Beaver Reintroduction to the Isle of Wight

Feasibility study for release scenarios of Eurasian beavers (Castor fiber) to the Isle of Wight.

October 2020

Document prepared for Hampshire & Isle of Wight Wildlife Trust by Dr Róisín Campbell-Palmer, Derek Gow[1], Prof Richard Brazier and Dr Alan Puttock

*Cover photo: Overview of the lower section of the Eastern Yar © Alan Puttock

[1]Lead Contact: Derek Gow. Derek Gow Consultancy Ltd., Upcott Grange Broadwoodwidger, Lifton, Devon PL160JS. Email: derekgow@derekgowconsultancy.com

Content

1 Project Overview

1.1 Report Summary

This document has been prepared to advise the Hampshire & Isle of Wight Wildlife Trust on the potential for a beaver reintroduction project on the Isle of Wight. This project would aim to achieve multiple outcomes. Variously these would include biodiversity enhancement through the creation of a broad range of onsite habitats ranging from dam and pool complexes to the provision of more standing and fallen dead wood environments, sustainable water purification, slowing the flow, silt capture, accessible public engagement, education and ecotourism ventures. Additionally, the project would seek to increase understanding of population dynamics and landscape utilisation of wild beaver populations across a lowland, river catchment which has been previously dominated by agriculture. To address the forgoing, it is believed the following criteria would be relevant with specific regard to this proposal and that beavers would:

1. Assist with the development of a national and local research base with specific regard to their activities regarding biodiversity enhancement, water storage and flow attenuation.

2. Create an opportunity for a local environmental education and demonstration site with which to engage key stakeholders, helping people to reach an informed opinion about the future of beavers in the wider landscape.

A site visit undertaken by Derek Gow, Dr Róisín Campbell-Palmer, Prof Richard Brazier and Dr Alan Puttock, and mapping of habitat suitability and beaver dam capacity by Dr Alan Puttock, suggest that some riparian environments on the Isle of Wight afford entirely suitable beaver habitat, while others would provide for successful long-term colonisation.

A wider catchment release of multiple pairs / family units with permitted colonisation via natural dispersal from agreed release points in time would be entirely feasible. Lower numbers and densities of beavers would readily over time colonise the most suitable water bodies to fill the high-quality habitats first. While in these locations they would exist unobtrusively, as their populations expand into more marginal habitat conflicts could occur where burrowing, tree felling and dam complexes become established in undesirable locations. Management of these events using a toolbox of understood and commonly implemented mitigation measures would be required. Unenclosed projects have reduced capital costs and animal husbandry requirements, but these resources arguably could be better diverted into developing an effective and robust mitigation process. This strategy will result in the development of much wider ecological, catchment based and societal benefits.

A licence from Natural England would be required for any release of Eurasian beavers onto the Isle of Wight.

1.2 Isle of Wight and River Eastern Yar Overview

The Isle of Wight is a popular tourist destination with numerous recreational outdoor activities such as water sports, walking, seaside activities, fishing and horse riding all being important to the Island's economy. Rights of way and open access land proliferate in the wider landscape. As England's largest island, completely separated from the mainland by the Solent, the Isle of Wight represents a unique opportunity to investigate beaver reintroduction across a range of key English lowland environments. From the site visits undertaken to form thinking in this document it is clear that the potential exists to explore the impact of the species at a whole catchment level. Around half of the Island is classed as an

Area of Outstanding Natural Beauty, including sites of international, national and local conservation value, from Sites of Special Scientific Interest, National Nature Reserves and Sites of Importance for Nature Conservation.

In its uplands the Island is dominated by chalk grassland. Various woodlands including conifer plantations, wood pastures and pockets of ancient woodland exist. Mixed broadleaf and yew is the predominant woodland type. Areas of lowland meadows, reed beds and fens are also present though to a diminished extent.

Much of the lowland is managed as intensive arable, dairy or livestock farming. Hedgerows are more prominent in the north of the island. Livestock farming is the dominant activity followed by arable (mainly cereals and oil seeds, though garlic is a significant crop).

The main rivers present are the Medina and the Eastern Yar which are typically lined by low willow scrub and interconnected by numerous drainage channels. The Eastern Yar is the largest river on the Island (~24km) and is classed as being of moderate ecological quality. The Medina (~19km) is classed as good ecological quality. While the groundwater quality is classed as good, high levels of nitrate and pesticide pollution can be an issue by the time the outflows reach the Solent.

Collaborative partnership conservation and land-management projects already recognize and promote objectives such as managing scrub woodland, habitat connectivity, promotion of sustainable tourism, developing high value green spaces, woodland replanting and flood prevention. These activities all readily lend themselves to beaver reintroduction.

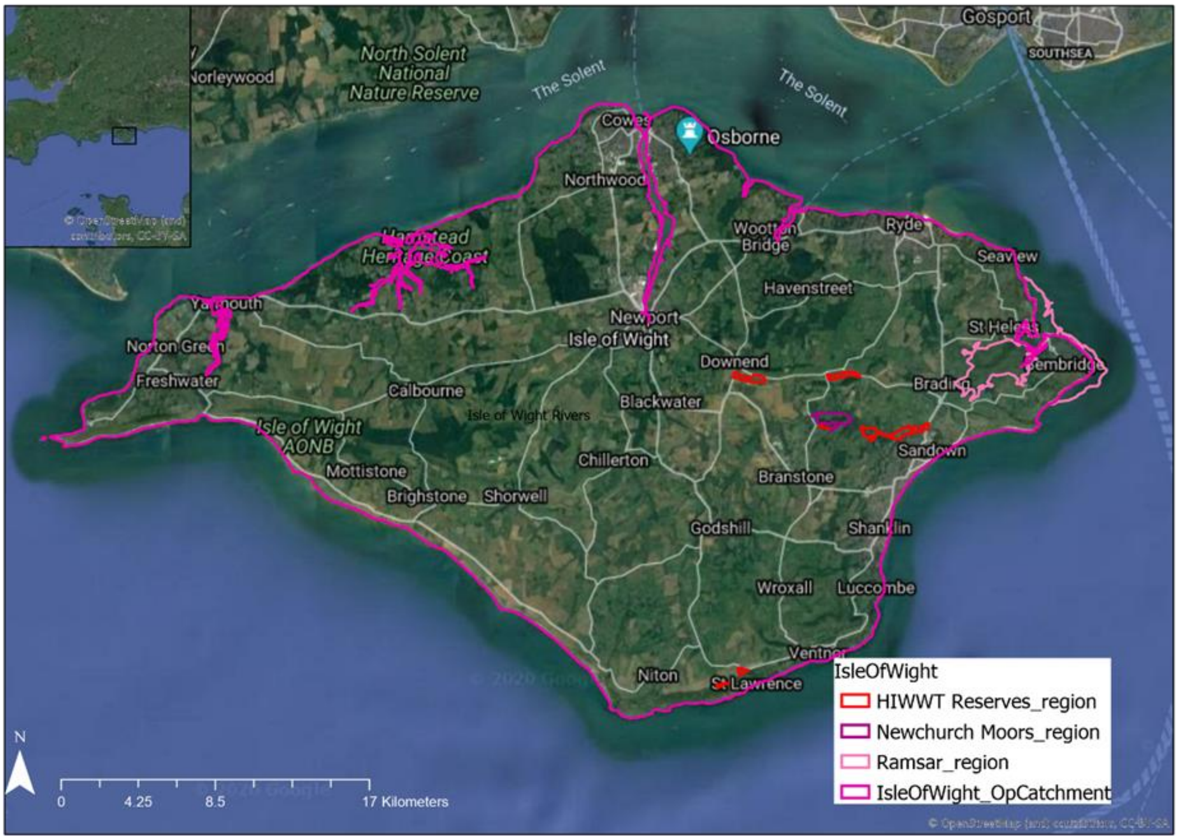

Figure 1. Area of Interest

2 Beaver Ecology and Lifestyle.

Beavers are a "keystone species" whose niche as wetland engineers has a significant impact on the natural landscape (Rosell et al., 2005). Beaver activity creates habitats that are dynamic in nature. While the species can provide a wide range of ecological and economic benefits, it is clear that, in landscapes which have been moulded by people, beaver activity will have to function within limits acceptable to human interests. Their behaviour can result in the formation of wetland habitats, with a positive effect on plant and animal diversity. A recent meta-analysis determined that overall beavers have a positive effect on biodiversity (Stringer & Gaywood, 2016).

Wetland habitats with lowered or intermittent tree canopies which are coppiced by beavers provide both a greater expanse and variety of living opportunities. These are readily exploited by a wide range of higher plant species which in turn increase the feeding and breeding opportunities for insects. A greater abundance of both standing and submerged dead wood habitat further enhances insect biodiversity and invertebrate densities can rise in beaver generated wetlands by up to 80 % (Gurnell et al., 2008).

This cycle provides a greater food resource for a broad range of fish and amphibian predators whose population densities rise in direct response. In the Devon Beaver Trial site, initial counts of the spawn clumps of common frogs (*Rana temporaria*) had risen from 10 in 2011 to 650 by 2016 (Devon Wildlife Trust, 2017). Small mammals adapt to exploit a variety of niche habitats while large herbivores exploit their greater grazing and browsing potential. Carnivores such as the common otter exist at greater densities in beaver-generated wetlands due to greatly enhanced fish densities and the presence of abandoned lodges which they utilise as breeding holts. Beavers are untidy feeders and their random feeding patterns can scatter some semi-emergent plant communities and trees more widely throughout their surrounding environments.

It is likely that many British species were formerly reliant on beaver activity to a significant extent. For example, the large copper butterfly (*Lycaena dispar*) is a species which is dependent on open, unshaded fenland edge. This habitat is ideal for the great water dock (*Rumex hydrolapathum*) which is the exclusive food plant of its caterpillars. It is highly probable that this complexity of reliance will be further demonstrated by other species as beaver reintroduction trials proceed in Britain and surprises unconsidered could come. In Belgium 20 years ago black storks (*Ciconia nigra*) were rare non-breeding vagrants. As beavers expanded from an initial release in the Ardennes to modify relict small farm and woodland environments in valley bottoms into pool complexes filled with a myriad of aquatic invertebrates, amphibians and fish, the black stork returned. By 2018 there were over 80 breeding pairs and this charismatic species which once bred in the UK is now overflying Britain on a regular basis. As suitable beaver-generated habitat in the form of woodland pool complexes becomes once again an available habitat, black stork is a real candidate for natural restoration (Schwab. 2018. Personal communication).

Beavers build dam systems in sub-optimal habitat to create an environment which suits their living purposes. Although literature commonly suggests that Eurasian beavers are less inclined to build dams than North American beavers this belief is largely drawn from a time when they were a rare animal confined to relict parts of their former range (G. Schwab, personal communication). The modern recovery of the Eurasian beaver as a result of both legal protection and widespread reintroduction demonstrates clearly that they can successfully colonise even intensively farmed and urban habitats with ease.

Methods for identifying the suitability and key habitat characteristics for beavers (both species) have been widely studied and published (including Allen, 1982; Bergman et al., 2018; Dittbrenner et al., 2018; Halley et al., 2009; Hood, 2020; Macdonald et al.,1997). The main features to consider in any site assessment for beavers are:

- The initial composition and structure of the vegetation within 30 m of the water's edge
- The distribution and abundance of palatable riparian trees
- The character of the riparian edge habitat
- The available range of emergent or submerged aquatic plants
- The hydrology of the water bodies available to the beavers, including flow speeds, level stability and shoreline features
- Water management and where beavers may cause conflict i.e. flood banks/low-lying farmland/agricultural drainage
- Topography – gradient of land, substrate type, valley shape
- Associated land-use – disturbance and land-management practices, infrastructure, water use

It should be noted that Habitat Suitability Index models are good for species with specific needs, such as capercaillie (*Tetrao urogallus*), but tend to be much less suited for beavers which can generally adapt the habitat to their needs. Previously some of these applied models have considered areas unsuitable for beavers which are now supporting healthy beaver populations. Caution and common sense should also therefore be applied (Campbell-Palmer et al., 2016). Map-based models need to take into consideration the spatial scale at which beavers select habitat. For example, riparian woodland far less than 10m deep may provide sufficient woody resources for a beaver family but is unlikely to be mapped at anything other than fine scale. This is the rationale for the multiple data products used in University of Exeter habitat index mapping (Graham et al., 2020) to capture for instance, thin strips of riparian woodland which form a large proportion of the suitable habitat in intensively managed GB landscapes. In time, and with growing population densities, beavers can occupy even the most modified landscapes if no other options are available. In summary, the considerable adaptive ability of beavers to modify their habitats to suit their needs should not be underestimated.

Despite the scientific evidence demonstrating that the net effect of beavers is positive for biodiversity, there may be cases where less mobile species of conservation value could be negatively affected by beaver activity (Stringer & Gaywood, 2016). Under such circumstances, conservation managers could be faced with conflicting management goals and judgements might have to be made on whether to apply conventional mitigation techniques to preserve stability, or to allow a successional process of environmental change. Examples of negative beaver impacts of this type have so far proved to be rare and European experience indicates that, in landscapes which are ecologically impoverished by intensive agriculture, forestry, water engineering or industrial activities, beaver-created habitats are important regenerators of biodiversity.

There is a growing body of evidence supporting the use of beavers as a habitat restoration and enhancement tool. There is now extensive evidence from the US where beavers and beaver dam analogues have been used as a technique by which to restore incised stream ecosystems, reconnecting floodplains and leading to habitat creation (Pollock et al., 2014; Bouwes et al., 2016). In Britain results from Scottish trials have shown how habitat engineering by beavers benefits both within stream aquatic biodiversity (Law et al., 2016) and broader wetland biodiversity (Law et al., 2017). In a recently published study Law et al., 2017 conclude that beavers can offer passive but innovative solutions to the national problem of wetland loss. In their study, it was reported that after 12 years of beaver presence mean plant species richness had increased on average by 46% per plot, whilst the cumulative number of species recorded increased on average by 148%. Heterogeneity, measured by dissimilarity of plot composition, increased on average by 71%.

We provide a current review of the literature regarding the environmental and societal impacts of beaver in the recently peer reviewed paper Beaver: Nature's ecosystem engineers (Brazier et al., 2020a, in press).

