availability towards lentic species, and lotic species abundance, typically found in in upland reaches, are reduced in abundance.

2.3 Ecosystem services

There is a growing literature on the ecosystem services provided by beavers (Campbell et al. 2007; Thompson et al. 2020). These include, but are not exclusive to, water quality improvements (from trapping contaminants and sediment; Pollock et al. 2003), attenuation of extreme flows (Pollock et al. 2003; Puttock et al. 2017), but mostly where dams are constructed across the river channel, provision of more diversity habitat and associated biodiversity (Elmeros et al. 2003; Rosell et al. 2005) and recreation (e.g. through the creation of habitats favourable for bird watching) and tourism potential (Campbell et al. 2007), including fisheries (see Table 2-1). Most of the services are generated by the impounded section of river and creation of a matrix of wetland habitats that are favoured by a wide range of biota, or the benefits of the dam on the downstream reach.

Thompson et al. (2020) attempted to put monetary value on the services generated by beavers, and estimated values of US$1.6 million from recreational hunting and fishing benefits and US$133 million for habitat and biodiversity provision per year (equivalent to 133

US$/ha) over the entire beaver distribution range in the Northern Hemisphere (Figure 2-9) This was compared with non-consumptive recreation estimated to be equivalent to 167 US$/ha. It should be noted these values are small in comparison to the services generated from recreational fishing (£1.6 billion in in England alone [Environment Agency 2018a, b]) or other nature-based activities.

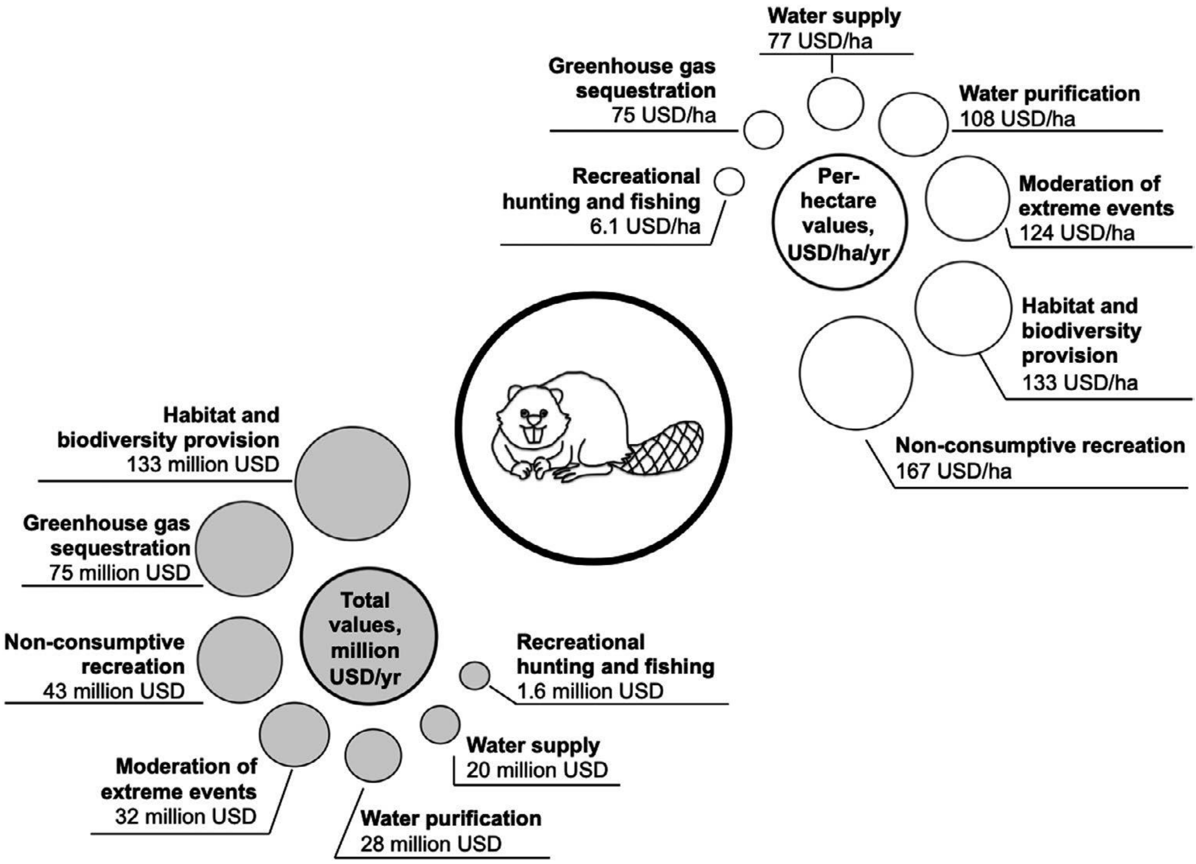

Figure 2-9. Value of ecosystem services produced by beaver ponds, given in annual per-hectare values (white circles) and aggregated over the one million ha Northern Hemisphere beaver range per year (grey circles). Circles are not to scale. (Source: Thompson et al. 2020)

Thompson et al. (2020) also suggested countries are realising the potential of utilising beaver activity for water management (Törnblom et al. 2011; Kaczyński 2014), wetland restoration (Pollock et al. 2017) and climate change mitigation (Baldwin 2017). Unfortunately the studies appear to be transferring the benefits from services delivered by wetlands in general to those delivered by beaver dams and associated wetlands, and not using values specifically derived from beaver-created wetlands. The values derived are enormous, but as Thompson et al. (2020) point out, they do not account for disbenefits, which could be equally large. Also transferring values from wetlands in general to beaver-created wetlands is questionable because the latter have different form and function, and vary from site to site depending on geographical location and type of habitat impounded. It is also important to note that disbenefits from beavers are likely to rise as the beaver populations grow and they colonise new areas, creating more human-beaver interactions and potential conflict, as was found by DeStafano and Bedlinger (2005).

Disbenefits arising from beaver activities include, but are not exclusive to, loss of agricultural land, flooding of urban areas, felling of trees, foraging on agricultural crops, disruption to fish community dynamics and associated fisheries, damage to infrastructure, including flood defences, and beaver attacks (see

Table 2-1). These losses can be large; for example, Vantassel et al. (2013) reported that flooding caused by beavers resulted in annual losses of $22 million to the south-eastern U.S. timber industry. In addition, the costs of mitigating beaver impacts, such as breaching of dams, repairing damaged flood banks, replanting trees or protecting trees and crops, are usually borne by a small number of individuals or land owners. The loss of fisheries or compensating for loss of fish recruitment are also borne by small groups of stakeholders, including land/riparian owners, fishery owners and river conservation bodies, with little support from government or recovery from those who benefit from beaver presence.

To give an indication of the potential scale of economic losses from disruption to fisheries, freshwater angling in England in 2015 contributed £1.46 billion to the economy (expressed as gross value added) and supported 27,000 full-time equivalent jobs (Environment Agency 2018a). A total of 22.3 million days were spent freshwater angling in England in 2015, and total non-trip related expenditure in 2015 was estimated at around £680 million (Environment Agency 2018a, b). This included items such as clothing, media, tackle and club memberships. More than half of this expenditure was on tackle and equipment (56% of the total). Non-trip related expenditure supported over 10,700 FTE jobs and contributed £583 million to household incomes in 2015.

Another interaction between beavers and humans is attacks on domestic pets and anglers[12][13]. Although considered rare, there are reports of such interactions and even death of a person killed from a beaver bite[14]; thus the risks are potentially high. Anglers fishing at night, especially sea trout anglers fishing in May, June and July, are at higher risk of attack than the public, because beavers are particularly protective of their new born kits at this time of year. Encounters of this nature are likely to increase as beaver numbers increase and their distribution widens into semi urban areas or beavers occupy fishing pools. These risks also apply to other groups such as canoeists, wild swimmers, and dog walkers and their dogs.

2.4 Potential mitigation and management options and further R&D

Possible impacts from the introduction of beavers into river systems (cause-effect and problem analyses) are summarised in Figure 2-1, and discussed in Sections 2.2.3-2.2.7 and Section 2.3. The information illustrates the problems that are likely to arise but not the magnitude of such problems. This issue of quantifying the impact of beaver activity on fish and fisheries has also been neglected when the valuation of ecosystem services attributed to beavers is assessed (Section 2.3).

2.4.1 Legal status

The European beaver (*Castor fiber*) is internationally protected as an Annex III species under the Bern Convention. The species is listed under Article III as requiring protection in general but can be hunted under certain circumstances. Under the EU's Directive 92/43/EEC

[12] https://www.bbc.co.uk/news/uk-england-devon-40503901
[13] http://www.cscf.ch/cscf/de/home/biberfachstelle/newsarchiv/biber-beisst-zwei-schwimmer-in-s.html
[14] https://www.dailymail.co.uk/news/article-2307572/Beaver-attack-Fisherman-killed-BEAVER-tried-photo-lake-Belarus.html

Conservation of Natural Habitats and Wild Flora and Fauna (the Habitats and Species Directive) Article 22, EU member states must consider reintroductions of extinct native species in Annex IV, which includes beaver. If introduced, however, beavers will still have the potential to cause problems, thus some form of action may be required. Annex IV of the Habitats Directive prohibits the deliberate capture or killing of beavers, further to disturbance, deterioration or destruction of breeding or resting sites (Habitats Directive, Article 12 (1)), thus national legislation is required to support this need.

Under Section 16 of the Wildlife & Countryside Act 1981, a licence is required from DEFRA to release species into the wild that are not normally present in Britain. This licence requires sound justification for the reintroduction and action plan for control and is aimed at preventing illegal introductions and avoiding the potential detrimental impacts of species like beavers. Where beavers have been introduced under licence or illegally, they still have the potential to cause intermittent and localised problems, such as those outlined in Sections 2.2.4-2.2.7, including flooding, crop damage, tree felling, and obstructions to fish migration, thus some form of action may be required. Interestingly, the illegal release of beavers on Tayside in Scotland has been accepted by the Scottish Government because "it is perceived to be politically impossible to be officially testing beaver reintroduction in Knapdale while culling them on Tayside". As a result, on 1 May 2019, beavers were given protected status in Scotland allowing them to naturally expand their range across the country from the existing populations in Tayside and Argyll. The Scottish Government has, however, recognised that there will be a need manage populations where beavers impact on other interests, and in 2019 issued 45 licenses to moderate beaver activity. Under these licences, 83 beaver dams were removed, 15 beavers were trapped and translocated, and 87 beavers were shot by accredited controllers. **The unofficial release of beavers in the River Otter was also approved in August 2020 following the beaver trial, although it is questioned whether the weight of evidence of the impact of beavers in the catchment or elsewhere has been fully evaluated in either case**.

2.4.2 Mitigation measures

Whilst beavers may play an important ecological role in creating and maintaining ponds and wetlands for fish and wildlife habitat, their dams can cause a number of key problems associated with disruption to fish migration and flooding of fish spawning and nursery areas. In addition, beavers can cause considerable damage to riparian trees, including destroying stands of trees along river banks. Beavers can also damage infrastructure, including burrowing into flood banks and causing them to collapse, as was see in Poland where beaver damage caused considerable flooding of a town following the collapse of a flood bank they had undermined[15]. Where these problems are deemed to be excessive, preventative measures or actions to mitigate the damage are required. These take three main forms of action: 1) controlling beaver foraging activities; 2) managing the impacts of the dam and impoundment; and 3) regulating beaver numbers and relocation.

Controlling foraging activities largely orientates around preventing access to tree trunks or

[15] "Beavers Responsible for Flooding" reported in The Telegraph, 10 November 2010. https://www.telegraph.co.uk/news/worldnews/europe/poland/7764347/Beavers-responsible-for-Polands-flooding.html

agricultural crops. Beaver repellents (e.g. mixture of alkyd paints with coarse sand or putrefied blood products painted on tree bark), screens, drain piping and wire cages to prevent beavers being able to gnaw on trees are the most common methods used to protect trees, while fences are commonly used to restrict access to crops. Electric fences are another option but usually only work in open areas and the system needs to be well grounded. These measures are labour intensive, only work in the short term, and are not practical for protecting hectares of timber or tree belts, or large fields of arable crops.

To reduce upstream flooding several options are available, including breaching, notching or removing the dam. This can negatively affect the upstream habitat, reduce the benefits of flood attenuation and can also result in the release of large amounts of fine, perhaps contaminated, sediments that can negatively affect aquatic biota. Dewatering or reducing water levels in the upstream pond can also lead to stranding of fish and loss of habitat for amphibians and other aquatic biota. The fundamental problem with this measure is that beavers tend to quickly rebuild the dam to maintain their waterways and protect their lodges. Completely destroying dams is particularly problematic. For example, a beaver dam breaching programme in Upper Kitwanga River in Canada to improve access for coho salmon highlighted the difficulties with destroying dams. Although the programme opened up 50% of lost habitat, it took 2-3 years to be effective and required considerable resources over an extended period of time to deter beavers from rebuilding the dam (Kingston 2004). Similar difficulties in destroying dams were encountered in the River Otter Trial by West (2019) (Figure 2-10), where attempts to breach a dam on River Tale were repaired very quickly, and as found elsewhere, repeated action was needed to discourage beavers from reconstructing their dams and protecting their territory. Persistent breaching or removing a beaver dam can also increase the risk of negative impacts to habitats, and not necessarily prevent future beaver activity in the immediate area as beavers will move to a new location and potentially just divert the problem.

Figure 2-10. Beaver dam on the River Tale before, immediately after making an intervention and one day later being rebuilt (Source West 2019).

An alternative option to controlling upstream water levels and overcoming the problem of beavers rebuilding their dams is beaver pond levelling devices, colloquially known as “beaver deceivers”. Whilst beaver water level control devices can regulate upstream flooding, particularly of agriculture land or other assets, they can also create a challenge for fish passage. Their design and construction create potentially greater barriers to fish movement than the dams themselves (Figure 2-11). The inlet for the water is usually surrounded by a cage to stop beaver blocking the pipe, but more importantly the outlet pipe is suspended above the river in the dam surrounded by woody debris, which will prevent fish access to the entrance. The dissipation of flows overtopping the dam in high flow conditions will also reduce the likelihood of rivulets or side channels forming around the dam during high flow events. Furthermore, pond levellers and fences will require regular maintenance and thus incur recurrent costs, presumably to be paid by the impacted party.

Figure 2-11. Example of a piped beaver dam in Scotland (photo courtesy of Dylan Roberts)

Most of the potential negative effects of beavers on fish are related to dam construction, and as indicated above these may be difficult to destroy because of their inherent response to rebuild them. Where such action proves unsuccessful the only possible option is to reduce the population numbers either by culling or translocation to other catchments. Whilst the latter may be an option at present, potential sites for translocations may decline rapidly as beavers expand their range and relocation efforts fill all available opportunities.

Culling the beaver population is an option that is potentially available. The problem with such an action is the public response to culling the animals, although there is a precedent in Scotland and the practice is well established in Europe with where many tens of thousands of beavers (e.g. over 31,000 in Latvia in 2014) are hunted (e.g. Belova et al. 2017). The other problem is that culling may require considerable justification to obtain licences under legislative protection measures, and no clear thresholds are currently available to define when damage is considered unacceptable. Currently, this is based on best judgement of the licencing authority (e.g. in Scotland). One possibility that could be consider to ease this potential bottleneck is devolving responsibility to landowners or authorised persons to control populations (as elsewhere in Europe) and has been adopted elsewhere, such as to control deer in the UK[16]. A strategy of this nature to control beaver activity will likely become increasingly necessary as beavers expand their range, more problems arise, and local agencies are unable to cope with the scale of problems.

Finally, it should be recognised that beaver management is largely focused on single disservices/impacts in localised areas and measures to prevent or mitigate damage. As Thompson et al. (2002) pointed out, when broadening the analysis from individual disservices to landscape-level effects, the number of stakeholders and their interests naturally increases many-fold. They therefore recommend “future active beaver management should incorporate a broader horizon, including not only small-scale hindrances, but also a wider paradigm shift towards considering landscape-level and societal effects as well”.

[16] https://www.thedeerinitiative.co.uk/uploads/docs/24.pdf

2.4.3 Beaver Management Plans

A number of beaver management protocols/strategies/best practice guidelines are available from various sources, not least the ROBT Beaver Management Strategy Framework (DWT 2020), the Scottish Beaver Salmonid Working Group (2015) and Management Strategy Framework[17], Valachovič (2000) for the Danube, and the best practice manual from the EU CAMARO-D project. Most of the guidelines provide systematic steps to address problems that may arise from the establishment of beaver populations. They tend to operate on a number of tiers, such as that of the Sottish Natural Heritage (now Scottish Nature) (Pallai et al. 2012: Figure 2-12). Here it is assumed beaver populations will remain relatively small, which is not the case elsewhere in Europe (Halley et al. 2020), or indeed in Scotland (Gaywood 2018), but recognises there will be some potential impacts from flooding, damage to infrastructure, damage to trees and disruption to fisheries. Where such conflict arises, and intervention is required, the guidance usually suggests a hierarchy of responses such as that outlined for Scotland by Pillai et al. (2012; Figure 2-12).

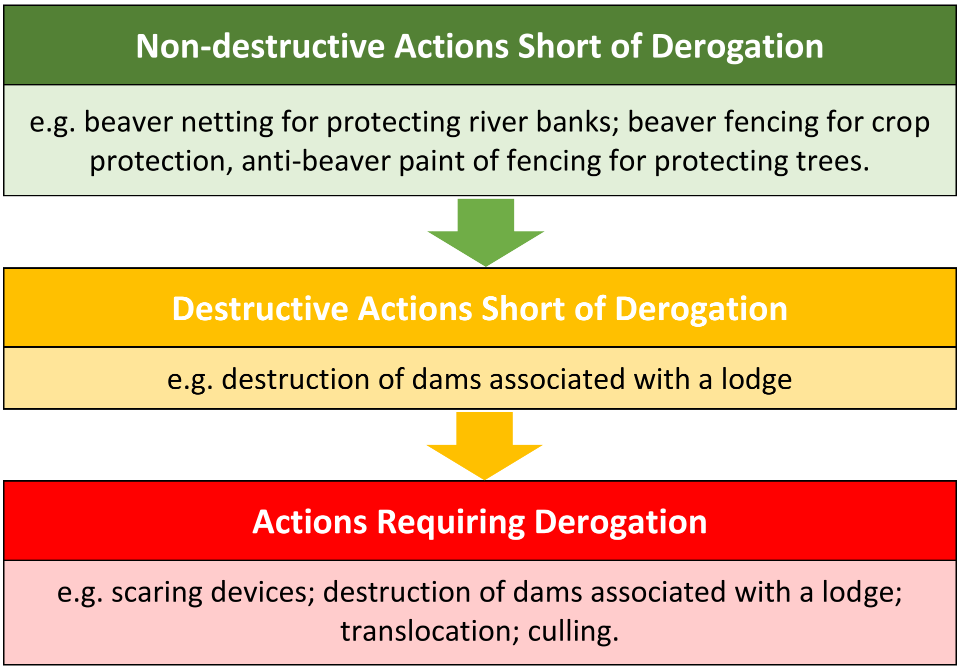

Figure 2-12. Beaver management actions and derogation (licence) requirements under The Habitats Regulations (Source: Pillai *et al.* 2012).

The hierarchy is designed to protect beavers in line with legislation, although licences can be designated to allow culling, translocation or dam destruction where preventative actions do not address the problem or key infrastructure is at risk. Unfortunately there appears to be no quantitative criteria on which to base the decision to upscale the action, and it appears to be up to the licencing authority to make a judgement on how this is interpreted. **This is a fundamental weakness in the derogation process and, along with funding and provision of trained personnel, is something that needs to be resolved before further introductions into open systems are permitted.** Similar problems are found in the issuing of licences to cull cormorant populations where they are found to adversely impact on fish populations in inland

[17] www.nature.scot/professional-advice/protected-areas-and-species/protected-species/protected-species-z-guide/beaver/management-framework-beavers-scotland

waters across Europe (Cowx 2013).

Defining the thresholds when various levels of action can be derogated is fundamentally important because most populations based on reintroductions have yet to reach their terminal sizes – i.e. achieve the carrying capacity of the river system they are colonising. This is likely to take 20-30 years in larger catchments, and where it has been reached, such as in Bavaria and The Netherlands, major problems are now being experienced. To address the problems arising, killing of beavers under derogation has now become routine in Bavaria and the Baltic region, where many tens of thousands of beavers (e.g. over 31,000 in Latvia in 2014) can be hunted each year in each country (Belova et al. 2017). It is debatable whether such a major culling action will be allowed in the UK.

