Ennerdale: Feasibility for Beaver Reintroduction

Feasibility study for habitat suitability and release scenarios of Eurasian beavers (Castor fiber) to Ennerdale.

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Document prepared for Forestry England by Prof Richard Brazier[1], Dr Róisín Campbell-Palmer, Derek Gow and Dr Alan Puttock

*cover photo: Overview of Ennerdale Valley © Alan Puttock

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Content

1 Project Overview

1.1 Report Summary

This document has been prepared to advise Forestry England on the potential for a Eurasian beaver (*Castor fiber*) reintroduction project in Ennerdale Valley. The aim of this feasibility study is to assess the suitable potential of habitats in both sites for beaver release sites and, to identify what habitat improvements, and over what timescale, might be desirable prior to any release.

To address the forgoing, it is believed the following criteria would be relevant with specific regard to this proposal and that beavers would:

1. Instate a system of sustainable habitat creation and diversification throughout the project area. This would predictably include the provision of a significant mass of fallen, standing and submerged dead wood; wet woodland; pool; multi braided stream/foraging canal systems; ox bow meanders, bankside restructuring and fen meadow habitats.
2. Assist with the development of a national/local research base with specific regard to the impacts identified above and the associated reforming of ancillary wildlife species in these developing environments.
3. 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 suggests suitable beaver habitat currently exists in the lower reaches of the river section examined. Though it should be noted that throughout the site this river is powerful, subject to energy and fluctuation changes, with bank substrate predominantly stone based making dam and burrow construction difficult. The upper catchment would prove challenging with any released animals most likely to quickly disperse downstream, though these areas could be colonised in time this would be most likely as a result of population pressure downstream. The utilisation of section of the middle region could be significantly increased with deciduous tree plantation and creation of additional open water areas through scrapes / small ponds being artificially dug and allowed to scrub up. Livestock access and grazing should be revised in both the upper and lower extents of the river course, as this is impacting on riparian vegetation development, diversity and regeneration of woody species. Even if buffer zones lining any water course could be protected, then their complexity and foraging potential would greatly improve encouraging beavers to utilise and modify such areas.

Two to three potential release sites are proposed each for a pair or small family units (consisting of a breeding pair and any dependent offspring at time of trapping). Given the extent and complexity of the habitats Ennerdale presents for this species the option to include in the forgoing an even sexed group of single 2 year olds from different genetic sources could also be considered. The favoured release locations for families/pairs include the Moss Dub which offers immediate potential; the Gillertwhaite mire, lower Gillertwhaite woodland and Middle bridge areas that would require some pre-release management in form of increasing open water/pond areas and deciduous tree planting. These and further areas fringing them could be improved for beaver utilisation through pond creation and tree planting. This would further enhance the prospects of rapid habitat take up/development by singletons/ disperses. These releases could be staggered once initial territories have been established, to encourage future outbreeding and further habitat colonisation for an expanding population.

A licence from Natural England would be required to release beavers into Ennerdale.

1.2 Ennerdale Valley and Overview

The study site Ennerdale Valley is located above Ennerdale Water in the north-western edge of the Lake District National Park. The 4300ha site is dominated by the River Liza that flows through Ennerdale Water a sub catchment of the Ehen-Calder management catchment. The valley is glacial in origin and in its upper reaches dominated by open land, scree and reforming deciduous woodland. The valley floor has been the location of one of England's longest running 'rewilding' projects with natural regeneration, active planting programs and a reduction in grazing all contributing to an increase in native broadleaf woodland.

Ennerdale Valley is home to the Wild Ennerdale Partnership a consortium led by the National Trust, Forestry England and United Utilities who are the primary land owners in the Ennerdale valley and Natural England, the Government's advisory body on the environment (http://www.wildennerdale.co.uk/). The partnerships vision is *to allow the evolution of Ennerdale as a wild valley for the benefit of people, relying more on natural processes to shape its landscape and ecology* (https://www.forestryengland.uk/ennerdale).

Figure 1. Looking down on the study area within Ennerdale valley above Ennerdale Water.

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 which are 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 formed 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 this process 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 (*Lutra lutra*) exist at greater densities in beaver generated wetlands due to greatly enhanced fish populations and the presence of abandoned lodges which they utilise as breeding holts. Beavers are untidy feeders and their random feeding patterns can distribute semi-emergent plant and tree species 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 from an initial release in the Ardennes expanded to modify relict small farm or woodland environments in valley bottoms into pool complexes filled with a myriad of in aquatic invertebrates, amphibians and fish the black stork returned. By 2018 there were over 80 breeding pairs and this charismatic species which was 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 are a real candidate for natural restoration (Schwab, 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 (*Castor canadensis*) 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 healthly 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 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 a 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 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 and 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).

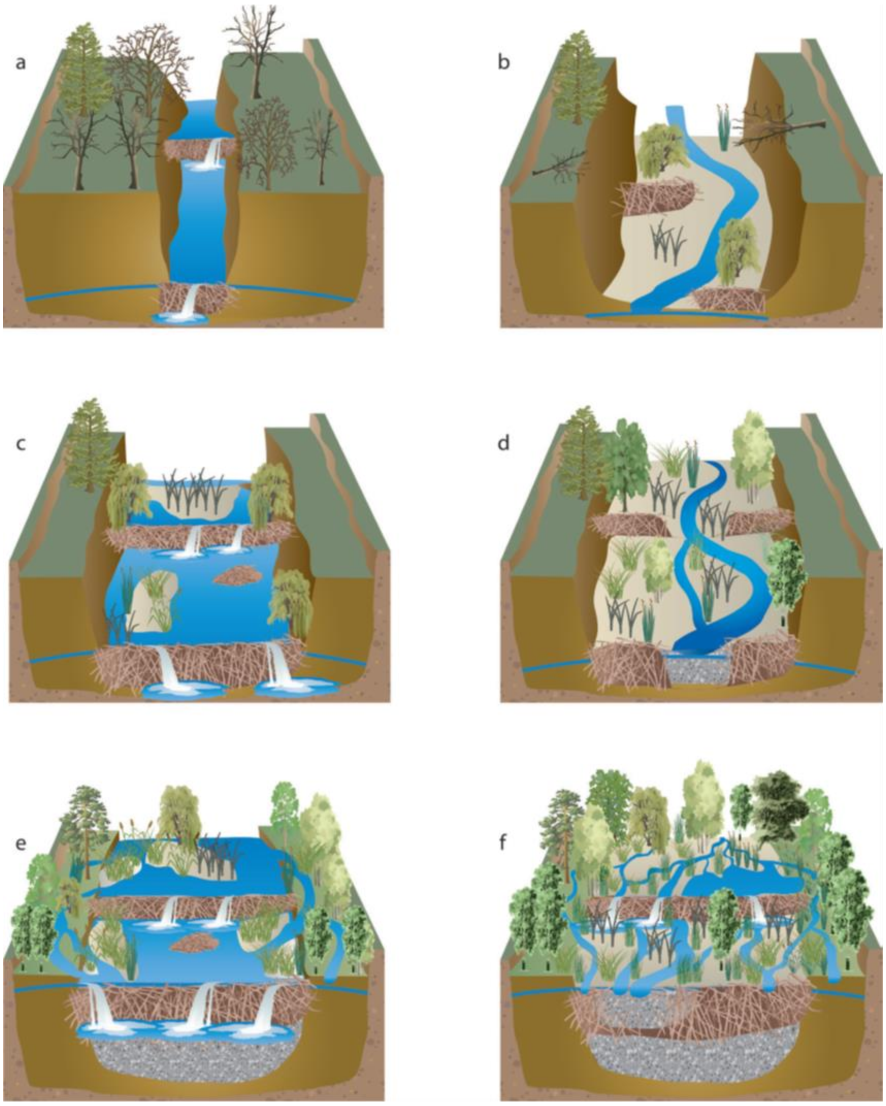

Figure 2. Process by which beaver dam or beaver dams or beave dam analogue creation can restore incised or single stream systems and lead to wetland creation (Pollock et al., 2014).