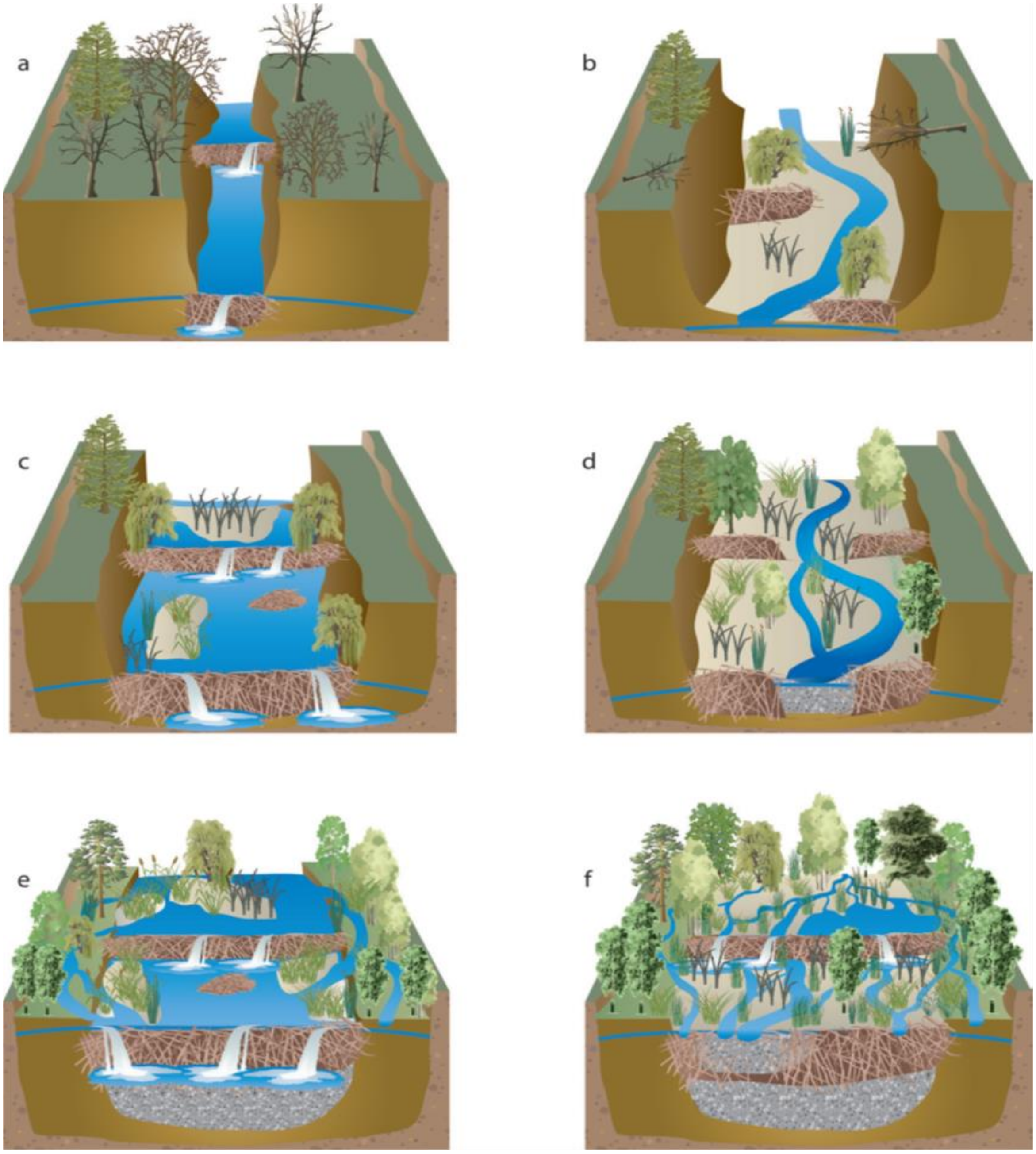

Figure 2. Process by which beaver dam or beaver dam analogue creation can restore incised or single stream systems and lead to wetland creation (Pollock et al., 2014).

3 Update on Current Policy and Status of Beavers in GB

The status of the Eurasian beaver varies throughout Great Britain. In Scotland, from May 2019 beavers were formally recognised as a native species and legal protection as a European Protected Species (EPS) was extended to the two official populations in mid-Argyll and Perthshire. Under NatureScot's Beaver Mitigation Scheme a range of management support measures are available to landowners experiencing conflicts with the species in intensively farmed agricultural land. In order to facilitate beavers' presence on the landscape where their activities cause conflict, landowners are provided free expert advice on managing beaver activity. This advice covers strategies to minimise damage to trees by recommending fencing or painting with sand-based paint to deter gnawing, and installing flow devices to manage localised flooding behind beaver dams. The Scottish Beaver Management scheme also provides equipment and covers the cost of installation of such mitigation measures. Live trapping and translocation are permitted under circumstances where mitigation strategies are insufficient to solve landowner conflict, and if licenced rehoming options are available. Where all mitigation strategies have failed and live-trapping is not feasible, licences for lethal control can be issued. Eurasian beavers are listed on Schedule 9 under the Wildlife and Countryside Act as a species not normally resident or a regular visitor to Britain and a licence is therefore required to release them into the wild. No licence is required to release beavers into enclosures in Scotland but is listed as a 'policy' from Natural Resources Wales (NRW). In England a licence is required to possess and release beavers into enclosures and although a licence has been granted for a free-living beaver population on the River Otter in Devon and other breeding populations exist elsewhere no other licences are currently being issued direct into the wild while Natural England and DEFRA consider the detail of a forward policy for the species. No official reintroduction has occurred in Wales though proposals have been submitted to NRW and three enclosed projects exist.

Any proposed release on the Isle of Wight will be a licensed process under conditions set by Natural England. This generally includes a release site feasibility study, responsible sourcing of animals, and health screening requirements, including disease and genetic testing during holding and transfer. Any licence application would only be sought after significant consultation with the local community to ensure local buy-in, and under the guidance of a Steering Group formed of all interested parties and stakeholders.

It is expected that a position to afford the above will be established in the winter of 2021. Considerable high level political support currently exists for the restoration of this species.

4 Considered Areas

This report considers two potential release option scenarios:

- Reserve release unfenced and Eastern Yar release with permitted natural spread
- Wild release for entire Isle of Wight

Reserve Release

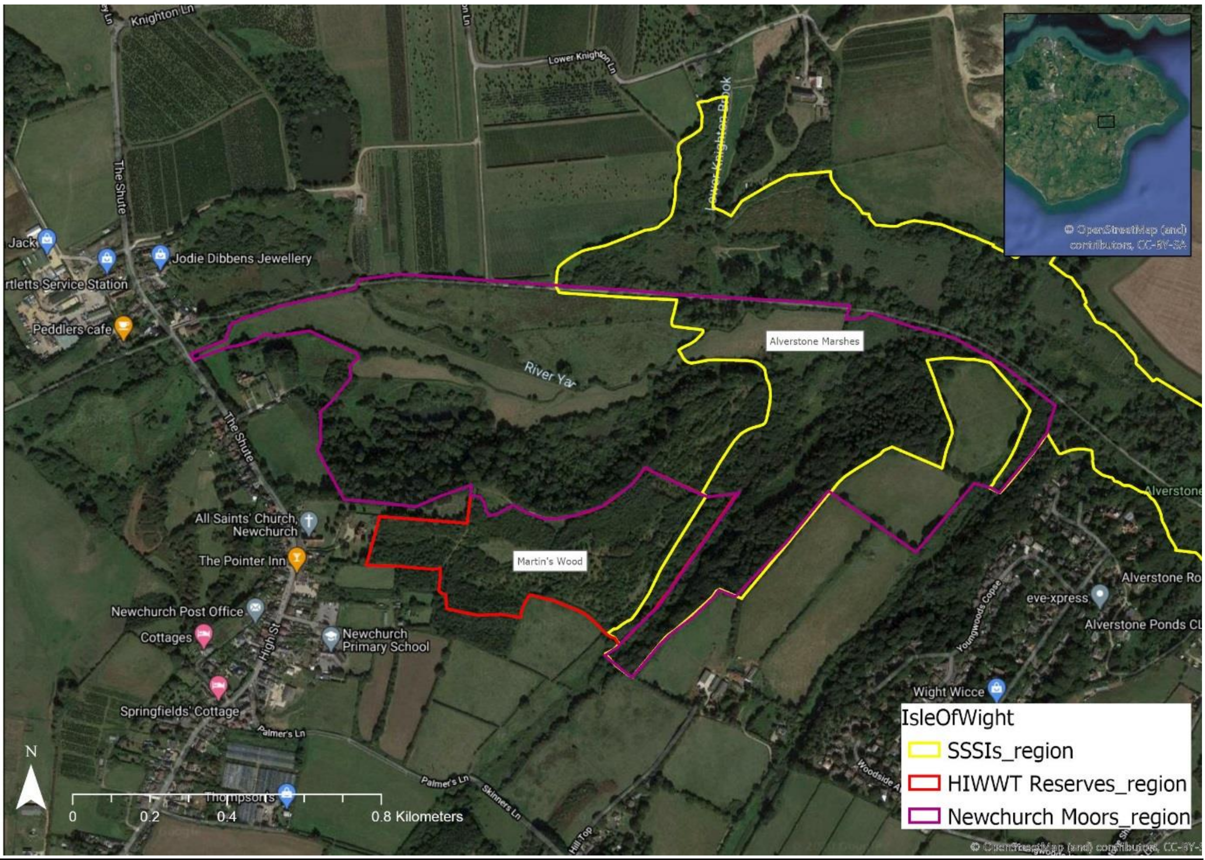

Figure 3. Area for proposed enclosure in Martins Wood and the neighbouring Newchurch Moors region. Also highlighting location of Alverstone Marshes SSSI.

Martins Wood Nature Reserve and the neighbouring Newchurch Moors region is owned and managed by Hampshire and Isle of Wight Wildlife Trust. Within the reserve are a series of interconnecting freshwater ponds, heavily lined by woody vegetation including shrubby willow and a range of mature tree species. These ponds also possess a good coverage and range of semi-emergent and aquatic plant species, all of which would provide beavers with rich, year-round forage.

The banks are low gradient so may limit some burrowing potential, though beavers are perfectly capable of constructing more typical lodge-type shelters. The mass of overhanging and fallen woody material lining much of the pond areas will also provide multiple shelter opportunities. Burrow collapse or burrowing into path banks, in particular those spanning water on either side, may be a potential issue but this is not expected to be an excessive issue and could be resolved with sections of board walk if required.

This site would be a highly suitable release point and would not require any pre-release site preparation for beaver release. One pair or family unit could be readily released at this point.

The surrounding area is flat and would hold water, enabling the beavers to expand wetland and wet fen habitats. The main single outflow lends itself readily to dam construction, which in turn would push water out of the main channel and into the meadow habitats lining the outflow. Increased water holding in these areas would rapidly develop open water and diverse fenland habitats, providing an abundance of living opportunities for other riparian species. The initial outflow has been previously grazed, with trees set further back, which is likely to act as an additional factor to encourage beavers to dig canals and even create open water to access these. Further downstream this water course is well vegetated both on its banks and within its channel. This feature presents a rich diversity of plant species for foraging within elevated burrowing/lodge construction banks.

There are some sections of this channel which run close to or alongside a well-used walking and cycle path. The potential for burrowing and tree felling in this area will require a watching brief approach to preventative or reactive management if beavers chose to utilise this area. Regular monitoring with an informed ability to react to any conflicts quickly would be the most sensible approach.

This larger area would enable them to express habitat modification behaviour and provide a tangible example of how beaver activity can be used as a habitat restoration tool. Beavers could either be released at additional sites further downstream and/or be permitted to expand naturally from the release site.

The proposed release site neighbours or may encompass sections of the Alverstone Marshes SSSI (https://designatedsites.naturalengland.org.uk/SiteDetail.aspx?SiteCode=S1004250&SiteName=&countyCode=22&responsiblePerson=&SeaArea=&IFCAArea=) which is currently in unfavourable condition. As a wetland restoration area, it is noted for water voles (*Arvicola amphibious*) which ideally require open sunny, well vegetated complexes of pool systems for their existence. It is perfectly credible that beaver engineering will benefit this species. If an enclosed, semi-enclosed or wild release of beavers was undertaken in this area their impact on the functioning of the SSSI would have to be considered. But since Alverstone Marshes was designated as a SSSI for the presence of peat deposits and relict fen habitats within a wider complex of riparian floodplain, it is anticipated that beavers can only enhance the condition of the site.

Wider Eastern Yar Release

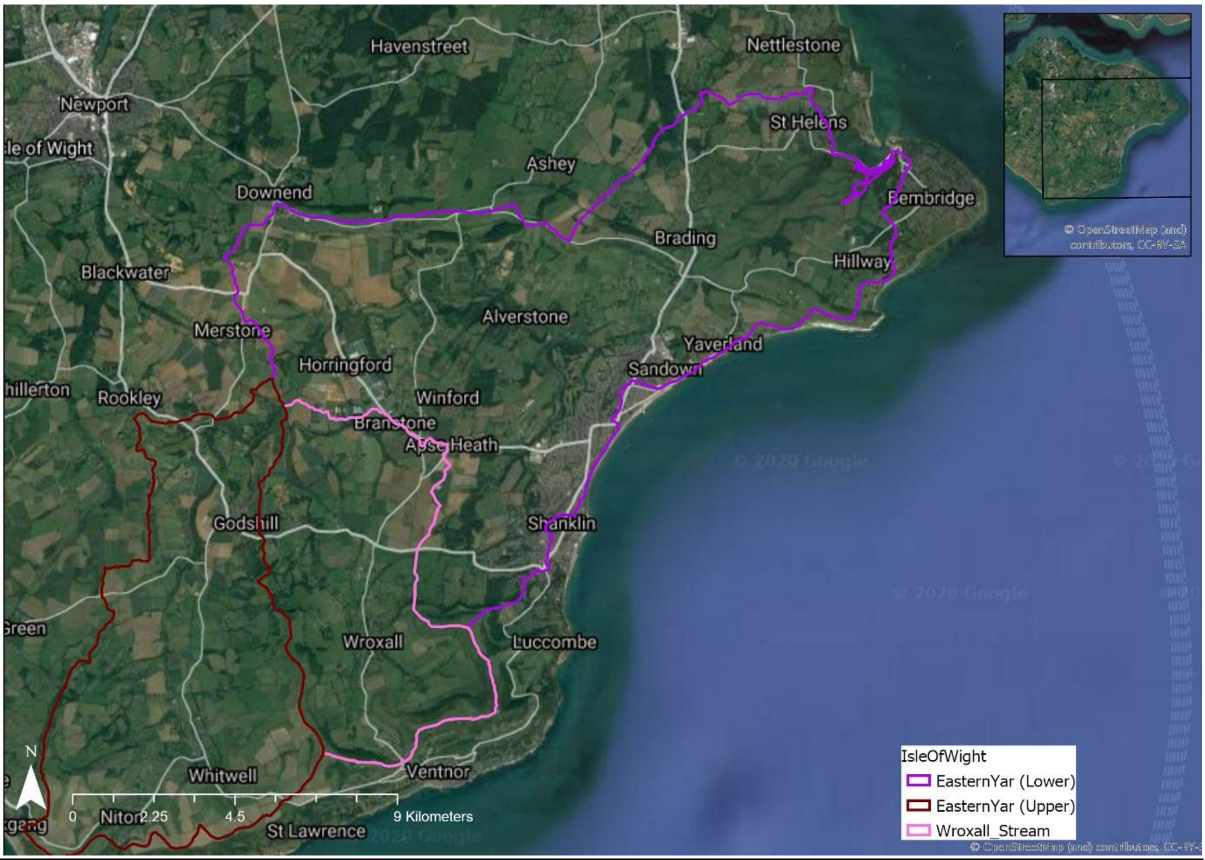

Figure 4. Eastern Yar sub-catchments

The wider habitats of the Eastern Yar would be highly suitable for wider beaver colonisation. Their restoration could be effected by either direct, active release or over time through expansion from the initially enclosed release site discussed above. The riparian vegetation - emergent, semi-emergent and aquatic - on the river is rich in terms of both quantity and diversity and is entirely suitable for beaver foraging. Willow (*Salix spp*) is abundant throughout the environment and within easy reach of beaver foraging activity there are many other palatable, deciduous trees. Large beds of common reed (*Phragmities australis*) are present in this area and this single species would provide a ready resource of both sugar-rich root systems in the early spring and seasonal summer browse.

Beavers will cut canal systems through reed beds with relative ease and maintain these features as open water where they are active. This action is of significant importance for a broad range of wildlife species which are in large part reliant on features of this sort for access to breeding or feeding opportunities in reed beds. These can include bearded tits (*Panurus biarmicus*), bitterns (*Botaurus stellaris*), garganey (*Spatula querquedula*) and common cranes (*Grus grus*).

The riverbanks are predominantly earthen and could easily be utilised for burrowing and lodge construction.

Given the entirely suitable resources for foraging and shelter creation, beavers could be readily released directly into the Eastern Yar where they might be expected to flourish. The long-term goal of this project would be to create a best practice example to promote both positive habitat restoration through beaver activity and to ensure a targeted approach to the selection of founder stock sufficient to maximise complete genetic diversity. This approach would essentially afford both a suitable beaver population for eventual colonisation of the whole island and a resource specifically designed to provide an excellent future stock for further release in time elsewhere. While its genetic composition should therefore be carefully planned to optimise the forgoing with both wild and unique captive bred individuals being sourced where possible, the best physical process for restoration would be to release in family clusters or as lone individuals in the beginning when any population was numerically low. Providing the latter were available in sufficient numbers, they could be expected to move readily throughout the river system in order to establish territories and source mates. This process is best left for them to select residential areas themselves rather than trying to determine exact locations for occupancy which is unlikely to be effective in any case as a strategy. The most likely areas for occupancy will however be larger patches of wet willow and woodland on the river's edge or in its easily accessible hinterlands.

