

FINAL REPORT OF THE BEAVER SALMONID WORKING GROUP



28th JANUARY 2015

Prepared for

**The National Species Reintroduction Forum (NSRF)
c/o Scottish Natural Heritage
Great Glen House
Leachkin Road
Inverness
IV3 8NW**

Prepared by

The Beaver Salmonid Working Group (BSWG)

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(I) FOREWORD

Ron Macdonald
Chair
National Species Reintroduction Forum (NSRF)
c/o Scottish Natural Heritage
Great Glen House
Leachkin Road
Inverness
IV3 8NW

28th January 2015

Dear Dr MacDonald,

I have pleasure in submitting the final report of the Beaver Salmonid Working Group (BSWG).

Since the first consultation on beavers in Scotland in 1998, concerns have been raised by the fisheries sector about the absence of any significant analysis of the potential impacts of a reintroduced beaver population on fisheries and an accompanying management strategy to address a range of probable scenarios. Against this background, and without a consensus in the literature from abroad, the BSWG was established to consider a number of issues in respect of the interactions with salmonids if beavers are to be reintroduced to Scotland. The specific terms of reference are available in section 1.2 of the report.

In this report we look to provide an assessment and an estimate of the likely impacts, based largely on what information we have been able to identify from comparable environments and from the wider considerations of the members of the Group. It is also important to highlight that as salmonids are only one of a number of components of our freshwater ecosystem, we have also made efforts where possible to consider other species of conservation importance including eel, lamprey and freshwater pearl mussel. However, relevant information on such species is very sparse.

Beaver-salmonid interactions are complex, and there is a clear lack of identifiable data of direct relevance to the Scottish situation. Therefore, the findings and recommendations suggested here should be considered indicative of the future interactions, research and management requirements, rather than being conclusive predictions. Given that the natural behaviour of beavers is to construct dams across water courses that can sometimes create barriers to the upstream movement of migratory fish, it should therefore not come as a surprise that whilst appreciating there are undoubtedly a wide range of environmental, socio-economic and biodiversity-related benefits, those stake holders with salmonid fishery interests are concerned that suitable breeding areas may be denied, thus reducing the potential for maximising the breeding of young salmonids for return to the sea from rivers in Scotland. Indeed in recent decades man made barriers have been removed or modified by fishery managers to allow for the passage of fish. In some cases the negative presence of beaver constructed obstacles may outweigh the positive benefits that are also identified in this report. This statement must however be viewed in the context of limited information on such negative impacts in Europe. The information we have examined is based on scientific study from Europe and North America, and while helpful, is by no means conclusive in a Scottish context. Nevertheless, there appears to be a risk particularly to those salmon that return in spring, rear in upper tributaries and have been subject to the steepest declines in populations over recent

decades. It is not clear how responsibilities under EU legislation to protect these fish will be balanced with EU imperatives stimulating a reintroduction of beavers.

It is clear that if the determination is reached that beavers are to remain in Scotland, management and appropriate resource availability will be essential if salmonid and indeed other land use interests are to be fully considered. It is likely that many potential negative aspects of beavers in respect of salmonids can become neutral or positive through the development and implementation of a clear and flexible management programme. It is important that the details of this strategy are a prerequisite of any decision to reintroduce beavers, and that these provisions are clearly understood by all stakeholders at the outset. Management of beavers in Europe and North America is not without cost, and it will be important to be clear where the burden of such costs will fall in Scotland.

During the course of our discussions we have recognised that if it is decided that beavers should be reintroduced there are a number of release strategies that might be considered. A decision will have to be made as to how the Knapdale and Tayside populations are to be managed, to prevent compromise to the long term integrity of the species. In the event that the Tayside population are to remain, we would advocate that no further releases are permitted except for the genetic improvement of the existing population(s) and that this population is the subject for immediate collection of baseline information, and in future years, extensive beaver-salmonid research. Further consideration is required on the design of this research and how it is to be resourced. Of equal importance we have identified the potential use of this population for the testing and development of management activities, their applicability and their effectiveness. The flexibility and efficiency of which are recognised as fundamental to maintaining the conservation status of salmonids.

While research is already ongoing in Tayside (under the Tayside Beaver Study Group for example) and at Knapdale (under the Scottish Beaver Trial), and through a number of other projects, we have identified a range of potential scientific and monitoring requirements, although these would need to be considered in the wider context of priority and cost.

I would like to thank BSWG members for their input in helping to set up a promising beaver-fish PhD project led by The University of Southampton. Furthermore, we greatly anticipate the results of a beaver-salmonid research fellowship, led by the Norwegian Institute for Nature Research, due to conclude in 2016.

Lastly, I wish to thank all the individual members of the BSWG and their representative organisations. I also wish to thank other organisations who have contributed to the deliberations and outcomes which form the basis of this report, the names of which appear in the acknowledgements. In the years leading up to this report we have held a number of workshops, field visits, and video conferences across the Atlantic. All of which were voluntarily attended by a range of individuals, who's support I gratefully acknowledge. I am most grateful to SNH for the practical support provided through the provision of facilities, administrative help and through financially supporting the appointment of the BSWG Project Officer. They also assisted through the provision of specialist advice on natural heritage matters and mapping data. It should be noted that SNH has a much wider brief in respect of beaver reintroduction and that the views expressed in this report are not necessarily those of SNH. I specifically wish to thank Sean Dugan for his commitment to the work of the BSWG and for putting together this report based on the input and expertise provided by the BSWG stakeholders.

Roger J Wheeler

Chairman

Beaver Salmonid Working Group

(II) EXECUTIVE SUMMARY

1. The probability of a Eurasian beaver reintroduction to Scotland has been a matter of debate for a number of years. More recently, as part of a much wider assessment being led by Scottish Natural Heritage, Scottish Ministers invited the Beaver Salmonid Working Group (BSWG) to consider the potential impacts of beaver activity on salmonids (Atlantic salmon and brown trout).

2. Membership of the BSWG comprised representatives from:

*Indicates original full members of the BSWG at its inception.

Association of Salmon Fishery Boards (ASFB)*

Marine Scotland (MS)*

National Museums of Scotland (NMS)*

Scottish Government (SG)*

Scottish Environmental Protection Agency (SEPA)

Scottish Natural Heritage (SNH)*

Tay District Salmon Fisheries Board (TDSFB)

University of Southampton

3. The BSWG was tasked with considering the following:

- **To arrange for further, continuing review of new beaver-salmonid information from Eurasia and North America;**
- **To examine the availability of potential beaver habitat that overlaps some Scottish salmonid catchments;**
- **To examine the issue of beaver presence on particular Scottish catchments and whole ecosystems, in relation to possible interactions with salmonid populations;**
- **To examine the specific issue of possible beaver dam presence on Scottish rivers in relation to possible interactions with salmonid populations;**
- **To examine potential management issues, methods and options in relation to beavers and salmonids;**
- **To examine options for field-based assessments of beaver and salmonid interactions in Scotland.**

4. To take that work forward the BSWG has looked at literature and experience from Scotland and abroad, and considered the extent to which this is examined and can be applied directly to the particular fish fauna, river characteristics and current fisheries management context in Scotland. A number of important themes emerged and remained prominent throughout the considerations of the BSWG, some of which made it difficult to reach consensus, while others required further work and discussion.
5. Through deliberations, field visits, and consultation with experts in Scotland and abroad, the BSWG have reached the following key conclusion:
 - As a fundamental pre-requisite for any decision to formally reintroduce beavers, the BSWG make the case for a general beaver management plan, including provisions for salmonids, further to a consideration of where responsibility for meeting any associated management costs should rest.
6. In addition, the Group identified the following key points:
 - The management strategy should be developed, in full consultation with all key stakeholders.
 - In constructing dams, beavers may utilise pinch-points for construction adjacent to in-stream human infrastructure including culverts, weirs and fish passes. Experience from abroad and recently in Scotland suggests that in this particular scenario, fish passage concerns may be exacerbated, presenting an elevated requirement for management intervention.
 - A beaver management plan should set out minimal intervention approaches as well as the criteria by which relocation or lethal control of beavers would be appropriate for the conservation of salmonids.
 - While beaver presence alone should not be a trigger for action, a strategy should allow a range of management interventions to be undertaken from short-term action to longer-term intervention.
 - It is envisaged that the requirement or otherwise for such intervention may partly be determined by river flow levels, and may be necessary in advance of fish migration periods during spring and/or autumn, particularly during prolonged periods of low flow.
 - Under the imperative of ensuring free passage of migratory fish, this strategy should recognise the dynamic nature of beaver dams, and the resources required in assessing such structures on multiple occasions.
 - In adhering to current regulatory guidance, any dam removals in watercourses must be completed without causing pollution, or impacts on stream biota.
 - Monitoring and management will have resource implications, and therefore it is vital that such resources are committed, over the medium to long term, to relevant management authorities.

- There are significant gaps in our knowledge of beaver-salmonid interactions, both within Scotland and abroad. There is also lack of data available to inform our knowledge of the interaction between beaver and other species of conservation interest including the European eel, lamprey spp. and freshwater pearl mussel.
- Further research in Scotland is considered necessary to help inform when management intervention may be required, and when it is not.
- Generally, there may be extensive overlap between known Atlantic salmon distribution and potential beaver habitat in major rivers, with potential overlap in minor rivers varying considerably between catchments.
- In these streams where beaver and salmonid habitats may overlap, interactions will vary over time, between catchments, and within catchments. As such it is not possible to predict whether the overall net impact of beaver presence will be positive, negative or negligible on salmonid fish or other species of conservation importance with certainty.
- However, beaver damming activity, and the associated potential hindrance to fish passage is of particular conservation concern to a component of the Atlantic salmon stock called spring salmon, which utilise upland nutrient-poor streams.
- It is recognised that there could be wider socioeconomic and ecosystem service benefits that will result from the presence of beavers. There are also benefits of beaver presence to salmonids, and these may be realised particularly where management options are available.