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 the species was formally recognised as native and accorded legal protection as a European Protected Species (EPS). This designation extended to the two official populations in mid-Argyll and Perthshire but to no others elsewhere. Under NatureScot's Beaver Mitigation Scheme a range of management support measures are now available to landowners experiencing conflicts with the species in intensively farmed agricultural land. There are particular circumstances for which licences to utilise lethal control can be issued. Translocation is also permitted and if suitable rehoming options are available they can be live trapped under licence and removed from points of tension. Eurasian beavers are listed on Schedule 9 of 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 into the wild. No licence is required to release beavers into enclosures in Scotland but this option is listed as a 'policy' by Natural Resources Wales. No official reintroduction has occurred in Wales though proposals have been submitted to NRW and 3 enclosed projects exist.

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 for direct releases into the wild while Natural England and DEFRA consider the detail of a forward policy for the species.

Any proposed release into Ennerdale will be a licensed process under conditions set by Natural England. While this could be approached on the basis that it affords as a project the potential for colonisation in the wider landscape over time a system of grilles and fences in the outflow of the river Liza before it meets Ennerdale Water would render it more appropriately as a semi-enclosed option for licencing. This generally includes a release site feasibility study, responsible sourcing of animals, health screening requirements, possession and capture.

It is expected that a position to afford the above will be established in the Spring/Winter of 2020/21. Considerable high-level political support currently exists for the restoration of this species.

4 Site Assessments

Based upon discussions with project partners in Forestry England, a set of sites were identified to assess their potential as initial release locations. These are illustrated in Figure 3. They comprised areas pre-identified by Forestry England and a further option identified after on-site liaison. For the purposes of this report, this site is referred to as: Additional site at top of Gillerthwaite Fields.

The assessment of the specific release locations below should be viewed not as an end or limiting aspect of beaver restoration to the Wild Ennerdale project site but rather locus's from which initial populations after securing a base location can expand out. It is obvious that while some areas of the landscape are not currently suitable for beavers they will become so as alterations from any initial construction activities readjust the riparian environment.

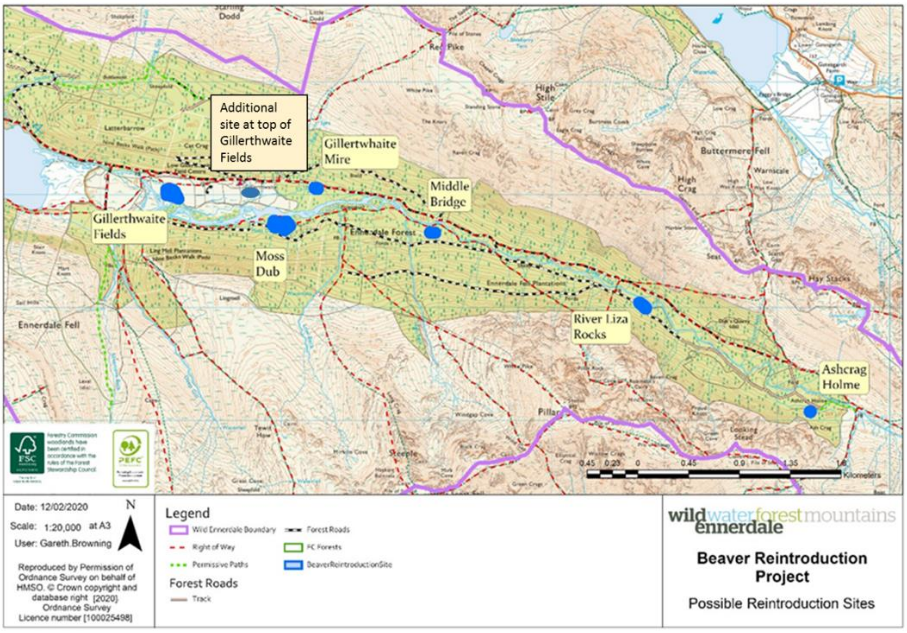

Figure 3. Sites identified for consideration by Forestry England.

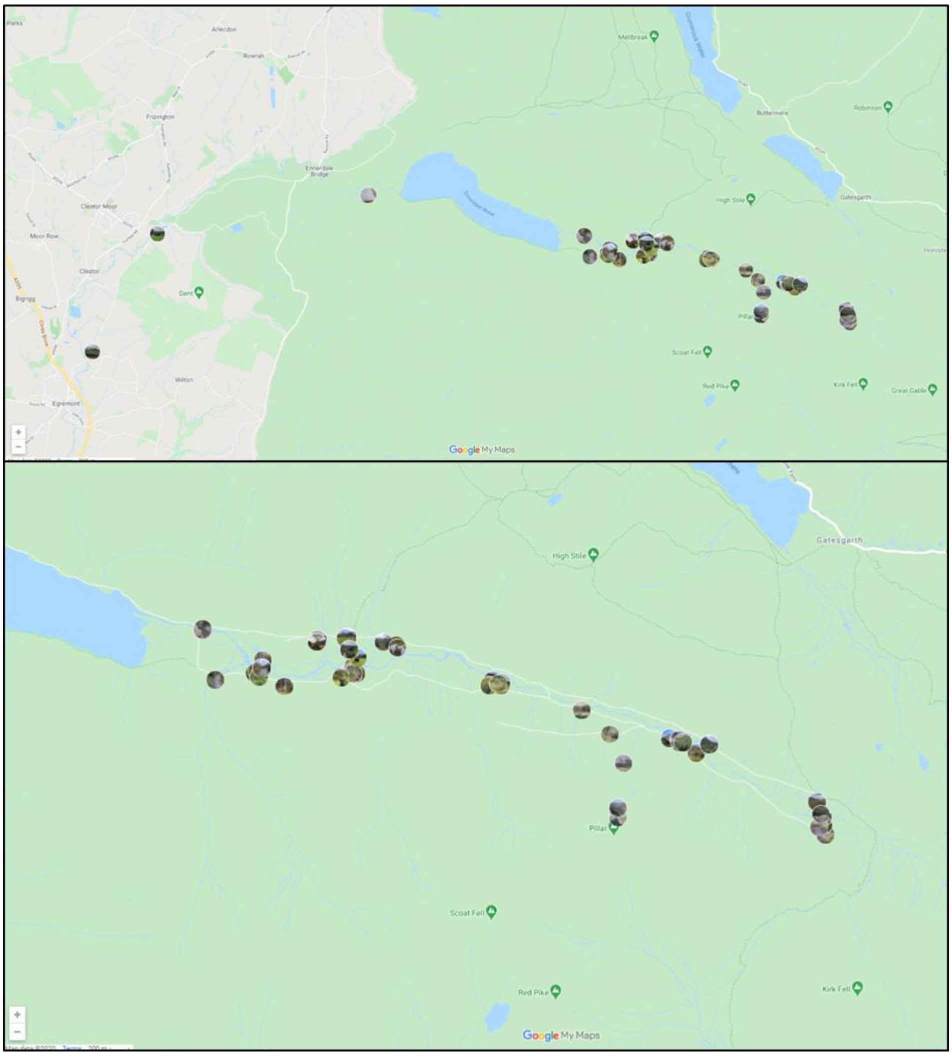

Figure 4. Ennerdale Feasibility Study Geolocated images from 2020 field survey: https://www.google.com/maps/d/edit?mid=19NB6QBpBJ3pwnpD9HquoX72K0CXLcWk3&usp=sharing

4.1 Ashcrag Holme

Figure 5. Upper section of Ennerdale valley.