In the UK, it is only the beaver population in Tayside Scotland that has potentially reached it terminal population size and this case highlights the scale of the problems likely to arise under such conditions. Here five licences were permitted for dam removal or manipulation only and 40 for lethal control and dam removal in 2019[18]. This scale of derogation for a single year based on an estimated beaver population of 433 individuals (range 319- 547) in the Tay and Forth in 2017/18 highlights that the problems caused by beavers is not trivial and not easily resolvable without lethal control. **Whether such actions will be acceptable to the general public should the beaver numbers increase rapidly once in open systems is an issue that cannot be taken lightly and needs to be considered before a decision is taken on allowing free movement of beavers.** Indeed concerns have already been expressed about the level of lethal control in the Scotland populations[19]. Further, to put the above number of beavers that were culled in 2019 into context, prior to the species being given protected status on 1 May 2019, control of beavers in the area was unregulated, yet the numbers have continued to expand by as much as 20% per annum.

One critical element that is missing in all these best practice guidelines/ strategies is the absence of protocols to inform decisions on re-introductions to specific watersheds in different regions. This is particularly important for habitats of high conservation importance, such as chalk streams, around ancient woodlands and key salmonid spawning grounds, which are likely vulnerable to beaver activity. Risk-based assessment methods, such as those available for non-native species introductions, should be at the forefront of active beaver management protocols. The Department for Environment, Food and Rural Affairs (Defra) have a draft *Code and Good Practice Guidance for Reintroductions and Conservation Translocations in England* (Defra 2020), which is intended to give advice on the use of reintroductions for conservation purposes, including how to decide when to allow reintroductions, steps to maximise success and how to avoid negative outcomes, is a good starting point for such a protocol. The Defra protocol is based on the project cycle, and reviews and adapts as it progresses in response to monitoring information and experiential learning (Figure 2-13). The *Code and Good Practice* is aligned with the Scottish approach to conservation translocations and is based on the international standard established by the International Union for the Conservation of Nature (IUCN). Notwithstanding, this *Code and Good Practice* guidance needs to be tested for beaver in the UK, both retrospectively (Knapdale and Otter populations in particular) and for proposed reintroductions, and lessons

[18] https://www.nature.scot/naturescot-beaver-licensing-summary-1st-may-31st-december-2019
[19] https://theferret.scot/beavers-tayside-killing-87-pressure-reduce/

learned need to be included in the guidance. The assessments should be carried out by an expert panel with a range of expertise covering all stakeholders likely to benefit and lose out from any reintroduction.

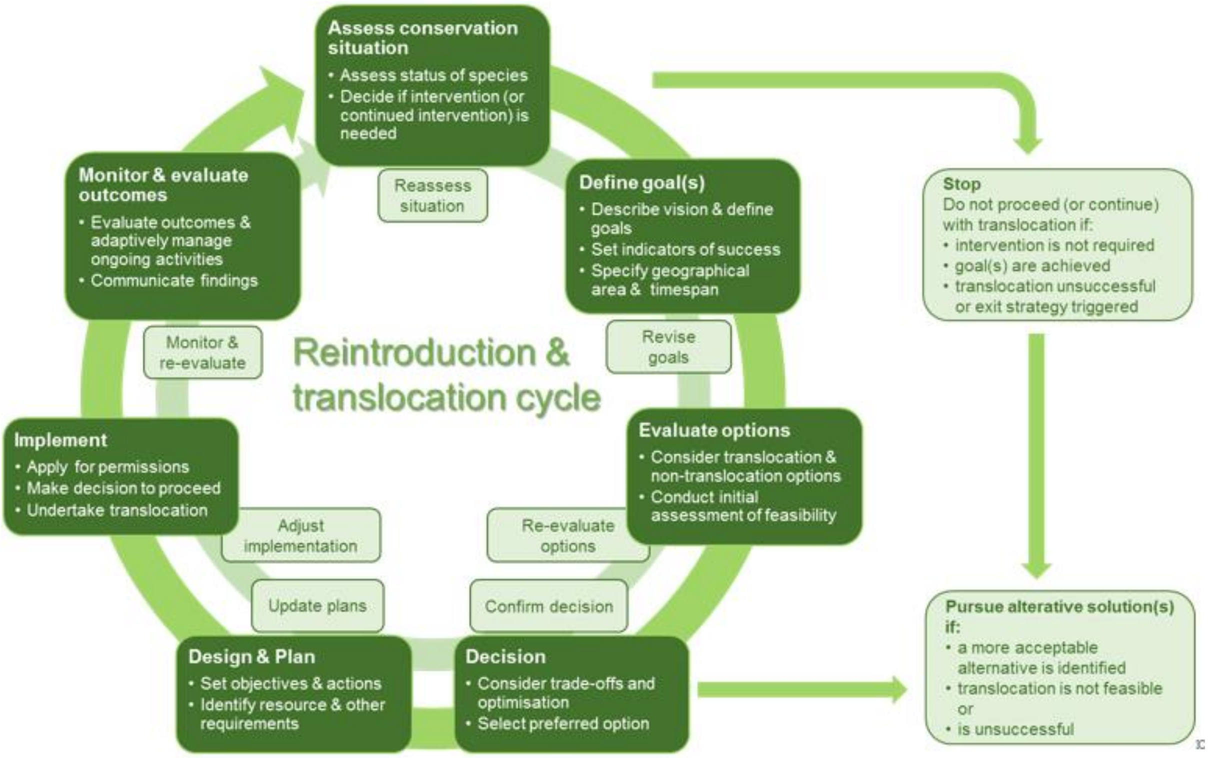

Figure 2-13. Reintroduction or conservation translocation cycle from *Code and Good Practice Guidance for Reintroductions and Conservation Translocations in England* (Defra 2020)

Finally one issue that needs to be resolved when considering allowing free movement of beavers is who decides on what mitigation measures, including culling, are carried out should they be required and who pays for such actions or compensates lost enterprises, landowners, farmers or other stakeholders. Evidence from elsewhere suggest these costs can be substantial[20] and must be formalised at the onset of any derogation.

[20] https://www.bbc.co.uk/news/blogs-news-from-elsewhere-35773349

3 Overview of the River Otter and its fisheries

A full overview of the River Otter catchment characteristics is provided by Knott (2019). Knott provides details of the catchment's physical geography, land use and ecological characteristics, together with an account of the designated sites and features of interest. Beavers and fish and fisheries are not mentioned other than the latter in relation to the EU Water Framework Directive waterbody status, thus key features of the catchment and the status of the fisheries are described here to underpin the review of the ROBT documentation.

3.1 Catchment characteristics

The River Otter rises at an altitude of approximately 275 m in the Blackdown Hills near Otterford and flows some 65 km through East Devon to the western end of Lyme Bay at Budleigh Salterton. It has approximately 594 km of water course divided into eight principal sub-catchments, but the main ones are the rivers Tale, Wolf, Love and Middle Otter (Figure 3-1).

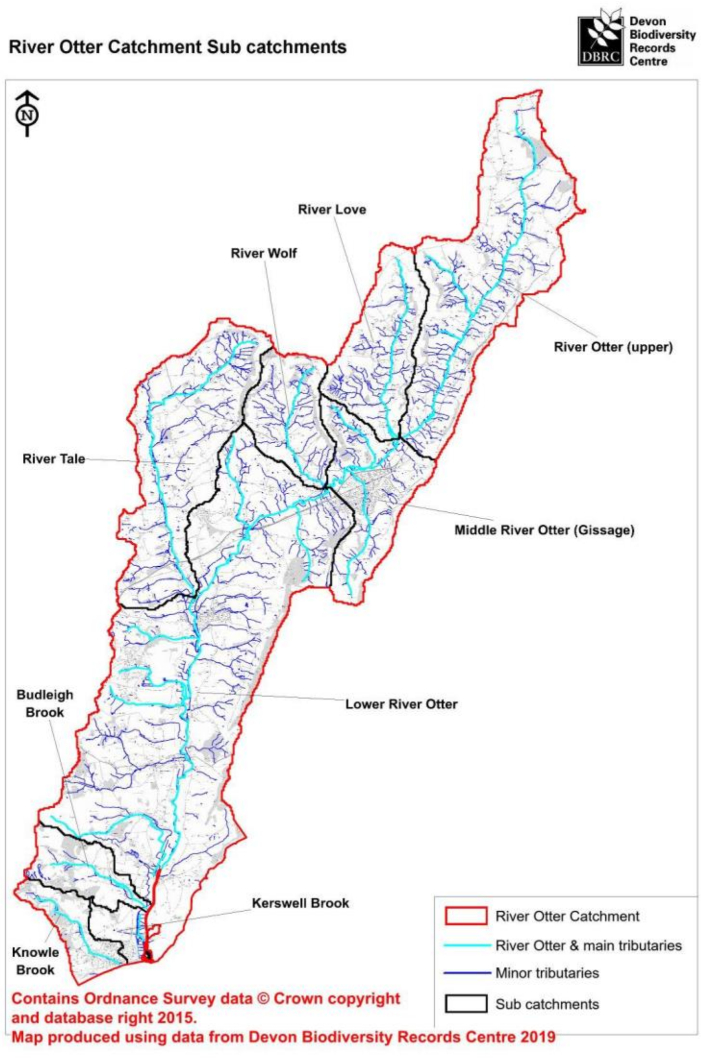

Figure 3-1 River Otter catchment and main tributary systems (source: Knott 2019)

The catchment has an area of approximately 250 km^2, predominantly rural landscape dominated by livestock and arable farming, especially in the lower reaches, below Honiton (50% improved grassland and 28% arable), but with several coniferous and broadleaved plantations on the northern and eastern side of the catchment. The main urban areas are Honiton, Ottery St. Mary, and Budleigh Salterton. The Otter is one of Devon's largest groundwater sources supplying drinking water to over 200,000 people.

The steep and rolling terrain means that heavy rain often runs-off rapidly into the river system, and can carry large amounts of soil and nutrients. This is reflected in the Water Framework Directive (WFD) ecological status of the sub-catchments; the Lower Otter and Wolf were both classified as Poor in 2012, and had not changed in 2016 (latest publicly available data). The Middle Otter has deteriorated from Moderate to Poor, while the Tale has improved from Poor to Moderate. The River Love and the Upper Otter have also changed from Good to Moderate (Knott 2019). The river is also impacted by a number of major barriers to fish movement that contribute to the WFD status.

3.1.1 Flood risk

A total of 28,198 people are at high or medium risk to flooding in east Devon (Figure 3-2; Environment Agency 2012). In the River Otter catchment, there are 85 properties and 200 people vulnerable to flooding (1% annual probability) in Budleigh Salterton, 75 properties and 180 people in Ottery St Mary, and between 25 and 50 each in Newton Poppleford and Honiton if no flood prevention measures are taken into account. These numbers could rise as a result of climate change, mainly increasing the number of houses that are vulnerable to flooding in Honiton to between 100 and 150, again not accounting for flood prevention measures (Environment Agency 2012).

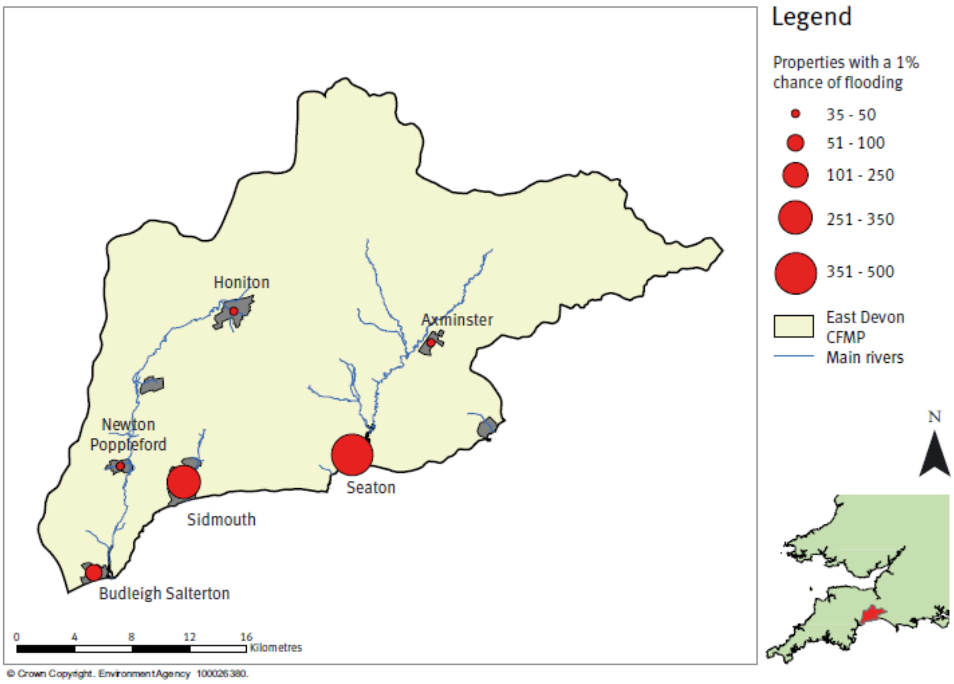

Figure 3-2. Flood risk to property in a 1% annual probability river flood, taking into account current flood defences (Source EA 2012)

A number of measures to reduce the risks of flooding are proposed including, but not exclusive to, the following (Environment Agency 2012):

- With partners, identify locations, and implement measures for increased attenuation and retention of floodwater by floodplain storage, creating wetland habitat and restoring natural river banks. Working with our partners, ensure that areas identified for increased attenuation or water retention do not adversely impact upon designated features (including the historic environment).
- Identify locations with the potential to improve land management and land use to benefit flood risk management. In addition to reducing damage from river and 'muddy' land drainage flooding, this action should also improve water quality in the Otter, ….. Wolf and Tale rivers.
- For towns the main strategy is that Sustainable Drainage Systems should be incorporated into development to restrict surface water runoff and land use planners should seek to reduce the vulnerability of property at risk and behind defences.

Technically beaver dams can be used to attenuate floods (see section 2.2.5) and could contribute to Water Framework Directive targets, but conversely they may exacerbate issues with fish and fisheries because of disruption to migratory fish distribution and abundance, and alteration of channel form and function, especially if breached under high flow events. This is also at odds with the East Devon Catchment Action Plan 2019[21], which indicates the requirement for "Catchment-scale river and fisheries improvements to meet WFD targets and restore rivers" and states the need "To improve fish migration throughout catchment for all fish species".

3.2 River Otter fish and fisheries

As a first step to understanding the status and trends in the fisheries and fish community dynamics of the River Otter, the EA annual rod catch statistics (https://www.gov.uk/government/publications/salmonid-and-freshwater-fisheries-statistics) and National Fish Populations Database (NFPD: https://data.gov.uk/dataset/d129b21c-9e59-4913-91d2-82faef1862dd/nfpd-freshwater-fish-survey-relational-datasets) were interrogated.

3.2.1 Rod fisheries

The River Otter supports a small, but significant sea trout (*Salmo trutta*) rod fishery (

[21] (East Devon Catchment Action Plan 2019 (2019) East Devon Catchment Partnership C22)

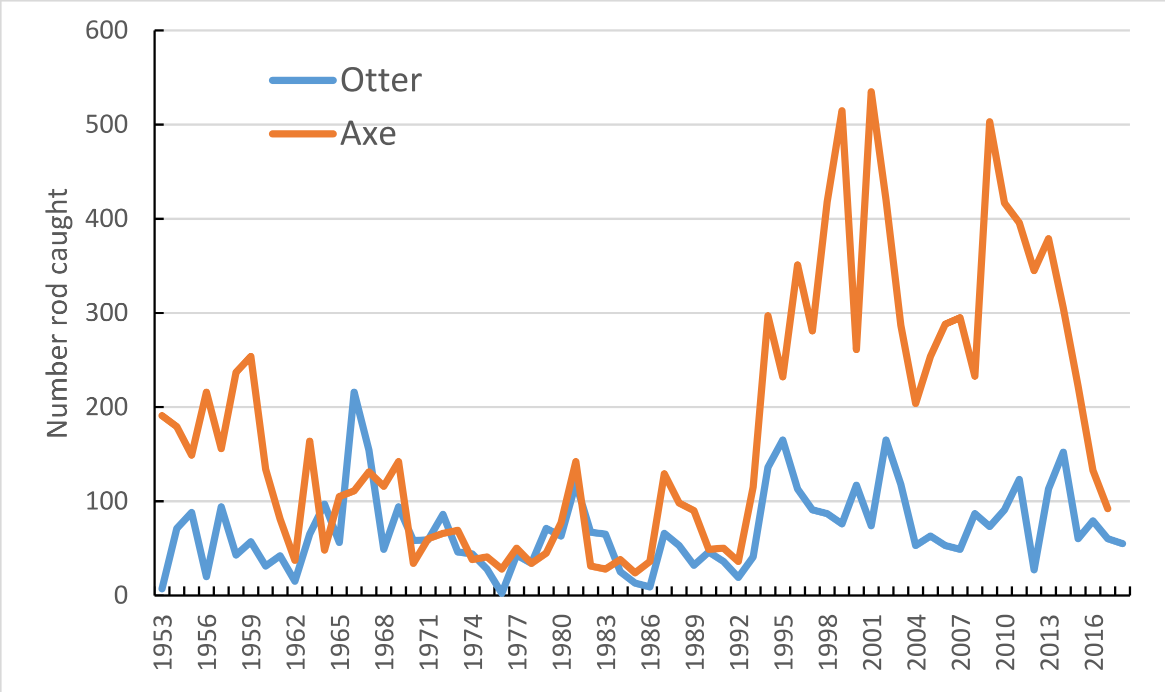

Figure 3-3) with the occasional salmon also caught. Reported catches of sea trout have fluctuated widely over the years, peaking on what appears to be a decadal cycle, and somewhat follows a similar cycle to that observed in the nearby River Axe (Figure 3-3). Such cycles are observed in other migratory salmonid fisheries and may be related to marine conditions. Catches in the Otter have increased marginally since the 1990s and fluctuated between 27 and 165 (mean 89) fish between 1995 and 2018, but have not increased as much as has been observed in the Axe (Figure 3-3). It should be noted that reporting of rod caught sea trout (and salmon) in the River Otter and other rivers in England is not precise and many more fish are known to be caught (River Otter Fisheries Association, personal communication).