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1. INTRODUCTION

1.1 Background, global and European conservation context

The Eurasian beaver *Castor fiber* L. is currently Europe's most widely reintroduced species (Pillai & Heptinstall, 2013) having been re-established in all countries of its former range except Britain, Portugal, Italy and the South Balkans. In 2008 the beaver's IUCN status was re-classified to a species of 'Least Concern,' but it remains on Annex IV of the EC 'Habitats Directive', which provides special protection through prohibitive and preventative measures (Pillai *et al.*, 2012). The species is also listed on Annex II, which requires the designation of Special Areas of Conservation (SAC), where appropriate. Reintroduction of the Eurasian beaver has been put forward as a contribution to the aims of the EU Biodiversity Strategy (European Commission, 2011). Once widespread across the northern forest belt of Europe and Asia, hunting and trapping for fur, food and castoreum and to a lesser extent habitat loss resulted in its extinction in Scotland by the 16th century (Kitchener & Conroy, 1996).

The initial vehicle for the reintroduction of beavers to Scotland arose from the EC Habitats Directive launched in 1992 (European Directive 92/43/EEC on the conservation of natural habitats of wild fauna and flora). Article 22(a) requires member states to assess the desirability of reintroducing animal species listed on Annex IV to areas of their former native range, and to contribute to monitoring and to the re-establishment of these species at favourable conservation status. In 1995 Scottish Natural Heritage (SNH) began assessing the desirability of beaver reintroduction, commissioning a range of studies in the late 1990s, which drew upon European and North American experiences. As beavers have the ability to profoundly alter aquatic environments, they also have the potential to influence fish populations. Scotland's native freshwater fish and salmonid fisheries are of significant conservation, economic and cultural value and therefore it is important to assess how these assets could be influenced in both beneficial and detrimental ways by beaver activity.

1.2 Beaver Salmonid Working Group (BSWG) Terms of Reference and purpose

Following the approval of a trial reintroduction at Knapdale in Argyll, beavers of Norwegian origin were released in 2009. Post-release monitoring was conducted for five years, concluding in May 2014. However, because of a lack of consensus within the literature, concerns raised by members of the Scottish wild fisheries sector, and partly due to the fact that migratory salmonid fish were not routinely present within the Knapdale trial site, the Beaver-Salmonid Working Group (BSWG) was established in 2009 as a sub-group of the National Species Reintroduction Forum (NSRF). The BSWG's remit is to consider the potential impact of beavers on salmonids, interpreted for the purposes of informing the debate in Scotland as being Atlantic salmon *Salmo salar* L. and brown trout *Salmo trutta* L. (hereafter referred to as salmon and trout). This report will form a significant part of a wider package of information which is being collated to inform the Minister on all aspects of beavers and beaver reintroduction issues (Gaywood, 2014).

The terms of reference of the BSWG are:

- **To arrange for further, continuing review of new beaver-salmonid information from Eurasia and North America;**
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University of Southampton

Scottish Ministers, through the NSRF have asked the BSWG to consider the potential impacts of beaver activity on salmonids, and while this report is based on an extensive reference list, it is not a scientific publication. Although not stated in the above terms of reference, this report has also briefly discussed beaver interactions with European eel *Anguilla anguilla* (L.), lampreys *Lampetra planeri* (Bloch), *L. fluviatilis* (L.) and *Petromyzon marinus* L., and freshwater pearl mussel [FWPM] *Margaritifera margaritifera* (L).

Information is garnered to understand the potential requirement and applicability of any beaver monitoring and management measures, and their resource implications, with some consideration about where that duty should rest. While the focus of this report does fall on the management costs which may arise from beaver presence, it is important that the ecosystem service and socio-economic benefits provided by beavers are also discussed.

The purpose of this report is raise awareness of the need for a management strategy to be developed, and for it to be adaptive, in response to new knowledge and experience arising in Scotland and elsewhere. General beaver management practice from eastern North America and Europe is considered in the context of current EU legal requirements, and while these are noted, the BSWG does not intend to interpret the complexities of the Habitats Regulations, the interpretation of which only a legal authority can provide. In the scenario that a strategic and limited reintroduction plan is implemented, the requirement for those involved in such activity to work in co-ordination with salmonid conservation interests and vice-versa is discussed.

1.3 Beaver ecology

In assessing the likely interactions between beavers, salmonids and fisheries, it is important firstly to understand the ecological requirements and behaviour of beavers, with particular focus on those aspects that may lead to interactions with salmonids in Scotland. The Eurasian beaver is a semi-aquatic, herbivorous, and highly territorial mammal, living in family units (colonies) typically comprising three to five individuals. Young are born in late spring, and the previous year's young leave the colony at around the same time. Beavers sometimes build dams on low-gradient small streams to create impoundments which may also serve to conceal the entrances to their lodges or burrows and allow secure access to food and building resources (Naiman *et al.*, 1986). Beavers can exert a strong influence on riparian landscapes, with flooding killing most woody species if flooded for multiple years, and they can create wetlands of varying size. By felling trees, beavers can also create open areas in riparian woodlands and may, over time, change the species composition of riparian woodland at local levels. Beavers are considered as 'ecological engineers'. As stated by (Butler and Malanson, 1995), '*More than any other animal except humans, beavers geomorphically alter the landscape through their dam building and related activities*'.

Beaver colonies can often exist without creating dams. Beaver dams are generally ephemeral structures and can be reduced in size and integrity or removed during periods of high flow e.g. (Taylor *et al.* 2010), with the density of functional dams in a river landscape expected to vary with season and flow regime (Gurnell, 1998). The range of physical conditions under which beavers can construct dams has been described using a variety of metrics, including stream gradient, stream order, stream power, depth, width and valley shape in North America (e.g.; Naiman *et al.*, 1986; Suzuki and McComb, 1998; McComb *et al.*, 1990; Pollock *et al.*, 2003, 2004; Green and Westbrook, 2009), Germany (Schulte, 1989), and Sweden (Hartman and Törnlov, 2006). In general terms, Eurasian beavers can be expected to maintain dams on small, shallow streams of less than 2.5% gradient, and in a survey of 74 dams in Sweden, the mean water depth (downstream of dams) was found to be 0.36m (range 0.10-0.85 m) and the stream width 2.5m (range 0.5-6.0m) (Hartman and Törnlov, 2006). The density of dams in streams is known to vary considerably with one dam for every 14.3km of stream reported in a Norwegian study Parker & Ronning, (2007), while Zurowski, (1989) reported 24 dams in a 1.3km reach of a Polish mountain stream.

Structures can measure over 100m in length and over 2m in height, but most are much smaller. Construction can also involve the use of aquatic vegetation, mud and stones, in addition to woody material. Whilst it is likely that optimal damming locations will generally exist in lowland Scottish streams in proximity to deciduous trees (Gurnell, 1997), experience from Norway demonstrates that colonies can exist up to 1200m above sea level in the montane woodland zone (Schandy, 1979). The interaction of beaver population dynamics, food supply, stream power, channel shape and the intensity of floods acts to govern the longevity and density of beaver dams within the river landscape (Pollock *et al.*, 2014; Kemp *et al.*, 2012).

In established populations beavers commonly utilise habitats ranging from agricultural ditches to river main-stems and lakes. In Scotland areas impacted by hydropower impoundments could be inhabited in certain circumstances, but beavers are not known to tolerate excessive unnatural water-level fluctuations. Should beavers be reintroduced to Scotland, they will probably eventually colonise all suitable habitat. However, this may happen over multiple decades, affected by factors including release strategies and habitat connectivity. During the colonisation phase, beavers select optimal habitat, which often may require damming. With beaver populations expected to increase in size by between 5-34% annually (Gorshkov, 2006; Gurnell, 1998; Sluiter, 2003; Heidecke *et al.*, 2009; Balodis *et al.*, 1999), the availability of optimal habitat for new individuals will decrease.

In Scotland beavers are thought to have been present in Tayside since the early 2000's. These individuals, that escaped from private collections or were released illegally, have recruited successfully and as of summer 2012 comprised approximately 39 family groups (Campbell *et al.*, 2012) of at least three genetically distinct groups (McEwing, in prep). It is important to note that, newly established populations such as this are not expected to produce the widespread ecosystem modifications which, for Eurasian beaver, would be predicted to occur at peak

population density 11-34 years after initial colonisation (Hartman, 1994, 2003; Vissing *et al.*, 2012). These approximate timescales should be borne in mind when considering the potential for interactions with salmonids, and the requirement for future management action.

1.4 Scotland's freshwater fish populations

A total of 42 species of freshwater fish have been recorded in Scotland. Those which are considered native and first entered Scottish freshwater environments from the sea include species such as: Atlantic salmon, trout, European eel, brook, river and sea lamprey, powan *Coregonus lavaretus* (L.), Arctic charr *Salvelinus alpinus* (L.) and sticklebacks *Gasterosteus aculeatus* (L.) and *Pungitius pungitius* (L.). Other freshwater species thought to be native to parts of Scotland, with a restricted natural distribution, include: pike *Esox lucius* (L.), roach *Rutilus rutilus* (L.), perch *Perca fluviatilis* (L.), minnow *Phoxinus phoxinus* (L.) and stoneloach *Barbatula barbatula* (L.). Others have been introduced from other parts of Britain (e.g. grayling *Thymallus thymallus* (L.), dace *Leuciscus leuciscus* (L.), chub *Leuciscus cephalus* (L.), rudd *Scardinius erythrophthalmus* (L.), barbel *Barbus barbus* (L.), ruffe *Gymnocephalus cernuus* (L.) and bullhead *Cottus gobio* (L.)) or Europe (e.g. carp *Cyprinus carpio* (L.)). One native species, the vendace *Coregonus albula* (L.), is now naturally extinct in Scotland, but has been re-established here using stock from northern England. Compared with England and central Europe, the Scottish freshwater fish assemblage can be considered to be species-poor, reflecting its recent colonisation since the end of the last Ice Age.