This represents the head of the catchment, where the landscape is typically open and exposed. The water course is bare banked and lacks vegetative structure and complexity. It is additionally rocky. While there is some limited foraging potential amongst the bankside vegetation of grasses and forbs, this and any suitable deciduous tree/scrub regeneration which might result from beaver coppicing is already compromised by high levels of sheep grazing. Any sheep would ideally need to be removed in entirety from this location. Cattle grazing also could be reduced or removed for a period of several years to enable the vegetation structure to recover and adjust. If silver birch (*Betual pendula*) seed is available in the surrounding environment scarification to encourage its re-colonisation coupled with a programme of replanting willow (*Salix* spp), aspen (*Poplus tremula*), alder (*Alnus nigra*), rowan (*Sorbus aucuparia*), white beam (*Sorbus aria*) and other upland riparian tree species should commence. The likelihood of beaver colonisation of this area is otherwise challenging and unlikely. An additional limiting factor for beaver colonisation will be its exposure. The construction of lodges, dams or any other structure will be prone to repeated destruction during extreme water level rises. Though beavers are capable of living along stoney banks and on faster water courses, this is usually due to population pressure elsewhere dictating the selection of less suitable habitat once other territories have been infilled. Some of this activity as a result can be seasonal and opportunistic with the individuals attempting to utilise environments of this sort failing repeatedly to do so.

Figure 6. Looking down on site in upper section.

4.2 River Liza Rocks

Figure 7. Improving habitat in River Liza Rocks Area.

At lower slightly elevation this area affords improving habitat. Although still not ideal there are increasing patches of scattered broadleaf woodland in deeper pockets of fertile soil. Grazing pressure here is also significantly reduced compared to the upper catchment and beaver coppicing should rapidly regenerate. The bankings are still quite rocky but with greatly vegetation cover, structure and diversity. Crevices which could be exploited for burrow and shelter manipulation are more likely. This area could be exploited by beavers in time, when with the pressure of an expanding pressure downstream forces sub-adults to disperse and explore new territorial options. Alternatively, this area could form potential release points for any additional singletons/ sub-adults to encourage the formation of new pairs. Without the creation of off channel ponds and additional broadleaf planting, it would seem unlikely any initially released pairs would remain in this area as better habitat exists downstream

4.3 Middle Bridge

Where the gradients become less steep with a growing coverage of deciduous trees along with evident regeneration results in the availability of higher quality habitat here pre-release site preparation would be recommended to provide suitable resources for beaver colonisation and to increase the species ability to utilise the upper catchment more effectively in time. In its current state beavers could not be released without some form of pond being artificially created to provide an area of stable water, surrounded by suitable foraging opportunities. This area lends itself readily to this option with numerous marshy areas and threading through channels. These water courses will predictably be dammed and canalised by beavers to create diverse wetland areas aside from the main water course. Additional food resources and open water bodies in this area would greatly enhance the likelihood of beavers adapting living spaces rapidly.

Figure 8. Small channels running through mire in Middle Bridge Area

4.4 Additional Site at top of Gillertwhaite Fields

Figure 9. Good habitat example in Gillertwhaite Fields

This area although similar to the above affords more significant foraging opportunities, building resources and opportunities for habitat manipulation. Beavers will extend their range of material recovery quite extensively, including onto steeper hill slopes providing there is water in the general vicinity. They prefer stable, deep water which from which they can extend as a starting point their further modification. Their foraging at this location could be expected to encompass the main river body where additional l burrows might be created. Their use of this area would in time be greatly increased as complexity develops. Once well-established they are likely to retreat to an extensive wetland of this sort during periods of significant water flow.

4.5 Gillertwhaite Mire

Figure 10. Existing structures holding water.

This area and its surrounding deciduous woodland affords considerable potential as both an initial release location and the starting point of a significant wetland. As this feature develops it is already clear that an abundance of woody vegetation and increased vegetative diversity/structure would result from beaver foraging activity. It contains several water courses which have been previously cut for land drainage which already retain significant flows. Once impounded these features will broaden rapidly and as the heights of beaver dams increase result in open pool systems of depth.

Figure 11. Downstream habitat deemed suitable.

There is a broad sufficiency of deciduous tree species in its immediate vicinity, grasses, herbs and other shrubs. Where rich silts coagulate behind a myriad of beaver impoundments these will in time assist the development of much lusher plant growth. Beavers would readily build lodges and creating canal systems to further access patches of the surrounding woodland. Any additional creation of small water bodies near to the existing woodland will only serve to increase its habitat use by beavers away from the main channel. This mire area would readily function as a release point for an initial pair/small family unit of beavers.

4.6 Moss Dub

Figure 12. Moss Dub pond offers high quality habitat and a immediate release site for a pair or small family unit.

This location provides the best release area for beavers as is. It contains an entirely adequate sufficiency of food tree species including beech (*Fagus sylvatica*) and holly (*Ilex aquifolium*). The water levels here are stable and the landscape surrounding is complex with amounts of bramble (*Rubus fruticosu*s) and a broad range of semi-emergent plants. Set back form the main river channel, water levels here would be stable throughout the year and its deep banks are entirely suitable for burrow or lodge construction. Beavers would readily construct canals into the surrounding woodland to exploit woody resources, as well as foraging down into the main river below and providing hydrological stability during period of high water flow on the main channel. Beavers might also extend the area of open water by damming of any small outflows to retain more water.

4.7 Gillerthwaite Fields

Figure 13. Existing landuse.

These field areas would benefit greatly from a reduction in livestock grazing intensity. ideally this would involve several years of complete rest to allow a carpet of dead and structured vegetation to develop. This period might also kick start a reformation of young tree growth which is currently lacking. If this is not possible then the exclusion of livestock grazing from at least the riparian corridor to a depth of 10-15m would be recommended. Along the main river channel there is excellent wet woodland interwoven by a complexity of braided stream systems so beaver foraging in this area is a credible prospect given land use change.

Figure 14. Exisitng wetland from dynamic channel.

In this area, there is an abundance of suitable habitat complexity and an entirely adequate supply of woody vegetation and other plant life immediately associated with the main river channel. While the main channel is obviously of such velocity that it will not provide a suitable dam building space for beavers, seasonal dams could be located in the side channels. The felling of selective trees throughout these quieter back waters to create pools with woody blockages would enable prior to any beaver release an assessment of this potential. If these features remain in place after flood events consistently then this area might afford a focal point for release or the reinforcement of these initial blockages with beaver dams. This latter option might or might not determine this location's use as a direct site for release. In the event of uncertainty, it would be best to allow natural colonisation over time from elsewhere.

Figure 15. However going to be high stream power during high flow. Exhibits why not thebest release site. Let them get here 'naturally' if release at (1) Moss dub (2) gillterhwaite mire (3) middle bridge mire.

Figure 16. Vegetation is complex and diverse, offering attractive foraging opportunities. Substrate is still predominantly stony but there are deeper banks with friable substrate that would permit burrow and lodge construction. Multi-thread side channels could be dammed especially in periods of low water flow though these could be seasonally washed out or breached, there is potential for more complex pond formation in time.

An alternative release site would be the deeper pools in the oxbow area/side channel just aside from the main river channel below. Water stability and depth are ideal at this point for release. Even if the beavers do not immediately remain here, they would readily access the woodland pictured above on the main channel and/or use this location during periods of high water flow on the river. Its tree cover is predominantly alder (*Alnus glutinosa*). Although beavers will utilise this species if alternatives are lacking, it is not a preferred food species. There is little understorey or tree regeneration in its immediate vicinity given the current level of cattle grazing and as a result most of the trees are all typically mature and of the same age category. Once felled by beavers this area would not offer sustainable foraging in the long-term if grazing confounds the coppicing of the trees. The most significant recommendation for this area would therefore be to revise the current livestock grazing practices. Ideally with their removal for a number of years - which could then be coupled with diversification through planting of the riparian tree community to significantly improve the locations carrying capacity. It should be noted that these lower reaches will be the most attractive to any future beaver population over time and their enhancement now would be prudent.