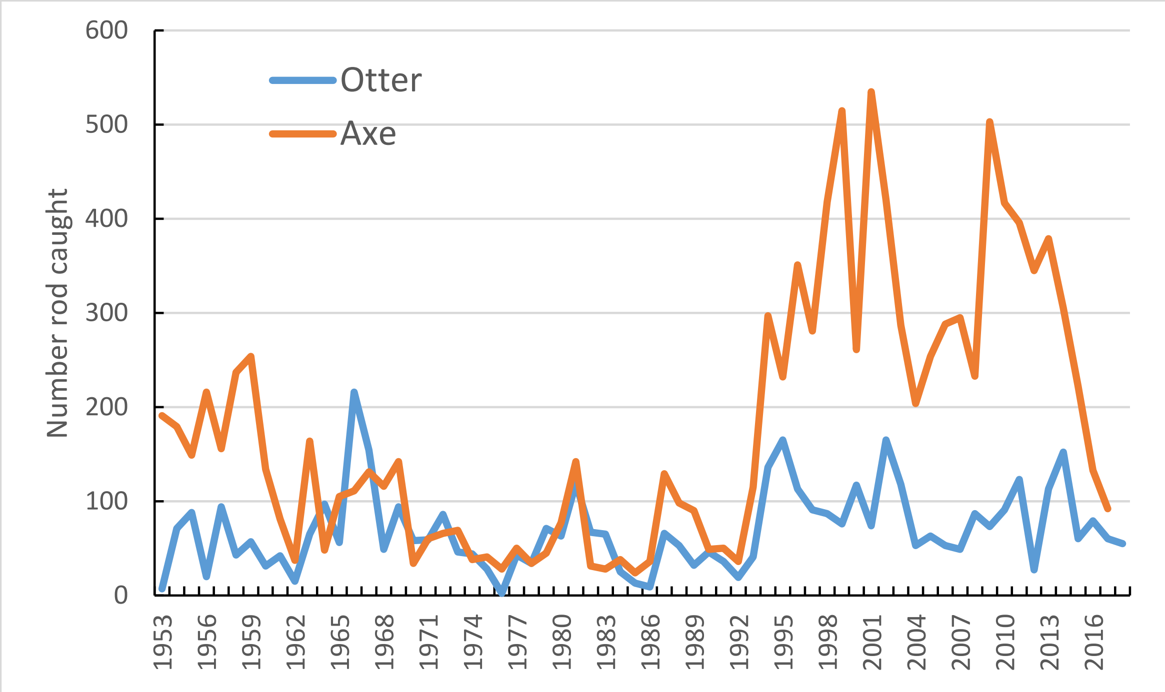

Figure 3-3. Annual sea trout rod catches for the rivers Otter and Axe

The occasional salmon (*Salmo salar*) is caught by rod in the River Otter each year, with at least two caught in 2020, but these are often not reported. A few juvenile salmon have been caught in EA fisheries surveys (Figure 3-6). Salmon have also been stocked in the past. The river does not support a substantial salmon population allegedly due to historical barriers affecting fish migration (East Devon Catchment 2019), but there is also anecdotal evidence that the stocks were once heavily exploited[22]. This precept seems to be supported by the distribution of some 61 artificial barriers across the catchment (reported in the EA barriers database and EU AMBER barriers database[23]) (Figure 3-4). However, the argument is somewhat incongruous given there is a sea trout run (and fishery) in the river. Both species are anadromous requiring migration upstream to spawning and nursery habitats. The prime salmonid spawning areas in the River Otter are considered to be above Monkton, between Honiton and Upottery. Fish can typically reach this far upstream when the river is in spate. Currently only three of the weirs have fish passes, all in the lower reaches of the river, including a new pass on the weir at Tipton St John. Tracey Weir, to the north of Honiton, is an obstacle.

[22] https://www.riverotterfisheriesassociation.org/history-fishing-the-otter
[23] https://amber.international/european-barrier-atlas/

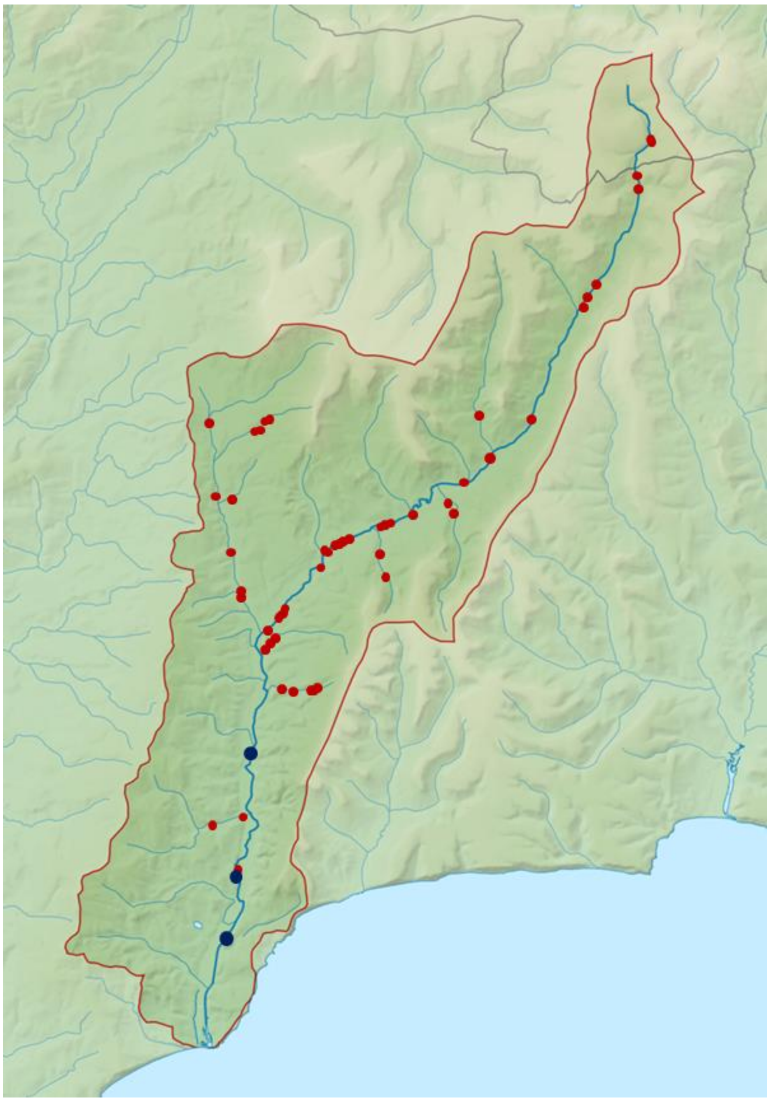

Figure 3-4. Location of major physical barriers to fish migration on the River Otter and tributaries. Blue dots represent barriers with fish passes.

3.2.1 River Otter national fisheries surveys (Source Environment Agency, National Fish Populations Database)

Routine fisheries monitoring data for the River Otter were available in the NFPD from 1998 until 2019. Surveys were carried out on an approximately 3-year cycle at 18 spatial survey sites and annually at three temporal survey sites (Twistgates, Metcombe Vale & Colliton Bridge) (Figure 3-5). In addition, ad hoc (investigative) surveys were carried out at 11 sites across the catchment. These data provide a good baseline of the spatial and temporal trends in the fish communities across the catchment over the past 20 years. To understand spatial variability in fish community structure, the mean percentage fish catch composition from four annual surveys carried out at the 18 spatial sites in 1998, 2003, 2011 and 2016, or on occasions the following year, were compared. Differences in fish community composition were assessed using cluster analysis based on the Bray Curtis similarity index of main species densities at all sites and tested for significance using PERMANOVA.

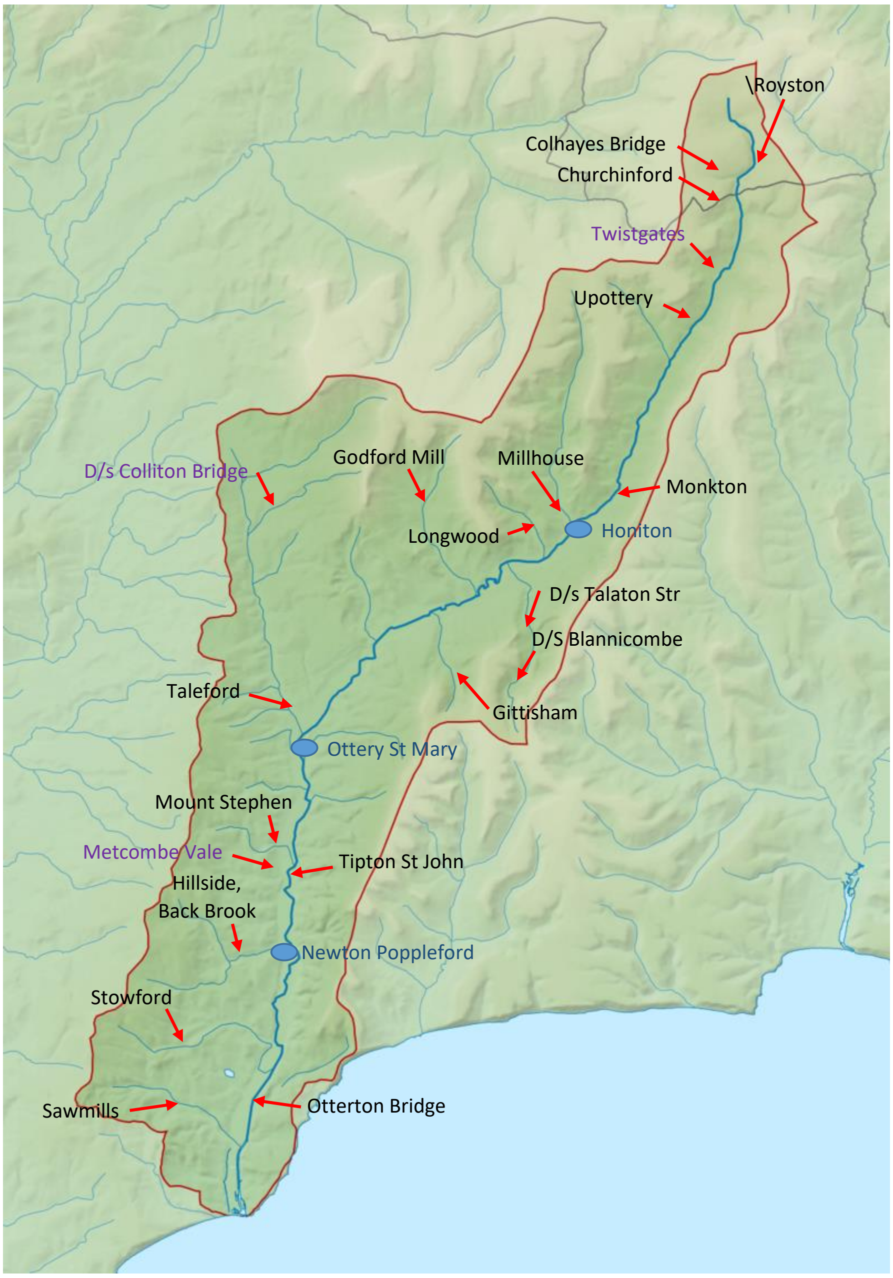

Figure 3-5. Location of main spatial (black) and temporal (purple) survey sites reported in the EA NFPD

The River Otter is characterised by a trout community type (Noble et al. 2007) throughout the mainstem and tributaries (Figure 3-6). The fish community is dominated by trout (*Salmo trutta*), bullhead (*Cottus gobio*) and stone loach (*Barbatula barbatula*), with evidence of juvenile salmon in the lower reaches at Tipton St John and Otterton Bridge. Minnows (*Phoxinus phoxinus*) were also found throughout the catchment, although their numbers were generally recorded as an abundance category rather than relative abundance (no per unit area), and the occasional dace (*Leuciscus leuciscus*) was found in the mainstem river. Eels (*Anguilla anguilla*) were found throughout the catchment and brook lamprey (*Lampetra* spp.) were occasionally observed in surveys, the latter observations for lamprey were recorded semi-quantitatively because this species requires a species specific sampling strategy to determine their abundance and distribution quantitatively (Harvey & Cowx 2002).

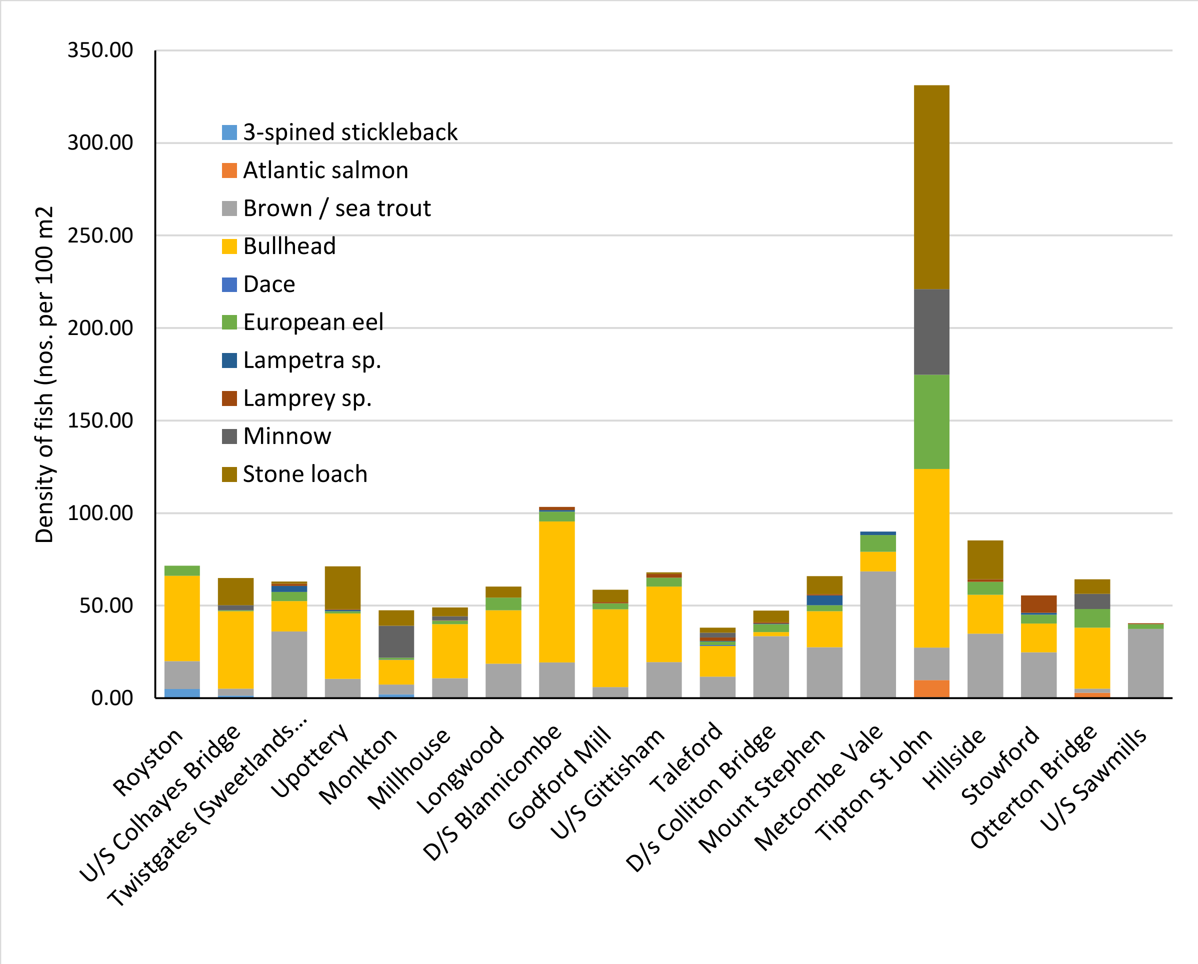

Figure 3-6. Relative abundance of fish species (density no/ 100 m^2) at different temporal and spatial sites in the River Otter (based on mean density in 1998, 2003, 2011 and 2016 surveys)

No significant differences in fish community composition (PERMANOVA analysis based on Bray Curtis similarity index) were found between sites, although clusters representing the mainstem river and higher gradient streams were evident (Figure 3-7). This analysis provides evidence that sites on tributaries that have not been impacted by beaver activity could have provided suitable control sites for impact assessment. The same could be said for understanding the impact of beavers on the mainstem of the Otter where significant beaver presence is reported.

Differences were found in the dominant species at the three temporal sites, with trout the most abundant species and bullhead the second most important species at Twistgates, whilst stone loach was the second most important species at Collington Bridge. An increase in the prevalence of bullhead was observed at the Metcombe Vale site in recent years, but this could have been the result of the species being reported in terms of number caught per unit area as opposed to relative abundance categories in the past. The contribution of these 'lesser' species to the fish community varied over time at the temporal survey sites with no obvious trends.

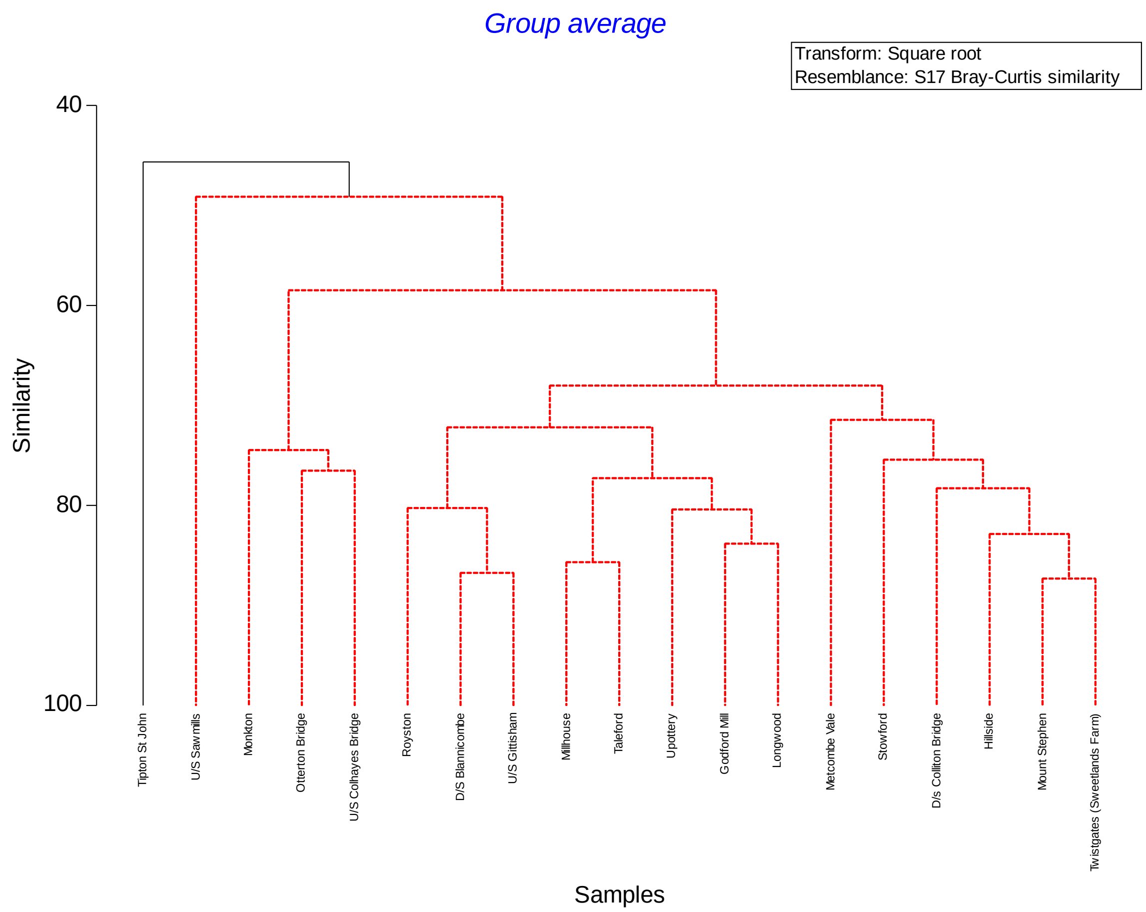

Figure 3-7. Cluster dendrogram showing the similarity between fish communities at various EA survey sites in the River Otter catchment. There is high levels of similarity in fish community structure between tributary systems

Trout density estimates derived from fisheries surveys were compared using the current fisheries classification scheme. The Environment Agency Fisheries Classification Scheme (EA-FCS) was developed to allow comparison of juvenile salmonid monitoring data with a juvenile database derived from over 600 survey sites in England and Wales (Mainstone *et al.* 1994a). The classification of salmonid populations is based on a grading scale (A–F) and provides an indication of the status of salmonid populations in surveyed rivers. The EA-FCS grading scheme is translated as follows: Grade A (excellent), Grade B (good), Grade C (fair or average), Grade D (fair/poor), Grade E (poor) and Grade F (fishless). The population density grades for the EA-FCS are detailed in Table 3-1.