1.5 Atlantic salmon

The Atlantic salmon is an important component of freshwater ecosystems in Scotland and is of cultural and commercial importance. At the last national assessment in 2004 it was estimated to provide over £73 million per year to the local economy (Radford *et al.*, 2004). Salmon exist in much of the accessible, clean, oxygen-rich river habitat. A selection of the available habitats in 17 rivers in Scotland have been designated as Special Areas of Conservation (SACs) for Atlantic salmon (Figure 1).

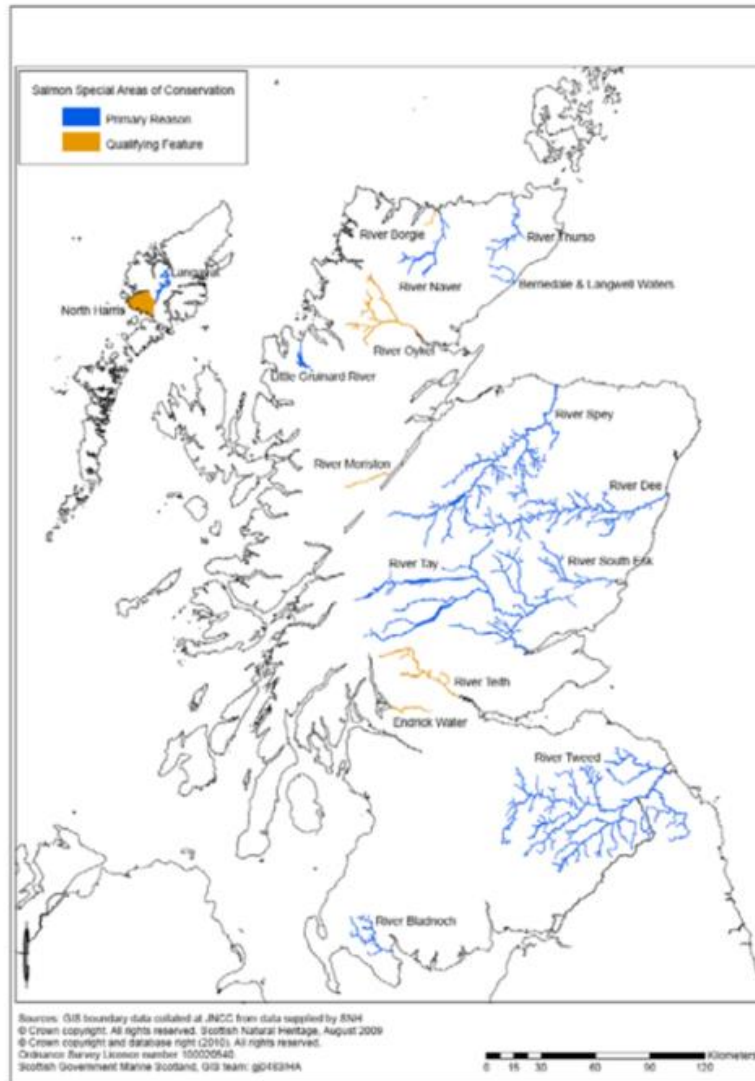


Figure 1: Map showing the distribution of Special Areas of Conservation (SACs) for Atlantic salmon in Scotland.

The conservation objectives for these SACs are as follows.

To avoid deterioration of the habitats of the qualifying species or significant disturbance to the qualifying species, thus ensuring that the integrity of the site is maintained and the site makes an appropriate contribution to achieving favourable conservation status for each of the qualifying features; and

To ensure for the qualifying species that the following are maintained in the long term:

- *Population of the species, including range of genetic types for salmon, as a viable component of the site*
- *Distribution of the species within site*
- *Distribution and extent of habitats supporting the species*

- *Structure, function and supporting processes of habitats supporting the species*
- *No significant disturbance of the species*
- *Distribution and viability of freshwater pearl mussel host species*
- *Structure, function and supporting processes of habitats*

The Habitats Directive (Article 6) requires that *Member States shall take appropriate steps to avoid, in the special areas of conservation, the deterioration of natural habitats and the habitats of species as well as disturbance of the species for which the areas have been designated, in so far as such disturbance could be significant in relation to the objectives of this Directive.*

The physical habitat requirements of salmon (and trout) during the freshwater phases of their life cycle are reviewed elsewhere (Armstrong *et al.*, 2003). Atlantic salmon inhabit fresh water for up to four years of life in Scotland before the majority of the population changes to a pelagic form called a smolt. Smolts undertake extensive migrations to feeding areas in the North Atlantic, where individual growth is relatively fast. Mature adults return, predominantly homing to rivers where they were spawned, after one or more winters at sea. The main outward migration of smolts occurs in spring, whereas adult fish may return throughout the year. Owing to homing behaviour, salmon can become highly adapted to their local environment, in which distinct populations develop. In Scotland the salmon fishery, particularly on large east coast rivers benefits from a long fishing season (compared to Norway, for example) because adult salmon enter fresh water in most or all of the calendar year. Of particular conservation concern are the *spring salmon* stock component (see Figure 2), which return to fresh water as adults early in the calendar year and are thought to originate from the upland areas of catchments.

Within-river spawning migration of salmonids is governed by a range of complex interactions between natural and human-mediated factors, including: previous experience; water discharge, temperature and velocity; required jump height over obstacles; fish size; fish acclimatisation; light levels; water quality; time of the year; and fish stress levels (Thorstad *et al.*, 2008). Salmonids are characterised by their ability to ascend considerable barriers including some waterfalls in certain conditions, dependant on a range of factors, such as water depth below the obstruction. Movement of juvenile salmonids is also found to occur throughout the year, in some cases enabling the utilisation of habitats not accessible to adult spawners. In order to reduce competition and thereby maximise feeding opportunity, it is important that adult salmon are able to utilise spawning gravel as far upstream as possible (Hay, 1989).

1.6 Conservation status of salmon

Atlantic salmon populations have declined across much of their range (Windsor *et al.*, 2012). In Scotland at a national level, the annual rod catch which may indicate the trends in the size of the spawning population within limits, has been maintained by factors such as a reduction in the activity of coastal net fisheries (Marine Scotland Science, 2014). However, there is variation in the conservation status among components of these populations. The spring salmon stock component has been in decline in recent decades, although there is some indication that this stock component has stabilised at a historically low level (since the 1950's) in recent years. In recognition of this decline, the Scottish Government has introduced statutory measures which came into force on Friday 9th January 2015 to ensure that no salmon is taken in Scotland before 1st April each year (Scottish Government, 2014). Of particular concern for all salmon populations is the downward trend in marine survival across the North Atlantic observed since the 1960s (Table 1).

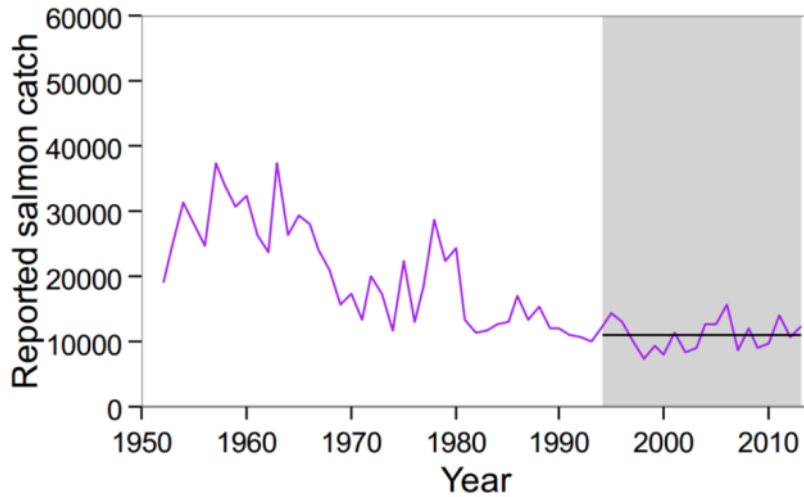


Figure 2: Reported catches of salmon in Scotland during spring months. (Marine Scotland Science, 2014).

Stock Group	% Decline in Abundance	
	Grilse	Salmon
N. Europe	49%	54%
S. Europe	66%	81%
N. America	40%	88%

Table1: Decline in abundance of salmon in the Atlantic region over the past 40 years. (Windsor *et al.*, 2012).

Atlantic salmon and sea trout (see section 1.7) populations may be impacted in varying degrees by a range of factors in the marine and freshwater phases of their lifecycles. In the freshwater environment these pressures are thought to be: aquaculture, barriers to migration, climate change, degradation of habitat, hydro-electricity generation, invasive non-native species, over-exploitation, pollution, predation and stocking of non-native species. Marine pressures include: aquaculture, by-catch in pelagic fisheries, climate change, marine energy developments, over-exploitation, pollution and predation. The magnitude of these potential impacts will obviously differ between river systems and indeed between tributaries within river systems depending on the local use of the resource.

These pressures, and their relative importance and potential cumulative impact in different catchments, form a crucial aspect of the context for any future decision on the licensed reintroduction of beavers. Some of these impacts, such as sea surface temperature and prey availability in the North Atlantic are clearly beyond the control of managers. Other aspects are under regulatory control, but action is not scheduled until the second or third round of river basin management planning (e.g. fish passage and water flow issues relating to hydro-electricity developments). Despite considerable effort from fishery managers and regulators to ease these pressures, it is likely that such (cumulative) pressures will continue to influence salmon in the foreseeable future and it is within this context that any future licensing decisions must be based.

1.7 Trout

Trout co-exist with salmon across much of their range, although they differ in respect of their in-stream habitat requirements (Armstrong *et al.*, 2003; Jonsson & Jonsson, 2011). The distribution of salmon in Scotland is well understood (see chapter 2), and although that of trout is less well known, it will likely be a wider distribution. However, small streams thought to be of greater relative importance to trout populations, and as such beaver activity in these small streams is a particular consideration of this report.