In the floodplains - some of which were which were dry at the time of survey - and narrower water courses dam creation would occur in time. The impact of the impoundments would predictably be to push water out into the floodplain, establish other water courses and bodies and retain both greater levels of standing and ground water. Where the forgoing process may be associated with intensively used agricultural environments, dam removal might be required as a management tool where landowners have concerns. Burrowing in the banks of the main river is likely to be of little consequence in well vegetated environments. While the ring barking and felling of mature amenity trees, garden specimens and fruit trees in close proximity to the shoreline could be a source of conflict, these can readily be protected in advance or monitored for an appropriate response. Where the river is crossed by roads an assessment of trees which could be readily felled should be undertaken prior to beaver release. Mitigation through coppicing, anti-game painting or wiring in advance are all cost-effective to implement.

Wider Island Release /Permitted Wider Island Colonisation

An Island-wide release, or perhaps more realistically a series of unenclosed releases on Wildlife Trust land under licence with the intention to extend the restoration of the beaver to the whole of the Island's riparian environments, could also be considered. This approach would represent an inspirational step in beaver restoration which is not currently being considered elsewhere in Britain. Resources that would otherwise be required for fencing or captive husbandry requirements, including rehoming of offspring, could instead be diverted into education and mitigation to support a truly extensive wild beaver population.

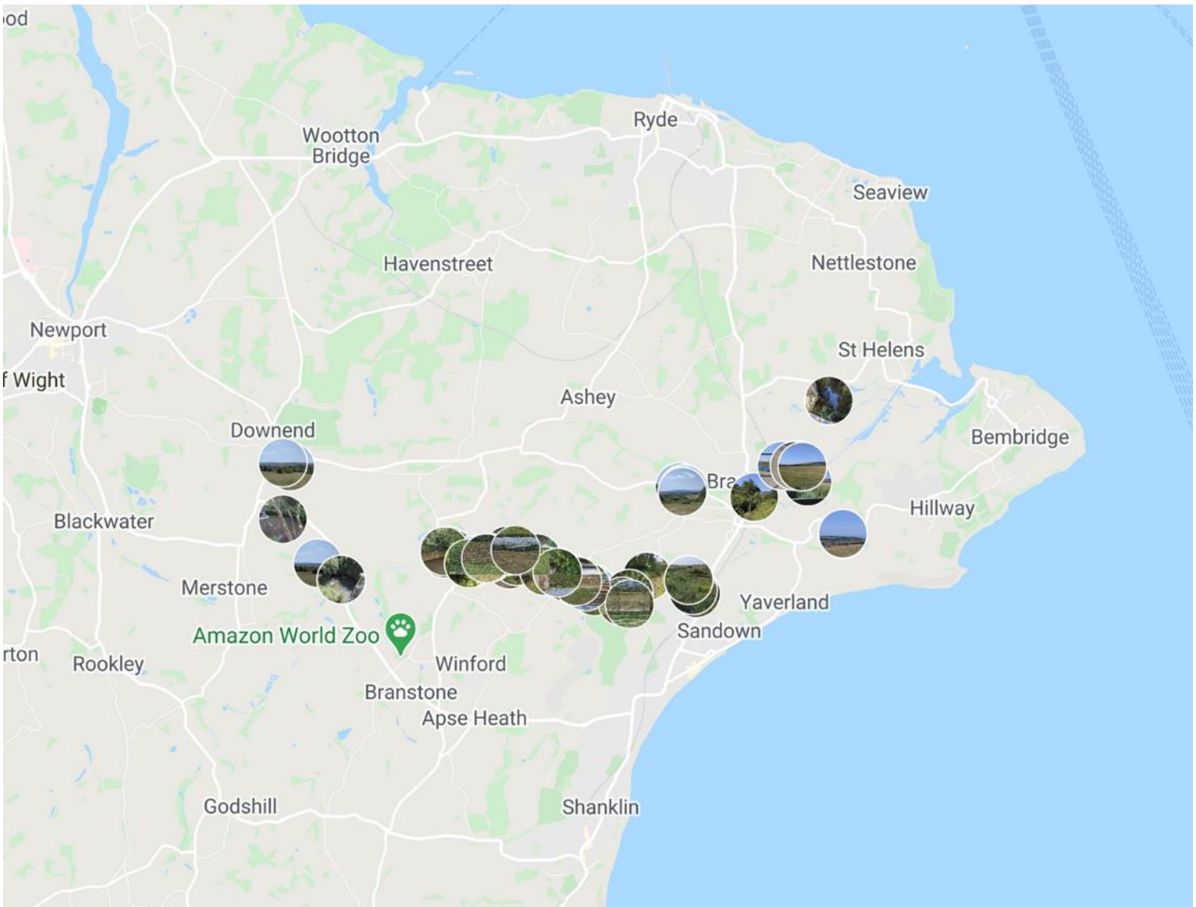

Figure 5. Areas visited during walkover survey, images available at link below

https://www.google.com/maps/d/edit?mid=1g42Gm5rQdBlj3kLyp_X3n0qnJZP5JF2R&usp=sharing

Figure 6. Reserve potential release site. These ponds offer highly suitable habitat for immediate release. Burrowing under walkway sections could be an issue in time.

Figure 7. The level of the land to the right is lower than the water course on the left. A combination of beaver generated impoundments, raised groundwater levels and the reopening of what were former water courses at this point could restore significant water bodies in this area. The vegetation response by the existing pasture is likely to regenerate riparian edge landscapes swiftly.

Figure 8. Channel downstream of reserve. Channels throughout all sites looked at were very well vegetated, with a diverse range of plant species and willow scrub. These water courses are entirely suitable habitat for both residential and dispersal routes. Beavers could readily dam these water courses, most likely to construct burrows behind and potentially fell trees that may impact on foot and cycle paths, but this could be monitored and appropriate mitigation implemented.

Figure 9. Weir further downstream with a gauging station next to this. In such sections of the landscape, for example like the above with gardens, mature trees next to the water course, or in which specific infrastructure should be protected from damming, tree guards, exclusion fencing and protective grills may be required.

Figure 10. Landscape downstream at Alverstone with established wet pasture where beavers would have little impact, although canals might extend out into fields.

Figure 11. Channel near Sandown providing ideal adaptive beaver habitat which, once impounded and trees felled, would rapidly revert to a complex wetland environment.

Figure 12. Brading Marshes has strong potential for irrigation as beaver impoundments block channels and spread water out in this flat landscape. Canal building would further extend water from channels into the floodplain which, if also dammed, would result in a much wetter landscape with increased water holding potential. This in turn would be colonised by a vast range of water loving plant and animal species, as well as offering breeding and feeding grounds for amphibians and waders for example.

Figure 13. Typical channel through Brading Marshes. These main channels provide entirely suitable beaver habitat with deeper water and banks for burrowing and lodge construction, and rich foraging resources.

Figure 14. Landscape overview at the mouth of the Eastern Yar.

5 Suitability for Beavers

Overall, all release site options provide highly suitable habitat for beaver. Release site areas are possible to enclose and could readily incorporate a large enough wetland area to provide resources for breeding families and expansion. Alternatively, strategic releases into the wider landscape into areas selected for minimal landowner conflict could enable beavers to colonise the Island as a whole and select partners naturally. The latter could represent a more realistic impact of beavers on the wider, mixed land-use landscape. Resources could then be developed to encourage people to live alongside beavers, with a robust and practical mitigation scheme.

5.1 Potential Conflict Issues

Conflicts are generally expected to be low given the extent of well-vegetated water channels and excellent habitat on the main stem of the river. With increasing population density and permitted colonisation within and between catchments, more obvious impacts and potential issues will occur according to specific beaver activities at specific locations. Overall these are most likely to include the felling of mature trees across access routes such as cycle and public rights of way where water bodies are close, burrowing into channel embankments, undermining paths, excavating in unprotected flood walls and damming of agricultural drainage ditches. The impact of the latter would be limited in extent to lowland or former floodplain areas.

6 Modelling of Beaver Habitat Suitability and Dam Capacity

Beaver habitat suitability and dam capacity modelling was undertaken across the entirety of the Isle of Wight using beaver modelling tools developed by researchers at the University of Exeter (Graham et al., 2020). Full methods, maps and summary statistics for the Isle of Wight are provided in the accompanying modelling report whilst results are provided below for the Eastern Yar and proposed release site.

6.1 Beaver Habitat Suitability Modelling for the Isle of Wight

In addition to site visits by beaver experts, the habitat suitability of the sites was assessed using the Beaver Habitat Index (BHI) model for both the proposed enclosure and Island-wide release options.

Summary Description: The aim of BHI modelling is to produce a continuous description of habitat suitability for beaver over the landscape. First a vegetation suitability index is created using multiple high-resolution spatial datasets from Ordnance Survey, the UK Centre for Ecology and Hydrology, and Copernicus. These datasets will be combined to provide detailed land cover and vegetation information which is classified based on empirical field observation of beaver habitat and preference. Vegetation suitability is combined with additional parameters describing stream networks and water bodies. Whilst beaver habitat suitability is primarily defined by vegetation suitability, beavers also require water for security and movement. Therefore, accessibility to waterbodies (i.e. channels, ponds, and lakes) will also determine the viability of beaver occupancy and therefore are required to classify habitat accurately.

Outputs: This product provides a high-resolution (5m cell size) resource (in raster Tiff format) for describing habitat suitability for beaver. This dataset can allow the user to explore which landscapes were most (or least) suitable for beaver reintroduction and also to understand where habitat enhancement might be useful to support future reintroduction.

6.2 Beaver Vegetation Index (BVI –prerequisite for BHI modelling)

Vegetation is important for classifying beaver habitat (Hartman, 1996; John et al., 2010; Pinto et al., 2009; St-Pierre et al., 2017). It was therefore critical to establish a reliable Beaver Vegetation Index (BVI) using nationally-available spatial datasets. No single dataset contained the detail required to depict all key vegetation types. Therefore, a composite dataset was created from: OS VectorMap data (Ordnance Survey, 2018), The Centre for Ecology and Hydrology (CEH) 2015 land cover map (LCM) (Rowland et al., 2017), Copernicus 2015 20 m tree cover density (TCD) (Copernicus, 2017) and the CEH woody linear features framework (Scholefield et al., 2016).

Vegetation datasets were assigned suitability values (zero to five). Zero values were assigned to areas of no vegetation i.e. buildings and values of five were assigned to favourable habitat i.e. deciduous woodland. Values were assigned based on a review of relevant literature (Haarberg & Rosell, 2006; Jenkins, 1979; Nolet et al., 1994; O'Connell et al., 2008), field observation and comparison with satellite imagery. Vector data were converted to raster format (resolution of 5 m). TCD data were resampled to 5m and aligned with converted vector layers. An inference system was used to combine these four raster datasets to create the BVI. The workflow prioritises the reliability followed by the highest value data.

Examples of highly suitable land (graded 5) include broad-leaf woodland, mixed woodland and shrub; examples of suitable vegetation (graded 4) include shrub and marsh; examples of moderately suitable vegetation (graded 3) include coniferous woodland, marsh, shrub and unimproved grassland; examples of barely suitable vegetation (graded 2) include reeds, shrub and heathland and boulders, neutral grassland; examples of unsuitable vegetation (graded 1) include heather, acid grassland, unimproved grass and boulders, bog; examples of no accessible vegetation (graded 0) include shingle and sand, buildings, rock, urban, freshwater and saltwater habitats.

6.3 Beaver Habitat Index Model (BHI)

Whilst vegetation is a dominant factor in determining habitat suitability for beaver, so is proximity to a waterbody (Gurnell et al., 2008). With beavers being strong swimmers, they utilise waterbodies both to provide security as a means of escaping predators, and to access foraging areas. It is thought that most foraging occurs within 10 m of a watercourse/body (Haarberg & Rosell, 2006), and rarely beyond 50 m (Stringer et al., 2018). However, greater foraging distances have on occasion been observed and as in Macfarlane et al., 2015, 100m has been accepted as a maximum distance in which the vast majority of foraging occurs. Therefore, to determine suitable habitat for beaver incorporating both BVI vegetation suitability and water accessibility a 100m buffer was applied to water bodies. To do this the OS master map river network and OS vector in land water bodies were combined to get the best readily available national waterbody and watercourse coverage.

Whilst BVI was run nationally on a 5m scale it is best viewed as a preparatory step for BHI (and later Beaver Dam Capacity) modelling and is superseded in usefulness by the BHI dataset. It is strongly recommended that most analysis and management applications use BHI i.e. if there is an area of preferred vegetation such as willow woodland more than 100 m from a waterbody it is thought inaccessible to beaver and therefore does not form suitable habitat.

Both BVI and BHI use a scoring system of zero to five (Table 1). Scores of five represent vegetation that is highly suitable or preferred by beavers and that also lies within 100 m of a waterbody. Zero scores are given to areas that contain no vegetation or are greater than 100 m from a waterbody. It is important to note that the habitat model considers terrestrial habitat where foraging primarily occurs and that watercourses themselves are also scored zero. It is also important to note that all scores above 1 contain suitable vegetation.

Table 1. BVI and BHI value definitions. It is critical to note that all values above 1 are suitable for beaver.

BVI and BHI Values	Definition
0	Not suitable (no accessible vegetation)
1	Not suitable (unsuitable vegetation)
2	Barely Suitable
3	Moderately Suitable
4	Suitable
5	Highly Suitable

6.4 Beaver Habitat Index Map for the Eastern Yar

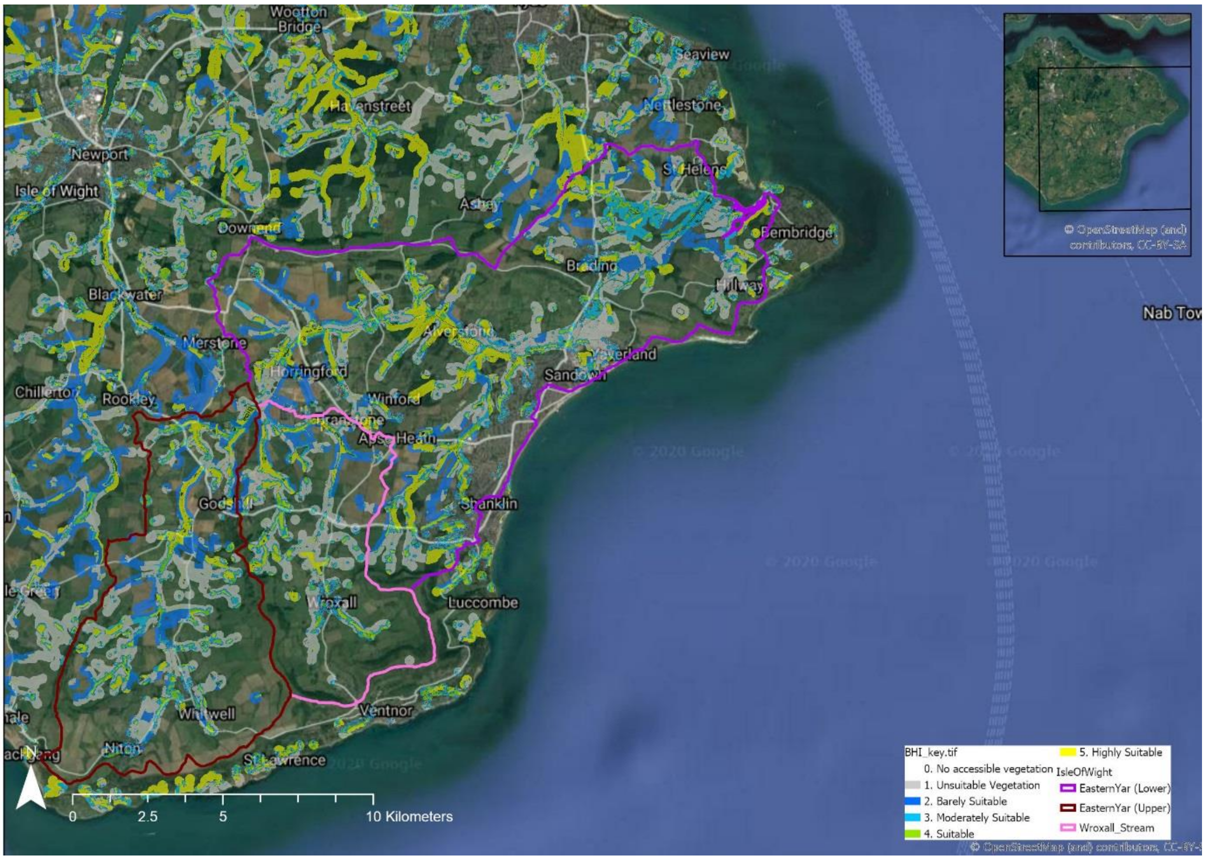

Figure 15. BHI model output for the Eastern Yar. *Contains Ordnance Survey data © Crown Copyright 2007, Licence number 100017572 and some features of this map are based on digital spatial data licensed from the Centre for Ecology & Hydrology, © NERC (CEH). Aerial imagery: Open-Source Google imagery © OpenStreetmap (and) contributors CC-BY-SA.*