Table 3-1. 0+ and ≥1+ brown trout abundance (N/100 m^2) classifications used in the Environment Agency Fisheries Classification Scheme (EA-FCS)

	Abundance classification					
Species group	A	B	C	D	E	F
0+ brown trout	≥38.00	17.00-37.99	8.00-16.99	3.00-7.99	0.10-2.99	0.00
≥1+ brown trout	≥21.00	12.00-20.99	5.00-11.99	2.00-4.99	0.10-1.99	0.00

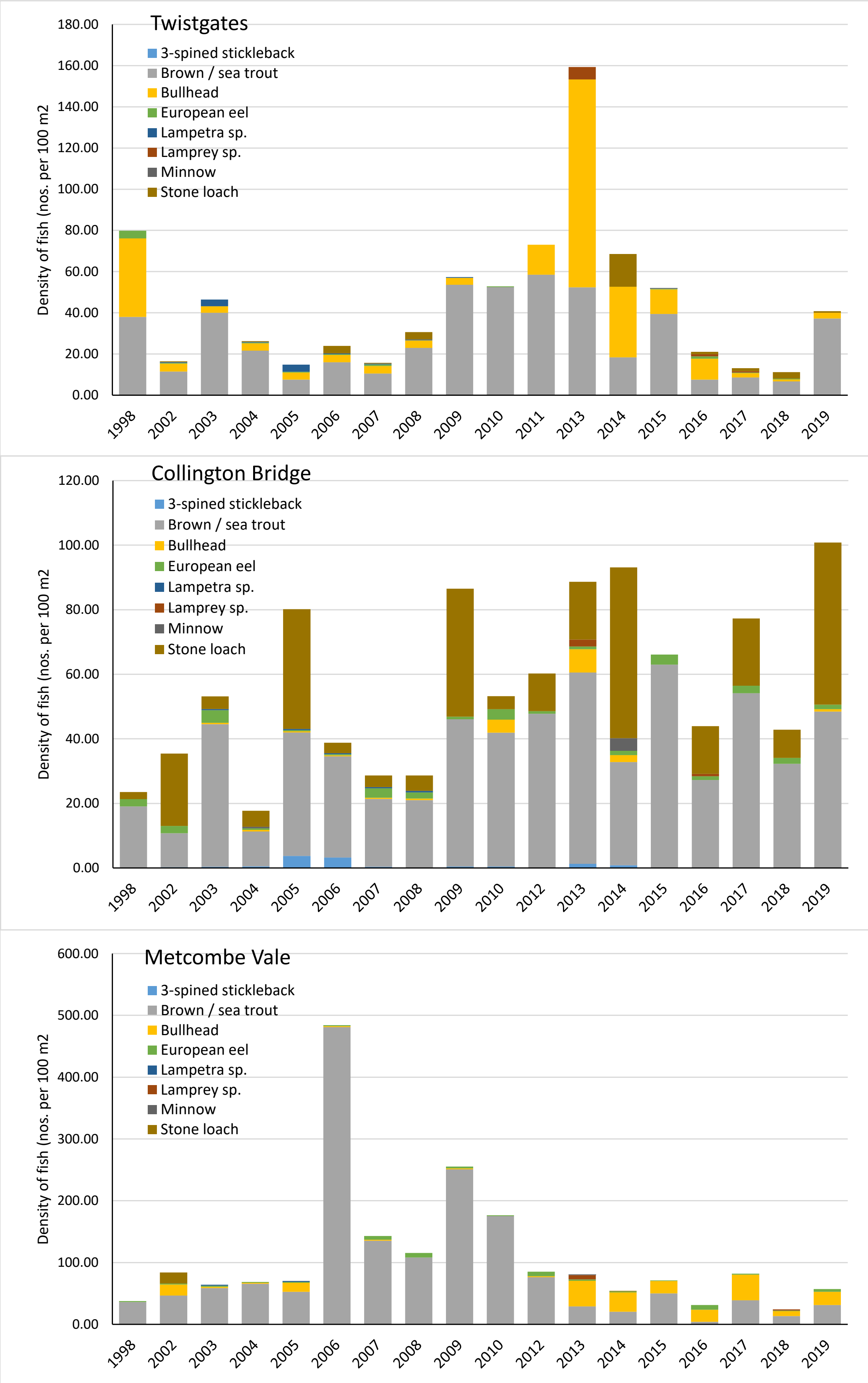

Figure 3-8. Relative abundance of fish species (density no/ 100 m^2) over time at different temporal survey sites in the River Otter

The density estimates derived from the NFPD suggest that the trout populations through the Otter catchment were generally in fair to good categories, although there was some evidence to suggest the fish community at Metcombe Vale had deviated somewhat in recent years and the abundance of trout had declined, but bullheads increased. No explanation for this shift was found.

This review of the EA rod catch statistics and NFPD data provides a substantial baseline for the fisheries of the River Otter against which the outputs of the ROBT could have been compared and contrasted. The rod catch data illustrate the relatively small **but locally important** sea trout rod fishery supported by the River Otter, which clearly highlights the need to maintain connectivity in the river between the sea and spawning and nursery areas in the Otter catchment and tributaries. As noted earlier, the rod catch statistical data registered for migratory salmonids in the River Otter is probably an underestimate as fishing effort fluctuates from year to year and not all anglers report their catch. The NFPD data are collected in a standardised way over time and cover a wide range of habitats and reaches across the River Otter catchment. The data also provide evidence of temporal shifts in fish community composition and relative population abundance, which can be used to help explain any shifts in the fisheries population status in the ROBT studies. Importantly, the NFPD data show the widespread distribution of potamodromous (freshwater resident) brown trout. This species, as well as many other freshwater species, also needs to migrate between different reaches of the river to complete its lifecycle, hence the need to maintain free movement of fish throughout the catchment. The importance of this connectivity for all fish species was recognised by the Environment Agency, which recently installed a new fish pass on Otterton Weir at the bottom of the catchment.

It is somewhat surprising the ROBT Science and Evidence review and associated studies did not make full use of the Environment Agency fish population data to help design the survey strategy or provide a comprehensive overview of the fisheries of the Otter catchment as baseline information for the trial. Arguments that these data do not align with the distribution of beaver dams in the River Otter are invalid given the original and current distribution of beavers (see Figure 4-1). Also the impact of beavers on river fish ecology is much more that the disruption to fish migration cause by dams (see Figure 2-1).

4 Review of the River Otter Beaver Trial Science and Evidence Report

4.1 Background

A systematic review of the River Otter Beaver Trial [ROBT] Science and Evidence Report (DWT 2017; Brazier et al. 2020) and associated materials was carried out with specific focus on evaluating the findings of the impacts of beavers on riverine ecosystems, fish populations and the fisheries they support. This review assessed the evidence available online or provided through secondary sources (see Section 6.1 for reports reviewed) and compared this evidence base with information from similar introductions in the UK and Europe (where appropriate) to determine the legitimacy of the outputs of the project. Consideration was also given to the Beaver Management Strategy Framework for the River Otter (post 2020) to provide options for management of the River Otter beaver population and utility of applications elsewhere in the UK.

The objectives of the ROBT, as outlined in the licence application to Natural England in 2014, were to:

- **Identify and assess impacts of beavers on habitats, wildlife, built infrastructure and local communities.** In particular this will concentrate on recording any impacts on farmers, wildlife, fish populations, water management infrastructure, roads, paths and the people that live and work in the valley.
- **Identify wider public benefits associated with beaver activity in the landscape.** This includes the potential benefits of beaver dams storing floodwater, reducing pollution, which will be the subject of a PhD with Exeter University. This objective also includes other benefits such as economic benefits for local tourism businesses.
- **Develop an effective management process for a free living beaver population.** Protecting important trees and structures, and trialling "beaver deceivers" in any dams will form the basis of mitigation measures. These techniques and the decision making steps are all outlined in the "Beaver Management Strategy" published in January 2016.
- **Understand the ecology, behaviour and population dynamics of a beaver population in a lowland productive agricultural landscape.** Research will seek to understand how the beavers colonise the catchment and utilise the resources within it, and will enable the carrying capacity for the catchment to be calculated. Monitoring the population of the beavers and how they form territories will be a key aspect of this.
- **Increase knowledge and awareness with local communities and other key stakeholders of beavers and their interactions in the landscape.** Public engagement and local education work will seek to explain the ecology and behaviour of beavers to local people, and ensure decisions about their future are based on factual information, rather than myths.
- **Provide data and evidence to augment national knowledge base re beaver re-introduction.** The knowledge gained as part of the ROBT will be disseminated to various national and international audiences. There are numerous projects around Britain seeking to restore beavers to wetlands, and advice and experience will be provided to these where appropriate.

To achieve these objectives, the ROBT Science and Evidence Forum published a Monitoring Plan on 1 April 2016, outlining eight core Research Objectives that were detailed in the Monitoring Framework included within the licence application submitted by DWT on behalf of the ROBT partners to Natural England in 2014. These objectives were updated in 2017 (DWT 2017) and indicate how they would be investigated over the 5 years of the trial. The main objectives, with specific sub-objectives related to fisheries were:

1. Economic and land-use impacts: Assess and quantify the associated costs and benefits of beavers in a productive English landscape including impacts on agriculture and forestry and infrastructure.
2. Economic and land-use impacts: Further economic benefits of beaver re-introduction will be determined, such as through eco-tourism, fisheries and education.
    - 2c. To characterise the socio-economic value of the river Otter fishery, and any impacts of beavers on this. Produce a short summary of the use and economics of the River Otter fishery, including the CDE land, Deer Park and other syndicates.
3. Biodiversity - Habitats and Species: Determine the impact of beaver activity on vegetation communities, in particular semi-natural habitats. Studies should determine changes in both the nature of and extent of the habitats.
4. Biodiversity - Habitats and Species: Determine the impact of beaver activity on key fauna populations. The monitoring will focus on impacts on fish populations, but will also include amphibians, and invertebrates (aquatic and terrestrial) and birds
    - 4a. To characterise fish populations in the River Otter, and in the event of any beaver damming or other significant changes, to investigate their impacts on fish populations, including passage and recruitment.
5. Ecosystem Services - Water Resources: Quantify the impact of beaver activity on water resources regulation at a range of scales in the Otter catchment.
6. Ecosystem Services - Water Quality: Quantify the impact of beaver activity on water quality including sediment, and macronutrients (Nitrogen, Phosphorus, Carbon) retention at a range of scales in the Otter catchment
7. Social Impact: Provide a qualitative analysis regarding community interaction with this controversial issue. The study would consider the involvement and perception of the project by the general public and other stakeholders.
8. Beaver Health, behaviour and population change: Monitor the health of the beavers before and after release and their behaviour and population demography through time.

4.2 Beaver activity

Monitoring techniques were established at the start of the ROBT to assess beaver activity. The surveys were designed to be quarterly (every 3 months), but this proved impractical because of dense vegetation impeding access to the river. Monitoring was thus revised to record feeding signs on woody material once a year (January to March). Heat maps were used to capture intensity of feeding (Figure 4-1) and thus territories of beavers. This approach was used to assess relative beaver numbers/activity because of difficulties in determining actual numbers.

In February and March 2015, the initial beaver population, on which the ROBT was based, was two family groups located in the vicinity of Otterton and Ottery St Mary (Figure 4-1). At the start of 2016, an additional young pair of beavers was found in the Honiton area. At that time, there were thought to be approximately 11 beavers living in three loose family groups between Honiton and Budleigh Salterton, with signs that at least one beaver had explored the upper catchment into Somerset, and the River Tale (ROBT Annual Report 2017). Numbers have increased steadily since then to an estimated 7 family groups in 2019 (ROBT Annual Report 2020; Figure 4-1). At this time, six other areas of activity in addition to those around the seven known family groups were identified, suggesting up to 13 territories could exist or be in the early stages of establishment (Table 4-1). These latter groups probably include a number of singletons representing dispersal of young animals in the population.

Table 4-1. Changes in estimated territory numbers from 2015-2019 (source ROBT 2020)

Situation in April of:	Focus of activity	Known breeding pairs
2015	2	2
2016	3	3
2017	6	5
2018	8	6
2019	<13	7

In 2019, three additional beavers were released into the catchment to enhance the genetic diversity, bringing the total to five for the ROBT period – the maximum permitted by the licence. One of these animals died shortly after release, and in January 2020, another apparently move some 3 km from near Otterford in the headwaters of the River Otter, to Widcombe Grange at the head of the River Culm, a major tributary of the River Exe[24]. Its presence was noticed because it felled a large willow tree and was later caught and repatriated to the River Otter trial site. This highlights the capacity of the species to colonise new habitats (see Figure 4-2, which shows the proximity of adjacent catchments and potential for colonization) and the potential issues that may need to be controlled with dispersion from open sites.

The distribution heatmaps produced annually by ROBT (Figure 4-1) show the expanding range of beaver activity in the Otter catchment from the onset of the trial. Beavers are now found throughout the main River Otter and along many of the main tributaries, including the rivers Tale and Wolf. The ROBT Science and Evidence Report (Brazier et al. 2020) using what is referred to as a Territory Capacity Model, estimated the maximum number of territories in the River Otter catchment was between 147 – 179, which would equate to 500+ beavers. It is thus likely that the beavers will come into greater conflict with different land-users before this ecological limit is reached, something that needs more in-depth analysis and evaluation. Of further concern with such high numbers of beaver territories is the uncontrolled dispersion of beavers into neighbouring catchments, especially as two-year old beavers are vulnerable to attack from larger adults, and typically seek to set up new territories. The reported migration into the River Culm catchment suggests this will likely happen with commensurate impact on the landscape, vegetation and fisheries in the newly colonised river systems (Campbell-Palmer et al 2016).

[24] https://www.dailymail.co.uk/news/article-7856837/Beaver-escape-River-Otter-Beaver-Trial-Devon-estate-Somerset.html

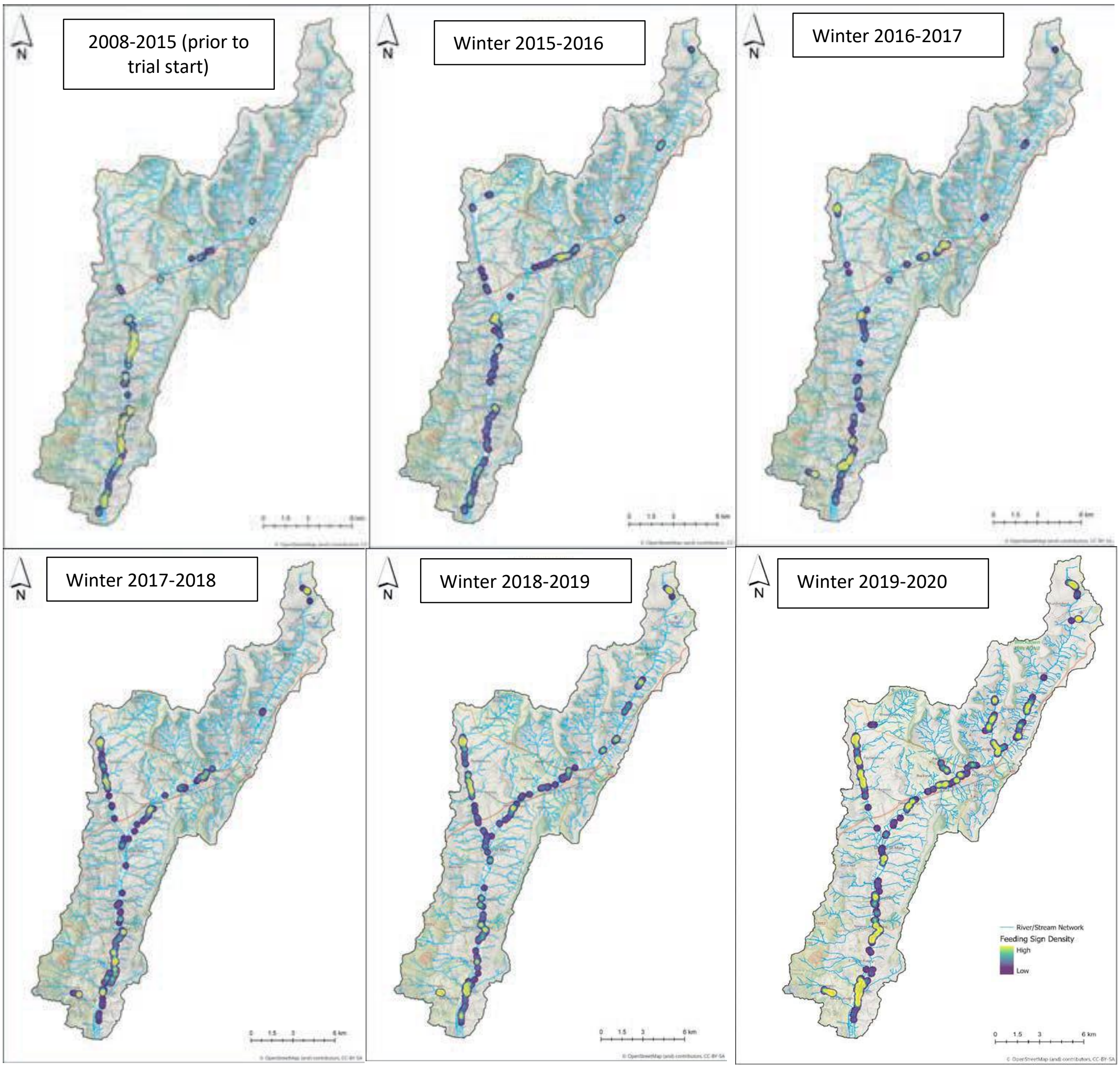

Figure 4-1. Heatmaps of the distribution of beaver feeding activities in the Otter catchment between 2015 and 2019

An assessment of the number of beaver dams in the River Otter was attempted in October 2018. It was concluded that 26 dams were in place at that time, but that approximately 80 had been constructed since the start of the Trial at 55 locations on seven different land holdings. It appears that the construction of dams were largely in the narrower tributary streams rather than the mainstem of the River Otter. This is in line with the precept that beavers construct dams in higher gradient streams where suitable ponds are not available to establish a territory. One territory was established on the River Tale, where the beavers appear to have built dams to raise the water to access maize crops. They also built bank lodges nearby, which could have impacted on agricultural land causing problems with operation of agricultural machinery. As previously stated, however, the total number of dams that could be constructed on the River Otter was anything between 262 and 814 dams (; Brazier et al. 2020), and this suggests the distribution, and any impact, will likely grow in future years until the population stabilises. During this period, the propensity for dispersion into adjacent catchments is likely to increase and need to be controlled.

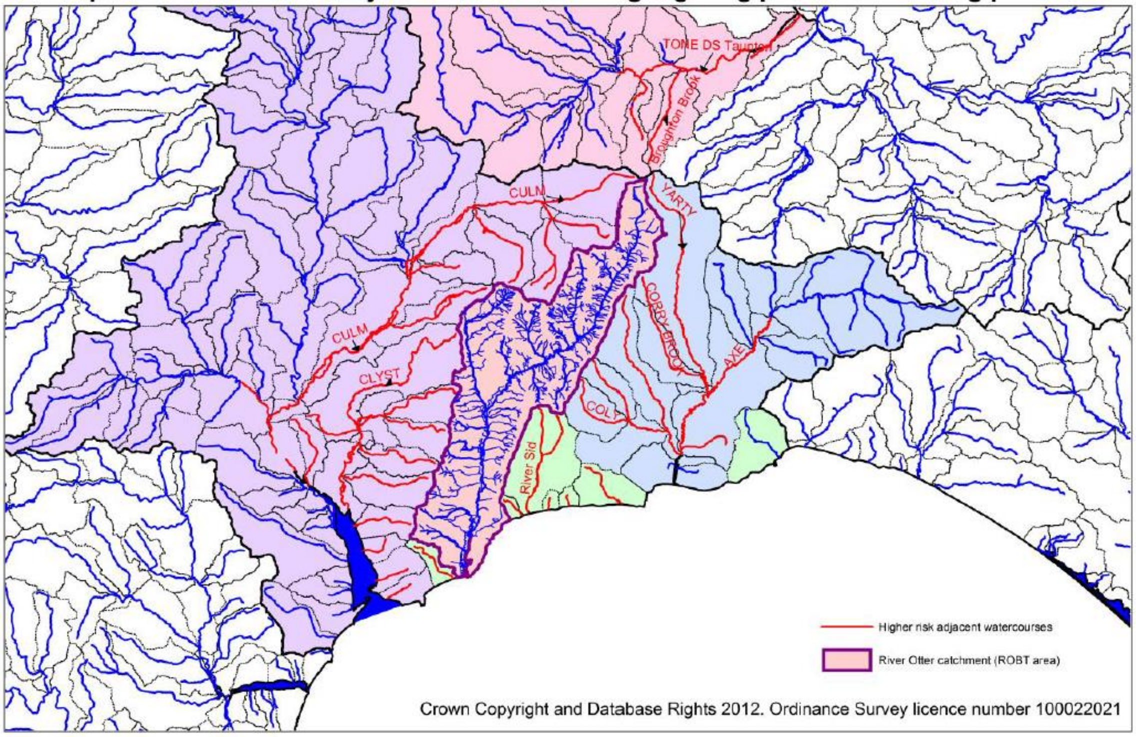

Figure 4-2. Map pf River Otter and adjacent catchments highlighting potential crossing points (source DWT 2016)

The data presented in the heat maps provide an indication of the distribution of beavers in the River Otter, but appear to reflect mainly where surveys were carried out. What is critical in these maps is the prevalence of beaver activity in the mainstem River Otter and River Tale throughout their entire lengths and more recently the River Wolf. This has considerable connotations for designing fisheries surveys to understand the impact of beavers on the fish and fisheries in the catchment. Studies should go beyond understanding the impact of dams on fish movements, as has been the main focus of the ROBT studies, to explore the impact of foraging and borrowing activities on larger streams, which seems to be the preferred habitat of beavers in the River Otter.