In Scotland, trout can be found in a variety of freshwater habitats, and are a highly plastic species that exhibits a wide range of life history strategies. Trout may spend their entire life in freshwater habitats, or migrate to estuarine and coastal areas before returning to freshwater to spawn. Those fish which remain in freshwater are called 'brown trout', whereas those which adopt an anadromous life history pattern are referred to as 'sea trout'. 'Resident' brown trout, as this term suggests, complete the whole of their life cycle in fresh water. Some may, however, undertake significant migrations within fresh water. The most common life-cycle pattern in Scottish brown trout populations is the migration of juvenile fish from nursery areas, where they begin to feed, into lochs or larger, deeper, channels within rivers where they may remain until becoming adults. Generally speaking, the life history of sea trout is similar to that of Atlantic salmon - that is sea trout spend a variable time in freshwater as juveniles before undergoing the changes that allow them to migrate to sea as smolts. They do not, however, undertake the same oceanic migration as salmon.

Sea trout catches in Scotland have fallen since the 1950s although the pattern of catches vary regionally (Marine Scotland Science, 2014). Neither form of trout, resident or anadromous, receive extensive protection within conservation legislation. Some protection in terms of exploitation controls exist within fisheries legislation and sea trout are further protected within fisheries acts relating to the protection of 'salmon'. In 2007, however, both ancestral brown trout and sea trout were added to the UK Biodiversity Action Plan Priority Species List. The habitat requirements of trout (compared with salmon) are reviewed elsewhere (Armstrong *et al.*, 2003).

1.8 Other species of conservation value

All native fish species contribute to the functioning of aquatic ecosystems. Within the context of this report additional migratory and non-migratory species of European conservation significance found in Scotland include European eel, anadromous and non-anadromous lamprey species, and freshwater pearl mussel (listed in the EC Habitats Directive). The ecology and conservation legislation relevant to the species is discussed below.

The European eel inhabits a variety of freshwater and estuarine habitats during the juvenile phase of its life cycle. Adults migrate to the Sargasso Sea to spawn and it is assumed that their eggs drift eastwards towards Europe with the Gulf Stream current before hatching, and when the larvae reach the continental shelf they metamorphose into eels. On entering fresh water they migrate upstream, feeding on invertebrates and fish, with eels known to move overland through wet terrain to access other water bodies. Juvenile eels (known as yellow eels) can remain in fresh water for more than 20 years. Upon reaching sexual maturity, these adult eels turn silver and they begin their migration to the Sargasso Sea. European eel populations have undergone a drastic decline in recent decades, estimated at 90% (ICES, 2014). The European Commission has deployed a Recovery Plan, with the aim of returning stocks to sustainable levels. Each Member State is required to establish a national Eel Management Plan.

Like salmonids, lampreys spawn in clean gravel substrates by constructing a 'nest' in which to lay their eggs. After hatching, young lamprey ammocoetes drift downstream to settle in nursery habitats comprising fine sediment in well-oxygenated pools or marginal areas. These larvae remain in the substrate for up to five years before (in the case of migratory river and sea lampreys) commencing their seaward migration during late autumn (sea lamprey) and late winter-early summer (river lamprey). These species are threatened across their range with the river lamprey featuring in Annexes II and V of the EC Habitats Directive, Appendix III of the Bern Convention and the UKBAP Priority List. The sea lamprey features on Annex II of the EC Habitats Directive, Appendix III of the Bern Convention and the UKBAP Priority List.

Originally widely distributed throughout Scotland, the freshwater pearl mussel is now extinct in most of the lowlands, and scarce everywhere except for some Highland rivers (Cosgrove *et al.*, 2000). If the present rates of extinction continue, it has been estimated that surviving Scottish populations may only persist for a further 25 years. Protected under Schedule 5 of the Wildlife and Countryside Act (1981), the freshwater pearl mussel is also listed on Annexes II and V of the EC Habitats Directive and Appendix III of the Bern Convention. It is included on the IUCN Invertebrate Red List, where its status is described as Vulnerable. Freshwater pearl mussels live buried or partly buried in coarse sand and fine gravel in clean, fast-flowing and unpolluted rivers and streams. Mussel larvae, called glochidia, are released from July to September. Almost all the larvae are swept away and die, but a few are inhaled by juvenile Atlantic salmon and brown or sea trout, and they remain attached to the gills of juvenile salmonid fish until the following spring. At this point they settle in the substrate to start to grow. Therefore, any changes in the species composition or overall abundance of salmonid fish will directly affect the local freshwater pearl mussel populations.

1.9 Salmonid fisheries management in Scotland

The priority for contemporary salmonid fisheries management in Scotland is to maximise the production of naturally reared juvenile salmon, and output to the marine environment (smolt output). Concern has been raised within the BSWG that beaver activity may impact some recent efforts of fishery managers. For example, considerable resource has been invested in; the removal of artificial barriers to migration, the reduction of diffuse pollution by creating and maintaining riparian buffer strips, the prevention of bank erosion through riparian fencing and livestock exclusion, and the reduction of legal and illegal exploitation of salmon and trout populations. In recent years, fishery managers and conservation organisations have begun planting trees to provide shade and improve riparian habitat, while others have trialled the input of woody structures into streams, with the aim of enhancing cover and substrate diversity, with potential knock-on benefits for invertebrate and fish populations.

Responsibility for the stewardship of all freshwater fish resources ultimately lies with Scottish Ministers, but District Salmon Fishery Boards (DSFBs) have a legal remit to regulate and manage salmon (legally interpreted as covering both Atlantic salmon and sea trout) fisheries in Scotland. The administration of freshwater fisheries on the River Tweed is the responsibility of the River Tweed Commission. DSFBs work closely with Fishery Trusts, who deliver local-level monitoring of fish populations and deliver projects including habitat improvement. Marine Scotland, part of Scottish Government, facilitates the delivery and implementation of freshwater fisheries legislation, scientific programmes designed to underpin fisheries policy, and the monitoring and analysis of catch statistics. In January 2014 the First Minister announced that an independent review of wild fisheries management would be undertaken during 2014, the aim of which was to:

- Develop and promote a modern, evidence-based management system for wild fisheries fit for purpose in the 21st century, and capable of responding to the changing environment;
- Manage, conserve and develop our wild fisheries to maximise the sustainable benefit of Scotland's wild fish resources to the country as a whole and particularly to rural areas.

The review panel reported to the Minister in October 2014, and as a result management structures for freshwater fisheries in Scotland are likely to change, following forthcoming consultation and potential changes to legislation. It is not known how these changes may influence the future management of catchments which support beavers and salmonids, if beavers are to be reintroduced.

1.10 Beaver-salmonid interactions

The main remit of the group is to consider beaver-salmonid interactions, which for the purposes of this report are defined as: the interaction between Eurasian beaver and salmonids native to Scotland (Atlantic salmon and trout), hereafter referred to as salmon and trout. For millennia, beavers naturally co-existed with salmonids and other freshwater fish species in Scotland. The population size of either species and their level of interaction is unknown. However, the context for possible beaver-salmonid interactions has changed through pressures on river habitat, such as land use (for forestry, agriculture and urban development), water impoundment and abstraction for domestic and industrial use, riparian habitat degradation (through, for example, overgrazing and encroachment by invasive non-native plants), climate change (particularly in the marine environment), and diffuse pollution. These pressures may have been absent or less prevalent when salmon previously co-existed with beavers, and there may have been less or more salmonids produced historically in the presence of beavers regardless of these other factors.

Much of the scientific research into the interaction between beavers and a range of freshwater fish species relates to interactions with North American beavers (*C. canadensis* Kuhl) and a diverse range of freshwater fish species (Kemp *et al.*, 2012). Whilst this research is valuable in presenting the broad mechanisms by which beavers may interact with salmonids, caution should be applied when interpreting these findings in the Scottish context. The character of river systems and the nature of the fish communities is different between Scotland and North America. Upland river rearing areas can make important contributions to overall smolt output and it is thought that spring salmon in particular arise from upland tributaries. The major salmon (and sea trout) fisheries which exist in lowland river main-stems are often dependent on smolt output from such small streams.

Beaver-salmonid interactions have been the subject of several extensive reviews including Collen & Gibson, (2001) and Kemp *et al.* (2012), although neither of these exclusively consider salmonids. As is common in species ecology, these potential interactions are complex and would be expected to vary between catchments and over time. The mechanisms by which beavers may interact with salmonids are well established and these processes, along with the underpinning scientific data are considered further in Chapter 3. Collen, (1997) summarised the situation as follows, a position maintained by the Beaver-Salmonid Working Group:

'In Scotland, beaver would have no major predators, they would be capable of travelling within and between catchments, and they would be able to alter the environment to suit their own needs. Such alterations could be harmful or beneficial to fish populations and it would be difficult to generalise as each case would have to be assessed individually. Thus beaver reintroduced to Scotland would require a policy of active management. It is concluded that, following any successful reintroduction, there would eventually be areas of conflict with fisheries interests. The time taken to reach this situation and the seriousness of the problems would depend ultimately on the effectiveness of the beaver management programme. Fisheries authorities would be unlikely to support the reintroduction of this mammal unless they were presented with such a programme.'

2. MAPPING OF KNOWN SALMON DISTRIBUTION AND POTENTIAL BEAVER HABITAT IN SCOTLAND

2.1 Introduction

A basic requirement in considering the potential for interactions is to determine the potential magnitude of spatial overlap between the possible range of beavers and the distribution of salmon. A geographic information system (GIS) approach was used to consider such distributions in six river catchments that cover much of Scotland's geographical and hydrological diversity; the Ayr, Awe, Tweed (in Scotland), Tay, North Esk, and Conon. Salmon distribution is that recorded in recent years, whereas beaver distribution is based on predictions of suitable habitat, defined as existing broadleaf and mixed broadleaf woodland within 200m of freshwater habitats including rivers and wetlands, but excluding high gradient streams, tidal areas and land above 400m in elevation. The data are also considered in a preliminary comparison of larger and smaller river reaches, taking 10m width as a cut-off. This approach intends to provide an estimate of how the area of overlap may differ between main stems and tributaries.