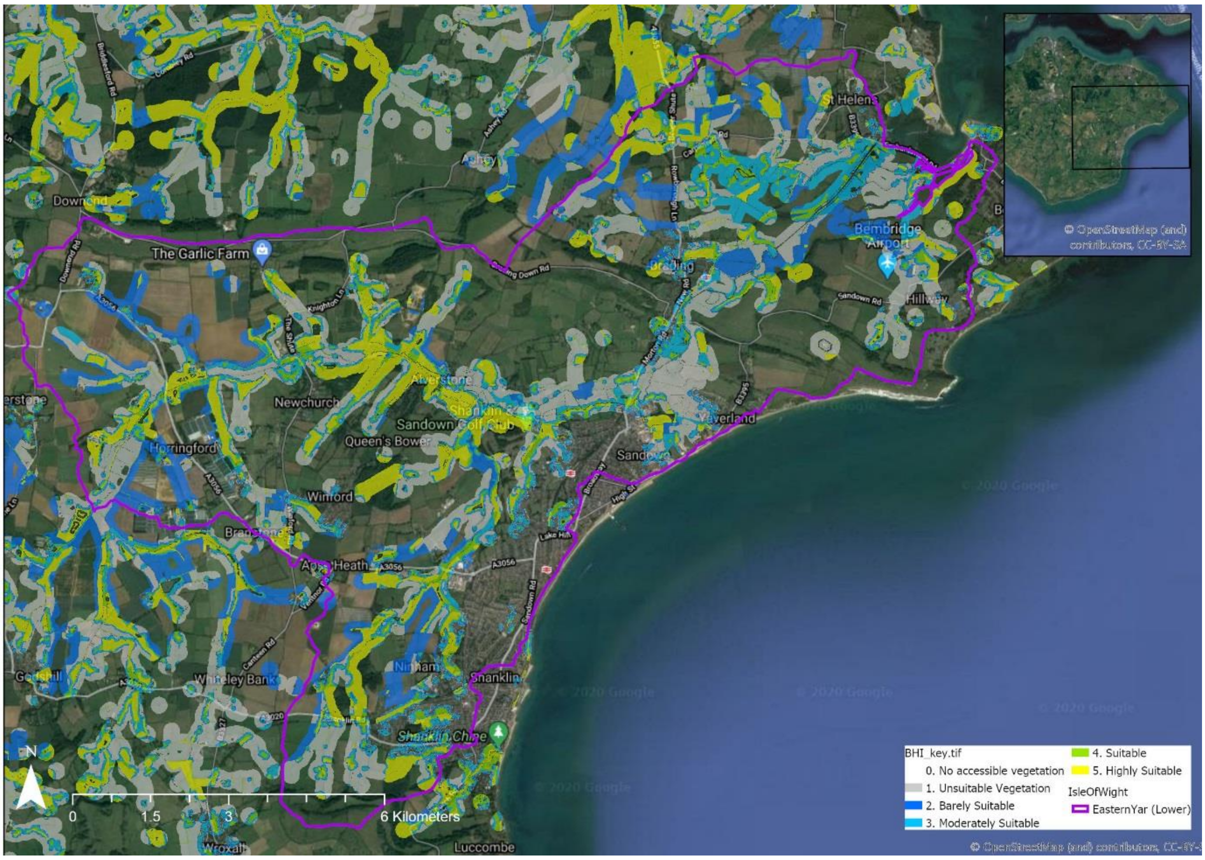

Figure 16. BHI output for the Lower Eastern Yar. Contains Ordnance Survey data © Crown Copyright 2007, Licence number 100017572 and some features of this map are based on digital spatial data licensed from the Centre for Ecology & Hydrology, © NERC (CEH). Aerial imagery: Open-Source Google imagery © OpenStreetmap (and) contributors CC-BY-SA.

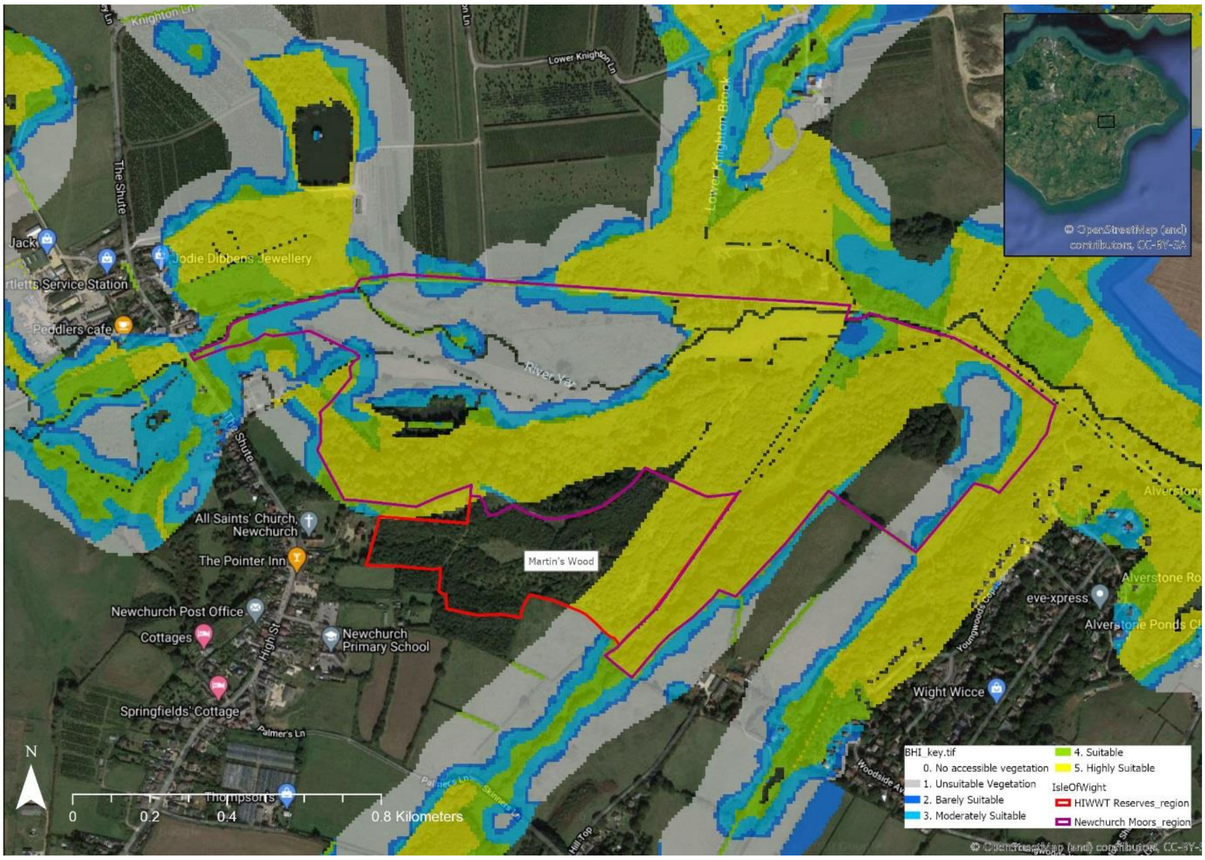

Figure 17.BHI output zooming into Newchurch Moors region. Contains Ordnance Survey data © Crown Copyright 2007, Licence number 100017572 and some features of this map are based on digital spatial data licensed from the Centre for Ecology & Hydrology, © NERC (CEH). Aerial imagery: Open-Source Google imagery © OpenStreetmap (and) contributors CC-BY-SA.

6.5 Beaver Habitat Suitability Summary

The entire catchment including the proposed release site is highly suitable for beaver release and long-term occupation. Given the connectivity both within and between river catchments, beavers could readily access all suitable water courses on the Island in time unless restrictive fencing is employed. Beaver conflicts with certain landowners and land-uses may be likely in time, these are not expected to be widespread and significant. Readily tried and tested mitigation solutions are available and could be deployed in a reactive manner as issues may arise, in a cost affordable way. Key to any mitigation programme is resource availability over the long-term, a support system capable of disseminating relevant and up-to-date information, and the ability to quickly react to any concerns. As has been the case with unfenced beaver projects in both Scotland and Devon, informed staff must have the capacity to speak directly to local people to dispel mis-information, explain the ecology of the species and discuss mitigation options. This community-embedded strategy successfully alleviates many of the initial concerns associated with beaver restoration.

6.6 Beaver Dam Capacity Model Summary

The Beaver Restoration Assessment Tool (BRAT) was developed in North America (Macfarlane et al., 2014, 2015) to determine the capacity for river systems to support beaver dams. The BRAT model has been further deployed in a range of different river systems to aid both beaver recolonisation and beaver dam analogue led restoration. The BRAT model not only provides an invaluable tool for designing effective, empirically based, restoration strategies, but it also indicates where beaver dams might be constructed and therefore where they may cause potential management/conflict issues. The BRAT model structures the framework of the model around the river network itself and uses a fuzzy logic approach which builds in the considerable uncertainty that is associated with beavers' ability to dam reaches. Furthermore, it provides a range of output values to predict the dam capacity which has implications for beaver preference towards a given location.

We have therefore used the BRAT framework to develop an optimised Beaver Dam Capacity (BDC) model for Great Britain; and although many of the datasets used are specific to GB, these could readily be adapted to enable its use globally.

The BDC model estimates the capacity of river systems to support dams at the reach-scale (c.a. 150m). The model also highlights reaches that are more likely to be dammed by beaver and estimates the number of beaver dams that could occur for a catchment at population carrying capacity. As such, this highly detailed tool would provide understanding of where dams are most likely to occur and in what densities, supporting future work on the conflicts and opportunities that might accrue from beaver reintroduction.

The model infers the density of dams that can be supported by stream reaches (111.1m ± 52.5) across a catchment. Using low-cost and open-source datasets, the following attributes are calculated for each reach: (i) stream gradient, (ii) low (Q80) and high flow (Q2) stream power, (iii) bank full width, (iv) stream order, and (v) the suitability of vegetation within 10m and 40m of the bank for beaver dam construction. These controlling variables are combined using a sequence of inference and fuzzy inference systems which follow an expert-defined rules system that allows for the considerable uncertainty often associated with these types of complex ecological processes.

Each reach was classified for damming capacity using five categories from none, defined as no capacity for damming, to pervasive where a maximum capacity of 16-40 dams could theoretically be constructed in a kilometre of channel. It is important to note that the model assumes both reach and catchment population carrying capacity for beaver. Therefore, in reality the maximum number of dams indicated in a category class is unlikely to occur. A full list of BDC classifications is included in Table 2.

Table 2. BDC classifications and definitions.

BDC Classification	Definition
None	No capacity for damming
Rare	Max capacity for 0-1 dams/km
Occasional	Max capacity for 1-4 dams/km
Frequent	Max capacity for 5-15 dams/km
Pervasive	Max capacity for 16-40 dams/km

6.7 Beaver Dam Capacity Model Map

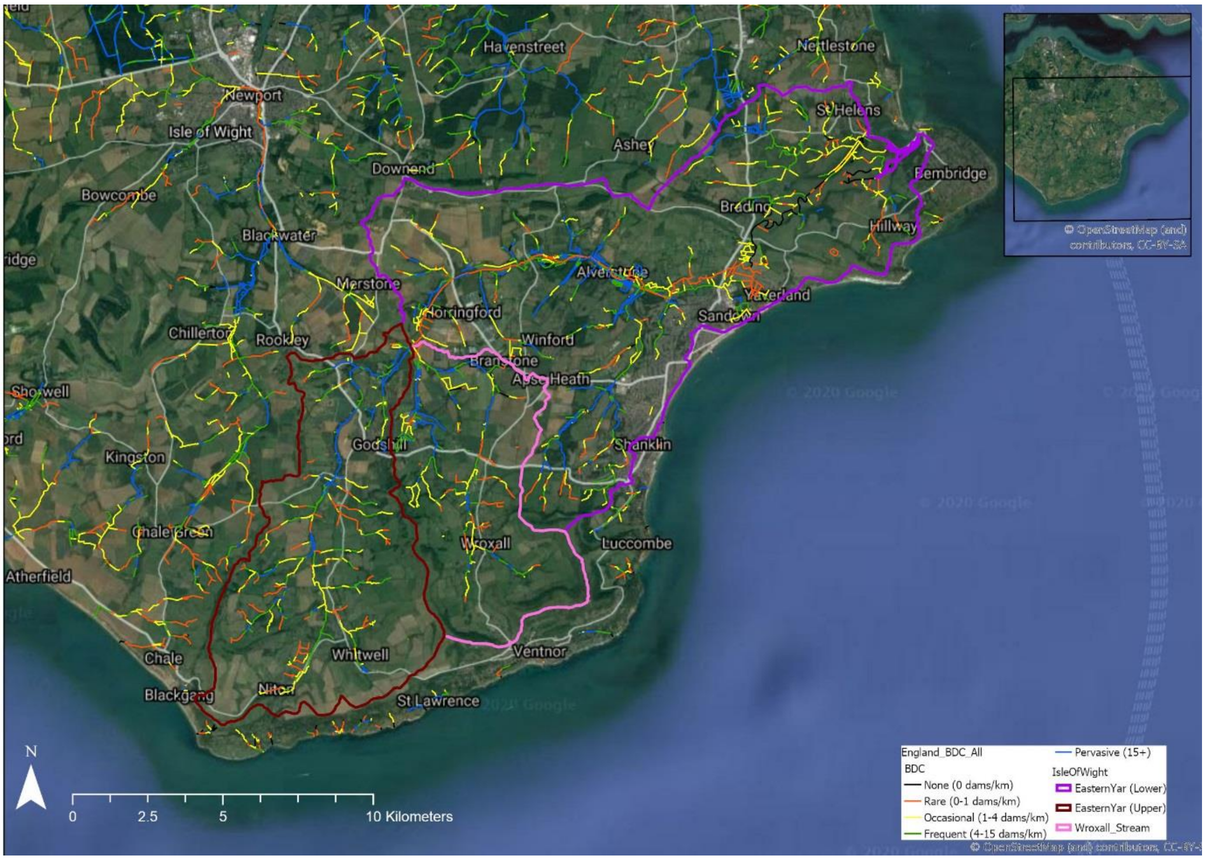

Figure 18. BDC output for the Eastern Yar. Contains Ordnance Survey data © Crown Copyright 2007, Licence number 100017572 and some features of this map are based on digital spatial data licensed from the Centre for Ecology & Hydrology, © NERC (CEH). Aerial imagery: Open-Source Google imagery © OpenStreetmap (and) contributors CC-BY-SA.