Studies on the distribution of beavers in the River Otter have also moved beyond reporting empirical evidence of beaver activities. Graham et al. (2020) used algorithms of likelihood of construction of dams at various locations on the Otter (and other river systems –River Tay and Coombeshead sub-catchment) to determine the density of beaver dams that can be supported within a given reach. The outputs (Figure 4-3) suggest beavers are likely to construct dams in the headwaters of streams and not so much in the larger rivers, as would be expected. The outputs agree to some extent with where beaver dams have been constructed in the Otter and show where dams are likely to be constructed in the future as beavers increase in abundance and expand their range in the catchment. Interestingly, as predicted by the simple classification tree presented in Figure 2-5, there appears to be little likelihood of dams being constructed on the mainstem River Otter. Notwithstanding, the modelling only determines the likelihood of dams being constructed and not the presence of beavers or the likelihood of them colonising specific reaches. As already observed, the main beaver activity in the River Otter is in the mainstem of the river and in the River Tale (Figure 4-1), where the models suggest there will be few or no dams constructed. **It is thus important**

that future studies on the impact of beavers on fisheries cover areas where beavers are active not just where dams have been constructed, i.e. in the main river channels and larger tributaries. This is particularly important because beavers tend to burrow into river banks where they do not build dams and thus create a different set of issues related to infrastructural damage and bank damage, including loss of other wildlife such as water voles. In this context, the trial should have modelled the areas that beavers are likely to inhabit and burrow into river banks, particularly as the population continues to grow towards the predicted 147 – 179 territories (Brazier et al. 2020), by the 2030s. **Any models produced also need ground-truthing against existing distribution patterns and systematically cross-checked against expanding abundance and range.**

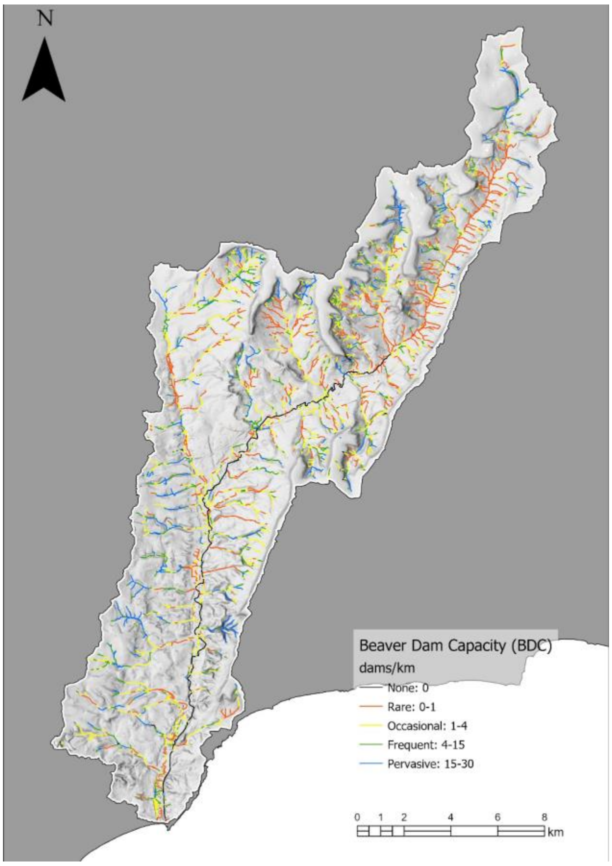

Figure 4-3. Beaver Dam Capacity (BDC) modelling shows watercourses capable of supporting beaver dams. (Source Graham et al. 2020)

4.3 Fish and Fisheries Assessment

4.3.1 Fisheries surveys

The specific aims of the fisheries assessment (DWT 2017) were: "to determine the impact of beaver activity on key fauna populations. The monitoring will focus on impacts on fish populations, but will also include amphibians, and invertebrates (aquatic and terrestrial) and birds". In particularly the aim was "to characterise fish populations in the River Otter, and in the event of any beaver damming or other significant changes, to investigate their impacts on fish populations, including passage and recruitment."

Fisheries data to characterise the populations in the River Otter (including eels, lamprey, bullheads, other course fish and salmonids) were collected by the University of Southampton at Deer Park on the main Otter in 2015 and at one dam location at Danescroft on the River Tale in 2016, 2017 and 2019 (see Figure 4-2 for site locations). It was anticipated that detailed monitoring of the impacts of beaver dams on fish populations and fish migration would be carried out in the event that beaver dams were built in the river or streams in the Otter catchment (DWT 2017), but the one site on the main Otter and the one dam on the River Tale seem to be the only fisheries surveys undertaken. No complimentary surveys were carried out on the enclosed trial site on the River Tamar or on adjacent rivers to act as control or heavily impacted sites. **This is a major limitation given there is no baseline reference conditions for the status and trends in fisheries in the River Otter provided, including making use of the Environment Agency's NGPD data** (see Section 3.2).

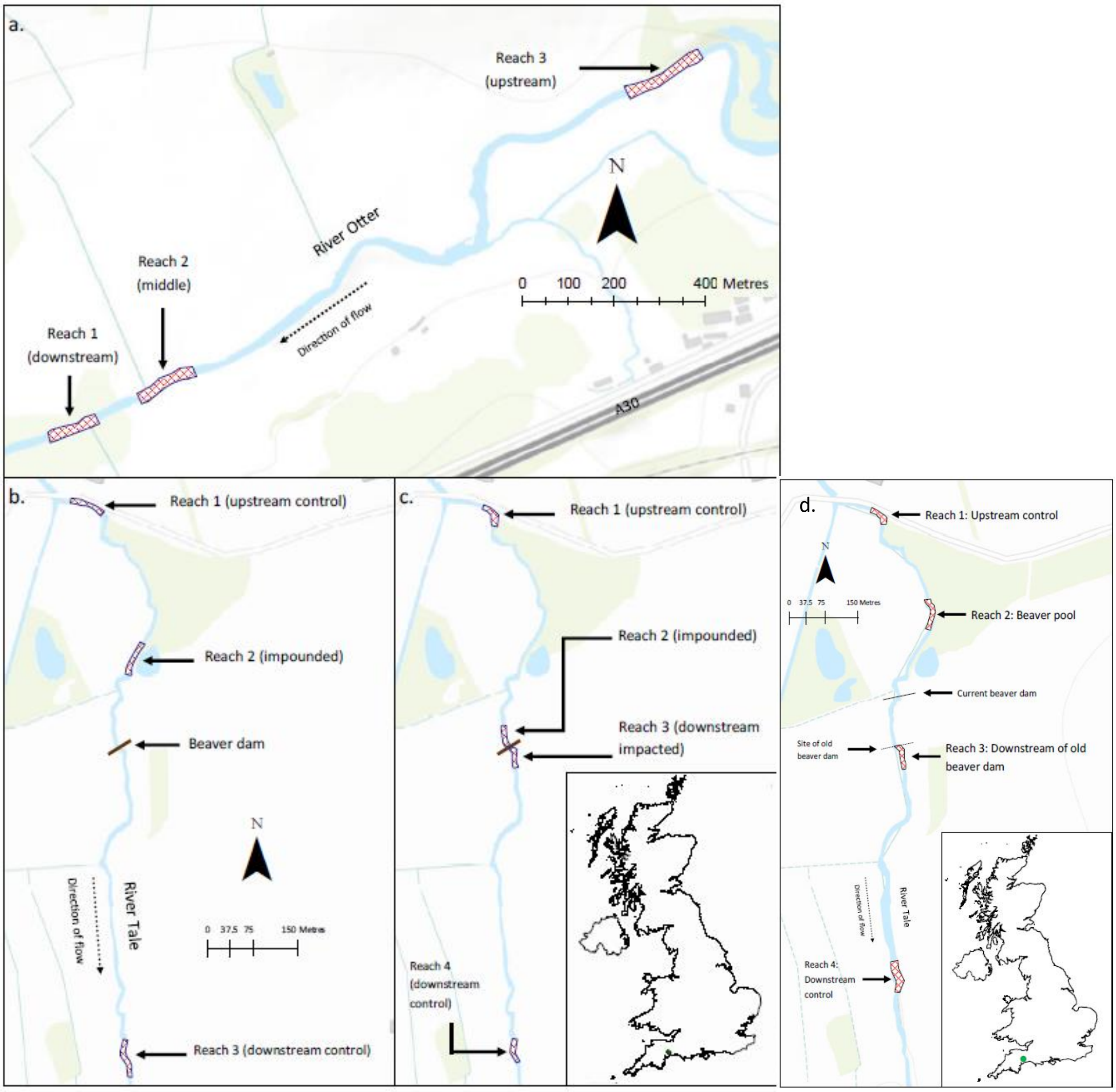

Figure 4-4. (a) Sites on the River Otter (Devon, UK) where single pass electric-fishing was conducted; (b-d) sites on the River Tale (Devon, UK) where multiple pass electric-fishing was conducted in2016, 217 and 2019, respectively, to determine the impact of a beaver dam on the fish community (source: ROBT Annual reports)

In 2015, three, 100-m long reaches were surveyed by electric-fishing in the River Otter at Deer Park Country House Hotel, near Honiton, using a single pass strategy without stop nets.

Subsequent surveys carried out on the River Tale, used a control / impact survey design. Two control reaches were surveyed, respectively, upstream and downstream (and not in close proximity) to the beaver dam. Impacted sites were the impounded section and immediately downstream of the beaver dam (2017 and 2019 only). Reaches were surveyed using a multiple-pass electric fishing strategy between stop nets. **Different lengths of river were surveyed in the different years** (50-m reaches in 2016, 25-m reaches in 2017 and 30-m reaches in 2019). It should be noted the minimum length of survey site recommended by the EA Fisheries Monitoring Programme Guidance is 30 m, thus the 2017 surveys are inconsistent with this criteria. Further, **the location of the sites surveyed, including the control sites, were not consistent between years**, although this was, in part, due to shifts in location of the dam under study between years (Figure 4-2). The area fished immediately upstream of the dam (impounded area) appears to be approximately 120 m upstream of the beaver dam in the headwater of the impoundment, where it was probably possible to sample by wading, and not the impounded area proper, which would likely be deep water that cannot be easily surveyed by electric fishing without using a boat. This zone is likely a transition zone between river lotic and lentic environment and the fish populations/community structure are not representative of the beaver pond per se. Electric fishing efficiency for the quantitative three-catch sampling for brown trout in the wadeable sections surveyed was between about 0.5 and 0.8 and is consistent with the 0.6 recommended in the EA guidelines for electric fishing, except for the downstream control site in 2017 when the efficiency was inexplicably low at 0.17. Electric fishing efficiency for other species was generally must lower and reflects species-specific sampling characteristics, especially for cryptic benthic species, such as bullhead and stone loach, which are notoriously difficult to survey accurately, and usually have a low capture efficiency.

In addition, the surveys on the River Tale were carried out in different months of the year: October in 2016, July in 2017 and August in 2019. This can have considerable impact on the efficiency of the electric fishing for small-sized individual fish, especially young-of-the-year fish, that are not of a sufficient size to be captured effectively until later in the year (typically late August until early October is the best time to sample juvenile salmonids). Comparison of the size of fish between years will also be problematic given most of the growth of fish in English rivers occurs in the spring and summer months (Cowx 2001), and the different timings of the surveys do not necessarily account for movements between habitats.

Physical habitat characteristics (depth, velocity and substrate composition) were also measured.

A total of 1067 individual fish from eight species were captured by electric fishing from three sites on the River Otter in 2015 (Vowles and Kemp, 2018). These comprised mostly bullhead (43.4%), minnow (37.9%) and stone loach (10.2%). Small numbers of brown trout (3.3%), three-spined stickleback (*Gasterosteus aculeatus*) (2.3%), lamprey (1.9%), eel (0.9%) and Atlantic salmon (0.09%) were also caught. These catches are broadly similar between sites, although more bullheads were caught in the upstream site and more minnows in the lower site. No reasons were provided for the differences but this could be related to the topography and gradient of the river channel, perhaps with more pool-type habitat in the lower sites. The species composition and abundance appears consistent with surveys carried out by the EA at sites close to Honiton (e.g. Monkton; Figure 3-6).

The surveys on the River Tale adopted an impact-control strategy to understand the potential effects of the beaver dam at Danescroft on the fish population structure and dynamics. The most upstream and downstream sites were designated as the controls, whilst the sites immediate adjacent to the dam were the impact sites. In 2017 and 2019 an additional site immediately below the dam that was the site of an old dam was also surveyed, presumably to determine whether the fish populations returned to pre-dam status.

A consistent number of fish, mainly bullhead, stone loach, brown trout and minnow, were caught in the River Tale surveys (555 in 2016, 543 in 2017 and 748 in 2019), but brown trout dominated the biomass of fish present (Figure 4-5). The contribution of different fish species to relative abundance and biomass of the fish communities varied between different survey sites in the same year and between the same sites in different years. The fish communities in the most upstream and downstream [control] sites were similar in terms of densities and biomass of fish species in the same year and between years, but the composition and relative abundance of fish in the beaver pool change dramatically over time. In 2016, fish species composition (proportion of each species) in the pool was similar to the control sites, although abundance (densities) was slightly less. In 2017, abundance (densities) was markedly less in the pool [impact] site but recovered somewhat in 2019, although this recovery was largely due to a large catch of minnows.

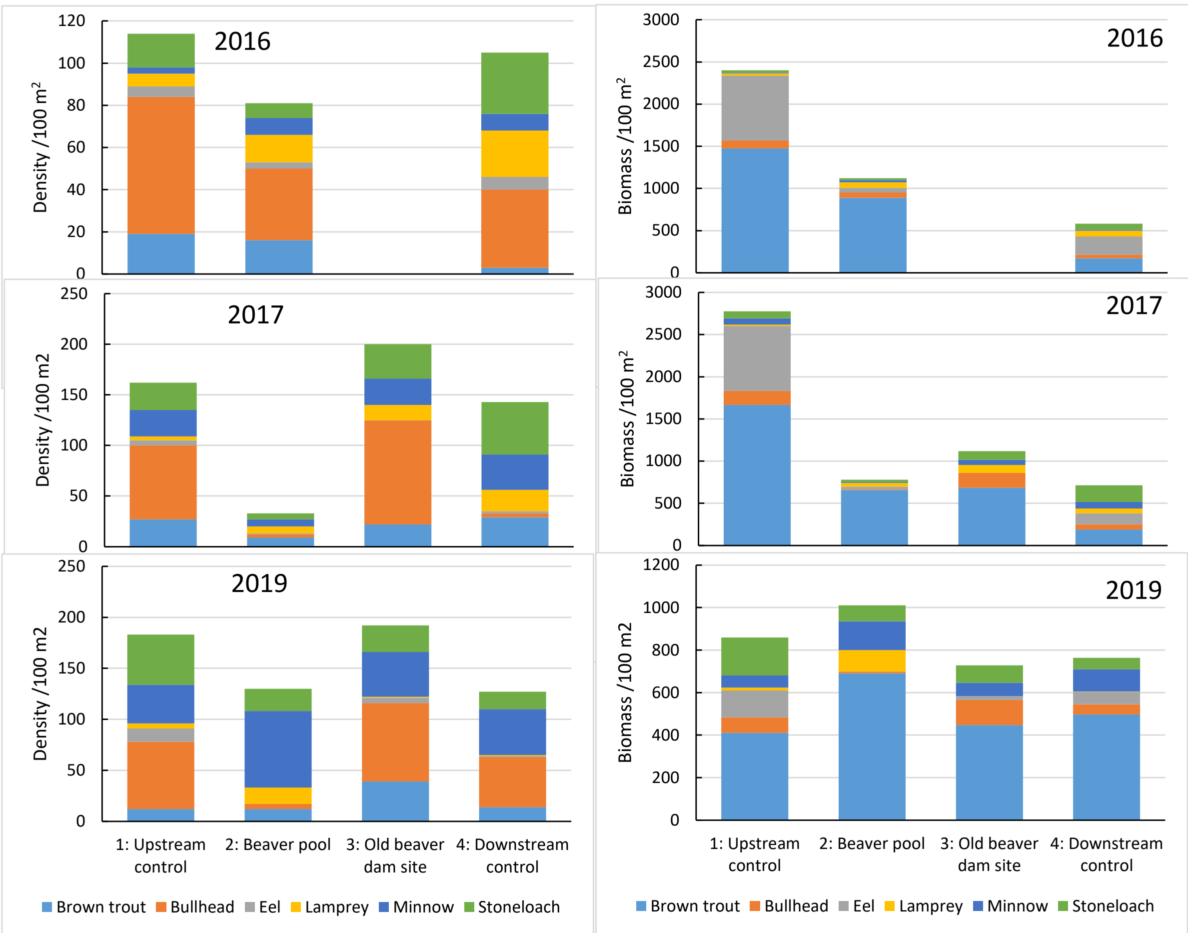

Figure 4-5. Relative abundance (density [no./100 m²] – left; biomass [g/100 m²] – right) of fish species in the River Tale electric fishing surveys in 2016, 2017 and 2019 (Source Vowles & Kemp 2018 and Vowles 2019)

Interestingly, the ROBT Science and Evidence report (Brazier et al. 2020) presented the increase is abundance of fish in the beaver pool in 2019 as a positive, but they used total number of fish caught at the site as a direct measure of abundance for comparison with other sites (Figure 4-6). Such data do not take into account fishing effort or area of river sampled, and when standardised as relative densities (fish per 100 m^2), the numbers were considerably lower (Figure 4-5). In addition, the majority of fish caught in the beaver pool in 2019 was minnows, which is a shoaling species. It is likely the survey encountered a large shoal of minnows to account for this contribution, although Vowles (2019) suggested the increased abundance may have been the result of more large woody debris accumulating in the pool upstream of the dam in 2019. Minnows are better adapted to slower flowing, pool conditions and this may also account for this increase in abundance. This example highlights the need for long-term sampling using standardised capture and reporting methodologies, and use of replicate surveys in multiple dam reaches.