2.2 Methods

GIS was used to determine the percentage of river habitat known to be currently occupied by Atlantic salmon that might also be used by beavers should they extend to their current predicted full potential range. Salmon distribution data, last updated in 2008, includes the spatial range over which juvenile salmon have been detected in Scotland. Potentially suitable beaver woodland habitat data includes habitat types and topographies known to be used by the mammals in other European countries. As this dataset excludes the Tweed in England, analysis of potential beaver-salmon overlap for the Tweed relate to the Scottish part only. A full explanation of methods and datasets within the full report is provided in appendix 1.

2.3 Results

At the full catchment scale in six rivers (Ayr, Awe, Tweed, Tay, North Esk and Conon), the potential percentage wetted area of salmon habitat that may occur in proximity to potential beaver habitat (termed percentage overlap) ranged from 47-73%. In all six rivers the degree of potential overlap in the habitat distributions was greater in major rivers (54-87%) compared with minor rivers (15-59%).

	River					
	Awe	Ayr	Conon	North Esk	Tay	Tweed in Scotland
Area of beaver woodland in catchment (m ²)	18655128	16728110	21516908	23437700	121500771	86154807
Area of salmon habitat in catchment (m ²)	2328842	2530925	3094610	2572830	17605365	17468072
Area of salmon habitat in major rivers (m ²)	1531006	2028734	2665312	1793813	14723015	11127785
Area of salmon habitat in minor rivers (m ²)	797835	502191	429298	779018	2882350	6340287
Potential beaver-salmon overlap in catchment (%)	62	71	55	73	72	47
Potential beaver-salmon overlap within major rivers (%)	70	80	61	87	75	54
Potential beaver-salmon overlap within minor rivers (%)	46	32	15	39	59	36

Table 2. Estimates of key parameters from current distributions of salmon and predicted area of suitable woodland for beavers. Potential beaver-salmon overlap is the percentage of salmon distribution within 50m of suitable beaver habitat. Major rivers (predominantly main stems) and minor rivers (mainly tributaries) refer to rivers width deemed to be above and below 10m respectively.

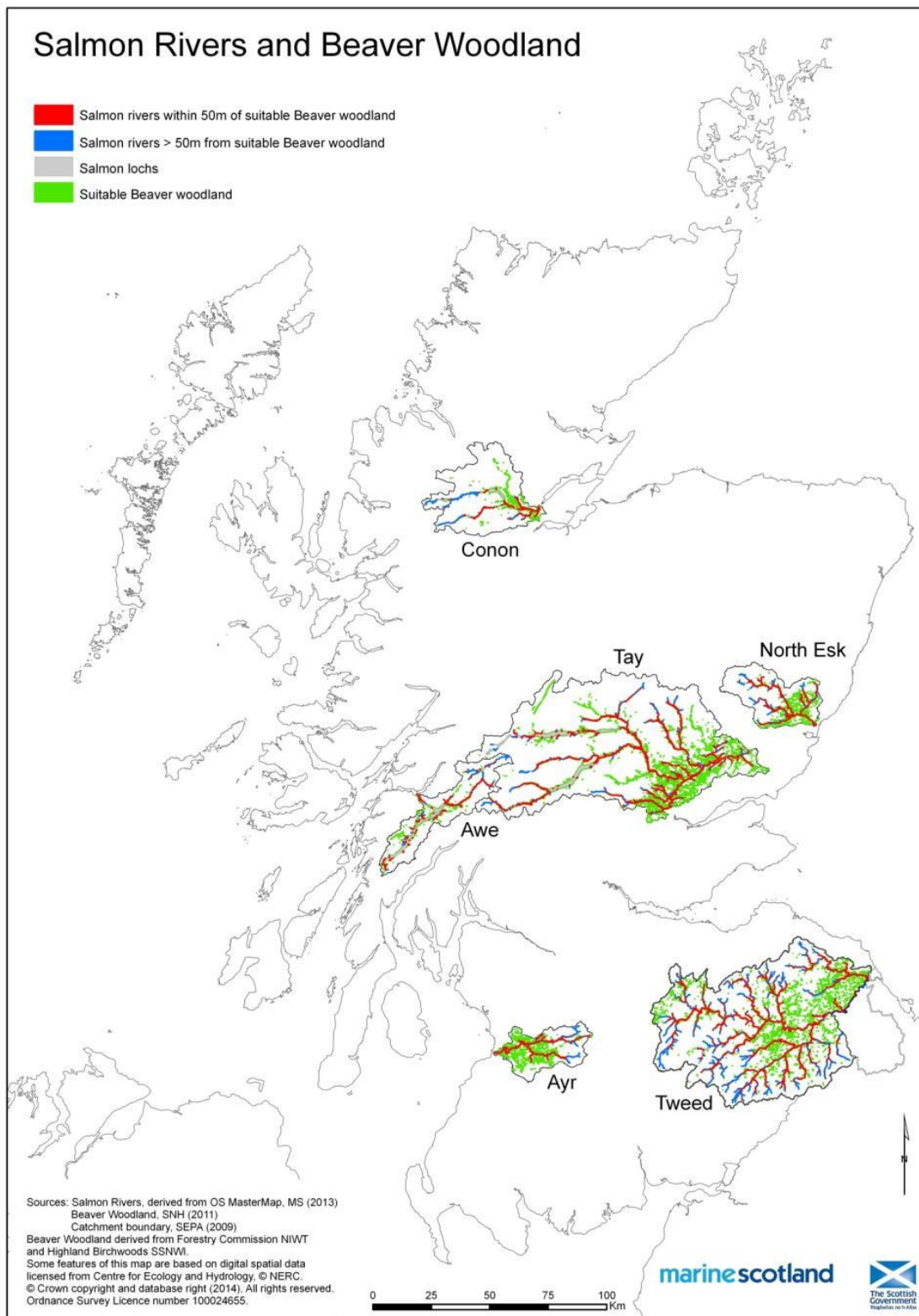
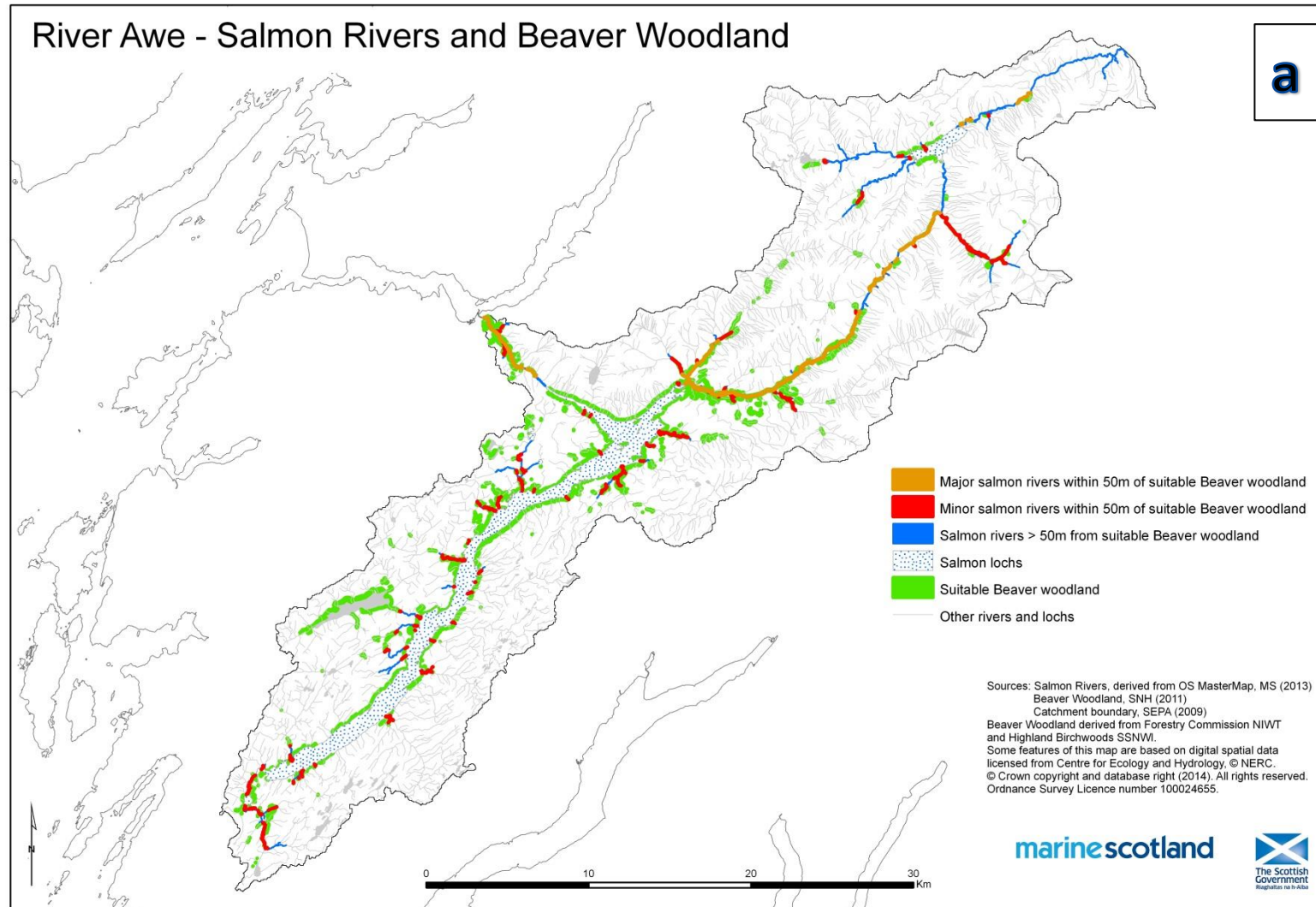
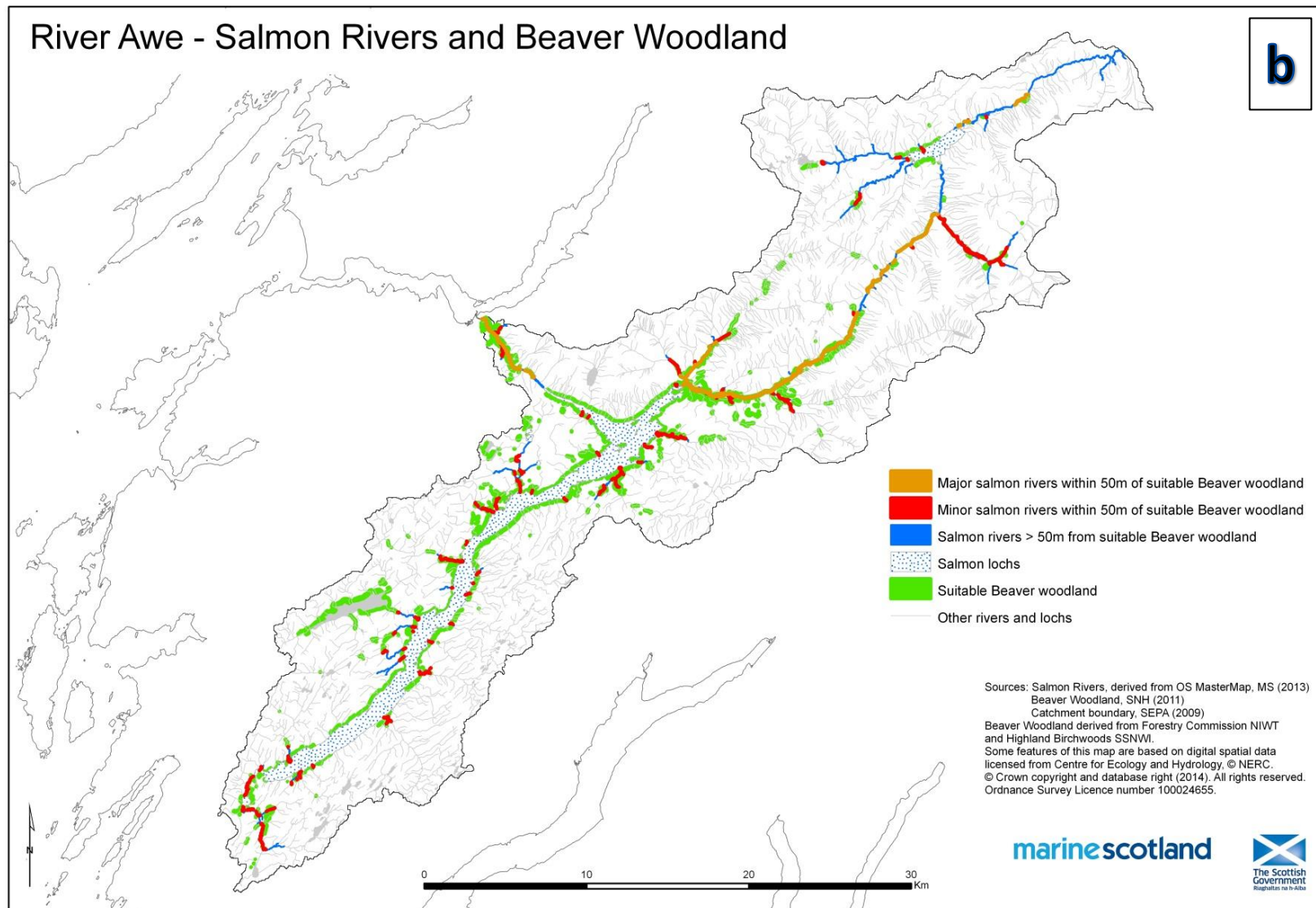
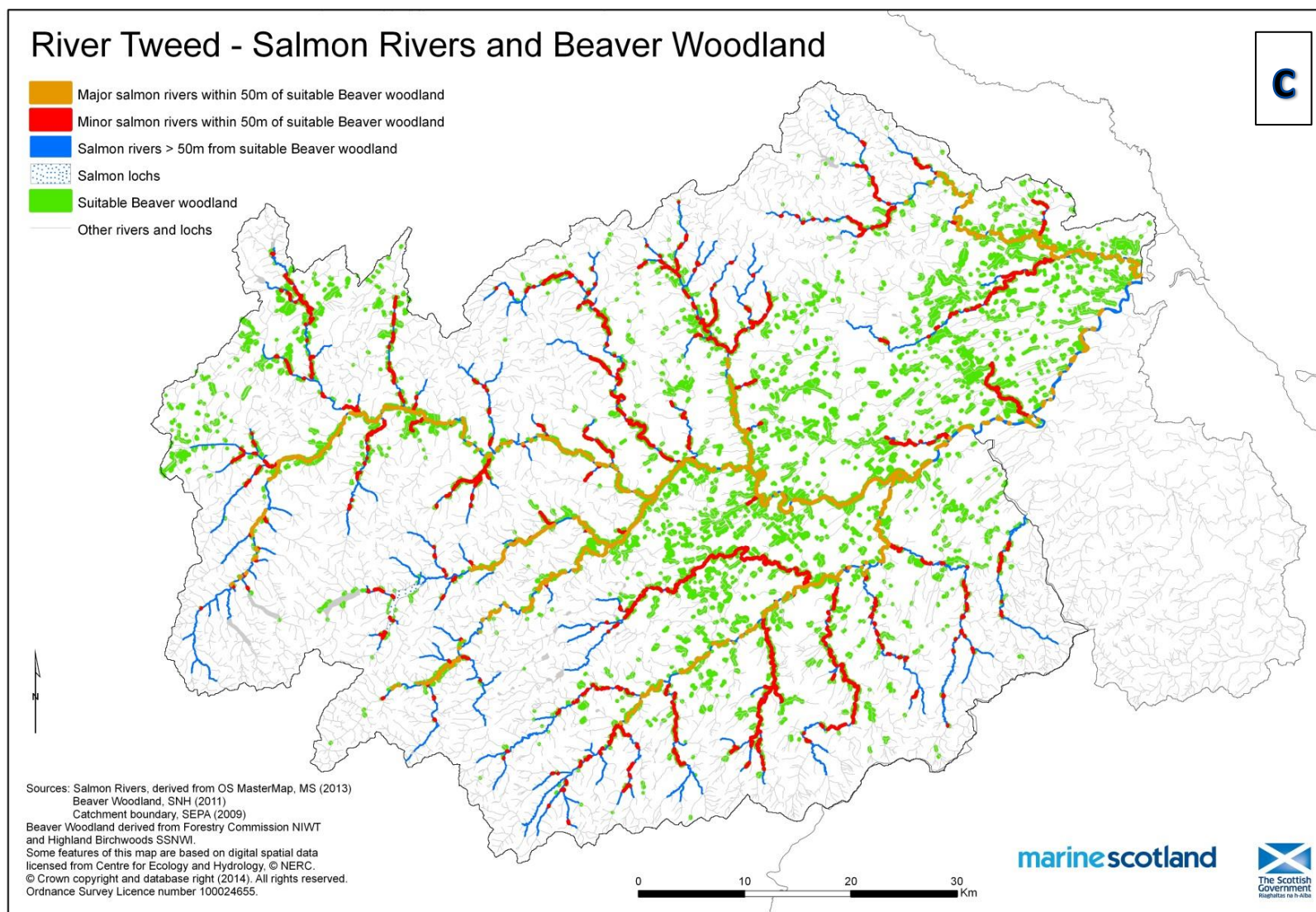