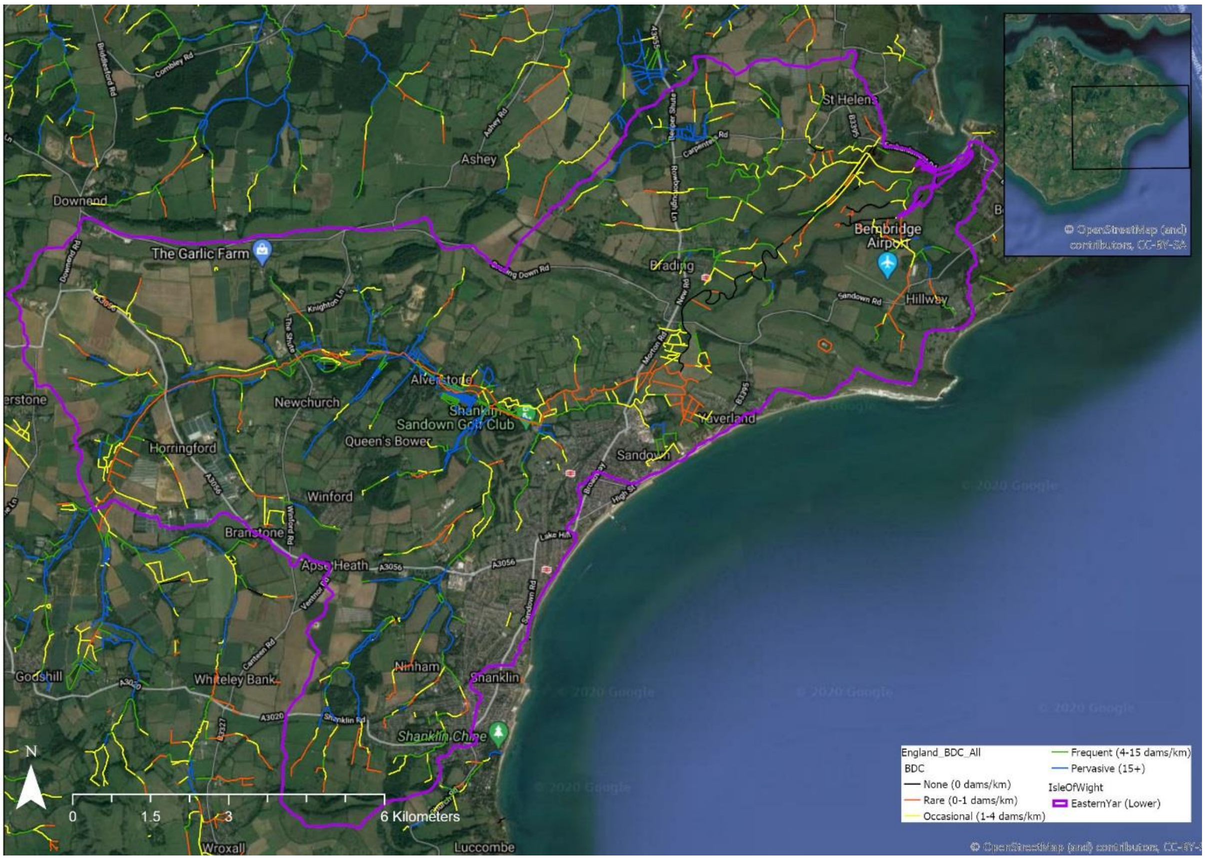

Figure 19. BDC output for the Lower Eastern Yar*. Contains Ordnance Survey data © Crown Copyright 2007, Licence number 100017572 and some features of this map are based on digital spatial data licensed from the Centre for Ecology & Hydrology, © NERC (CEH). Aerial imagery: Open-Source Google imagery © OpenStreetmap (and) contributors CC-BY-SA.*

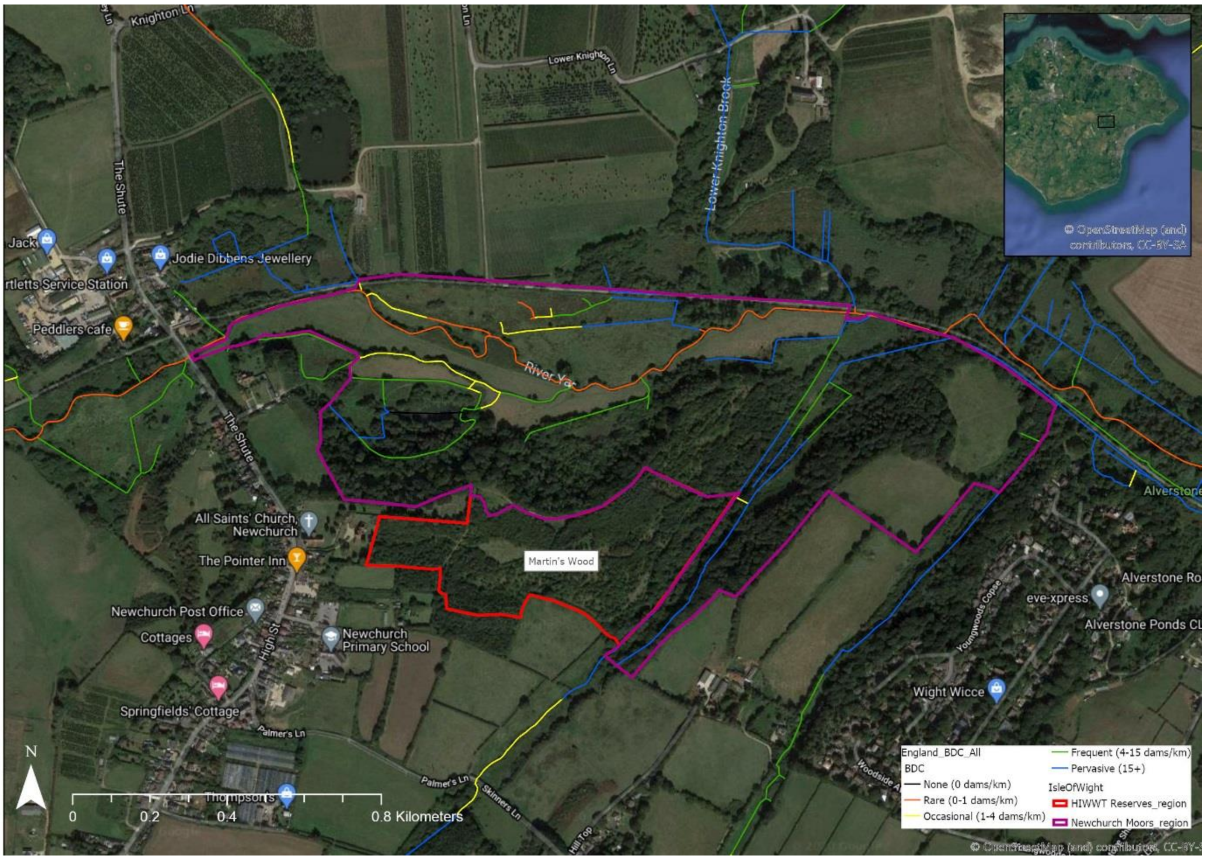

Figure 20. Newchurch Moors region BDC. Contains Ordnance Survey data © Crown Copyright 2007, Licence number 100017572 and some features of this map are based on digital spatial data licensed from the Centre for Ecology & Hydrology, © NERC (CEH). Aerial imagery: Open-Source Google imagery © OpenStreetmap (and) contributors CC-BY-SA.

6.8 Beaver Dam Capacity Model Summary

Table 4 below includes summary BDC summary statistics for the Isle of Wight, the Newchurch Moors release site, and sub catchments of the Eastern Yar. Results illustrate there are extensive areas where beavers would have the capacity to dam, although exact dam configurations are hard to predict and would depend strongly on the release scenario chosen.

Table 3. BDC summary statistics for areas considered within the Isle of Wight.

		Study Area				
	Statistic	*Isle of Wight*	*Newchurch Moors*	*Wroxall Stream*	*Eastern Yar (Upper)*	*Eastern Yar (Lower)*
Summary	BDC Mean	9.93	12.07	10.37	9.46	9.77
	BDC STD	10.52	10.69	10.46	10.05	10.79
	Length of channel (km)	827.57	6.25	37.86	55.17	150.45
% of each BDC class	None	2.03	1.89	1.45	0.13	5.1
	Rare	19.28	20.15	17.51	23.01	20.65
	Occasional	29.39	10.77	31.85	29.65	27.56
	Frequent	26.51	28.76	24.88	25.81	22.93
	Pervasive	22.8	38.42	24.32	21.4	23.76
Length (km) of each BDC class	None	16.76	0.12	0.55	0.07	7.67
	Rare	159.56	1.26	6.63	12.69	31.07
	Occasional	243.22	0.67	12.06	16.36	41.46
	Frequent	219.35	1.8	9.42	14.24	34.5
	Pervasive	188.68	2.4	9.21	11.8	35.74

7 Potential Research Objectives

Potential research objectives that could be studied for this project can be separated into three main categories (hydrology, biodiversity and socio-economic), which are summarised below along with associated research hypothesises that could be tested.

7.1 Utilisation and Modification of Catchment by a Wild Beaver Population

Due to the scope of potential study opportunities, and the extent of land in the proposed release area owned by the Hampshire & Isle of Wight Wildlife Trust (HIWWT), the Isle of Wight presents a unique opportunity to study the reintroduction of beaver into a catchment starting from initial colonisation. In contrast, studies on both Tayside in Scotland and the River Otter in England began after beavers were discovered already living in the catchments. Exact research questions would need to be formulated with project partners but they could involve.

Q1. How do beavers expand and utilise the catchment?

Q2. Do beavers provide a complimentary management strategy to other approaches being deployed by HIWWT and project partners?

Q3. Does the presence of beavers increase or decrease management costs within the Isle of Wight?

Q3. Do beaver management approaches formulated elsewhere (i.e. River Otter, GB; Bavaria, Germany; Tayside, Scotland) form an appropriate management plan for the Isle of Wight?

In addressing Q1, beavers leave distinctive signs i.e. feeding signs, dams, lodges, burrows which provide a way of monitoring their distribution, impact and territory dynamics (i.e. see Campbell-Palmer et al., 2018). In reporting on the River Otter Beaver Trial (Brazier et al., 2020b) a management template has been proposed, developed with all trial project partners that could provide a template for other locations. However, investigating whether the same approach advocated for the River Otter works elsewhere would be a valuable research objective.

7.2 Water Quantity and Flow Attenuation

Via the building of dams, it is increasingly recognised that beavers can alter hydrology through reducing downstream connectivity and resulting in flow attenuation (Puttock et al., 2017). The altered flow regimes and water storage capacity can also modify nutrient and chemical cycling in freshwater systems. Pond-dam complexes often act as sediment traps, storing fine sediments and nutrients which alter in-pond nutrient cycling (Klotz, 2007), supporting a positive effect on downstream water quality (Naiman et al., 1986). Key summary points are:

- Beaver dam-pond structures can trap and store significant amounts of sediment
- Beaver ponds can also result in significant stores of particulate associated phosphate, nitrate and carbon.
- A key driver behind nutrient storage is the physical immobilisation of nutrient-rich sediment in ponds and subsequent bio-assimilation (i.e. uptake by plants).
- Long term storage dynamics are dependent upon site evolution (i.e. long term storage if ponds fill and stabilise as beaver meadows vs. transient storage if beaver dams fail).

Whilst pilot studies have shown positive results for downstream nutrient concentrations and loads in GB (Puttock et al., 2017; Law et al., 2016) much of the previous work undertaken into the water quality impacts of beavers has been undertaken in very different environments (particularly North America) to the intensively managed agriculturally dominated landscapes characteristic of Great Britain. Further research would have value nationally but would also address whether beavers could help to achieve Water Framework Directive standards and therefore function as an innovative approach to tackling contributions from point and diffuse sources of eutrophication.

Hydrological research questions could include:

Q1. Do downstream flow regimes show attenuation following beaver reintroduction, with reduced peak flows and elevated base flows?

Q2. Does water storage and spatial extent of surface water increase in the site due to dam building activity?

Research presented in Puttock et al., 2017, provides a template for quantifying hydrological impacts.

Water storage within the site could be quantified using ground-based or aerial surveys of pond extent, combined with either physical spot surveys of water depth or, if funds permit, continuous monitoring via level sensors. Annual surveys could also quantify sediment accumulation and storage within ponds, with additional sampling and laboratory analysis allowing for an understanding of nutrient content and storage (i.e. Puttock et al., 2018).

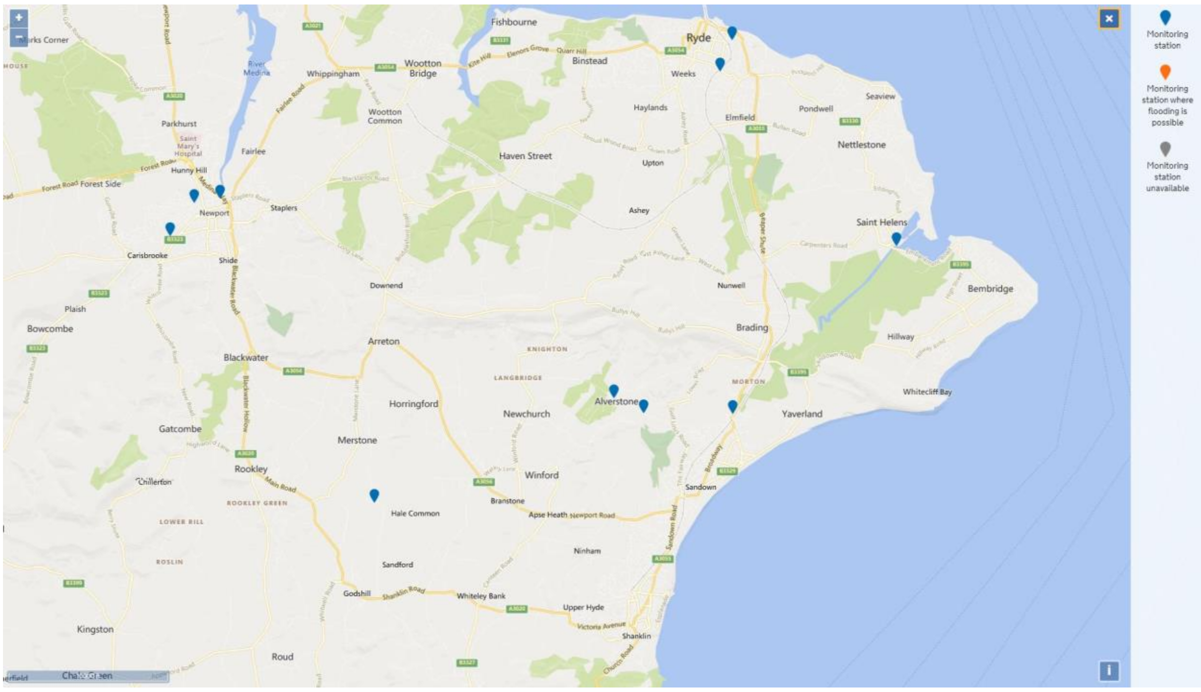

Figure 21. EA flow gauging stations within the study area (source: Environment Agency)

7.3 Biodiversity

Beavers are a "keystone species" whose niche as wetland engineers has a significant impact on the natural landscape. Beaver activity creates habitats that are dynamic in nature. Beaver activity can provide a wide range of ecological and economic benefits, but it is clear that in heavily modified landscapes, beaver activity will have to function within limits acceptable to human interests. Their activities can result in the formation of wetland habitats, with a positive effect on plant and animal diversity. Whilst a recent meta-analysis determined that overall beavers have a positive effect on biodiversity (Stringer and Gaywood, 2016), there is a need for further research to determine how beaver activity can act in conjunction with existing wildlife conservation objectives and methods.

Although a major reason for this feasibility study is to explore how the introduction of beavers might modify the environment, it is possible to envisage what might happen upon the Eastern Yar based on experience elsewhere (see the Devon studies in particular). In terms of biodiversity, the chief expected change will be the amount of standing water held within a number of new ponds and a significant increase in both dead standing and submerged woody debris. This is likely to increase populations of fish, aquatic invertebrates, amphibians, bats and other species. Increased light from coppicing of the willow and other tree species should have a major beneficial impact on ground flora.

Example non-directional research questions that could be addressed by the continuation or initiation of ecological surveying include:

Q1. Do beavers change the vertical and horizontal structural heterogeneity of the woodland?

Q2. Will there be a different diversity of bat species using the site?

Q3. Will there be a change in bird species breeding on site?

Q4. Will the diversity of butterfly species change?

Q5. Will the diversity of moth species change?

Q7. Will there be a change in the species diversity of amphibians using the site?