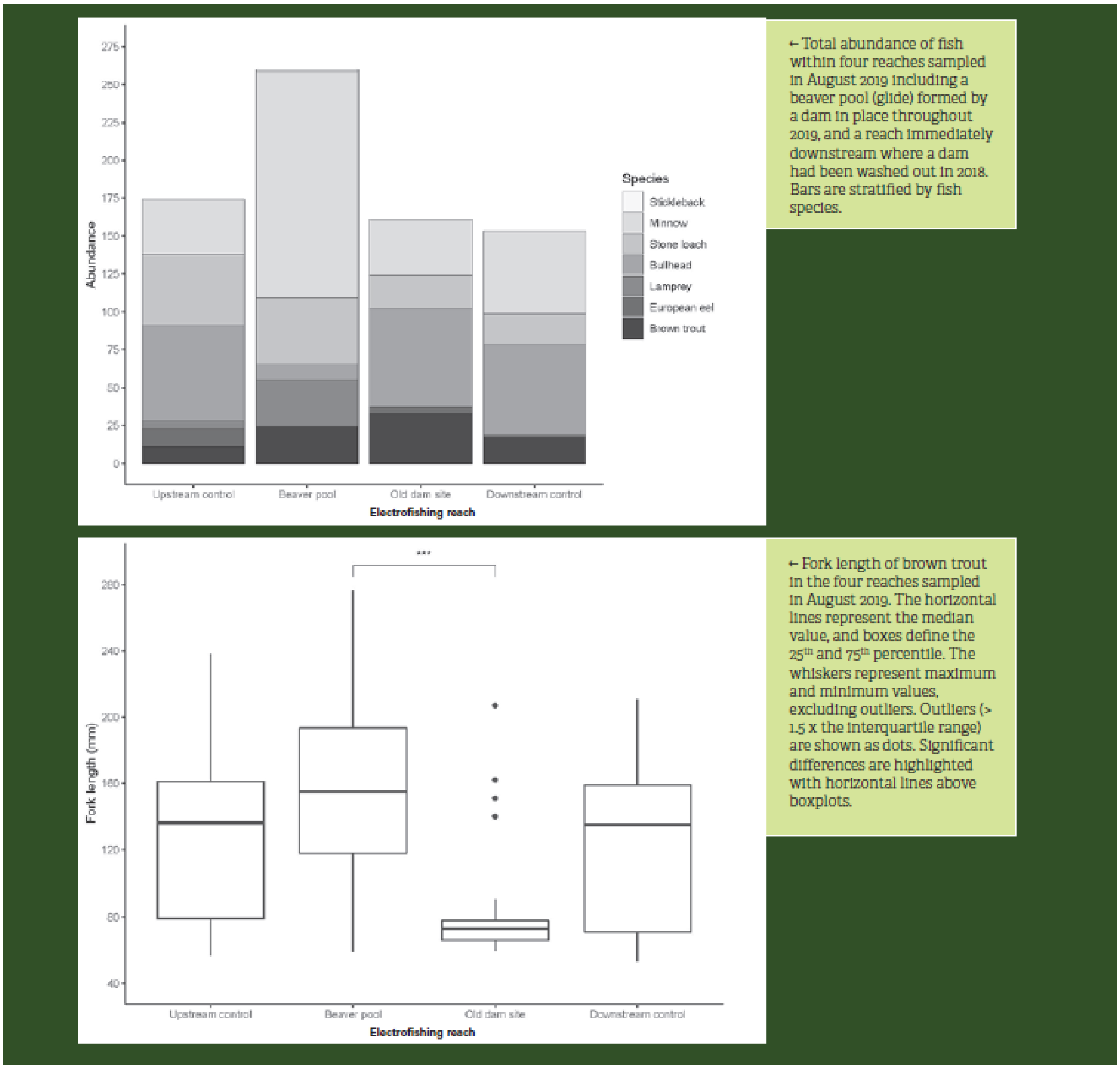

Figure 4-6. Abundance (total number of fish caught) and mean fork length of brown trout in different fisheries surveys sites in 2019) (Source: ROBT Evidence report 2020)

Further, abundance of fish in the upstream impoundment cannot be considered representative of improvement in fisheries. These habitats flood spawning and nursery areas and allow the proliferation of fish species that prefer lentic habitat such as minnow. Other rheophilic species such as bullhead (a species of concern under the EU Habitats Directive) and stone loach also declined. Whilst it is recognised that other species of conservation concern, such as lamprey, may be benefit, they are not typically found in great abundance in higher gradient rivers where the beaver dams are built.

Biomass of fish was generally higher in the most upstream [control] site except in 2019 when the highest relative abundance was found in the beaver pool (Figure 4-5). This was largely the result of larger trout occupying the pool, the large catch of minnows and an increase in the contribution of lamprey making use of the silty habitat. Note, interpretation of larger fish in the impoundment being equated to better growth can only be proven from growth studies based on scales from the fish. Biomass of fish in the most downstream [control] site was less than the upstream sites in 2016 and 2017, despite the abundance [densities] being similar. This apparent anomaly was because few trout were caught at the downstream site in 2016 and the trout caught at the downstream site in 2017 were smaller (mean 70 ± 22 mm FL) than upstream (130 ± 78 mm FL), which may indicate the downstream site was a nursery area for the species. Abundance and biomass of fish species in the site downstream of the dam, representing a site recovering from a dam break, were similar to the upstream control site suggesting the river may recover rapidly after dams have been removed or washed away.

With the exception of the smaller brown trout in the downstream control reach in 2017 and smaller brown trout in the old dam site in 2019 (see Figure 4-6), the size of fish caught of each species were similar at all sites in the same sampling year. However, brown trout, eel, lamprey and stone loach were on average smaller in size in 2019 than 2016, and this probably reflects the later sampling date in 2016.

The main fisheries studies to assess the impact of beavers on fisheries of the River Otter were the annual surveys carried out by Vowles & Kemp (2018) and Vowles (2019). These surveys only targeted extant fish communities, and in the case of salmonids mostly the juvenile life stages. Such information provides an approximation of the current distribution of sea trout (and salmon) spawning habitat but does not provide an assessment of the potential habitat that is lost or could be lost due to beaver dams. To partially address this issue the West Country Rivers Trust (WCRT) surveyed approximately 7 km of two tributaries of the River Otter (Stowford Stream and River Tale) where beaver dams were located between 30 November and 4 December 2017 as part of the ROBT (West 2018). The survey employed WRT's salmonid redd count methodology alongside a fisheries-based walkover survey to map habitats and points of interest such as beaver dams and other obstructions. No salmonid redds were confirmed, although one possible redd was observed on the River Tale near Danes Mill. It was concluded that middle and upper reaches of the Stowford Brook and the River Tale represent suitable nursery areas for migratory salmonids.

During the walk-over surveys, eight beaver dams were observed between the confluence with the Otter and Colaton Raleigh on the Stowford Brook, and it was concluded these structures may impact returning sea trout, other salmonids, brown trout and minor fish species such as bullhead and stone loach from accessing their spawning grounds. **This type of survey is critical to understanding both the ongoing impact of beaver dams on the spawning and**

recruitment of migratory fish species and should have been carried out for the entire catchment and validated against EA fisheries survey data. This is a major limitation of the fisheries assessment in the ROBT evidence report (Brazier et al. 2020)**.**

Overall, surveys to assess the impact of beavers on extant fish populations and communities were based on one semi-quantitative survey on the main River Otter in 2015 and quantitative surveys at four sites representing controls and impacted reaches up and downstream of a single dam on the River Tale in three different years (2016, 2017 and 2019). Further, no evaluation or conclusion on the likely impact of the expanding beaver population on fish population and community dynamics towards 2030, particularly the impact of barriers and impoundments on fish migration and recruitment, is provided. **Given the ROBT was set up to assess the impact of beavers on fish and fisheries and serve as a reference study** for deciding whether a) beavers should be allowed to remain 'wild' in the River Otter and b) to support the decision to allow further releases of beavers into the wild in England, **the sampling framework falls well short of that expected for a robust impact assessment.** At the very least, a number of dams representing different locations, construction design, environmental and habitat conditions and several cascades of dams should have been surveyed in a consistent manner over a number of years. This is particularly relevant given there are 28 known dams ranging height from 15 to 180 cm in at least 13 areas of activity (Brazier et al. 2020, Table1.2), but with a potential 147 – 179 territories and 262 and 814 dams (; Brazier et al. 2020) that could be occupied and constructed, respectively, by 2030. The upstream-downstream control-impact strategy used in the study is considered suitable but should have been supplemented by control sites in different tributaries that have not been impacted by beavers to date. This is feasible given the similarity in fish community structure between tributaries in the Otter catchment (Figure 3-7).

In addition, surveys on reaches of the River Otter known to be occupied by beavers but where they have not built dams should have been conducted, e.g. the Otterhead Lakes area. It is currently unknown if beaver foraging and burrowing activities or retaining banks built off the line of the water course are having an impact on fisheries or the ecosystem functioning in these larger, wider river reaches.

In conclusion, the evidence presented on the impact of beavers on fish populations is superficial and lacks a comprehensive survey programme one would expect of such a strategic assessment that will used support decisions on the reintroduction of beavers. ROBT study should have sampled a range of dams in the same year and repeated over multiple years, rather than one dam three times over a 4-year period, to provide a robust, defensible, assessment of the spatial and temporal impacts of beaver dams and beaver activity on fish and fisheries in the Otter system, and give confidence in the outputs. In addition, repeat surveys should have been carried out in areas of the river where beavers are known to inhabit but do not build dams. This survey strategy of repeat surveys at a range of sites where dams have and have not built dams is particularly critical because there are no baseline fisheries surveys on the River Otter to compare changes in the fish populations and communities brought about by the reintroduction of the beavers, and no use has been made of the Environment Agency's fisheries survey data to supplement this need.

4.3.2 Barriers to fish migration

Figure 2-6that caused the flows to overtop the dam and create a rivulet to the side of dam. The ROBT Science and Evidence report describes the observations on sea trout ascending or trying to ascend the Tale dam, noting that five fish succeeded in ascending the dam but six (i.e. the majority) did not, despite multiple attempts. Whilst larger fish were seen to negotiate the dam in the videos after several unsuccessful attempts, it appears the hydraulic conditions were not suitable for smaller trout with lower swimming capacities to bypass the structure. Smaller fish were seen failing to ascend the dam at the same time large fish were successful. Regrettably, these videos do not substantiate the conclusion that beaver dams are passible, instead that only show that certainlarger, fish can bypass the dam when the hydraulic conditions are optimal for passage. They do not show that all species and sizes of fish can pass the dams at all times, and do not consider the issue of multiple dams.

As a result of concern from fisheries stakeholders, South-West Rivers Trust was commissioned to develop a methodology to assess the impact of beaver dams on fish migration (West 2019). The draft protocol Passage Assessment of Beaver Dams (PAB) based on the SNIFFER protocol (SNIFFER 2010; King et al. 2017) was developed. It is stated this is an industry standard and a coarse resolution rapid assessment technique. This tool has not been adopted by industry and the full protocol is considered too onerous and data hungry, and simpler methods are available (Kemp & O'Hanley 2010).

As stated, the PAD protocol (West 2019) is a modified version of the SNIFFER methodology (see Table 2-2) that requires surveys of in-channel characteristics. This carries health and safety risks and the tool only measures the downstream pool depth and hydraulic head, and not the hydraulic conditions through any side channels or bypass routes, which is the way migratory fish will likely negotiate the dam. No results of applying the assessment tool were available but the conclusion from surveying nine dams in October 2018 was: "Whilst it is clear that some dams have the potential to impede the movements of some fish in some situations, whether these impacts have a significant impact on fish populations is a highly complex and controversial area of science" (West 2018). This statement highlights the importance of a robust assessment of fish passability and not reliance on observations of fish negotiating a barrier. **This study does not prove that each individual fish that needs to bypass the barrier can do so, and does not confirm that the barrier is passable under all flow conditions and at all times of the year.**

Another of the outputs of the PAD tool (note the full description of the PAD tool was not available for scrutiny) is a flow diagram to enable management to make 'educated' decisions on whether or not to intervene at a dam for the benefit of fish passage. The tool is a series of steps that makes use of local knowledge and the dam survey results (Figure 4-7). The steps are followed assuming: 1) there is no reason why the dam cannot be interfered with and the landowner permissions gained and 2) the dam being assessed is in an area of value to migratory trout. It is based on the criteria that **s**uccessful migration depends on: hydraulic head, pool depth; head height versus pool depth relationship; damaging debris present, depth at crest and resting locations, all of which are linked to hydraulic conditions. Critical with beaver dams is that they are constructed from woody debris and the ends of sticks and branches stick out and may be sharp and damage fish trying to ascend the barrier or returning downstream, but also debris can block the downstream pool affecting the fishes ability to ascend the dam. Even small dams can be impassable if the depth of water in front of the dam is shallow and prevents the fish from jumping or if the dam width is great and there is no channel over the barrier.

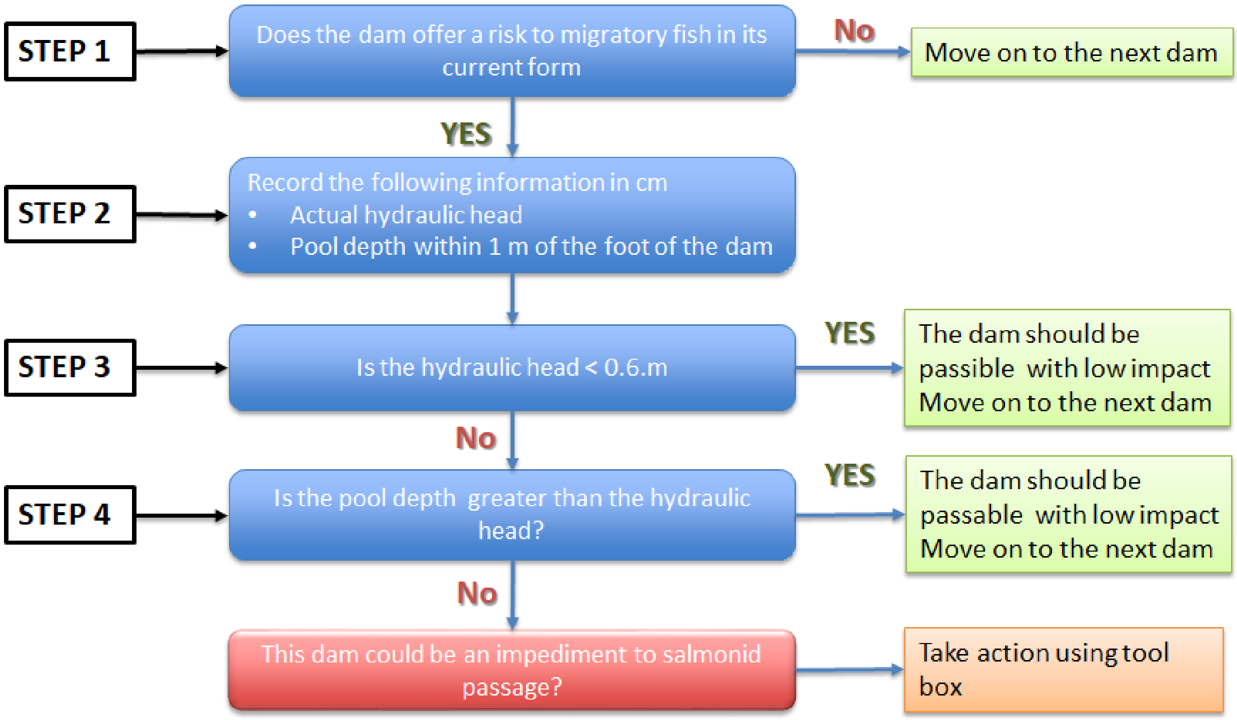

Figure 4-7. Flow diagram to enable management to make decisions on whether or not to intervene at a dam for the benefit of fish passage (modified from West 2019)

The ultimate step in the assessment protocol guides the assessor to a tool of actions if the dam is considered to impact on fish migration in one form or other (Table 4-2). Unfortunately the associated tool box only deals with modifications to the dam form and structure to overcome any impediment to fish passage. There is no step in the assessment tool or associated tool box about whether to consider dam removal as an option. This is a weakness in the value of the tool, which could perhaps have been used to support the wider decision support system on managing beaver impacts. In addition, the mitigation measures proposed are only short term fixes and there is no evidence the measures proposed will work at the dams under all flow conditions. Further, as indicated previously, beavers will tend to rebuild/improve the dam (usually within a day or two) to maintain its integrity and protect their lodges, so further interventions such as beaver deceivers (but see comments on applicability in Section4.3.5) or complete removal of the dam should also form part of the tool box. An alternative solution is to prevent beaver damming spawning areas in the first place.

Table 4-2. Actions to take and why if a dam is highlighted as a potential risk to fish passage

Element causing an issue	Action to take	Outcome
Hydraulic head too high	Remove materials at the crest of the dam to reduce the height, try to focus this on one side to increase flows in one area.	A reduction in head height and concentrated flows will also deepen the pool depth over time.

Pool depth too shallow	Reduce the difference between pool depth and head height by reducing hydraulic head.	Narrowing the difference between the height and pool depth.
No resting locations present	Try to create small indentations in the bank downstream of the dam.	Creating areas where fish can rest when making multiple attempts at passing the dam.
Damaging material present	Remove any material that would stop fish making effective jumps or damaging themselves while moving up or downstream.	Increase efficiency of pool depth; allow safe passage both up and downstream.

The tool described above has a utility for determining whether barriers will block upstream fish migration. It is somewhat surprising therefore that the tool was not used to assess all dams constructed within the Otter system and provide an overall impact assessment of the likely impact of dams on fish and fisheries in the catchment. Whilst onerous and time consuming to assess all dams, it would have removed some of the conjecture over whether dams are passable and provided confidence to the fisheries stakeholders that efforts were being made to understand the impact of dams on fish migration and recruitment processes. Further the tool could have been tested fully as part of the decision support system for those deciding on whether actions should be taken where problems from dams arise.

One aspect that has been largely overlooked in the ROBT documentation is downstream movements of fish, either migration of adults, or, critically for salmonids, smolts. The argument that dams are 'leaky' and do not block downstream migration (see Section 2.2.6) is unacceptable and needs to be evaluated in a robust and defensible way, preferably using PIT tagging technology or similar modern tools.

Regardless of the above discussions on tools to assess the impact of beaver dams on fish migration and given the importance of the River Otter trial to support national decisions on whether beavers should be introduced to the wild, more robust fish migration studies using modern telemetry equipment should have been employed. These tools could be used to ascertain whether the dams are passable both upstream and downstream, and under what conditions, and should be coupled with robust hydraulic modelling to match the conditions at the dam with the fish's capacity to utilize the flow conditions encountered. The most influential factors affecting upstream migration were pool depth in relation to the hydraulic height of the dam, especially for large dams, and flow velocity through the bypass channel and opportunities for resting. Criteria for downstream migration are yet to be determined, but these are likely to be associated with availability of bypass channels, especially during the times of year when smolts migrate downstream (spring and autumn) and or when juveniles of all species disperse into the lower reaches.

The main conclusion from the ROBT study about trout and salmon spawning areas and fish migration impacted by beaver dams and culvert blockages (Appendix 5a) is: "Impacts on the passage of individual fish could occur, but overall impacts on populations of fish are likely to be positive". The arguments for this are that "dams can trap silt and enhance flows, and the import of woody debris and the increased heterogeneity enhances habitats and resources for all aquatic life including fish". The ROBT Science and Evidence Report (Brazier et al.2020) also concluded that there is no scientific evidence of population scale negative impacts on salmonids, but noted that concern has been raised that beaver dams may impede the passage of individual migratory fish, particularly where there are larger dams in incised channels, and impact on existing spawning gravels. ROBT considered that "beaver dams and any impacts on fish passage and spawning gravels are temporary and as flows increase, many dams become easily passable". Unfortunately the ROBT fisheries studies do not support these conclusions, particularly in relation to impeding fish migration. It is likely that only larger sea trout are able to bypass some of the barriers under high flow conditions when the hydraulic characteristics of the dams are optimal. It does not demonstrate that conditions are appropriate for all species and sizes of fish that need to bypass the barrier, or that optimal conditions regularly occur. In addition, fish migrate throughout the year, not just at spawning time, thus access to upstream habitats is required under all flow conditions, and this is clearly not the case. Further no studies were carried out to assess the impact of beaver dams on downstream movements of fish.

The conclusion of the ROBT that loss of spawning gravels as a result of the construction of beaver dams is only temporary (ROBT Appendix 5a) also needs reconsidering. Multiple dams have been constructed on some tributaries (e.g. Stowford Stream and River Tale) flooding possible considerable lengths of potential spawning and nursery areas for salmonids and dams could also prevent access to these areas. Dams can also remain intact for up to 10 years so this scenario is not temporary. Unfortunately, no comprehensive inventory of spawning and nursery habitat throughout the River Otter catchment was carried out and this is a major limitation of the trial. Comprehensive walk-over surveys should have been carried out as part of study. Instead habitat surveys seem to be limited to surveys carried out on the Stowford Stream and River Tale by WCRT.

4.3.3 Alteration of habitat

One aspect that was also examined during the fisheries surveys on the River Tale beaver dam was the topography of the sites and substrate composition. The upstream impoundment had greater depth and a higher proportion of finer sediments than at the upstream and downstream control sites. The impacted area immediately downstream of the barriers also had a higher proportion of finer sediments suggesting flow velocities have been suppressed and were not sufficient to disperse finer materials, making the substrate less suitable as salmonid spawning and nursery habitats. The restoration benefits instead appear to arise from displacement of the woody material from the dams causing sinuosity and probably scouring of the river bed to create a meandering pool riffle channel. This will add habitat diversity and potentially enhance fisheries and biodiversity, but these structures are temporary and will potentially be altered in subsequent high flow events. In addition, the woody material may cause blockage at pinch points causing localized flooding. This is contrary to the conclusion that beaver dams can help restore river habitat. In reality the restoration benefits appear to accrue from dam breaks rather than the changes in habitat quality brought about by the dams per se.