5 Overall suitability for a semi-enclosed release

The section of the Ennerdale catchment proposed for beaver release offers a range of habitats and suitabilities. The head of the catchment offers natural retainment, whereas the lower stretches afford suitable and attractive beaver habitat. There are sections which would be improved by some form of habitat adaption which would provide for a better overall future in terms of habitat quality.

The Liza is a powerful river with periods of significant water flow. The banks are predominantly rock with stony substrate. Though beavers are highly adaptive and do live in these gradients and habitat across their range, additional consideration should be given when attempting to establish a population in a location of this sort. Beavers will first select lower gradient areas, with stable water levels and the best foraging opportunities. As such v this proposal focuses on the selection of 2-3 high quality release sites where the released individuals are more likely to remain. Additional recommendations for habitat improvements on the fringes of these areas to encourage later dispersal and colonisation have also been made.

The upper regions examined from Ashcrag to Liza Rock offer poor beaver habitat given the vegetation type, steep gradient, rocky shoreline and their shallow fast flowing character. This last renders durable dam creation unstable. Although dispersing individuals may sporadically explore and forage in these regions permanent colonisation is unlikely without significant downstream population pressure. Changes in the current regime of livestock grazing and additional large-scale deciduous tree planting may change this situation marginally.

Further downstream pockets of habitats to the sides of the main river channel begin to become potentially more suitable - Middle bridge. These areas would benefit most from additional tree planting and importantly from the creation of ponds and/or the artificial damming of small burns. In the area upstream of this potential release site these actions would enable beavers to expand naturally as their number rise or afford locations where additional singletons could be added to the population to encourage outbreeding.

Without modification, the prime release site is undoubtedly Moss Dub where a beaver pair or family could be released here in its current form. Beavers would immediately use and modify the open pond and woodland area and would be likely to utilise the lower stretches of the main river below where the habitat is more complex and diverse. The lower wet woodland associated with the Gillerthwaite fields could potentially act as a release point during periods of stable water and high vegetation growth. There may be a high likelihood that beavers disperse from this area during periods of high water flow or establish territories elsewhere but this shouldn't present issues with animals free to exercise habitat selection.

The Gillertwhaite mire and lower field with its associated woodland offer perhaps the most potential as a release points and for future habitat expansion. This prospect could be enhanced with some pre-release management. Livestock access; the temporary damming of small streams or small pond creations and further tree planting along the water course, would all serve to significantly increase suitability of this habitat and additional beaver utilisation of sections out width the river channel.

Modelling of beaver habitat suitability

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

5.1 Beaver Habitat Suitability Modelling for Ennerdale

In addition to site visits by beaver experts the habitat suitability of the sites were assessed with Beaver Habitat Index (BHI) model was undertaken across Ennerdale.

Summary Description: Production of a continuous description of habitat suitability for beaver. First a vegetation suitability index is created using multiple high-resolution spatial datasets from Ordnance Survey, CEH and Copernicus will be combined to provide detailed land cover/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 water bodies (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 (raster Tiff format) for describing habitat suitability for beaver. This dataset can allow the user to explore which landscapes were most (or least) suite to beaver reintroduction and also to understand where habitat enhancement might be useful to support future reintroduction.

5.2 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 (graded 3) include coniferous woodland, marsh, shrub and unimproved grassland; examples of barely suitable (graded 2) include reeds, shrub and heathland and boulders, neutral grassland; examples of unsuitable (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.

5.3 Beaver Habitat Index Model (BHI)

Whilst vegetation is a dominant factor in determining habitat suitability for beaver, so is proximity to a water body (Gurnell et al., 2008), with beavers being strong swimmers, using water bodies both to provide security, as a means of escaping predators and to access foraging areas. It is thought that most foraging occurs 10 m of a watercourse/body (Haarberg & Rosell, 2006), and rarely above 50 m (Stringer et al., 2018). However, greater foraging distances have on occasion been observed and as in Macfarlane et al., 2015 it 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 water course coverage.

Whilst BVI was run nationally on a 5m scale it is best viewed as a preparatory step for BHI (and later BDC) 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 100m 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 100m of a waterbody. Zero scores are given to areas that contain no vegetation or are greater than 100m 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

5.4 Beaver Habitat Index Map

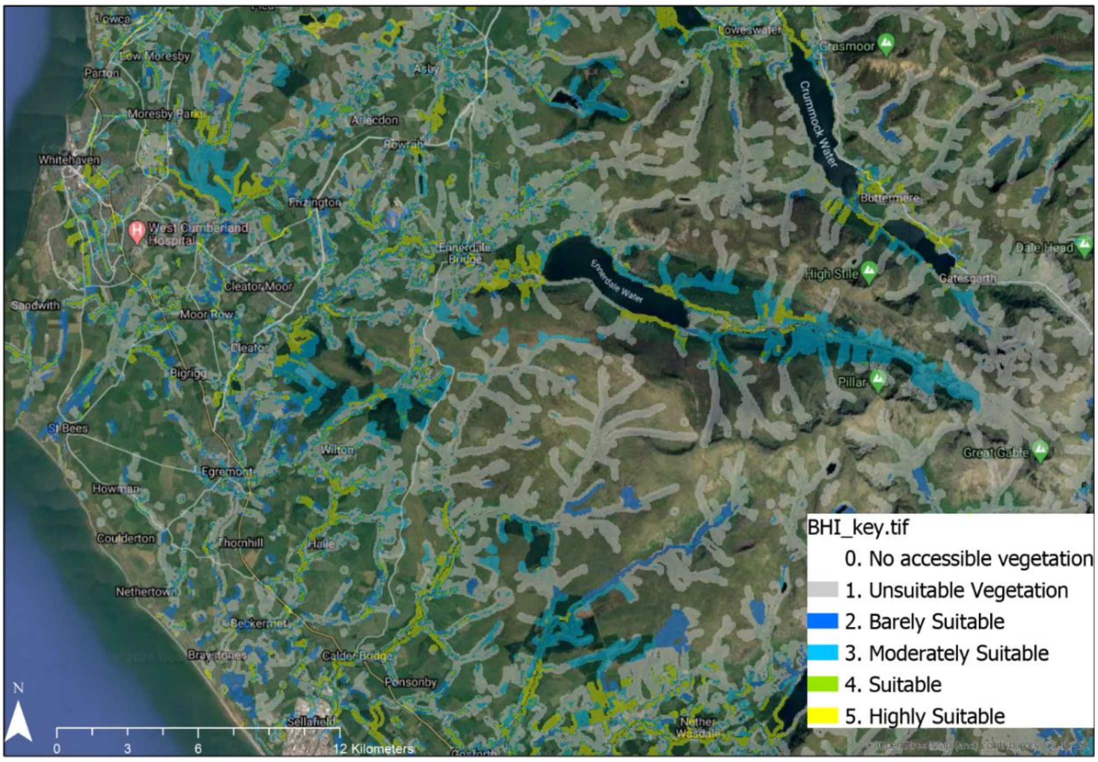

Figure 17. BHI model output for the wider area of interest. *Contains Ordnance Survey data © Crown Copyright 2007, Licence number 100017572 and some features of this map are based on digital spatial data licensed from the Centre for Ecology & Hydrology, © NERC (CEH).Aerial imagery: Open-Source Google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