7.4 Ecotourism and Socio-economic Impacts

Beavers are a popular species (Macmillan et al. 2001; Gurnell et al. 2009). The development of a process of re-learning how to live with and manage a species that has been absent for nearly 400 years is an essential component of their effective restoration. Projects which provide information regarding the ecology of the beaver have been associated with increased levels of tolerance for its activities (Parker and Rosell 2012). The dissemination of factually correct information at sites where people can see beavers and the results of their activities goes a long way to promote their restoration, and such projects can provide additional educational resources through public talks, school outreach programmes, social media and nature walks. An example of this system of activities has been effectively developed by the Scottish Beaver Trial. Publications such as leaflets or booklets have been produced for interested organisations, local authorities and wider communities at targeted events. These materials can also be designed to support talks or lessons. It should also be recognised that the way in which the activities of beavers (and those of other animals) are perceived is often closely bound up with wider human–human social issues. The same beaver activities can be very differently perceived by a society, and subgroups within it, depending on the social context involved.

The reintroduction of a charismatic species such as the beaver, which can be watched at dusk and dawn, could provide a strong selling point and generate opportunities for overnight accommodation and hospitality spending in some places (Campbell et al. 2007). Evidence from Belgium, where a proactive marketing strategy was developed by the NGO responsible for beaver reintroduction on the basis of 'Beavers, Beer and Castles', demonstrates that this animal has popular appeal. Annually, this project generates approximately €50,000 for the guides, organisers and landowners (O. Rubbers, personal communication). The scheme has proven particularly popular with the owners of guest houses, hotels and pubs, who proactively encourage their visitors to attend in order to receive the resultant food and drink revenue.

As a result of significant television, newsprint and general media coverage, an interest in viewing beavers has already developed on a small scale within Britain. Evidence from the Scottish Beaver Trial has recorded visitors from all over the UK and Ireland, and a range of European countries (Jones and Campbell-Palmer, 2014). Over 32,000 members of the public took part in SBT-held education events (>8,000 attending local events), including outreach classes and teacher training events, with an estimated additional 6,582 participants on walks made due to the presence of beavers in the area (Moran and Lewis, 2014). The authors estimate that the value of these visitors was £355,000–520,000, in addition to the ecological knowledge gained through school engagement with SBT valued at £55,690, and the value of volunteering at £84,000. A survey of tourism-related businesses for the Tayside area found on the whole there was generally a positive attitude towards beaver presence, with ~26% noting increased turnover (Hamilton and Moran 2015).

Wildlife tourism is a rapidly growing sector of the UK economy. This is recognised by government, tourism and economic development agencies. Guided walks to see beaver habitat and field signs, or to try to see the animals themselves, have proved popular in Scotland through public events held by the Scottish Beaver Trial and/or through more informal tours undertaken on Tayside. Landowners with the appropriate facilities may be able to offer hide-viewing opportunities if beavers are resident. Any estimate of the economic value of the presence of beavers should also take into account local amenities that may benefit, such as businesses that provide accommodation and food, and the potential for training local people as guides. For example, the reintroduction of the White-Tailed Eagle/Sea Eagle (*Haliaeetus albicilla*) by the RSPB on the Isle of Mull has been estimated to generate £1.69 million per annum for the local economy (Dickie et al. 2006).

Like the successful reintroduction of the White-Tailed Eagle to the Isle of Wight, it would be an interesting research area to investigate whether wildlife tourism including perhaps the presence of beaver (i.e. see Auster et al., 2020) plays a quantifiable role in attracting visitors.

8 Beaver Sourcing, Health and Welfare

Beavers could be sourced from wild-caught Scottish-born individuals from conflict areas where lethal control has been licensed by Scottish Natural Heritage. Alternatively, some UK-born captive animals may become available to provide additional individuals.

Any beavers used will be responsibly sourced and undergo appropriate health screening in line with current statutory requirements following procedures previously employed by similar beaver projects and using experienced veterinary and captive care personnel. Particular attention will be given to their trapping location and /or known family relationships in order to increase genetic diversity and avoid inbreeding.

8.1 Pre-release Health Screening

Pre-release health screening for beaver release in Britain has been well documented and veterinary knowledge greatly improved (Campbell-Palmer et al., 2016; Goodman et al., 2012). From a health and biosecurity perspective, beavers are currently considered to present no greater risk to human, livestock, or other wildlife health than any other native mammal (Goodman et al., 2012; Girling et al., in press). Health screening requirements and diagnostic methods have been published and experts experienced in these have been consulted. Pre-release health screening has two purposes; to ensure individuals are suitable for release and their welfare is not compromised, and ensure released individuals do not introduce a disease risk to wildlife, livestock or human health following release.

Any pre-release health screening will vary according to where animals have been sourced from, in line with recognised disease risk assessment and following statutory requirements for mammal release in Britain and IUCN wildlife disease risk analysis. Therefore, common diseases already present in British wildlife populations do not generally present a direct welfare issue or exclusion from release and which beavers may be exposed to following release, such as leptospirosis. Any beavers captive or wild-born within the UK will not present any risk of non-native pathogens and diseases such as Rabies, the tapeworm *Echinococcus multilocularis* or Tularaemia due to their absence in the UK and therefore do not require screening. A further number of notifiable diseases and parasites may require diagnostic testing but trialled and tested screening methods exist and have been applied effectively for numerous projects including the Tayside population.

8.2 Post-release Monitoring

Monitoring of the beavers would largely be undertaken via remote trail cameras to determine individual presence, reproductive status, and body condition (Campbell-Palmer and Rosell, 2013). Throughout the project, health would be monitored via regular visual observations of individual animals, with particular attention paid to body condition and behaviours. Such observations should occur through visual sightings and camera trap observations, individual animals should be viewed out of the water as far as possible.

If necessary, beavers could be trapped to allow new offspring to be sexed and tagged, and to allow family health status to be monitored.

Animals in poor body condition and/or with obvious injuries or signs of disease must be discussed with a veterinary surgeon and trapped for examination and treatment if required. An animal may not be re-released if deemed not fit by a vet and euthanasia may be required. If the beaver is in very poor body condition (body score of 1-2) and/or obviously sick or injured with no chance of natural recovery in the immediate future then veterinary attention should be sought and appropriate facilities to potentially remove and recover such individuals provided. Borderline cases should be resolved by seeking veterinary intervention through a phone call or vet call-out. Any removed animals should be housed in holding facilities meeting the licence criteria and which enable easy recapture. They must receive veterinary attention as soon as possible.

8.3 Signs of Ill-health in the Field

Poor body condition - Weight loss is a common feature, which could be due to an underlying illness or the failure of an animal to cope or feed.

Poor coat condition – grooming and allogrooming should keep the fur shiny and smooth. If the coat appears unkempt it may be an indication that the animal is not grooming due to an underlying problem.

Change in behaviour – Changes may be noted in the behaviour of monitored beavers. Animals may appear subdued or lethargic.

Table 4. Specific signs of suspected ill-health and steps to be taken.

Condition	Body Part Affected	Description	Action Required
Change in behaviour	-	Subdued/lethargic/sleeping while exposed	Monitor and seek veterinary advice if prolonged
Reduced body condition	Whole animal	Sudden/obvious weight loss	Seek veterinary advice (see scoring below)
Musculoskeletal lameness	Limbs	Reluctance to bear weight while at rest	Monitor but if the condition deteriorates or no improvement is noted within 3 days seek veterinary advice
Severe musculoskeletal lameness	Limbs	Severely lame: unable to use leg or place weight on leg. The animal may stop frequently	Seek veterinary advice
Worsened external appearance	Fur	Unkempt coat/ ungroomed	May indicate underlying health problem, monitor and seek veterinary advice if continues
Minor wounds	Skin	Wounds to fur and tail are not uncommon	Monitor, assess animal management plan and time of year removal of sub-adults may be required
Moderate wounds	Limbs/skin	If bone is exposed	Seek veterinary advice
Major wounds	Limbs/skin	If wound covers a large surface area (>$10cm^2$)	Seek veterinary advice
Eye infection	Eyes	Discharge, bulging eye, eye continually kept closed or animal rubbing eye	Seek veterinary advice
Ear infection	Ears	Discharge, shaking head, head tilt or circling	Seek veterinary advice
Minor respiratory infection	Nose	Discharge	Monitor if clear, seek veterinary advice if becomes discoloured
Moderate respiratory infection	Lungs	Open mouth breathing	Seek veterinary advice
Major respiratory infection	Lungs	Increased chest or abdominal movement to compensate for respiratory problems	Seek veterinary advice
Dental disease	Teeth	Pawing at mouth, any swelling, chewing to one side and/or dropping majority of food from mouth	Seek veterinary advice
Gastro-intestinal infection/diarrhoea	Gut	It may be difficult to ascertain if an aquatic rodent has got diarrhoea. Look at area under tail being soiled and/or has obvious mucus or blood	Seek veterinary advice

8.4 Field Health Checks

There may be occasions where opportunistic animal handling and screening could occur. Any trapped animal should be checked for an individual PIT tag and micro-chipped if not found. A visual check of body condition should be made by experienced personnel, including looking for obvious injuries, external parasites and potential signs of disease (see Table 4 signs of ill-health). Biological samples should be collected under veterinary supervision as required. All screening should be carried out by trained staff, involve minimal handling time and take place near to their capture point.

8.5 Population Management

Beaver family units are typically composed of a breeding adult pair and offspring from two generations, with the older offspring most commonly dispersing from the natal territory around 2 years of age. Any enclosed animals would have to be monitored closely to determine numbers and family structure. Unless a large area is fenced or partially fenced, it is typical for one pair/small family unit to be released into an enclosure and breeding between the adult pair to occur. Offspring can remain within the family unit for at least the first two years of their birth, and this period may be extended if resources permit. Expert advice should be sought on when and how to remove any older offspring from a family unit, to most accurately reflect natural family dynamics and to ensure resources within the enclosure to ensure individual welfare.

With unenclosed situations, older offspring will typically start to explore more widely and seek their own territory usually in the autumn. These dispersing individuals will seek both unoccupied territories and breeding opportunities in the wider catchment, therefore ensuring that there are options for dispersers from neighbouring territories with diverse genetics to meet and outbreed with would be a very important consideration to minimise inbreeding as far as possible.

8.6 Post-Mortem Examinations

Any dead beavers should be recovered as soon as possible and sent for full post-mortem examination by an accredited pathologist. They should be kept refrigerated as far as possible and only frozen if pathologists are not immediately available. This is an important monitoring tool to confirm general population health and determine if cause of death has welfare implications that require further management intervention. For example, disease, lethal control or excessive road traffic accidents would require mitigation in order to promote animal welfare standards and population viability. Further postmortem protocols can be discussed with local veterinary practices that the Wildlife Trust would foresee working with to deliver this monitoring on as per need basis.

9 Enclosed Release Site Size and Location

9.1 Pre-release Work

Experience from other projects suggests the large existing area of open water and wet woodland found at Newchurch Moors, with enough food provisions and suitable substrate, provides suitable release habitat without further modification.

It is the conclusion of the authors that there is no other pre-release habitat management required.

10 Transport & Release Protocol

10.1 Transport

Any beavers sourced would undergo health screening and pre-release checks at point of capture. They will either come straight to the release site fully tagged and screened from their donor source, or be transported to Derek Gow Consultancy Ltd holding facility ahead of the release for temporary holding to complete family units and/or released pairs. Screening will include a blood test and as best practice a check on general condition of the animals. Steel lined crates will be used to transport the animals. These have metal draw doors at the front which are padlocked on either side once the beavers have been crated. The doors locate in steel angled grooves and cannot be opened from the inside. The animals will be provisioned with appropriate substrate and food for the journey and checked regularly throughout.

Dr Róisín Campbell-Palmer, supported by project staff and staff from Derek Gow Consultancy will affect the transportation, transfer and monitor the health and welfare of the beavers prior to loading, in transit and on arrival at the release site.

10.2 Tagging

Each beaver will be tagged with a unique sub-cutaneous microchip PIT transponder. This will ensure permanent, individual recognition as per licence requirements.

11 Escape Protocol

Required trapping equipment along with suitable storage and potentially temporary holding facilities for any re-trapped individual, those requiring veterinary intervention, and/or rehoming for any particular reason will be developed with the project

In the event that beaver trapping is required, beaver traps will be set on visible areas of beaver activity i.e. feeding areas or established trails. As appropriate these traps will be baited with desirable food or the scent of other beavers, and checked appropriately.

The field signs of beavers are obvious and easy to define – felled trees, regularly used paths emanating from a water body into the surrounding landscape, wood chips and tracks. Training courses for project staff to ensure suitable animal husbandry skills are developed can be delivered by Dr Róisín Campbell-Palmer.

Once trapped the beaver(s) will either be relocated back into the licenced catchment, or removed to another secure captive facility for rehoming depending on circumstance e.g. a sub-adult that has been pushed out of the territory by the parents following evidence of fighting.

11.1 Temporary Secure Housing

Should any individual beaver require temporary holding e.g. was found sick or injured and requiring veterinary examination or was re-trapped after an escape attempt, then they can be held short-term in existing facilities modified to be suitable to retain beavers. Animal holding pens could be modified as long as they are escape-proof, nothing can be gnawed through (e.g. wooden doors can be lined with fine mesh panels), a deep layer of substrate for bedding with hiding opportunities provided (deep layer of straw and some bales in a corner for cover), and water provided (drinking tough). Note such facilities are only a provision if required to hold an animal for only a matter of days before further management decisions can be made after seeking specialist advance.

12 Beaver Management

It is consistently reported that the vast majority of beaver 'damage' occurs close to the water's edge, within, but not limited to, 20-30m. Since their reintroduction, analysis of beaver conflict areas in Bavaria has concluded that these occur in areas where humans intensively utilise and/or have modified the narrow margin of fresh water shoreline (Schwab and Schmidbauer, 2003). The more naturalised this riparian edge is, the fewer the beaver impacts for several reasons. Naturalised riparian strips have a mixed range of plant species from which beavers can selectively forage and therefore demonstrate varying foraging pressure, allowing regrowth and encouraging biodiversity; the root systems stabilize banks more effectively than crops, grass or low numbers of single mature trees thereby making banks more resilient to burrowing; relocating human land-uses such as agriculture back from the riparian edge decreases the direct and conflicting impact of beaver foraging, digging or risk of flooding.

Effective and appropriate management actions are key to increasing the acceptance and tolerability of beavers, these have been well described and documented in the recent Eurasian Beaver Handbook (Campbell-Palmer et al., 2016). Any site may have several sources of conflict and/or require a combination of management solutions. Beaver mitigation programs can be expensive; such costs should be measured against the costs of no mitigation or setting land aside for nature conservation. Tree guards or anti-game paint are commonly used, and can be relatively cheap and accessible for landowners to implement themselves. Exclusion fencing can also be used to protect more valuable stands of trees, such as orchards accessible to beavers. Dam management can require more resources, with permission for damming being potentially more controversial. Blockage of drainage ditches, or dams likely to cause flooding of tracks can be removed typically requiring ongoing monitoring and removal efforts. In certain situations dams can be permitted with the level of impounded water controlled through use of flow devices. Burrowing in inappropriate areas, such as flood banks or undermining roads tends to be the more significant cause of beaver conflicts and harder to mitigate, though burrows can be infilled or banks protected with mesh.

Experience from across Europe and now both Scotland and Devon has demonstrated one of the most effective means to reduce beaver conflicts or perceptions of, is to give people access to high quality information, and provide resources to quickly address issues.

Table 5. Potential sources of conflict with mitigation options.

<table>
<tr><th>Type of activity</th><th>Potential conflict</th><th colspan="2">Potential solutions</th></tr>
<tr><td>Foraging</td><td>Loss of crops
Loss of ornamental vegetation</td><td>Temporary / deterrent fencing
Permanent/ deterrent fencing
Planting unpalatable species
Tree guards
Anti-game/sand paint</td><td rowspan="3">Create more wetlands and naturalized riparian zones</td></tr>
<tr><td>Burrowing</td><td>Bank erosion
Undermining of infrastructure</td><td>Riparian buffer zone
Greenbank protection/reinforcement
Livestock exclusion/grazing regimes
Mesh facing
Metal piling
Hardcore infrastructure – stone facing</td></tr>
<tr><td>Damming</td><td>Loss of crops
Loss of trees
Damage to infrastructure
Downstream effects of dam failures</td><td>Removal
Notching
Flow devices
Beaver dam analogs
Culvert protection
Building on higher ground/out of flood zone
Use oversized culverts/larger bridge arches</td></tr>
</table>

Figure 29. Examples of Scottish beaver mitigation including a fence-wrapped tree, and a flow device structure protecting a culvert.