The whole principle of reintroducing beavers to support flood mitigation actions is somewhat the obverse of the strategy adopted by the EA and its predecessors since the 1970s to remove wood debris barriers and fallen trees to prevent flooding, yet in the current context beaver dams are seen as solution. It is acknowledged that dams may fit well into the 'slowing the flow' natural flood risk management strategy being promoted by the Environment Agency.

However, these dams are temporary solutions and tend to blow out under high flow events, potentially exacerbating the downstream flood risk, particularly if several dams in a cascade break, although this is likely to be rare and the downstream dams could potentially act as buffers to protect surges in water and sediment. If dam breaks should happen they would not only result in an increase in flood risk but also a surge in fine, perhaps contaminated, sediment that could potentially clog interstitial spaces in gravels. This could impact on critical life stages of fish when eggs and alevins are in redds and require water circulation through the gravel substrate. Whether beaver dams qualify as a nature-based solution under such circumstances is open to debate, as is the loss of riparian vegetation that would normally slow pluvial run-off and associated sediments into the river channel.

4.3.4 Disease

As indicated previously (Section 2.2.3), beavers carry pathogens that can be harmful to humans. The origin of the River Otter beavers is now known to include mostly individuals from Southern Bavaria (Campbell-Palmer et al. 2020), a population known to be infested with the tape worm *Echinococcus multilocularis*. During the period of the trial, only five animals could be trapped (four adults and one youngster) to test for *E. multilocularis* infestation based on serology, ultrasound and laparoscopic examination. The question, however, remains of the disease status of the remaining beavers in the Otter population and those elsewhere. This is particularly pertinent given one beaver tested positive for *Leptospirosis* in the early trial and a further three later in the trial. *Leptospirosis* causes the dangerous and occasionally fatal Weil's Disease in humans; beavers on the Continent have also been identified as possible sources of zoonotic infections.

4.3.5 Mitigation measures

As part of the ROBT, officers undertook a series of consultations about the most appropriate mitigation measures (ROBT, Annex 3). The most commonly cited potential measures to control beaver activity were: education, payment of landowners to host beavers, compensation for losses, pulling back land use from the waterside, tree protection and fencing and flow diversion. Discouraging burrowing and dam building, dam removal and population control by relocation were also prominent. In all cases other than education, there are considerable costs needed to carry out the mitigation actions, yet no indication of the source of such funding is provided. It is also questionable whether education is a viable measure as the amenity and novelty value of beavers erodes and conflicts build with increasing beaver population size and distribution range. There are many examples worldwide where introduced beavers have become such a nuisance that public support for them has been lost and the animals are now being reduced in numbers using lethal control (e.g. the Baltic States; Belova et al. 2017).

As part of the ROBT, staff of DWT responded to a number of problems/conflicts that arose during the study. Most actions were lowering the dam height or notching the dams to reduce flooding, unblocking culverts, fencing off trees and undertaking considerable dialogue and educating the public on the “benefits” of beavers. In addition, some dams were destroyed but, as indicated earlier, this took multiple attempts as beavers rebuilt the dams quickly. A beaver deceiver was also installed on a field drain system to lower the extent of flooding (Figure 4-8). Whilst this may not have been on a stream utilised by trout or migratory fish species, it highlights the issue of ensuring the entrance is accessible to migratory fish highlighted previous (Section 2.4.2).

Figure 4-8. “Beaver Deceiver” flow device allows the height of the dam and extent of the flooding to be managed without destroying the dam or wetland (DWT 2016).

The fundamental issue that arises from these various intervention is who will pay for these actions into the future. The River Otter Beaver Management Strategy suggests that dedicated beaver officers should be appointed for catchments where beavers are present, but again this raises the issue of who pays for the appointment and who pays the costs (both capital and recurrent) of the mitigation activities, which can be quite substantial (see Section 4.3.9). Furthermore, many of the activities involve working in the river, which bring with it serious health and safety issues, especially when breaking dams that are holding back large volumes of water.

4.3.6 Attitudes to beavers

Stakeholder engagement was a major element in the ROBT study: many consultations with a diverse array of stakeholders were carried out. The positive attributes of beavers to the public were raised along with complaints from landowners, farmers and residents in houses adjacent to the river. The general conclusion in the ROBT Science and Evidence Report (Brazier et al. 2020) was that beavers cause few problems and these could be managed effectively at minimal cost. Most actions carried out by the ROBT/DWT team were destroying dams, or reducing the height through notching or other measures such as pipes (beaver deceivers) through the dam. But the ROBT Science and Evidence Report does not indicate that these actions had to be carried out multiple times and at considerable cost before the interventions worked. Further, many real concerns expressed by ‘stakeholders’ were not reported fully and landowners who lost specimen trees or livestock were unhappy with the situation. As indicated above, the complaints were treated individually and not cumulatively with time or as a result of construction of multiple dams in a stream. Critically, there is little indication of the human resources required or sources of funding for mitigation actions carried out and whether these costs fell on the estate or land owners. This has fundamental implications going forward with respect to resourcing management of beavers.

ROBT also undertook a series of consultations with stakeholders in several European countries and North America. The basic conclusion, mainly based on western European and USA, was that there were no impacts on migratory fish species, except possibly under low flow conditions (Bavaria), and in the USA beaver dams are actively promoted to improve wetlands for Pacific salmonids. These conclusions are at odds with many field-based observations (see Section 2.2) and appeared to be conducted with mammal societies and agencies actively promoting beaver recolonization. They also conflict with fisheries stakeholders who feel fish populations and fisheries have been impacted in numerous ways, especially migratory species. **There is a fundamental requirement for a multisector review of the issues and an impact/resolution matrix needs to be prepared based on the findings to support management decisions on the reintroduction of beavers under different scenarios** (wild open versus enclosed), to account for variability on catchment topography and ecosystem functioning as well as fish community structure and dynamics.

4.3.7 Economic characterization

An essential element of any impact assessment is to quantify the likely economic impacts and offset these against other benefits or evaluate compensation where appropriate. The ROBT study examined the social and economic importance of fishing in the River Otter, as well assessing the benefits from beavers to the rural economy and ecotourism and impacts of beaver activities on agriculture and property (Auster undated reports[25]).

As indicated in Section 3.2, the River Otter supports recreational brown trout or sea trout fishing, with a limited amount of coarse fishing. Data were collected on fishing licence sales from the Environment Agency and through consultation with fishing clubs and syndicates on fishing rents/rights; syndicate memberships; day/guest fishing tickets; fishing effort; fish stocking; insurance; individual angler expenses and capital value of fishing rights to determine the economic value of the fisheries. As found with previous studies (EA 2018a, b), determining the total economic value of fishing in individual catchments proved difficult but attempts were made to determine the flows between the different economic aspects of fishing. The total economic value was determined to be in the region of £100,000 per annum, which is not an insubstantial amount when compared with the value placed on beavers in the catchment. Impacts of beavers on fishing activities were described and largely related to loss of fishing locations or disruption of fishing because of felled trees preventing access, disturbance by 'beaver-watching' activities and attacks by beavers while fishing. These negative impacts were also coupled with positive experiences seeing the beavers in the water course. Unfortunately it was not possible to determine any likely economic impacts of beavers on the conservation value of fish (in relations to achieving obligations under the EU Habitats or Water Framework Directives) or fishing from the data collected.

In addition to determining the economic flows from fishing, Auster (undated) provided an

[25] https://www.exeter.ac.uk/creww/research/beavertrial/appendix1/

assessment of the likely costs of potential conflicts with agricultural activities and the benefits gained from ecotourism and associate services. Many of the conflicts with agriculture were caused by flooding of arable fields, flooding of access routes and loss of crops. Although the individual losses were not great, usually less than £2000 per conflict, the cumulative costs will likely to be substantial, and will increase as beavers disperse throughout the catchment, and potentially beyond. Mitigation actions were mostly undertaken by DWT project staff as part of the River Otter trial, but it raises the question who will pay for the remediation actions if beavers are reintroduced into the wild in the future. The benefits from tourism were largely based on contingent valuation methods (willingness to pay) and could bring substantial benefits to the rural communities. However, as the novelty value of beavers wears off, the benefits of 'beaver ecotourism' will likely decline, and opportunities for funding mitigation measures will be dissipated.

The ROBT Evidence report (Brazier et al. 2020) provided a summary cost-benefit analysis of the value of beaver presence in the River Otter, and concluded the benefits outweighed the costs. However, the analysis made some substantial assumptions, not least wildlife viewing was related to beavers and up to 40% of footpath use would be attributed to beavers, and contingent valuation methods reflect peoples' attitudes to payment to see beavers. It is also unsure whether the full economic costs of damage by beavers were accounted, especially where landowners, such as the Clinton Estates, bore the costs of repair and mitigation. Irrespective of this positive perspective, as a result of his analysis, Auster et al. (2019) stated "*the costs on agriculture resulting from the impacts of beavers* [and presumably on fisheries], *will need to be factored into future management decisions if beavers are to be formally reintroduced. These will need to be considered alongside the other impacts of beavers (whether positive and negative) and perceptions of wildlife management in the development of a strategy which would be more likely to reduce conflicts between humans and beavers or between humans about beavers"*. This clearly highlights the need for further robust economic analyses at a range of locations and river types, before any firm conclusions on the true value of beavers in the landscape can be confirmed.

4.3.8 Conflicts

Currently beavers are seen as charismatic megafauna largely in controlled environments. In the River Otter open trial a number of complaints were received and these were largely dealt with through interventions by DWT. In most cases the actions were to destroy dams, reduce the height of dams through notching or other measures such as pipes through the dam, or protecting trees. Costs of these actions were covered by the DWT, but in the long term these costs are likely to fall on the landowner or impacted stakeholder, and become increasingly burdensome. It should also be noted these interventions were generally not single measures and required recurrent actions, often over extended periods, to address the problems. The recurrent, and potential high, costs of mitigation measures are somewhat at odds with Recommendation 6 of the ROBT, which suggests resources are likely to reduce as beaver impacts become 'normalised' with their continued presence. However, with increasing distribution of beavers in the Otter catchment and eventually colonization of adjacent catchments, complaints are likely to increase, as was found elsewhere in Europe (e.g. Jonker et al. 2006). **Thus, it is somewhat surprising the ROBT conclusions did not predict the likely increasing level of complaints as the beavers reach terminal capacity in the catchment** (as determined by Graham et al. 2020). This is considered a major limitation because respondents of the study of Jonker et al. (2006) started to exhibit increasingly negative views about protecting wetlands and were less tolerant of beavers as damage became more prominent and more of a nuisance.

4.3.9 River Otter Beaver Management Strategy Framework

As part of the River Otter Beaver Trial, the Steering Committee developed the River Otter Beaver Management Strategy Framework (BMSF) to manage beavers in a sustainable manner and minimise conflict with other stakeholders. It is assumed the strategy is to be rolled out for other catchments given the wider expectation of allowing further reintroductions of beavers into the wild in England (and the rest of the UK). The purpose of the BMSF is to: "propose an approach that enables the wide range of benefits that beavers bring to the health and ecological function of the riparian environment to be maximised, whilst establishing the necessary means to minimise the negative effects that will occur".

The BMSF is targeted towards management of beavers already living in the wild and regulating, controlling, mitigating their impact. Its grounding principles are:

a) Beavers will be sustained as long-term viable components of the River Otter catchment;
b) Beavers will require active management. All proposed beaver management will be approached via a strict hierarchy of actions of increasing impact: education, risk avoidance, mitigation, trapping and relocation, and finally (in the absence of any other suitable alternative) lethal control;
c) Beaver welfare will be a critical consideration in all decision-making processes relating to beaver management;
d) The regulatory framework should enable the prevention of damage to agriculture, fisheries, and other land and river uses, housing and infrastructure. It should also prevent associated significant public safety risk and avoid new liabilities for those who own and manage these assets;
e) A spatially explicit risk assessment will identify locations of acceptability of the presence of beaver-engineered features. Tolerances will range from zero through to active encouragement of beaver activity where multiple benefits are clear. The risk assessment will provide a framework which will help inform the intensity of beaver management activities;
f) Resourcing mechanisms should be established nationally to ensure the management hierarchy is successfully delivered. We recommend that management initiatives reflect approaches taken in the EU which are locally led, financially supported, and able to deliver advice and support at all management hierarchy levels whilst adhering to a nationally agreed framework.

Within this context a proposal for how to respond to impacts depending on the scale of impact and location was provided, based on the following principles:

a) The management regime established, at the catchment level, should be robust and defensible, but it should also be pragmatic and enabling. It will be kept under constant review as beavers spread throughout the catchment and prepare for the likelihood of beavers colonising neighbouring catchments;

b) Processes associated with beaver advice, mitigation and management must be rapid, efficient and easy to access;
c) A suite of practical management interventions is available which will be deployed where there is a risk to key infrastructure from beaver activity;
d) Prior to lethal control of beavers in low-risk areas or areas where societal benefits may accrue, the applicant must first be able to demonstrate that mitigation advice has been sought and acted upon, and that a significant risk to land and/or property still remains;
e) In specific locations beaver activity may have direct negative impacts on local biodiversity. These areas will be identified, and targeted management measures implemented to mitigate risk.

The BMSF as it stands is also mostly a suite of recommendations that are not directly related to decision-making processes (but see below) and is more about input for managing beavers in individual catchments:

- RECOMMENDATION 1: The Local Management Group must be sufficiently resourced to deliver targeted education and awareness programmes.
- RECOMMENDATION 2: Pragmatic and timely support for all stakeholders
- RECOMMENDATION 3: Beaver management decisions need to be made at the catchment scale
- RECOMMENDATION 4: Phases of colonisation and associated management interventions
- RECOMMENDATION 5: A catchment-based Beaver Officer should be employed to lead the delivery of the BMSF
- RECOMMENDATION 6: The intensity of dedicated Beaver Officer resources is likely to reduce over time
- RECOMMENDATION 7: The importance of providing rivers and streams more space
- RECOMMENDATION 8: Monitoring of beaver health

Whilst the BMSF argues that the framework should operate at a catchment scale, the interventions are mostly related to localised impacts.

Whilst the BSMF is a welcome addition to the tools available to manage beaver populations now and into the future, the principles upon which the framework is based are considered aspirational and reliant on beavers becoming an accepted component of the aquatic ecosystems, plus sufficient resources being available to manage issues that are likely to arise. In particular, with reference to each of the principles above:

a. There remains insufficient empirical evidence to support beavers forming a 'long-term viable component' of water body ecosystem without understanding fully their impact on other biological and hydromorphological elements, including adverse effects on threatened fish populations.
b. There remains conjecture over whether the hierarchy of management practices proposed will protect fish/fisheries or indeed other services delivered by the target water body(ies).
c. Beaver welfare appears to override habitat and environmental needs of other species, including fish, which are equally vulnerable and should be afforded similar protection. There is a need to balance the needs and aspirations of other sectors and ecological needs of other biota with those of beaver management.

d. The argument that the proposed regulatory framework should enable the prevention of damage to agriculture, fisheries, and other land and river uses, housing and infrastructure is again aspirational and requires a full and quantifiable assessment of the likely impacts based on empirical studies together with an evaluation of potential future risks.
e. Again, the proposed spatially explicit risk assessment tool to identify locations that will be acceptable for the presence of beavers has yet to be developed and validated. While such a tool is welcome, the tolerance thresholds and accountability have yet to be determined for a range of river types that also account for the full range of catchment-scale land uses found across the UK.
f. As highlighted previously, resourcing mechanisms have yet to be established nationally or even locally to ensure the management strategy can be successfully delivered. Funding sources in Europe, in part at least, comes from hunting licences, but this option does not exist in the UK. Linking to Environmental Land Management schemes is a possibility, but consideration must be given to other biodiversity targets.

Fundamentally the proposed BMSF is addressing mainly problems arising post reintroduction and there is no primary risk assessment of whether the beavers should be reintroduced in the first place (see Section 2.4). In the first instance there is a need for a risk-based framework similar to that proposed by Defra (2020) (see Section 2.4.3) to support decisions on whether beavers should be permitted to be reintroduced into specific catchments. It is critical this evaluation is based on the catchment scale at minimum because of the capacity of beavers to colonise high proportions of river systems, but especially where trees are close to the water's edge.

Further, the evidence base on which a risk assessment for the reintroduction of beavers to UK systems is still emerging. Developing such a risk assessment protocol could learn from the many non-native species risk assessment protocols that are available (e.g. EPPO 2012; ICES 2003; GB Non-Native Organism Risk Assessment Scheme[26]), and be adapted to the potential benefits and impacts of reintroducing beavers in different catchments with varying typographical and hydro-morphological characteristics. The outputs should be reviewed by an independent panel with a balanced membership representing all sectors of society and expertise. Critical within any risk assessment is learning from retrospective analysis of previous reintroductions and mapping both the positive and negative effects of beaver reintroductions. Most actions to date have only examined the benefits accruing from reintroductions and are not fully balanced against the negative impacts observed.

The BMSF does provide a decision making framework in the form of a flow chart that guides the stakeholder through the routine management of beaver activity (Figure 4-9). Unfortunately, and in common with many decision making frameworks, quantitative criteria based on scale of impact to trigger decisions on actions or progression to more intense mitigation actions are not available, thus leaving decisions up to expert judgement of line agency experts or officers.

[26] http://www.nonnativespecies.org/index.cfm?sectionid=51

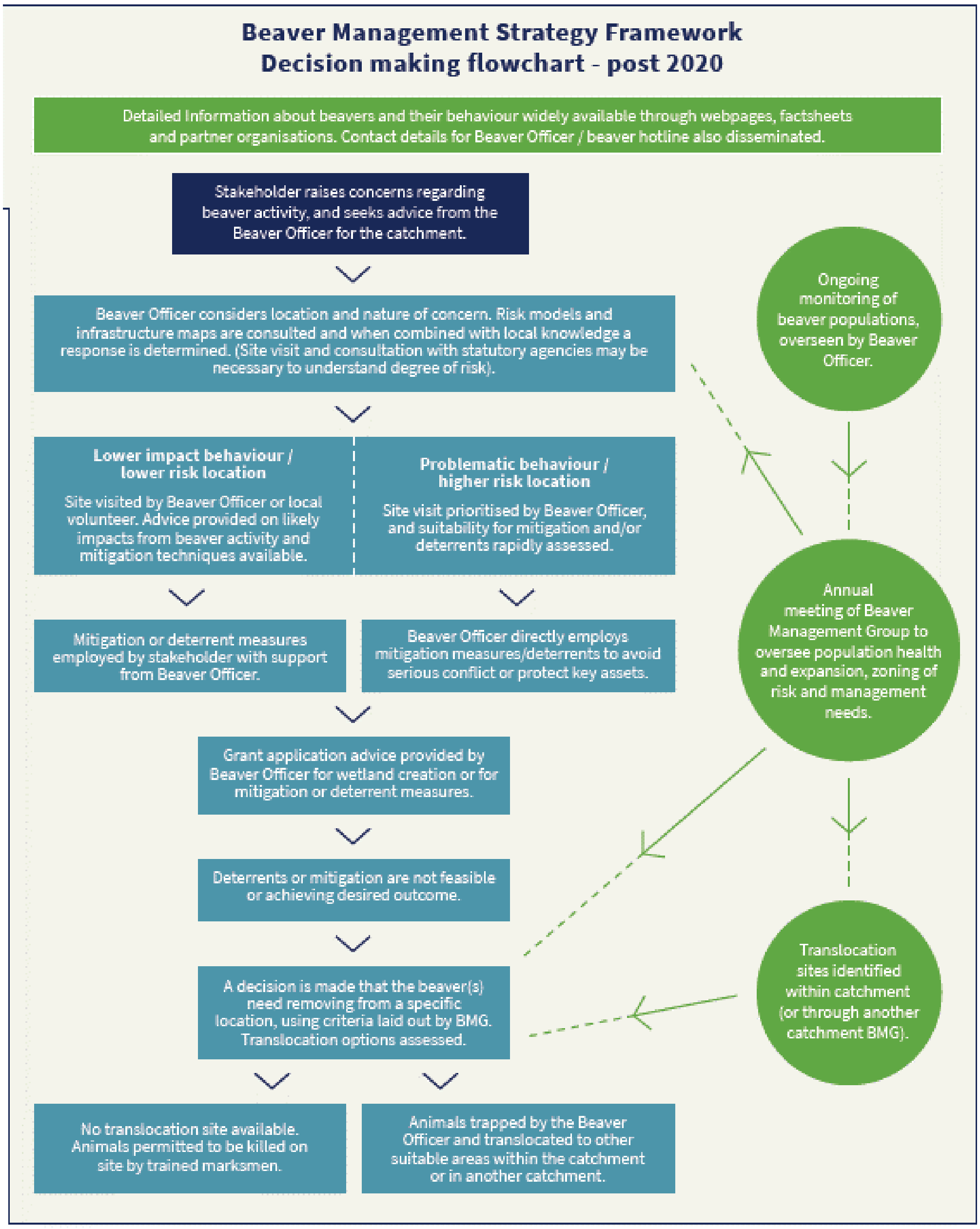

Figure 4-9. Flowchart of beaver management decisions (Source BMSF ROBT 2019)

One of the fundamental measures recommended by ROBT to handle any potential problems arising from beaver activity is establishing a beaver officer for each catchment. Unfortunately, there is no indication of how the post will be resourced, and what support will be available to fund mitigation or proactive actions. There is also no indication of how stakeholders who have been adversely impacted will be compensated for lost assets or services.