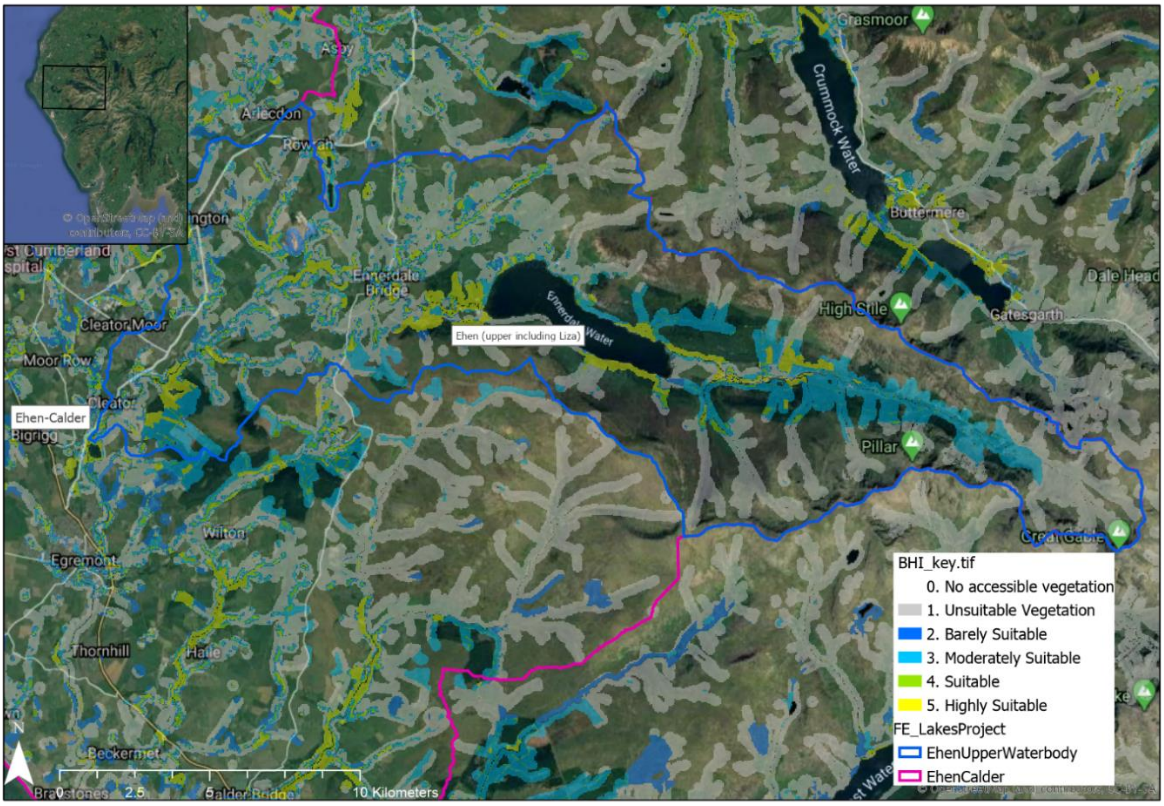

Figure 18. BHI output and location for Ehen Upper including the Lizza. Contains Ordnance Survey data © Crown Copyright 2007, Licence number 100017572 and some features of this map are based on digital spatial data licensed from the Centre for Ecology & Hydrology, © NERC (CEH).Aerial imagery: Open-Source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

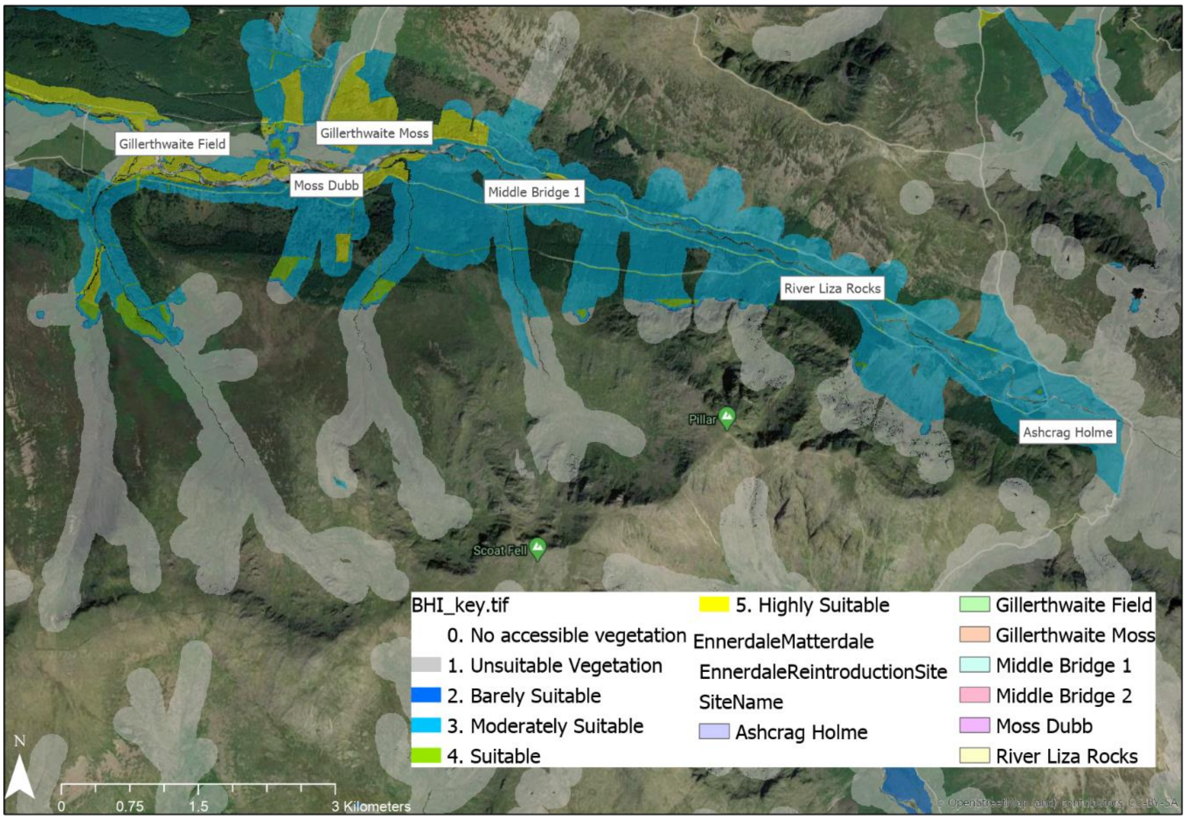

Figure 19.BHI output zooming into location of considered locations within the River Liza above Ennerdale Water. *Contains Ordnance Survey data © Crown Copyright 2007, Licence number 100017572 and some features of this map are based on digital spatial data licensed from the Centre for Ecology & Hydrology, © NERC (CEH).Aerial imagery: Open-Source Google imagery © OpenStreetmap (and) contributors CC-BY-SA.*

5.5 Beaver Habitat Suitability Summary

BHI modelling outputs support the conclusions of the site assessment summaries in Section 4. Whilst the upper section and slopes surrounding the site offer scant vegetation, the valley bottom above Ennerdale water has experienced enough habitat restoration to provide plentiful areas in the moderate to highly suitable habitat classes to support beaver reintroduction.