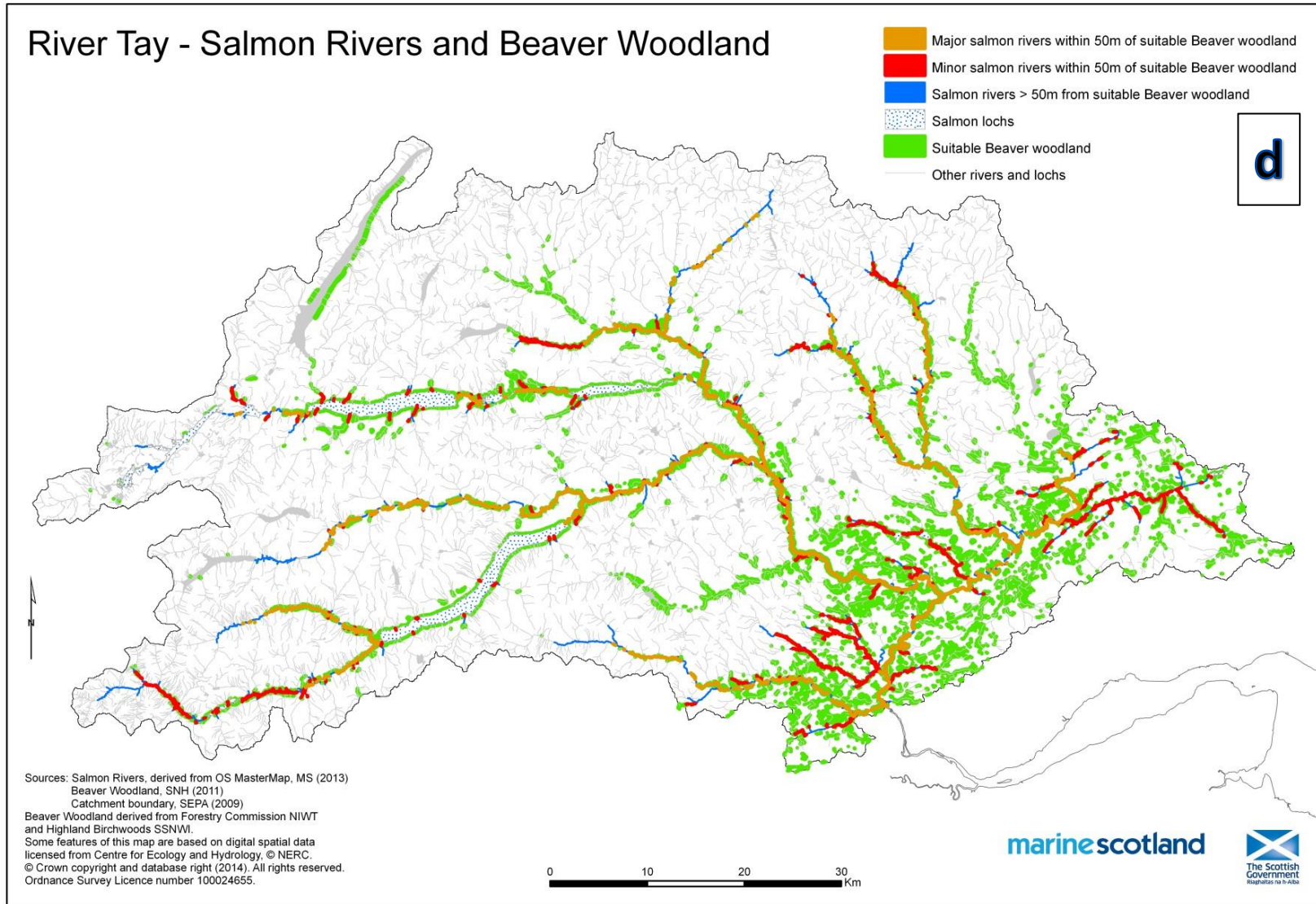
Figure 3. General overview of the six study catchments in which distributions of salmon rivers and potential beaver habitat were compared.