Whilst the BMSF action flowchart is informative, considerable effort and further information gathering is required to provide threshold criteria to support the decision-making steps in the framework. Until such time as threshold criteria for implementing the decision framework are quantified and financial support for management of beavers, including compensatory mechanisms, are established, conflict between sectors is likely to remain. Note education is just one tool to support this management process but definitive evidence on the costs and benefits of living with beavers is required.

5 Conclusions and recommendations

It is widely recognised that beaver is a keystone conservation species that once inhabited large areas of Europe, but was driven to extinction in many countries through hunting hundreds of years ago, including in the UK. There is now considerable traction to reintroduce beavers across the UK; and over the past 15 years, they have been reintroduced into a range of locations, mostly in controlled environments (Halley et al. 2020). To support this initiative, there is considerable emphasis in the literature and media on the positive benefits that beavers can bring to aquatic ecosystems and biodiversity. These include opening up dense riparian tree canopies, improving (temporarily at least) water quality, attenuating floods, and providing habitat heterogeneity through the creation of impounded areas that promote opportunities for enhancing aquatic biodiversity (see Sections 2.2, 2.3). However, the reintroduction of beavers can also cause a number of potential problems, such as disruption to fish migration and fish recruitment processes, shifts in fish species composition and abundance, damage to trees, loss of agricultural production and damage to banks and other infrastructure, with concomitant impacts on biodiversity and potential conflict with other catchment uses and resource sustainability (see Section 2.2, 2.3). These impacts have been less well documented and publicised.

Beavers have already been reintroduced into one closed location in Scotland and one open population has established, presumed because of an unlicensed translocation. A number of closed populations also exist in England and Wales, together with one “licensed” open population in the River Otter based on an unregulated introduction and several other unlicensed introductions. Further reintroductions or allowing beavers to naturally expand their ranges are planned. However, **the science behind the reintroductions and justifications for further open site reintroductions remain a source of considerable debate and conjecture.**

For example, the Scottish Government (2017) concluded that: “Based on experience of mitigation techniques and practice from elsewhere in Europe and North America and from some trial work in Scotland, there is sufficient evidence that the majority of the adverse effects identified can be satisfactorily and straightforwardly mitigated to avoid significant effects.” With respect to fish, the report concluded “beavers are likely to impact on fish species, mainly from changing the structure of the riparian woodland through foraging activity and changing the riverine habitat from running water to still water through damming activity. There will be both positive and negative effects on the variety of Scottish fish species from these activities. There are effective mitigation measures available to address adverse effects.” However, in the report there were several caveats to this conclusion, including: “The identification of cumulative and long and short term effects is complex when dealing with the interactions of a wild animal and its environment.” The report importantly recognised **the 3-5 year timeframe of the impact study was insufficient to understand the full implications of reintroducing beavers into open catchments.** This clarification is at odds with the previous statement that adverse impacts can be mitigated because the full impacts remain a huge unknown and evidence from Europe suggests these impacts escalate as the beaver populations become established and reach carrying capacity for the inhabited waterbody (see Sections 2.2.5, 2.2.6, 2.2.7).

The same limitations described above persist with the River Otter Beaver Trial. The population has a long way to develop, perhaps another 25 years, before it reaches its carrying capacity, and the impact on the catchment landscape, hydrogeomorphology and interactions with fish and fisheries are yet to be fully understood. There is clear need for predictive modelling on both the River Otter [initially] and other catchments where the beaver has been reintroduced or proposed for reintroduction, as well as different catchment types where beavers might recolonise. Of particular importance is understanding the differences encountered when beavers occupy headwaters of spate rivers and vulnerable habitats like chalk streams. This is needed to fully assess any potential impacts on aquatic ecosystem functioning, resultant ecological impacts, including on fish and fisheries, and potential impacts on other sectoral uses and demands of the target catchments.

Surprisingly, the illegal release of beaver on Tayside in Scotland has been accepted by the Scottish Government because "it is perceived to be politically impossible to be officially testing beaver reintroduction in Knapdale while culling them on Tayside". **The unofficial release of beaver in the River Otter was also approved in August 2020 following the beaver trial, although it is questioned whether the weight of evidence of the impacts of beavers in the Otter catchment or elsewhere has been fully evaluated, and whether the concerns of the wider array of stakeholders have been fully considered**.

With reference to the River Otter Beaver Trial, it ran for 5 years, during which time beaver numbers grew from six introduced animals to possibly 30-40 living wild. It is unwise to base any decisions on future reintroductions, especially into the wild, on the Otter trial outputs because:

- limited studies took place, and these did not fully assess actual and potential impacts;
- there was no baseline, or 'control' study, against which to measure change;
- the beaver population did not reach its potential max density (estimated 150+ territories);
- after just 5 years from first studying the population, long-term impacts have yet to emerge.

With respect to fisheries, the ROBT Evidence Review is considered to fall short of a full EIA that is needed to support a major policy decision on future reintroductions of beavers for a number of reasons.The study does not represent a full impact-control study or better still a BACI analysis. Whilst the latter was not possible in the technical sense, because beavers were already present in the River Otter before the trial started, studies on fisheries in tributaries and reaches where beavers were not present at the start of the trial could have been used as "before" sites. Notwithstanding, the fisheries surveys were also almost exclusively focussed on a single dam structure in the River Tale and only one survey was carried out on the mainstream River Otter in 2015, despite considerable beaver activity being reported in successive ROBT annual reports for this zone (Figure 4-1).

- The fisheries elements are limited and largely restricted to assessing population densities of fish species in control and impact sites associated with one dam over a four-year period (three annual surveys), observations of a small number of adult sea trout bypassing one dam, and establishing a protocol for assessing passability of beaver dams. The impact assessment is very much focussed on determining the positive benefits of beavers, but spatial and long-term temporal impacts on fish and fisheries are not investigated, nor modelled.
- The ROBT fisheries studies should have, at minimum, examined the fish population/ community dynamics above and below a range of dams and used control systems for

comparison, such as the studies of Smith and Mather (2013) and Bylak & Kukuła (2018) to account for variability between locations, a known modifier of the effects of dams on fish and fisheries.

- Further, because a river is wide and deep and does not have a dam structure does not mean that beavers are not present. Here beavers use pool characteristics and burrow into the banks potentially causing problems with flood mitigation measures and downstream sediment loading: the antithesis of the benefits portrayed. Studies should have focussed on the potential impact of beavers on fish and fisheries under these open water conditions where dams are not constructed as much as, if not more than, around dam sites.
- The ROBT study has also failed to capitalise on the considerable fisheries and environmental data available through the EA and other agencies in the region. As a consequence, the study has not provided a robust baseline of the status and trends in the fish population and community dynamics and fisheries, or provided a comprehensive assessment of the changes in fish communities brought about by the pressures of beavers inhabiting and colonising the catchment. Arguments that the fisheries data do not match the locations of beavers fail to acknowledge that beavers are found throughout the main river and in several tributaries where the EA fisheries surveys are regularly undertaken. Given weaknesses in the fisheries surveys carried out during the ROBT trial, building on such baseline data is imperative.

One of the defining features of the presence of beavers is the construction of dams, although beavers also occupy territories without constructing dams and creating burrows into banks where the eater depth is greater than one metre. It appears there are number of established characteristics of the river topography to determine whether beavers will construct dams across the river channel. This characteristics have now been modelled and thus could be used to predict potential impacts on fisheries, and this has been done at the catchment scale for the River and a few other systems. The efficacy of the modelling, however, needs ground-truthing, and this is only possible when the beaver population in a catchment has reached its capacity and occupies all suitable habitat.

Irrespective, ROBT has not provided a robust assessment of the impact of beaver dams on fish migration. Instead the interpretation is based on several videos showing adult sea trout attempting to bypass one barrier under what appear to be optimal hydraulic conditions, when the flows are high and create an overflow side channel. Occasional observations of fish bypassing beaver dams are not considered a true representation that all fish can pass, and this issue needs to be more robustly assessed using telemetry or tagging studies under a range of hydraulic conditions at the dam, especially at the time the fish need to migrate upstream or downstream, as well as for a range of species and sizes of fish. Further, the coarse resolution rapid barrier assessment tool (RAP) developed by the West Country Rivers Trust for the River Otter Beaver Trial (West et al. 2019) is currently limited in scope and needs to be field tested for validity with a range of dams in different water courses and with a range of migratory species, not just adult salmonids, before any confidence can be placed in its application and resulting outputs. **As a consequence, there is clear need for further research to assess the barrier effects and otherwise of beaver dams on fish migration and recruitment processes before any definitive conclusions can be drawn about passability of beaver dams. This will require fully funded studies, including telemetry studies, on a range dam types, including cascades of dams, and for a full range of species.** Whilst telemetry studies are technically an expensive option to assess fish passability at beaver dams, a full study on a range of dams would remove the controversy and ambiguity regarding passability. This is largely because the hydraulic characteristics of the dams, and thus ability to bypass the structures, change with discharge, and a simple model does not fit the complex diversity of conditions presented at different dams.

In addition, it is critical that the impact of beaver dams on downstream migration of fish is thoroughly investigated, as disruption to migration can cause increased mortality or delay or even prevent, passage to the sea of lower reaches of rivers. It is recommended PIT tagging or similar modern tools are used to quantify any impacts.

In addition, most interpretations of the impact of dams are based on individual structures, but there are many cases where a series of dams is constructed, thus the cumulative impact of these dams should be assessed in terms of habitat loss in the impacted stream, disruption to connectivity and alteration of the landscape. This is important because the beaver population in the River Otter catchment has not yet reached its terminal capacity, estimated at 150+ territories (Graham et al. 2020). **Understanding/predicting the impact of the terminal beaver population size is critical because it will provide a more appropriate assessment of the conflict between beavers and fish populations when the system comes into equilibrium.**

Although studies were carried out to assess the value and importance of ecosystem services provided by beavers on water courses, the cost benefit analysis has not been fully balanced against the impacts on other services delivered by water courses, the economic losses encountered by these services, nor have the values of disservices or costs of remediation and mitigation measures (both capital and recurrent costs) been fully discounted from the valuation. This type of analysis is critical because beavers are currently at low density in both the River Otter and elsewhere in the UK (possibly not Scotland where populations are being culled) and the full impacts and costs of management and remediation have not yet been experienced. It is only after the populations have reached their carrying capacity in a range of catchments that valid overall benefits and full impacts can be measured. This will likely happen after 15-30 years from first introduction. **Until such time as a full impact assessment across a number of rural and urban catchments has been carried out, it is recommended beaver reintroductions are restricted to enclosed systems only, and action is taken to control populations where they have been illegally introduced or colonized new river systems through active dispersal. Further reintroductions of beavers into the wild are not recommended until robust risk assessment procedures are developed and tested, and the criteria for implementing a reintroduction are established.**

In this context, **there is a need for a risk-based framework similar to that proposed by Defra (2020) on reintroducing biota to the UK to support decisions on whether beavers should be permitted to be reintroduced into target catchments.** The Beaver Management Strategy Framework proposed by the Beaver Trust (BMSF; Figure 4-9) falls short of this requirement because it addresses the problems post-reintroduction and there is no preliminary risk assessment of whether the beavers should be reintroduced in the first place (see Section 2.4). Currently the evidence base on which any of the principles supporting the proposed BMSF can be upheld is limited for UK systems (see Section 4.3.9). However, **an appropriate risk-based decision support tool can be developed building on similar protocols from other sectors,** e.g. non-native species risk assessment protocols, and be adapted to the likely benefits and impacts of reintroducing beavers in different catchments that have different typographical and hydro-morphological characteristics**. The outputs should be reviewed by an independent panel with a balanced membership representing all sectors of society and expertise.** Critical within any risk assessment is learning from retrospective analysis of previous reintroductions and mapping both the positive and negative effects of beaver reintroductions. All sectors should carry equal weighting and preference for one species group over another should be avoided.

One further problem that has been highlighted (Section 2.4) is related to the cost and implementation of management and mitigation measures. A hierarchical framework has been developed to enable decisions to be made on when and how to control beaver activities in line with legislation (Figure 2-12). This allows licences to be designated to cull or translocate beavers, or actions to destroy their dams where preventative actions do not address the problem or where key infrastructure is at risk. Unfortunately there appears to be no quantitative criteria on which to base the decision to upscale the action. **This is a fundamental weakness in the derogation process and needs to be resolved before further introductions into open systems are permitted.**

This issue is particularly important because there are many field-based observations and media reports that suggest the conflicts arising from beaver introductions are greater than reported in the ROBT Evidence reports, and that these issues are disproportionately greater as the abundance of beavers increases in catchments towards the system's carrying capacity. **There is a fundamental requirement for a multi-sectoral review of the issues and an impact/resolution matrix** (similar to that produced by Ecke et al. 2019) **needs to be prepared, based on empirical findings from validated studies, to support management decisions on the reintroduction of beavers under different scenarios (wild open versus enclosed), which accounts for variability on catchment topography and ecosystem functioning, as well as fish community structure and dynamics.**

Previous evaluations in Scotland[27] and Wales[28] have largely examined the impacts and strategies for reintroducing beaver into their respective countries, plus managing the populations through, for example, a dedicated 'beaver officer'. The ROBT BMSF also suggests a similar approach, but has not fully considered the costs of compensation to physical damage, and costs of mitigation or control, which can be substantial[29]. Currently these costs tend to fall on the landowner, farmer or stakeholder impacted. As beaver populations grow and animals disperse widely, the mitigation and control costs are likely to rise, and the issue of who pays will increase at least proportionally. A dedicated beaver officer is unlikely to address this problem because the damage could have considerable economic implications for affected persons, impact on infrastructure, or lead to changes in fish community dynamics, potentially leading to legal/litigation issues. Until mechanisms to fund compensation or mitigation actions, as well as the beaver officer if appropriate, can be formalised in legislation or local district budgets there will remain human-human and human-wildlife conflicts. **One possible solution may be to internalise costs from those benefiting from the presence of**

[27] https://www.nature.scot/professional-advice/safeguarding-protected-areas-and-species/protected-species/protected-species-z-guide/protected-species-beaver/beavers-scotland
[28] https://www.welshbeaverproject.org/home/
[29] https://www.bbc.co.uk/news/blogs-news-from-elsewhere-35773349

beaver, e.g. those benefiting from beaver tourism or flood defence agencies, to support a funding mechanism. Wilson et al. (2020) have suggested the Environmental Land Management scheme, due to replace agri-environment schemes, may be an opportunity to encourage farmers to accommodate the consequences of beavers. However, justifying the benefits of beavers to the farmers who may be impacted will be a challenge, and the impact on farming is only one of the many problems/sectors that need to be addressed. Regardless of the source, **evidence from elsewhere suggests these costs can be and must be formalised at the onset of any derogation.** One possibility to ease this potential bottleneck is to devolve responsibility to landowners or authorised persons to control and manage beaver populations similar to the strategy used to control deer in the UK.

What is evident throughout the literature and media are complex human-human and human-wildlife conflicts, and the somewhat opposed views of stakeholders that potentially can be impacted by beaver reintroductions and those promoting beaver reintroductions. Such interactions are common throughout the world with other human-wildlife conflicts (Marshall et al. 2007; Redpath et al. 2013, 2015) and often arise because of polarised debates and little attempt to understand the opposing stakeholders' motives and drivers (Meffe 2002). Similar conflicts arise with other wildlife species and fisheries, e.g. cormorants (e.g. Cowx 2013), or between fisheries and infrastructural development, e.g. small-scale hydropower development (e.g. Anderson et al. 2013). With respect to beaver-fish interactions, much of the literature and media presents the positive benefits brought by beavers, which cannot be ignored, but there seems to be an imbalance against the considerable evidence of actual and potential impacts, especially as beaver populations expand their ranges and increase in abundance. There is a clear need for **an independent panel with a balanced membership representing all sectors of society and expertise**, as highlighted above, **to discuss, in an open and frank manner, the issues arising from the complex interactions between beavers and fish and fisheries, and other sectors.** The science and evidence on which any decisions are to be based should be openly shared and transparent so the voices of all can be heard and represented in any final decisions made. Auster et al (2019) argued for a similar approach and the English Beaver Strategy Working Group[30] has been set up to this effect, but this group has yet to endorse a strategy for moving forward as there remain many issues to resolve. **Decision support tools,** such as that produced by Ecke et al. (2019), **which attempt to balance the beneficial and detrimental effects of beaver dams, will help focus on the problems that need to be addressed and help find solutions for potential conflict. It is also recommended that independent reviews of the interactions between beavers and other sectors of society, e.g. agriculture, silviculture or nature conservation, are carried out to fully understand and quantify potential areas of conflict, and find a way forward to allow beavers to be introduced into the UK landscape in a socially, environmentally and economically regulated manner that addresses the concerns of all stakeholders.**

In conclusion, based on the review of potential interactions between beavers and fish and fisheries, and on the current science and evidence available, further reintroductions of beavers into the wild should not take place until the recommendations made herein have been fulfilled. Once these knowledge gaps have been filled and management issues resolved, it may be possible to find solutions that would allow further controlled introductions of beaver, where their location, activities and numbers can be managed to

[30] www.wildtrout.org/assets/img/general/Proposals-for-an-English-Beaver-Strategy-FINAL.pdf

curtail any damage to fish and fisheries or other economic or social sectors.

6 Literature

6.1 ROBT documents reviewed

https://www.devonwildlifetrust.org/what-we-do/our-projects/river-otter-beaver-trial

https://www.exeter.ac.uk/creww/research/beavertrial/

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Auster R. (undated) Appendix to the 'River Otter Beaver Trial' Science & Evidence Report: An Investigation into Fishing and its Economic Activity in the River Otter Catchment, and Reported Impacts of Eurasian Beaver (Castor fiber) Presence on Fishing, Prior to Spring 2019

Auster R. (undated) Appendix to the 'River Otter Beaver Trial' Science & Evidence Report: Beavers, Agriculture and Land/Property-Owners Conflict Impacted by Beavers on the River Otter.

Auster R. (undated) Appendix to the 'River Otter Beaver Trial' Science & Evidence Report: Beavers, a Rural Community and Ecotourism: A Case Study on the River Otter, England.

ROBT Appendix (undated) Beaver Dams: stability and evolution, risk of partial or complete failure and impact upon sediment and water dynamics

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Devon Wildlife Trust (DWT) Beaver Management Strategy Jan 16

Devon Wildlife Trust (DWT) Beaver Management Strategy and Appendices:

River Otter Beaver Management Strategy Framework

Appendix 1: Background to the River Otter Beaver Trial

Appendix 2: Developing a Beaver Management Strategy Framework for the River Otter (post 2020)

Appendix 3: Beaver Ecology and Key Factors Informing Future Management

Appendix 4: International Perspectives

Appendix 5: Assessment of Likely Risks

Appendix 5a: Risk Assessment

Appendix 6: Governance Structures

Appendix 7: Beaver Management Strategy

Appendix 8: Considerations Regarding Legal Protection

Appendix 9: Outstanding Issues to be Resolved

Appendix 10: Key Literature, Resources and Glossary

Devon Wildlife Trust (DWT) River Otter Beaver Trial monitoring plan 2017

Devon Wildlife Trust (DWT) River Otter Beaver Trial Annual Report 2016

Devon Wildlife Trust (DWT) River Otter Beaver Trial Annual Report 2017

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