5.6 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 using a fuzzy logic approach which builds in the considerable uncertainty that is associated with beaver habitat/dammable 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) bankfull 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 km 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

5.7 Beaver Dam Capacity Model Map

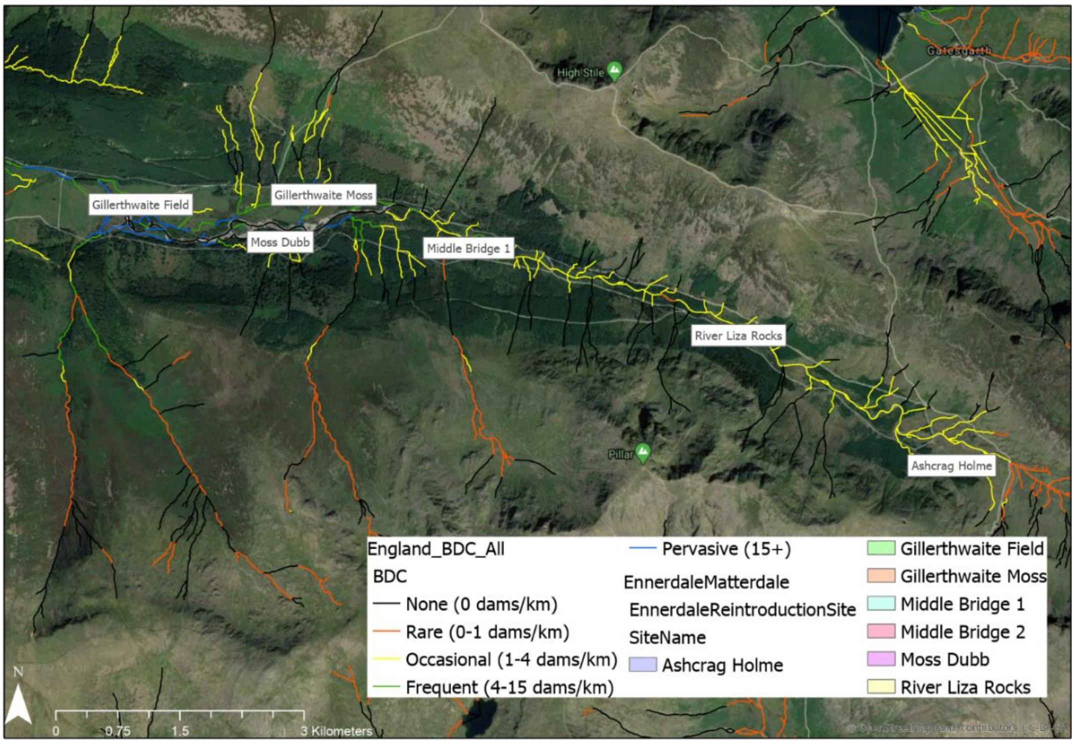

Figure 20. BDC output for key area of interest above Ennerdale water on the River Liza. Contains Ordnance Survey data © Crown Copyright 2007, Licence number 100017572 and some features of this map are based on digital spatial data licensed from the Centre for Ecology & Hydrology, © NERC (CEH).Aerial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

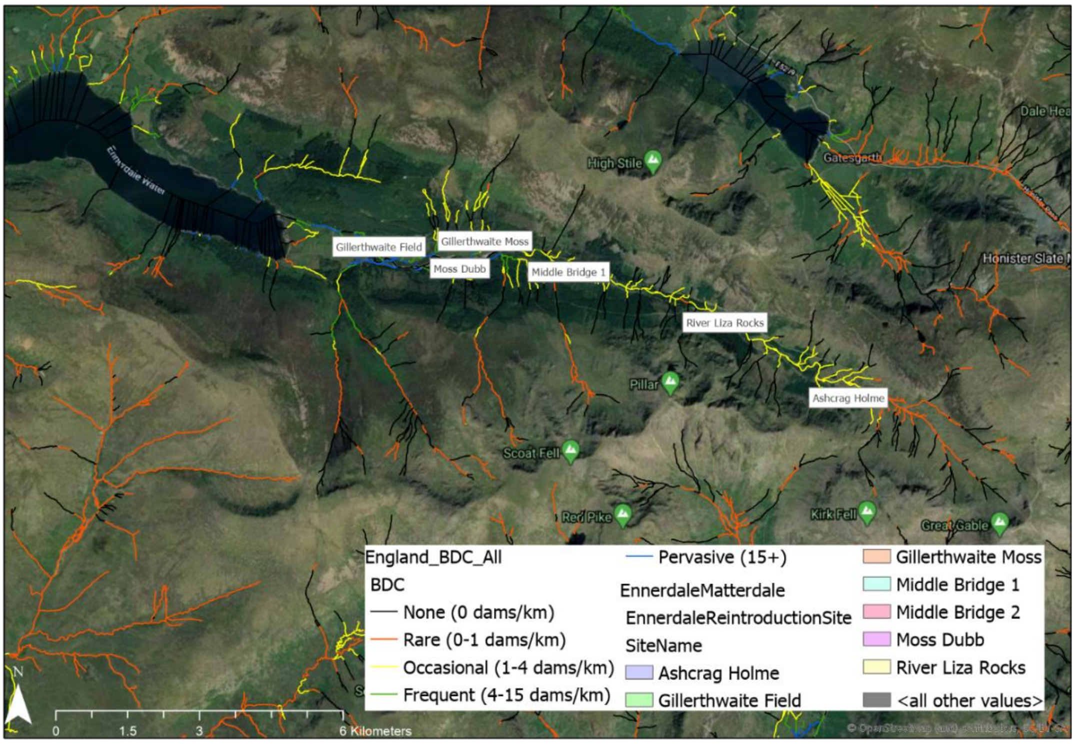

Figure 21. BDC output for Ehen Upper including Ennerdale water and River Liza. Contains Ordnance Survey data © Crown Copyright 2007, Licence number 100017572 and some features of this map are based on digital spatial data licensed from

the Centre for Ecology & Hydrology, © NERC (CEH).Aerial imagery: Open-Source Google imagery © OpenStreetmap (and) contributors CC-BY-SA.

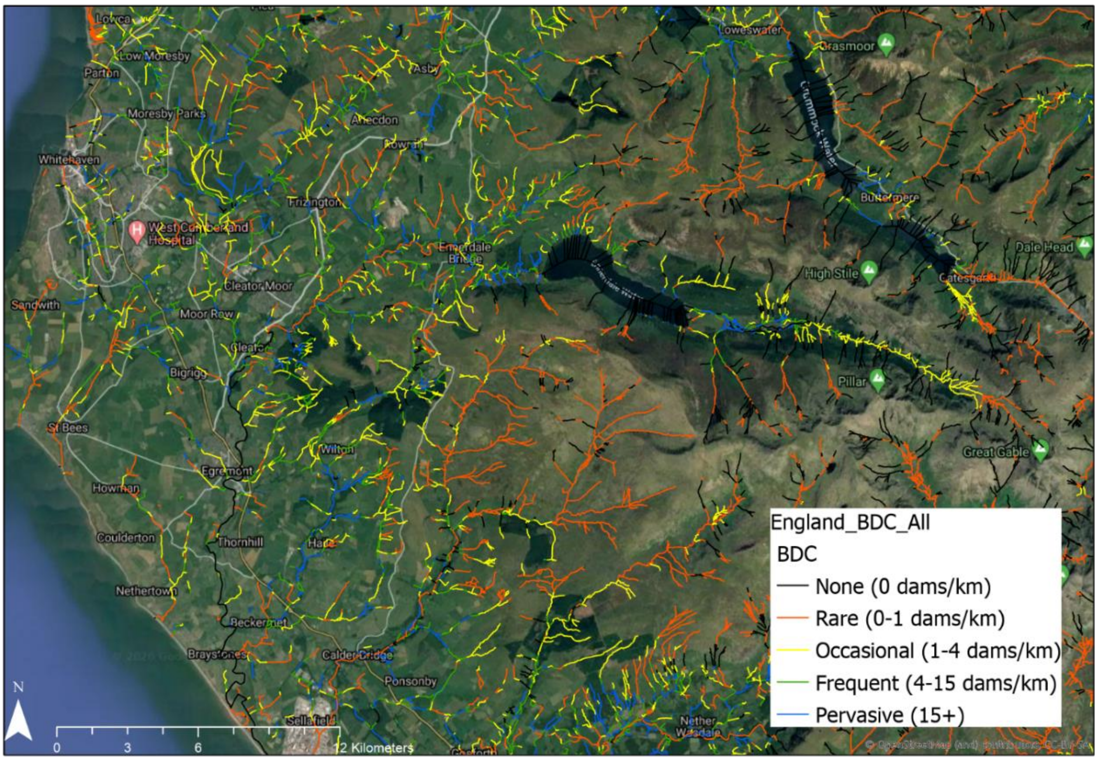

Figure 20. BDC output for the wider Ehen-Calder. Contains Ordnance Survey data © Crown Copyright 2007, Licence number 100017572 and some features of this map are based on digital spatial data licensed from the Centre for Ecology & Hydrology, © NERC (CEH).Aerial imagery: Open-Source Google imagery © OpenStreetmap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