13 Exit Strategy

The project could come to an end for a number of reasons, including but not limited to:

- Withdrawal of licence to retain beavers on the Island
- Landowner decision to return the site to woodland or other use
- Unacceptable threat to health and welfare or death of beavers.

If the project was terminated for any of the above reasons, the beavers would be relocated to other projects or suitable holding facilities as would be available at the time, following discussion. Note that movement of animals between projects is likely to be permitted only under licence or following notification to NE.

14 Study Authors

Derek Gow Consultancy

Derek Gow has worked with Eurasian beavers since 1994. During this time, he has visited many beaver sites/projects in North America and continental Europe. He has co-authored the Beaver Management Handbook with Roisin Campbell-Palmer and advised the SNCOs intermittently on beaver-related issues. He is a member of BACE and of the Eurasian Beaver Conference group. He has written and presented many articles and media features on beavers.

Dr Róisín Campbell-Palmer

Roisin is a highly experienced field biologist with over 19 peer-reviewed scientific publications on beaver reintroduction, health and biology and a PhD from the University of Southeast Norway on the importance of founder selection in beaver restoration programmes. Lead author on the recently published Eurasian beaver ecology and management book, and as Conservation Manager for the Royal Zoological Society of Scotland (RZSS) and Field Operations Manager for the Scottish Beaver Trial, she has considerable project management experience including all RZSS beaver research projects, SNH commissioned work for Tayside Beaver Study Group and in an advisory role on beaver management and landowner engagement. Roisin can also draw upon experience from working with wildcats, including delivery of RZSS responsibilities as part of the SWCAP, trapping programme for conservation breeding, project design, stakeholder engagement and contracted by Scottish Wildcat Action to undertake all TNVR and wildcat collaring in the Angus Glens; water voles (RZSS's role in the Trossachs Water Vole Project, health screening for English vole release projects); and pine hoverfly (captive breeding for release, project design, information dissemination). Roisin has delivered all aspects of field-based conservation projects including: project design, field operations and reporting, and line management of field staff. She is experienced in a wide range of data collection techniques (including field sign, GIS, remote camera traps, animal trapping and biological sample collection), with a proven track record of data handling and analysis, along with disseminating field work findings to peers and the broader public. Roisin is currently a self-employed ecologist, advising several projects and organisations on beaver-related projects throughout Britain including SNH, Devon Wildlife Trust, RSPB, Trees for Life, RZSS, and the Forestry Commission. Roisin is currently acting as a service provider on an 'on-call' basis for SNH to provide advice and practical support to the Scottish Government beaver mitigation scheme and recently led the surveying of the 2017 Tayside beaver population.

Prof Richard Brazier

Richard is an ecohydrologist, working at the University of Exeter and developing the emerging field of Landscape Restoration Science. Richard has published >100 peer-reviewed papers in international journals and is currently Principal Investigator on five beaver reintroduction projects and eight feasibility studies of beaver reintroduction across the UK. He is Chair of the Mid-Devon, River Otter, Cornwall and Forest of Dean Beaver Trial Science and Evidence Fora, which collects, collates and analyses all relevant research into the impacts of beavers in Devon (see Elliott et al., 2017 for example of comms on this work). Richard's team has strong GIS and spatial data analysis skills, having developed novel and efficient ways of digitally capturing spatial data describing beaver activity in the Tayside (and neighbouring catchments) and the River Otter catchment, comparing these data via annual surveys and statistically analysing the changes in beaver population dynamics. Richard works closely with decision and policy makers and a wide range of stakeholders/partners within all relevant bodies including EA, NE, Defra, NFU, CLA, FC, Highways England, Wildlife and Rivers Trusts, district and County Councils, National Parks, AONBs and a number of major landowners (e.g. NT, Duchy, Clinton Devon, Knepp and Spainshall Estates) to ensure that beaver reintroduction proposals are widely considered and fully engaged with by all concerned. He has recently hosted visits to beaver sites from the Secretary of State for the Environment, Rt. Hon. Michael Gove, local MPs including Neil Parrish, chair of the EFRA committee, EA, FC and NE Directors and Deputy Directors, demonstrating both a deep understanding of the national context of beaver reintroduction and the strong potential to influence national decision-making and legislation through the science and evidence around beaver reintroduction.

Dr Alan Puttock

Alan is a research fellow working with Professor Richard Brazier at the University of Exeter. Alan is an ecohydrologist whose research specialises in understanding the relationship between land use or vegetation change and the quality and quantity of water leaving our landscapes. Since 2014 Alan has been undertaking research, monitoring the impacts of reintroducing the Eurasian beaver, working across the Devon Beaver Project, River Otter Beaver Trial, Cornwall Beaver Project and Forest of Dean Beaver Project (see Puttock et al., 2015, Puttock et al., 2017, Puttock et al., 2018), whilst also leading on data analysis for the survey of the 2017 Tayside beaver population for SNH. Alan has undertaken multiple beaver feasibility scoping studies and is a member of the River Otter Beaver Trial Science and Evidence Forum. Alan has extensive expertise in field surveying, GIS analysis and the collection and processing of large datasets for geostatistical analysis.

15 References

Allen, A.W. 1982. Habitat suitability index models: beaver. US Fish and Wildlife Service FWS/0BS 82/10.30.

Auster, R. E., Barr, S., & Brazier, R. 2020. Wildlife Tourism in Reintroduction Projects: Exploring Social and Economic Benefits of Beaver in Local Settings. Auster, R. E., Barr, S., & Brazier, R. (2020). Journal for Nature Conservation. In Press.

Beedle, D.L. 1991. Physical dimensions and hydrologic effects of beaver ponds on Kuiu Island in southeast Alaska. Oregon State University. doi:http://hdl.handle.net/1957/9343

Benaud et al. 2017. What can we learn from national-scale geodata describing soil erosion? 19th EGU General Assembly, EGU2017, proceedings from the conference held 23-28 April, 2017 in Vienna, Austria., p.19050 19, 19050. [online] Available from: http://adsabs.harvard.edu/abs/2017EGUGA.1919050B

Bergman, B. G., Bump, J. K. and Romanski, M. C. 2018. Revisiting the role of aquatic plants in beaver habitat selection. *American Midland Naturalist*, 179, 222-246.

Bigler W, Butler DR, Dixon RW. 2001. Beaver-pond sequence morphology and sedimentation in Northwestern Montana. Physical Geography, 22, 531–540.DOI: 10.1080/02723646.2001.10642758

Bilotta et al. 2008. Rethinking the contribution of drained and undrained grasslands to sediment-related water quality problems. *Journal of Environmental Quality*, 37, 906–14.DOI: 10.2134/jeq2007.0457

Bilotta et al. 2010. Assessing catchment-scale erosion and yields of suspended solids from improved temperate grassland. *Journal of Environmental Monitoring*, 12, 731–9.DOI: 10.1039/b921584k

Błędzki, L.A., Bubier, J.L., Moulton, L.A., Kyker-Snowman, T.D. 2011. Downstream effects of beaver ponds on the water quality of New England first- and second-order streams. *Ecohydrology*, 4, 698–707. doi:10.1002/eco.163

Bouwes N, Weber N, Jordan CE, Saunders WC, Tattam IA, Volk C, Wheaton JM, Pollock MM. 2016. Ecosystem experiment reveals benefits of natural and simulated beaver dams to a threatened population of steelhead (*Oncorhynchus mykiss*). *Scientific Reports*, 6.

Bracken, L.J., Croke, J., 2007. The concept of hydrological connectivity and its contribution to understanding runoff-dominated geomorphic systems. *Hydrological Processes*, 21, 1749–1763. doi:101002/hyp.6313

Braskerud et al. 2005. Can Constructed Wetlands Reduce the Diffuse Phosphorus Loads to Eutrophic Water in Cold Temperate Regions? *Journal of Environment Quality*, 34, 2145.DOI: 10.2134/jeq2004.0466

Brazier R, Puttock A, Graham H, Anderson K, Cunliffe A, Elliott M. 2016. Quantifying the multiple, environmental benefits of reintroducing the Eurasian Beaver. EGU General Assembly 2016, held 17-22 April, 2016 in Vienna Austria, p.7243 18: 7243.DOI: 2016EGUGA.18.7243B

Brazier, R. E., Puttock, A., Graham, H. A., Auster, R. E., Davies, K. H., Brown, C. M. 2020a. Beaver: Nature's ecosystem engineers. *WIREs Water*, In Press.

Brazier, R. E., Elliott, M., Andison, E., Auster, R. E., Bridgewater, S., Burgess, P., Chant, J., Graham, H. A., Knott, E., Puttock, A. K., Sansum, P., & Vowles, A. 2020b. River Otter Beaver Trial: Science and Evidence Report. https://www.exeter.ac.uk/creww/research/beavertrial/

Butler, D.R., Malanson, G.P., 1994. BEAVER LANDFORMS. Can. Geogr. Géographe Can. 38, 76–79. doi:10.1111/j.1541-0064.1994.tb01519.x

Butler, D.R., Malanson, G.P. 2005. The geomorphic influences of beaver dams and failures of beaver dams. *Geomorphology*, 71, 48–60.

Burchsted D, Daniels MD. 2014. Classification of the alterations of beaver dams to headwater streams in north-eastern Connecticut, U.S.A. *Geomorphology*, 205, 36–50.

Burns, D.A., McDonnell, J.J., 1998. Effects of a beaver pond on runoff processes: comparison of two headwater catchments. *Journal of Hydrology*, 205, 248–264. doi:10.1016/S0022-1694(98)00081-X

Campbell, R.D., Dutton, A., Hughes, J. 2007. Economic impacts of the beaver. Report for the Wild Britain Initiative. Wildlife Conservation Research Unit, University of Oxford. http://www.scottishbeavers.org.uk/docs/003__021__general__Campbell_et_al_2007_Economic_impacts_of_the_beaver__1282729674.pdf.

Campbell-Palmer, R., Puttock, A., & et al. (2018). SNH Research Report 1013 - Survey of the Tayside area beaver population 2017-2018 | Scottish Natural Heritage. https://www.nature.scot/snh-research-report-1013-survey-tayside-area-beaver-population-2017-2018

Campbell-Palmer, R., Gow, D., Needham, R., Jones, S., Rosell, F. 2016. The Eurasian Beaver. Pelagic Publishing: Exeter

Campbell-Palmer, R., Gow, D., Campbell, R., Dickinson, H., Girling, S., Lisle, S., Lisle, S., Parker, H., Schwab, G., Rosell, F. 2016. The Eurasian Beaver Handbook: Ecology and Management of *Castor fiber*. Pelagic Publishing.

Campbell-Palmer, R., Pizzi, R., Dickinson, H., Girling, S. 2015. Trapping and health screening of free-living beavers within the River Tay catchment, east Scotland. Scottish Natural Heritage Commissioned Report No. 681. Scottish Natural Heritage, Battleby, Perthshire 26 pages.

Campbell-Palmer, R., Rosell, F. 2013. Captive Management Guidelines for Eurasian Beaver (*Castor fiber*). Royal Zoological Society of Scotland, BookPrintingUK.com.

Cirmo, C.P., Driscoll, C.T. 1996. The impacts of a watershed CaCO3 treatment on stream and wetland biogeochemistry in the Adirondack Mountains. *Biogeochemistry*, 32, 265–297. doi:10.1007/BF02187142

Collen, P., Gibson, R.J. 2000. The general ecology of beavers (*Castor* spp.), as related to their influence on stream ecosystems and riparian habitats, and the subsequent effects on fish – a review. *Reviews in Fish Biology and Fisheries*, 10, 439–461.

Correll, D.L., Jordan, T.E., Weller, D.E. 2000. Beaver pond biogeochemical effects in the maryland Coastal Plain. *Biogeochemistry*, 49, 217-239.

Curran JC, Cannatelli KM. 2014. The impact of beaver dams on the morphology of a river in the eastern United States with implications for river restoration. *Earth Surface Processes and Landforms*, 39, 1236–1244.DOI: 10.1002/esp.3576

Deasy C, et al. 2009. Mitigation Options for Sediment and Phosphorus Loss from Winter-sown Arable Crops. *Journal of Environment Quality*, 38, 2121.DOI: 10.2134/jeq2009.0028

Copernicus, 2017. Tree Cover Density, 2015. https://land.copernicus.eu/pan-european/high-resolution-layers/forests/tree-cover-density/status-maps/2015

Deasy, C., Brazier, R.E., Heathwaite, A.L., Hodgkinson, R. 2009. Pathways of runoff and sediment transfer in small agricultural catchments. *Hydrological Processes*, 23, 1349–1358. doi:10.1002/hyp.7257 de Visscher, M., Nyssen, J., Pontzeele, J., Billi, P., Frankl, A. 2014. Spatio-temporal sedimentation patterns in beaver ponds along the Chevral river, Ardennes, Belgium. *Hydrological Processes*, 28, 1602–1615. doi:10.1002/hyp.9702

Devito, K.J., Dillon, P.J. 1993. Importance of Runoff and Winter Anoxia to the P and N Dynamics of a Beaver Pond. *Canadian Journal Fish Aquatic Science*, 50, 2222–2234. doi:10.1139/f93-248

Devito, K.J., Dillon, P.J., Lazerte, B.D. 1989. Phosphorus and nitrogen retention in five Precambrian shield wetlands. *Biogeochemistry*, 8, 185–204. doi:10.1007/BF00002888

Dickie, I., Hughes, J. and Esteban, A. 2006. 'Watched Like Never Before …': The Local Economic Benefits of Spectacular Bird Species. Sandy, RSPB.

Dittbrenner, B. J., Pollock, M. M., Schilling, J. W., Olden, J. D., Lawler, J. J. and Torgersen, C. E. 2018. Modeling intrinsic potential for beaver (Castor canadensis) habitat to inform restoration and climate change adaptation. *PloS ONE*, 13, e0192538.

Ehrman, T.P., Lamberti, G.A., 1992. Hydraulic and Particulate Matter Retention in a 3rd-Order Indiana Stream. *Journal of North American Benthol Society*, 11, 341–349. doi:10.2307/1467556

Elliott, M., Blythe, C., Brazier, R.E., Burgess, P., King, S., Puttock, A. and Turner C. 2017. Beavers – Nature's Water Engineers [online] Available from: http://www.devonwildlifetrust.org/sites/default/files/files/Beaver Project update (LowRes) .pdf

Girling, S.J., Naylor, A., Fraser, M., Campbell-Palmer, R. 2019. Reintroducing beavers to Britain: A disease risk analysis. *Mammal Review*, 49, 300-323.

Giriat D, Gorczyca E, Sobucki M. 2016. Beaver ponds' impact on fluvial processes (Beskid Niski Mts., SE Poland). *Science of The Total Environment*, 544, 339–353.DOI: 10.1016/j.scitotenv.2015.11.103

Glendell M, Brazier RE. 2014. Accelerated export of sediment and carbon from a landscape under intensive agriculture. *Science of the Total Environment*, 476–477C, 643–656.

Goodman, G., Girling, S., Pizzi, R., Rosell, F., Campbell-Palmer, R. 2012. Establishment of a health surveillance program for the reintroduction of the Eurasian beaver (*Castor fiber*) into Scotland. *Journal of Wildlife Disease*, 48, 971-978.

Graham, H. A., Puttock, A., Macfarlane, W. W., Wheaton, J. M., Gilbert, J. T., Campbell-Palmer, R., Elliott, M., Gaywood, M. J., Anderson, K., Brazier, R. E. 2020. Modelling Eurasian beaver foraging habitat and dam suitability, for predicting the location and number of dams throughout catchments in Great Britain. *European Journal of Wildlife Research*, 66(3), 1–18. https://doi.org/10.1007/s10344-020-01379-w

Grand-Clement E, Luscombe DJ, Anderson K, Gatis N, Benaud P, Brazier RE. 2014. Antecedent conditions control carbon loss and downstream water quality from shallow, damaged peatlands. *Science of the Total Environment*, 493, 961–73.