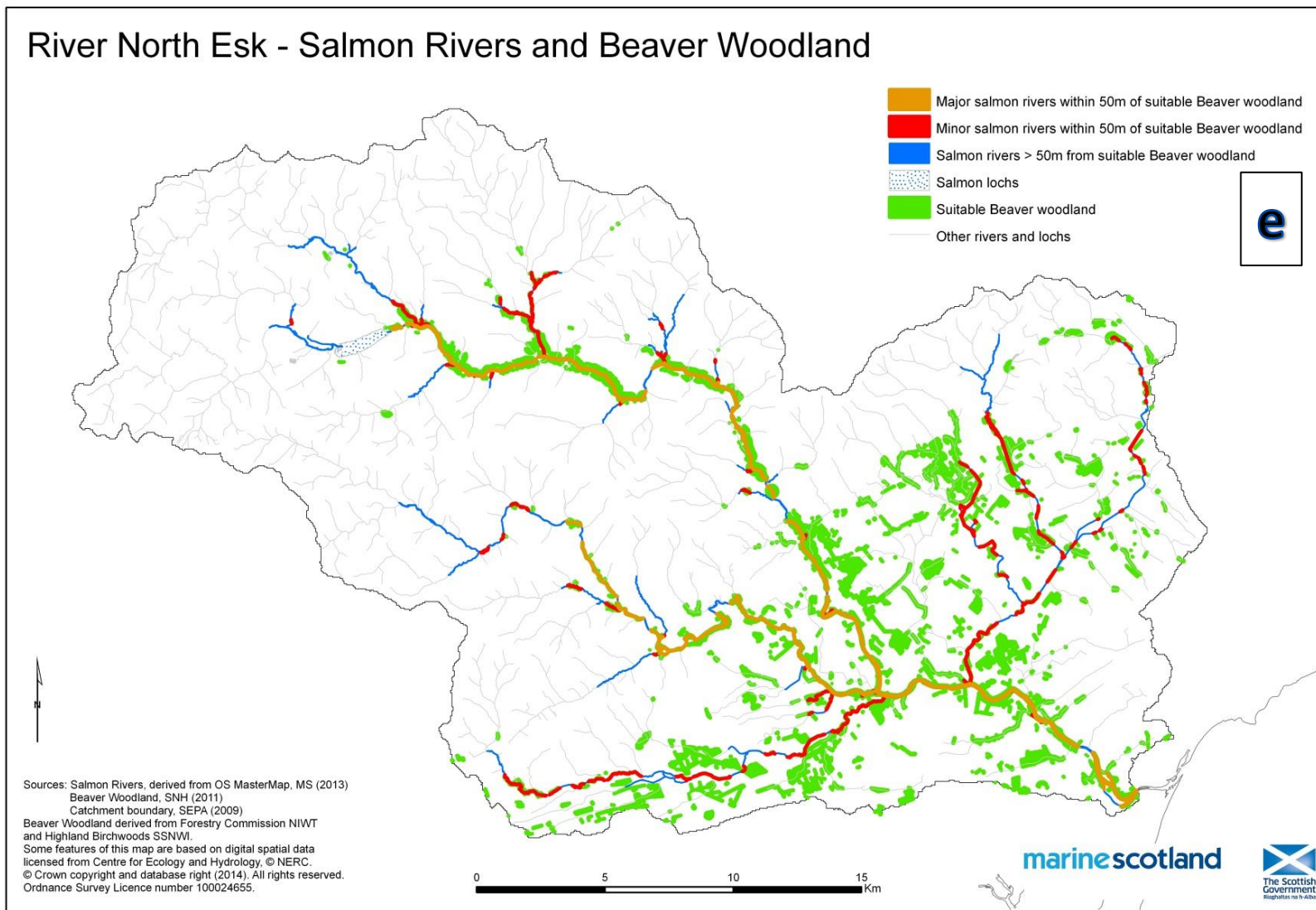
Figure 4. (a)-(f). Maps showing salmon rivers within 50m of suitable beaver woodland in six Scottish river catchments. Figure 2(a) River Ayr, Figure 2(b) River Awe, Figure 2(c) River Tweed, Figure 2(d) River Tay, Figure 2(e) River North Esk, Figure 2(f) River Conon.







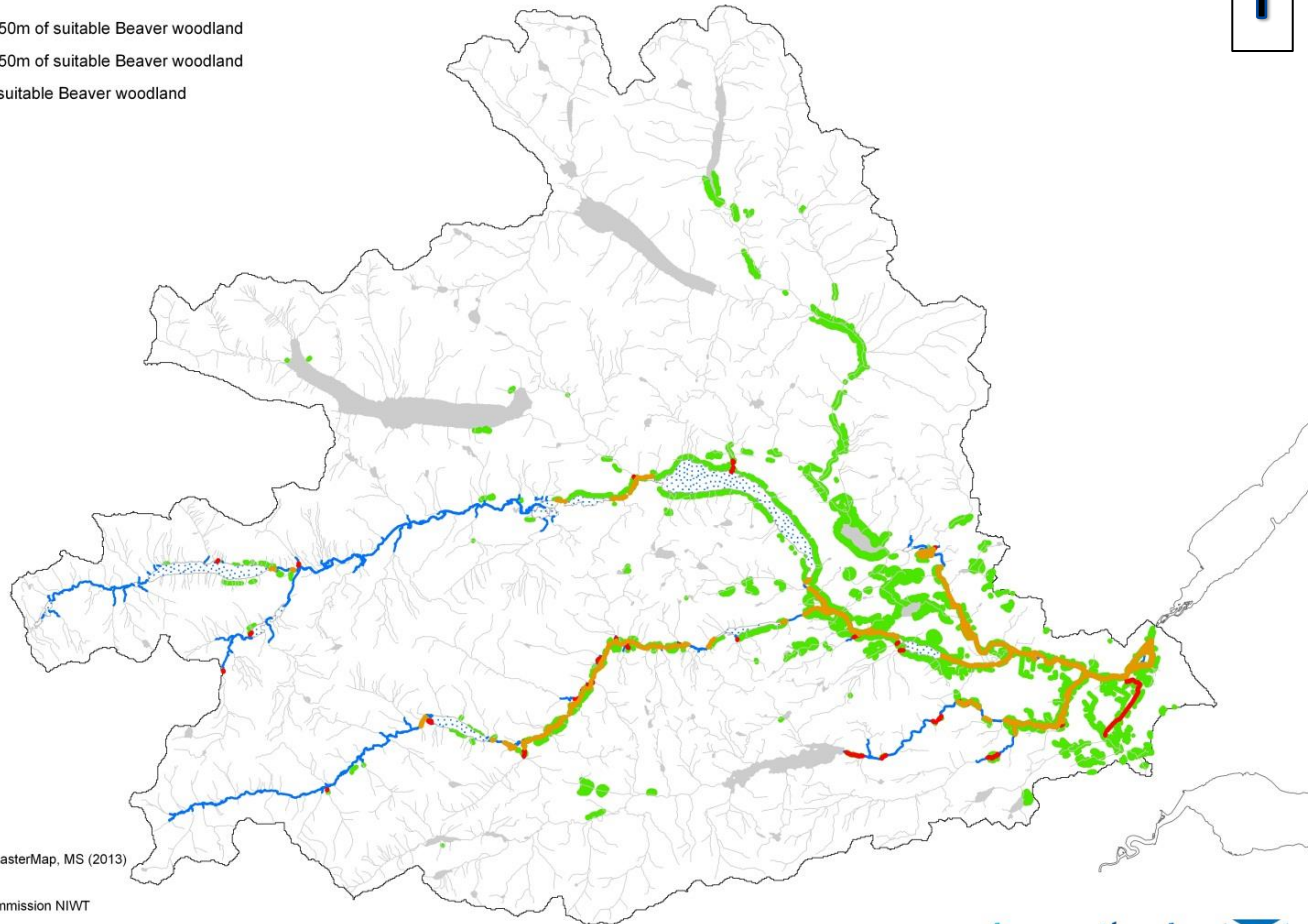




River Conon - Salmon Rivers and Beaver Woodland



- Major salmon rivers within 50m of suitable Beaver woodland
- Minor salmon rivers within 50m of suitable Beaver woodland
- Salmon rivers > 50m from suitable Beaver woodland
- Salmon lochs
- Suitable Beaver woodland
- Other rivers and lochs



Sources: Salmon Rivers, derived from OS MasterMap, MS (2013)
Beaver Woodland, SNH (2011)
Catchment boundary, SEPA (2009)
Beaver Woodland derived from Forestry Commission NIWT and Highland Birchwoods SSNW.
Some features of this map are based on digital spatial data licensed from Centre for Ecology and Hydrology, © NERC.
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marinescotland



2.4 Interpretation and conclusion

The analysis shows that based on potential beaver woodland, a large overlap would generally be expected but will vary spatially, both within and between catchments. It is important to recognise that the possible overlap does not in itself represent the total area over which interactions between beavers and salmon may occur. For example, there may be some additional positive benefits of general nutrient enrichment from activities of beavers extending downstream via nutrient spirals. Conversely, any negative effects of damming may potentially extend for the entire area upstream of beaver distributions. Ideally, mapping would derive locations of likely damming points. However, the data needed to explore this issue are not available in mapping formats, would require extensive ground survey, and even then would be speculative (see appendix 1).