5.8 Beaver Dam Capacity Model Summary

As illustrated in the model outputs above, the main stretch of the River Liza and side channels in the valley bottom would predominantly support beaver damming in the occasional-pervasive categories. Upstream damming potential would be limited on the many side channels due to both their steepness and lack of suitable vegetation. If in the future the extent of beaver activity was permitted to spread beyond the area upstream of Ennerdale Water, whilst beavers would not dam the lake itself, there is plenty of reaches downstream that would support damming.

6 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.

6.1 Utilisation and modification of an upland catchment by wild beaver population

Due to over a decade of restoration Ennerdale valley and the River Liza is already one of the more ‘natural’ environments in Great Britain. The legacy of forest plantations and grazing still has a significant legacy on the upper section and the lower section, directly above Ennerdale Water is still to an extent agriculturally dominated. However, it is one of the few river systems in Britain that have been allowed to spread across the valley floor, creating a dynamic anabranching channel. Such a situation is incredibly rare in Britain and definitely England. Combined with the semi-enclosed nature of the proposed release with beavers given free reign of the valley east of Ennerdale water and creates a unique opportunity to understand how beavers behave in such an environment and the impacts they may have.

Q1 . How do beavers utilise the study area?

Q2. Does channel planform and complexity change as a consequence of beaver activity?

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 addressing Q2 it is well recognised that beaver engineering can increase lateral connectivity and create complex wetlands (i.e. as conceptualised in Pollock et al., 2014). Channel planform surveys would give a fascinating insight into whether beaver's impact upon what is already a dynamic semi-naturally functioning river system. Such geomorphic understanding would also help address the hydrological questions outlined below.

6.2 Water quantity and flow attenuation

Via the building of dams it is increasingly recognised that beavers can alter hydrology, 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
- Can also result in significant stores of particulate associated phosphate, nitrogen and carbon.
- Key driver behind nutrient storage is 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 if beaver dams fail).

Hydrological research questions could include:

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

Q2. Does surface water storage (in ponds but also associated cannels etc.) increase in the site due to beaver engineering activity?

Research presented in Puttock et al., 2017 and 2018, provides a template for quantifying hydrological impacts. Monitoring points on in-flows and out-flows could also be equipped with flow, turbidity and/or multi-parameter probes to quantify the quality of water entering and leaving the site. Ecological water quality can be monitored by macro-invertebrate sampling prior and following release.

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).

6.3 Biodiversity and habitat enhancement

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 project is to explore how the introduction of beavers might modify the environment, it is possible to envisage what might happen at this site based on experience elsewhere (see the Devon Study 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. Does reintroduction of beaver impact upon (positive or negative) the regeneration of native broadleaf woodland at Ennerdale?

Q3. (a) Will there be a different diversity of bat species using the site? (b) Will be a change in the number of bat species using the site in the years?

Q4. Will there be a change in bird species breeding on site?

Q5. There will be a change in the species diversity of amphibians using the site.

Q6. Do beaver create habitat for the reintroduction of other species that are being considered as part of the Wild Ennerdale program such as water voles *(Arvicola amphibious*)

6.4 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 spends 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 of £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 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).

If the project partners deem the site as valuable either an eco-tourism or educational facility with public access there is a breadth of interesting research questions that could be addressed and quantified via visitor and local surveys. Additionally, site management cost could be quantified using data routinely collected by the research. Questions could include:

Q1. Following the initial outlay for the grilles and beaver release, do site management costs significantly change?

Q2. Is the 'natural' management approach of beaver complementary with the other 'rewilding' approaches being utilised at Ennerdale?

Q5. Does public awareness and understanding of beaver change following release into site? And do visitor numbers increase?

Q6. Do public perceptions (+/-) of beaver change significantly following release into the site?

7 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. Animals would be selected to ensure a broad genetic basis as possible.

7.1 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 which are captive born within the UK, including wild-born individuals will not present any risk of non-native pathogens and diseases such as Rabies, 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.

7.2 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 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 back into the enclosures 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.

7.3 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 3. Specific signs of suspected ill health and steps to be taken.

CONDITION		DESCRIPTION	MONITOR/SEEK HELP
Change in behaviour		Subdued/lethargic/sleeping while exposed	Monitor and seek veterinary advice if prolonged
Body condition		Sudden/obvious weight loss	Seek veterinary advice (see scoring below)
Musculoskeletal	Lameness	Reluctance to bare weight while at rest	Monitor but if the condition deteriorates or no improvement is noted within 3 days seek veterinary advice
		Severely lame: unable to use leg or place weight on leg. The animal may stop frequently	Seek veterinary advice
Fur		Unkempt coat/ ungroomed	May indicate underlying health problem, monitor and seek veterinary advice if continues
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
		If bone is exposed	Seek veterinary advice

		If wound covers a large surface area (>10cm^2)	Seek veterinary advice
Head	Eyes	Discharge, bulging eye, eye continually kept closed or animal rubbing eye	Seek veterinary advice
	Ears	Discharge, shaking head, head tilt or circling	Seek veterinary advice
	Nose	Discharge	Monitor if clear, seek veterinary advice if becomes discoloured
Respiration		Open mouth breathing	Seek veterinary advice
		Increased chest or abdominal movement to compensate for respiratory problems	Seek veterinary advice
Dental	Dental disease	Pawing at mouth, any swelling, chewing to one side and/or dropping majority of food from mouth	Seek veterinary advice
Gastro-intestinal	Diarrhoea	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

7.4 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 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.

7.5 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. Offspring can remain within the family unit for at least the first two years of their birth, and this period maybe extended if resources permit.

While it is typical for one pair/small family unit to be released at a point where a habitat is either near ideal or adapted to enhance its suitability by for instance by creating in areas of undisturbed or replanted woody vegetation receptor ponds to provide initial living space and a locus for expansion the scope of the Ennerdale project could render this adaptable. While the establishment of family pairs or units could be a first autumn option, low numbers of additional 2 year old individuals could be released into the valley in the following spring, away from any established territories, so that they could explore any gaps in between the established territories and acquire unrelated mates.

7.6 Post-Mortem Examinations

Any dead beavers should be recovered as soon as possible and sent for full post-mortem examination by 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 dead has welfare implications that require further management intervention. For example, disease, lethal control of excessive road traffic accidents would require mitigation in order to promote animal welfare standards and population viability. Further post mortem protocols can be discussed with local veterinary practices

8 Release site size and location

Experience from other projects suggests that a number of locations in the River Liza upstream of Ennerdale Water would provide suitable living environments for a beaver population. While it is the conclusion of the authors that there is no other pre-release habitat management required to enable the trial, a reduction in grazing and replanting/natural regeneration of woodland in the upper watershed would benefit the long-term sustainability of beaver habitat within the site.