Green, K.C., Westbrook, C.J., 2009. Changes in riparian area structure, channel hydraulics, and sediment yield following loss of beaver dams 10, 68–79. doi:jem/ISS50/vol10_no1_art7.pdf

Gregory AS et al. 2015. A review of the impacts of degradation threats on soil properties in the UK. *Soil Use and Management*, 31, 1–15.DOI: 10.1111/sum.12212

Grygoruk, M., Nowak, M., 2014. Spatial and Temporal Variability of Channel Retention in a Lowland Temperate Forest Stream Settled by European Beaver (*Castor fiber*). *Forests*, 5, 2276–2288. doi:10.3390/f5092276

Gurnell, A.M. 1998. The hydrogeomorphological effects of beaver dam-building activity progress. *Physical Geography*, 22, 167–189.

Gurnell, J., Gurnell, A.M., Demeritt, D., Lurz, P.W.W., Shirley, M.D.F., Rushton, S.P., Faulkes, C.G., Nobert, S., Hare, E.J. 2008. The Feasibility and Acceptability of Reintroducing the European Beaver to England. Natural England/People's Trust for Endangered Species, Sheffield, UK.

Haarberg, O., Rosell, F. 2006. Selective foraging on woody plant species by the Eurasian beaver (*Castor fiber*) in Telemark, Norway. Journal of Zoology, 270, 201–208. https://doi.org/10.1111/j.1469-7998.2006.00142.x

Hamilton, A., Moran, D. 2015. Tayside beaver socio-economic impact study. Scottish Natural Heritage Commissioned Report No. 805.

Haarberg, O., Rosell, F., 2006. Selective foraging on woody plant species by the Eurasian beaver (*Castor fiber*) in Telemark, Norway. *Journal of Zoology*, 270, 201–208. https://doi.org/10.1111/j.1469-7998.2006.00142.x

Hammerson GA. 1994. Beaver (*Castor canadensis*) - Ecosystem Alterations, Management, and Monitoring. *Natural Areas Journal*, 14, 44–57.

Hartman, G., Tornlov, S. 2006. Influence of watercourse depth and width on dam-building behaviour by Eurasian beaver (*Castor fiber*). *Journal of Zoology*, 268, 127–131. https://doi.org/10.1111/j.1469-7998.2005.00025.x

Hering, D., Gerhard, M., Kiel, E., Ehlert, T., Pottgiesser, T., 2001. Review study on near-natural conditions of Central European mountain streams, with particular reference to debris and beaver dams: Results of the "REG meeting" 2000. *Journal of Limnology*, 31, 81–92. doi:10.1016/S0075-9511(01)80001-3

Herr, J. and Rosell, F. 2004. Use of space and movement patterns in monogamous adult Eurasian beavers (*Castor fiber*). *Journal of Zoology*, 262, 257-264.

Hood, G. A. 2020. Not all ponds are created equal: long-term beaver (Castor canadensis) lodge occupance in a heterogeneous landscape. *Canadian Journal Zoology*, 98, 210-218.

Jenkins, S.H. 1979. Seasonal and year-to-year differences in food selection by beavers. *Oecologia*, 44, 112–116. https://doi.org/10.1007/BF00346408

Johnston, C.A., Pinay, G., Arens, C., Naiman, R.J., 1995. Influence of Soil Properties on the Biogeochemistry of a Beaver Meadow Hydrosequence. *Soil Science Society of America Journal*, 59, 1789. doi:10.2136/sssaj1995.03615995005900060041x

Jones, S. and Campbell-Palmer, R. 2014. The Scottish Beaver Trial: the story of Britain's first licensed release into the wild. Final Report 2014. http://scottishbeavers.org.uk/docs/003_143__scottishbeavertrialfinalreport_dec2014_1417710135.pdf

Kemp, P.S., Worthington, T.A., Langford, T.E.L., Tree, A.R.J., Gaywood, M.J. 2012. Qualitative and quantitative effects of reintroduced beavers on stream fish. Fish and Fisheries, 13, 158–181. DOI: 10.1111/j.1467-2979.2011.00421.x [online] Available from: http://doi.wiley.com/10.1111/j.1467-2979.2011.00421.x

Klotz RL. 2007. Influence of beaver ponds on the phosphorus concentration of stream water. *Canadian Journal of Fisheries and Aquatic Sciences*, DOI: 10.1139/f97-318

Law, A., McLean, F., Willby, N.J. 2016. Habitat engineering by beaver benefits aquatic biodiversity and ecosystem processes in agricultural streams. *Freshwater Biology*, n/a-n/a. DOI: 10.1111/fwb.12721 [online] Available from: http://doi.wiley.com/10.1111/fwb.12721

Law, A., Gaywood, M.J., Jones, K.C., Ramsay, P., Willby NJ. 2017. Using ecosystem engineers as tools in habitat restoration and rewilding: beaver and wetlands. Science of The Total Environment 605: 1021–1030.DOI: 10.1016/j.scitotenv.2017.06.173 [online] Available from: http://www.sciencedirect.com/science/article/pii/S0048969717315929

Lazar, J.G., Addy, K., Gold, A.J., Groffman, P.M., McKinney, R.A., Kellogg, D.Q., 2015. Beaver Ponds: Resurgent Nitrogen Sinks for Rural Watersheds in the Northeastern United States. *Journal Environ. Qual.* 44, 1684–93. doi:10.2134/jeq2014.12.0540

Leidholt-Bruner K, Hibbs DE, McComb WC. 1992. Beaver dam locations and their effects on distribution and abundance of coho salmon fry in two coastal Oregon streams. *Northwest Science*, 66, 218–223.

Levine R, Meyer GA. 2014. Beaver dams and channel sediment dynamics on Odell Creek, Centennial Valley, Montana, USA. Geomorphology, 205, 51–64.DOI: 10.1016/j.geomorph.2013.04.035

Lizarralde, M.S., Deferrari, G.A., Alvarez, S.E., Escobar, J.M., 1996. Effects of beaver (*Castor canadensis*) on the nutrient dynamics of the Southern Beech forests of Tierra del Fuego (Argentina). Ecologia Austral, 6, 101-105.

Macdonald, D.W., Maitland, P., Rao, S., Rushton, S., Strachan, R., Tattersall, F. 1997. Development of a protocol for identifying beaver release sites. Scottish Natural Heritage Research, Survey and Monitoring Report No. 93.

Macfarlane WW, Wheaton JM, Bouwes N, Jensen ML, Gilbert JT, Hough-Snee N, Shivik JA. 2015. Modeling the capacity of riverscapes to support beaver dams. Geomorphology DOI: 10.1016/j.geomorph.2015.11.019 [online] Available from: https://www.researchgate.net/publication/285590037_Modeling_the_capacity_of_riverscapes_to_support_beaver_dams (Accessed 9 May 2016)

Macmillan, D.C., Duff, E.I., Elston, D.A. 2001. Modelling the non-market environmental costs and benefits of biodiversity projects using contingent valuation data. *Environmental and Resources Economics*, 18, 391–410.

Maret, T.J., Parker, M., Fannin, T.E., 1987. The effect of beaver ponds on the nonpoint source water quality of a stream in Southwestern Wyoming. *Water Research*, 21, 263–268. doi:10.1016/0043-1354(87)90204-1

Mayer, M., Frank, S. C., Zedrosser, A., Rosell, F. 2020. Causes and consequences of inverse density-dependent territorial behaviour and aggression in a monogamous mammal. *Journal of Animal Ecology*, 89, 577-588.

Millhollon et al. 2009. Designing a Constructed Wetland for the Detention of Agricultural Runoff for Water Quality Improvement. *Journal of Environment Quality*, 38, 2458.DOI: 10.2134/jeq2008.0526

Moran, D., Lewis, A.R. 2014. The Scottish Beaver Trial: Socio-economic monitoring, final report. Scottish Natural Heritage.

Naiman RJ, Melillo JM, Hobbie JE. 1986. Ecosystem Alteration of Boreal Forest Streams by Beaver (*Castor canadensis*). *Ecology*, 67, 1254–1269.

Natural England 2015. Natural England approves trial release of beavers, licence and conditions available at: https://www.gov.uk/government/news/natural-england-approves-trial-release-of-beavers

Nolet, B.A., van der Veer, P.J., Evers, E.G.J., Ottenheim, M.M. 1995. A linear programming model of diet choice of free-living beavers. *Netherlands Journal of Zoology*, 45, 317–335.

Nolet, B.A. and Rosell, F. 1998. Comeback of the beaver *Castor fiber*: an overview of old and new conservation problems. *Biological Conservation*, 83, 165–173.

Novak, M. 1987. Beaver. In Novak, M., Baker, J.A., Obbard, M.E., Malloch, B. (eds) Wild Furbearer Management and Conservation in North America. Ontario Ministry of Natural Resources, Toronto, and Ontario Trappers Association, North Bay, pp. 282–312.

Nyssen, J., Pontzeele, J., Billi, P. 2011. Effect of beaver dams on the hydrology of small mountain streams: example from the Chevral in the Ourthe Orientale basin, Ardennes, Belgium. *Journal of Hydrology*, 402, 92–102.

Ockenden et al. 2012. Evaluation of field wetlands for mitigation of diffuse pollution from agriculture: Sediment retention, cost and effectiveness. *Environmental Science & Policy*, 24, 110–119.DOI: 10.1016/j.envsci.2012.06.003

Ockenden et al. 2014. Keeping agricultural soil out of rivers: Evidence of sediment and nutrient accumulation within field wetlands in the UK. *Journal of Environmental Management*, 135, 54–62.DOI: 10.1016/j.jenvman.2014.01.015

O'Connell, M.J., Atkinson, S.R., Gamez, K., Pickering, S.P., Dutton, J.S., et al. 2008. Forage preferences of the European beaver Castor fiber: implications for re-introduction. *Conservation and Society*, 6, 190.

Ordnance Survey, 2019b. OS VectorMap local [SHP geospatial data], Coverage: National, Updated Feb 2019. Using: EDINA Digimap Ordnance Survey Service.

Parker, H., Rosell, F. 2012. Beaver Management in Norway – A Review of Recent Literature and Current Problems. HiT Publication no. 4/2012.

Petts, G.E., Gurnell, A.M., 2005. Dams and geomorphology: Research progress and future directions. *Geomorphology*, 71, 27–47. doi:10.1016/j.geomorph.2004.02.015

Peukert, S., Griffith, B.A., Murray, P.J., Macleod, C.J.A., Brazier, R.E., 2016. Spatial variation in soil properties and diffuse losses between and within grassland fields with similar short-term management. E*uropean Journal of Soil Science*. 67, 386–396. doi:10.1111/ejss.12351

Peukert, S., Griffith, B.A., Murray, P.J., Macleod, C.J.A., Brazier, R.E., 2014. Intensive Management in Grasslands Causes Diffuse Water Pollution at the Farm Scale. *Journal Environmental Quality*, 43, 2009. doi:10.2134/jeq2014.04.0193

Pollock, M.M., Beechie, T.J., Jordan, C.E., 2007. Geomorphic changes upstream of beaver dams in Bridge Creek, an incised stream channel in the interior Columbia River basin, eastern Oregon. Earth Surf. Process. *Landforms*, 32, 1174–1185. doi:10.1002/esp.1553

Pollock MM, Beechie TJ, Wheaton JM, Jordan CE, Bouwes N, Weber N, Volk C. 2014. Using Beaver Dams to Restore Incised Stream Ecosystems. *BioScience*, 64, 279–290.

Polvi LE, Wohl E. 2012. The beaver meadow complex revisited - the role of beavers in post-glacial floodplain development. *Earth Surface Processes and Landforms*, 37, 332–346.

Puttock, A., Cunliffe, A.M., Anderson, K., Brazier, R.E. 2015. Aerial photography collected with a multirotor drone reveals impact of Eurasian beaver reintroduction on ecosystem structure. Journal of

Unmanned Vehicle Systems: 150429143447007. DOI: 10.1139/juvs-2015-0005 [online] Available from: http://nrcresearchpress.com/doi/abs/10.1139/juvs-2015-0005#.VaUe8vlVhBc (Accessed 1 May 2015)

Puttock, A., Graham, H.A., Cunliffe, A.M., Elliott, M., Brazier, R.E. 2017. Eurasian beaver activity increases water storage, attenuates flow and mitigates diffuse pollution from intensively-managed grasslands. *Science of The Total Environment*, 576, 430–443. DOI: 10.1016/j.scitotenv.2016.10.122

Puttock, A., Graham, H.A., Carless, D., Brazier, R.E. 2018. Sediment and Nutrient Storage in a Beaver Engineered Wetland. *Earth Surface Processes and Landforms*, DOI: 10.1002/esp.4398 [online] Available from: http://doi.wiley.com/10.1002/esp.4398

Rosell, F., Bozser, O., Collen, P., Parker, H. 2005. Ecological impact of beavers *Castor fiber* and *Castor canadensis* and their ability to modify ecosystems. *Mammal Review*, 35, 248-276.

Rowland, C., Morton, D., Carrasco Tornero, L., McShane, G., O'Neil, A., Wood, C. 2017. Land Cover Map 2015 (25m raster, GB). https://doi.org/10.5285/bb15e200-9349-403c-bda9-b430093807c7.

Rosell, F., Bozser, O., Collen, P., Parker, H. 2005. Ecological impact of beavers *Castor fiber* and *Castor canadensis* and their ability to modify ecosystems. *Mammal Review*, 35, 248-276.

Sear, D.A., Newson, M.D., Brookes, A. 1995. Sediment-related river maintenance: The role of fluvial geomorphology. Earth Surf. Process. *Landforms*, 20, 629–647. doi:10.1002/esp.3290200706

Schwab, G., Schmidbauer, M. 2003. Beaver (*Castor fiber* L., Castoridae) management in Bavaria S. 99-106 in: Biologiezentrum der Oberösterreichischen Landesregierung. Biber – Die erfolgreiche Rückkehr. 183 S. www.biologiezentrum.at

Scholefield, P., Morton, D., Rowland, C., Henrys, P., Howard, D., Norton, L. 2016. A model of the extent and distribution of woody linear features in rural Great Britain. *Ecology and Evolution*, 6, 8893–8902. https://doi.org/10.1002/ece3.2607

Scholefield, P.A.; Morton, R.D.; Rowland, C.S.; Henrys, P.A.; Howard, D.C.; Norton, L.R. (2016). Woody linear features framework, Great Britain v.1.0. NERC Environmental Information Data Centre. https://doi.org/10.5285/d7da6cb9-104b-4dbc-b709-c1f7ba94fb16.'

Stringer, A., Gaywood, M. 2016. The impacts of beavers on biodiversity and the ecological basis for reintroduction to Scotland. *Mammal Review*, 46, 270-283.

Stringer, A.P., Blake, D., Genney, D.R., Gaywood, M.J. 2018. A geospatial analysis of ecosystem engineer activity and its use during species reintroduction. *European Journal of Wildlife Research*, 64. https://doi.org/10.1007/s10344-018-1195-9

Thomas, H., Nisbet, T., 2012. Modelling the hydraulic impact of reintroducing large woody debris into watercourses. Jou*rnal Flood Risk Management*, 5, 164–174. doi:10.1111/j.1753-318X.2012.01137.x

Vecherskiy, M. V., Korotaeva, V. V., Kostina, N. V., Dobrovol'skaya, T.G., Umarov, M.M., 2011. Biological activities of "beaver landscape" soils. Moscow Univ. *Soil Science Bulletin*, 66, 175–179. doi:10.3103/S0147687411040089

Wilkinson, M.E., Quinn, P.F., Barber, N.J., Jonczyk, J., 2014. A framework for managing runoff and pollution in the rural landscape using a Catchment Systems Engineering approach. *Science of the Total Environment*, 468, 1245–1254. doi:10.1016/j.scitotenv.2013.07.055

Wilkinson, M.E., Quinn, P.F., Welton, P., 2010. Runoff management during the September 2008 floods in the Belford catchment, Northumberland. *Journal of Flood Risk Management*, 3, 285–295. doi:10.1111/j.1753-318X.2010.01078.x

Woo, M., Waddington, J.M., 1990. Effects of Beaver Dams on Subarctic Wetland Hydrology. *ARCTIC*, 43, doi:10.14430/arctic1615