8.1 Fencing Specification

Any required fencing would adhere to Natural England's requirements for the species. There are now in existence several documented and high-profile enclosure beaver projects in which fencing specs have been tried and tested.

This proposal is for a semi-enclosed project based on the gradient and topography of this site. Both the head waters and feeder streams all enter from very steep, vegetation bare and rocky slopes, all excluding the chances of any successful dispersal from the valley. Any beavers dispersing from this landscape would naturally do so by following the water course downstream which is both more energetically cost-effective but also offers increasingly attractive habitat. Therefore the downstream outflow above Ennerdale water would require significant and robust grilling and a beaver 'proofed' fencing design for at least ~150 meters on either side to turn any immigrating beavers back into the project area. The power of this water course should also not be underestimated and therefore requires site specific design. Elsewhere beaver fencing and water course grilling is standard and as described below.

Additionally, the stream, which inflows to Ennerdale Water should be either grilled or beaver proof fencing built to discourage beavers leaving the stream and accessing the channel leading directly to Ennerdale Water. Though the channel is very rocky and lined with conifers, and therefore initially unattractive to beaver colonisation, it is still one of the main tributaries into the main river and therefore very accessible, especially to dispersing animals, whom could them easily enter Ennerdale Water, bypassing the main outflow protection at Irish Bridge.

Any typical beaver fencing (land based) would be constructed of wooden fence posts which will be a min. of 1.2 m high with intermediate stakes buried in the ground to 60cm, straining and turning posts buried in the ground to 90cm. All timber should be placed on the outside of the fence so that it is protected by the metal mesh from any beaver gnawing. The wire mesh should then be securely attached to these posts. Commercially available meshing, such as 'pony netting' can be used though it should be noted that the mesh square dimensions should not exceed 10cm x 10cm. One example of such mesh fencing is Tornado RL19/180/5 C14 mesh.

At the base of any fencing it is crucial that an anti-dig mesh curtain should be laid on the surface of the ground attached to the base of the vertical mesh with hog rings or equivalent, and pegged to the ground surface where it will extend 90cm into the enclosure on the floor. The wire mesh sizes allow for an overlap of at least 10cm preventing beavers from getting through at the join. Alternatively mesh fencing can be sunk underground to a minimum of 60cm.

Regular twice weekly checks of the fence / grill would be required to ensure it was not breached, with additional checks occurring following any storm and flood events. All fencing and culverts would be carefully checked before any beavers were released and closely monitored in the days following release.

Figure 22. Example grilling to prevent beavers leaving an enclosure via the channel. Taken at the Yorkshire Beaver Project.

Figure 23. Example grilling to prevent beavers leaving an enclosure via the channel. Taken at the Yorkshire Beaver Project.

Figure 24. Example grilling to prevent beavers leaving an enclosure via the channel. Taken at the Yorkshire Beaver Project.

Figure 25. Example grilling to prevent beavers leaving an enclosure via the channel. Taken at the Yorkshire Beaver Project.

Due to the high flow conditions, essential fish passage and a gravel load transport the main outflow will require a grilling approach that is both more substantial and refined than the above. As illustrated below a grille developed by Forestry England could provide a required barrier to beaver escape which rises during high flow storm conditions. Combined with the fencing design described the authors consider this this concept with adjustment would afford an appropriate solution.

Figure 26. Section of grill raising during spate conditions. Source Forestry England.

Figure 27. Trial sections of grill providing a barrier during low flow conditions.

Figure 28. Slightly different grill approaches currently being trialled. All provide a barrier at low flow and raise as a result of stream power in storm conditions.

Suggested commercially available wire specification

Tornado Badger Wire, code HT15/158/8 (http://www.tornadowire.co.uk/product/ht151588/)

Specification

No. of Line Wires	15
Overall Height (cm)	158
Distance between stay wires (cm)	8
Top & bottom line wire specification	2.5mm dia - 1235-1390 N/mm²
Intermediate line wire specification	2.5mm dia - 1235-1390 N/mm²
Vertical stay wire specification	2.5mm dia - 695-850 N/mm²
Average Weight per 50 Metre Roll (kg)	87.86
Material Composition	Heavily galvanised steel wire

Figure 29. Wire Specification (product code HT15/158/8 Badger Fence) from http://www.tornadowire.co.uk/wp-content/uploads/2016/03/HT15-158-8-web.pdf [accessed 23rd March 2018].

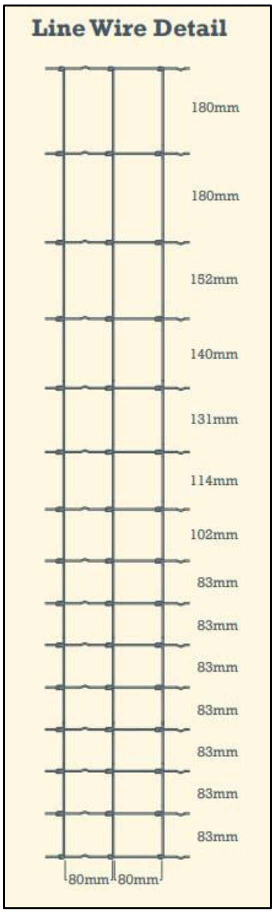

Figure 30. Line Wire detail (product code HT15/158/8 Badger Fence) from http://www.tornadowire.co.uk/wp-content/uploads/2016/03/HT15-158-8-web.pdf [accessed 23rd March 2018

9 Transport & Release Protocol

9.1 Transport

Any beavers sourced would undergo health screening and pre-release checks at point of capture. They will either come straight to 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 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.

9.2 Tagging

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

10 Escape Protocol

Recapture equipment along with temporary holding facilities for any beavers which exit the project area into Ennerdale Water and the Liza below this point will be required.

In the event that beaver trapping is required, beaver traps will be set on their visible areas of activity - 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 parents with any evidence of fighting.

10.1 Temporary secure housing

Should any individual beaver require temporary holding e.g. found sick or injured and requiring veterinary examination or 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 (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 made after seeking specialist advance.

11 Beaver management

While it is unlikely that any issue of significance could predictably arise in the proposed project location the vast majority of beaver 'damage' occurs within 20/30 meters of the water's edge.

Since their reintroduction, analysis of beaver conflict areas in Bavaria, has concluded that conflicts occur in areas where humans intensively utilise or have modified the fresh water shoreline (Schwab and Schmidbauer, 2003). The more natural the riparian edge, the fewer the impacts.

Any site may have several sources of conflict and as a result require a combination of management solutions. Tree guards or anti-game paint are commonly used; exclusion fencing can protect more valuable stands of trees and dams can be drained to a required level through the use of flow devices. Burrowing in inappropriate areas, such as flood banks or undermining roads tends to be the more significant though burrows can be infilled or banks protected with mesh.

Table 4. Potential sources of conflict with mitigation options.

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

Figure 31. Example of Scottish tree protection.

Figure 32. Flow device for mitigation in Scotland.

12 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
- The escape of beavers followed by re-capture and decision not to continue
- Unacceptable health and welfare or death of beavers.

At the end of the project the beavers could either be released (with appropriate permission), relocated to other projects or transferred to other suitable holding facilities.

13 Authors who have undertaken this study.

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 SNCO's intermittently on beaver related issues. He is a member of BACE and a Member 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. 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 advisory role on beaver management and land owner 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 vole (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 5 beaver reintroduction projects and 8 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 have 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, AONB's 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 all concerned. He has recently hosted visits to Beaver sites from the Secretary of State for the Environment, Rt. Hon. Michael Gove, local MP's 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.

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