Use of tributaries by salmon varies greatly depending on their abilities to access spawning areas. The relatively low predicted overlap between beavers and salmon in tributaries largely reflects the fact that the distribution of salmon extends in many cases beyond wooded areas in the lower reaches on to open moorland where beavers would not be expected to thrive (Figures 4 a-f). Upper tributaries rear spring salmon that are currently under most threat and hence most vulnerable to any obstructions from beaver dams (see chapters 1 and 3). For the full report, methods, and interpretation see appendix 1.

3. BEAVER-SALMONID INTERACTIONS, WITH NOTES ON OTHER SPECIES

3.1 Introduction

Species of fish that can be impacted by beaver activity range from largely sedentary pool-dwelling fish to highly migratory swift water specialists. The aim of this chapter is to consider specifically how beaver activity might be expected to directly affect river environments and indirectly salmonid populations in Scotland. The scale and direction of beaver fish interactions are dependent on a number of factors and may be influenced by catchment characteristics and the beaver/fish species involved. For example, temperature, flow regimes, species composition and fauna may differ (Kemp *et al.*, 2012). Generally, pool resident fish may benefit from an increase in quantity and quality of their habitat with no impediment to their movements. A full review of salmon biology is provided elsewhere (Aas *et al.*, 2011). The balance of potential positive and negative processes is less obvious. Of equal importance in making this assessment is an appreciation of beaver habitat requirements, and in particular the stream characteristics which are most likely to constitute potential damming areas (see section 1.3). Small streams are of particular importance to trout populations for spawning, and while trout may be more able to utilise pool habitats compared to salmon, beaver-trout interactions may be extensive because beavers can only routinely maintain dams on these small streams.

This chapter provides an assessment of likely interactions and a platform upon which to quantify knowledge gaps. Consideration is also made of possible interactions with the other freshwater species of current conservation interest; eel, lamprey and freshwater pearl mussel. It is important to state that the purpose of this chapter is not a further literature review. Rather the current understanding of salmon in Scotland is presented against the established processes and mechanisms by which beavers and fish may interact, as derived from recent literature reviews and specific beaver-salmonid studies from abroad.

3.2 Other species of conservation interest

The terms of reference of the BSWG only relate to salmonid fish, but it is important to note that salmonids are only one component of our freshwater ecosystem. We have also made efforts where possible to consider other species of conservation importance including eel, lamprey and freshwater pearl mussel. The interaction of beavers with these species has not received extensive scientific examination, and for lampreys and eels little quantitative data exist. While lampreys favour areas of sediment deposition (such as may be expected in beaver ponds) and eels are known to be capable of ascending considerable structures, it is not known how these species will utilise these habitats.

Beavers could have both direct and indirect effects on freshwater pearl mussel through alteration to habitat and indirect effects on salmonids as described in section 1.8. While high levels of sedimentation can be detrimental to the survival of juvenile mussels in particular, and beaver dams may function as a sediment trap, thereby improving substrate for juveniles downstream, if dams are constructed immediately downstream of existing freshwater pearl mussel colonies, monitoring should be considered, further to a consideration of dam removal. On the basis of the lack of evidence available, it is important that these species of conservation interest are fully considered in any future research and monitoring strategy (see chapter 5).

3.3 Literature reviews

There has been no review specifically of interactions between beavers and Atlantic salmon. However, two extensive reviews (Collen & Gibson, 2001; Kemp *et al.*, 2012) have assessed the general processes by which beavers may interact with freshwater fish. Subsequently, further relevant papers have been published which are discussed in this chapter. In the most extensive review, which considers 35 species of fish, and where the primary focus has been on North American countries where most work (88% of studies) has been done, there is more evidence of positive effects on fish than negatives (Kemp *et al.*, 2012). However, although these results cannot be extrapolated directly to salmonid communities in Scotland, these studies are valuable in highlighting the general interaction processes, upon which this chapter is founded (Figure 7).

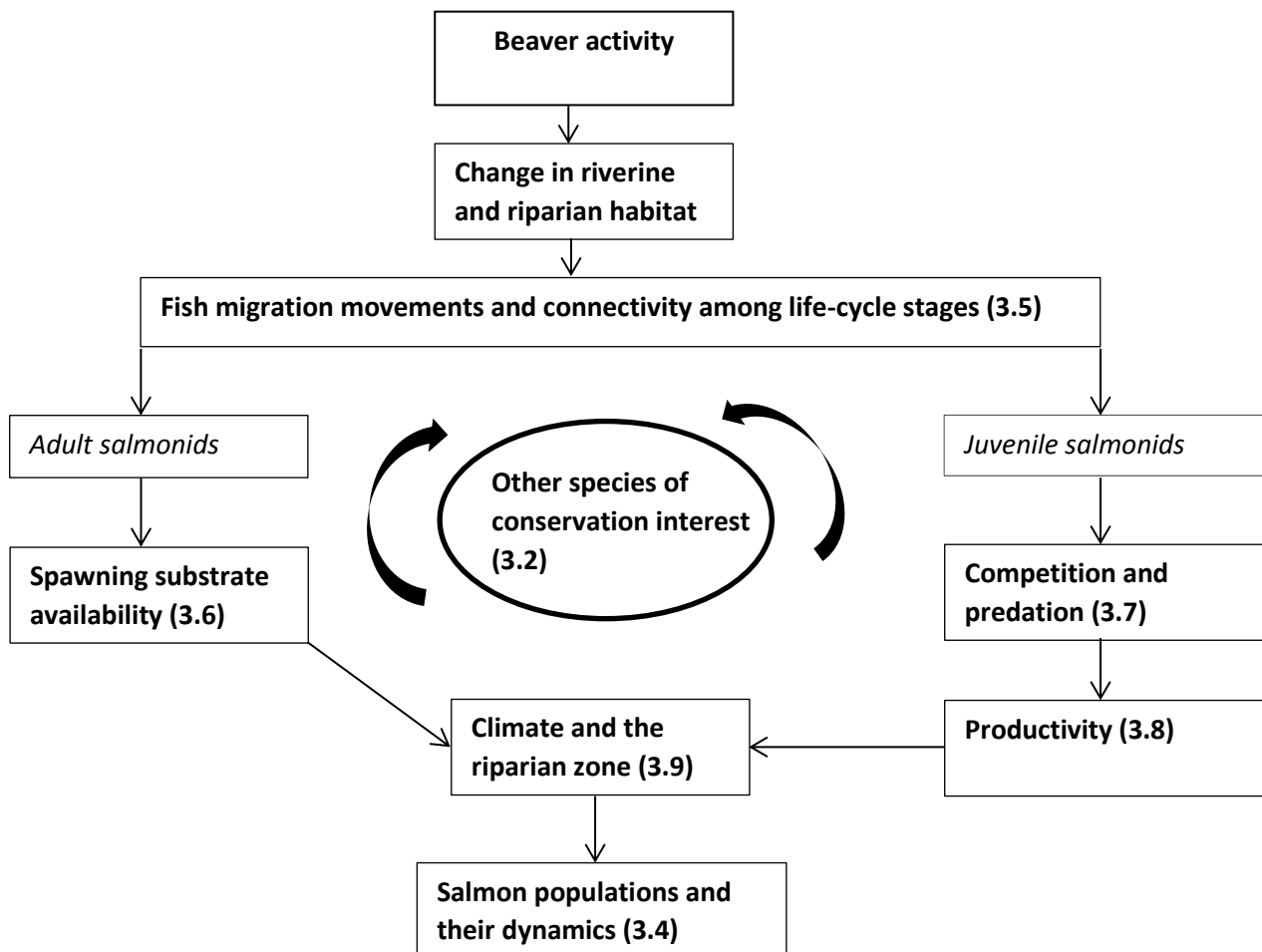


Figure 5: Flow diagram conceptualising the processes by which beaver activity may interact with salmonids and other species within the river system. Boxes with numbers in parenthesis refer to the sections as structured below in this chapter.

3.4 Salmon populations and their dynamics

Salmon in Scotland are structured into populations that are genetically distinct and adapted to their local conditions, and there may be several such populations within a river (Stewart *et al.*, 2006). Scottish salmon return to rivers throughout most of the calendar year, providing an extended angling season (see section 1.5). Generally, those salmon that return earlier in the year (called spring salmon) spawn higher up the catchment. Scottish salmon populations have generally declined in recent decades (see section 1.6).

The salmon's life cycle is described in section 1.5, including the juvenile freshwater phase, providing the link between spawners and recruits as shown in Figure 6. The relationship between annual numbers of spawners and the smolts that they produce may be simplified into what is called a stock-recruitment curve (Figure 6). Smolt production increases with number of spawners (rising limb of the graph) up to a saturation level (maximum production). The maximum number of smolts is limited by competition among fish for food and space, resulting in fish density-dependent growth and survival. Furthermore, there may be competition among juvenile fish of different ages (inter-cohort) within the stream. These processes are further affected by the spatial distribution of habitats that are most suitable for spawning and rearing these different life stages, combined with dispersal ability and predation. Once populations of salmon are released from the constraints of space and food in rivers as they migrate to sea, individuals grow rapidly. Although mortality of salmon at sea is highly variable from year to year, this mortality is independent of the population density (Jonsson *et al.*, 1998). It is important to understand this point because reduction in recruitment of smolts will result in a proportionate reduction in numbers of returning salmon.

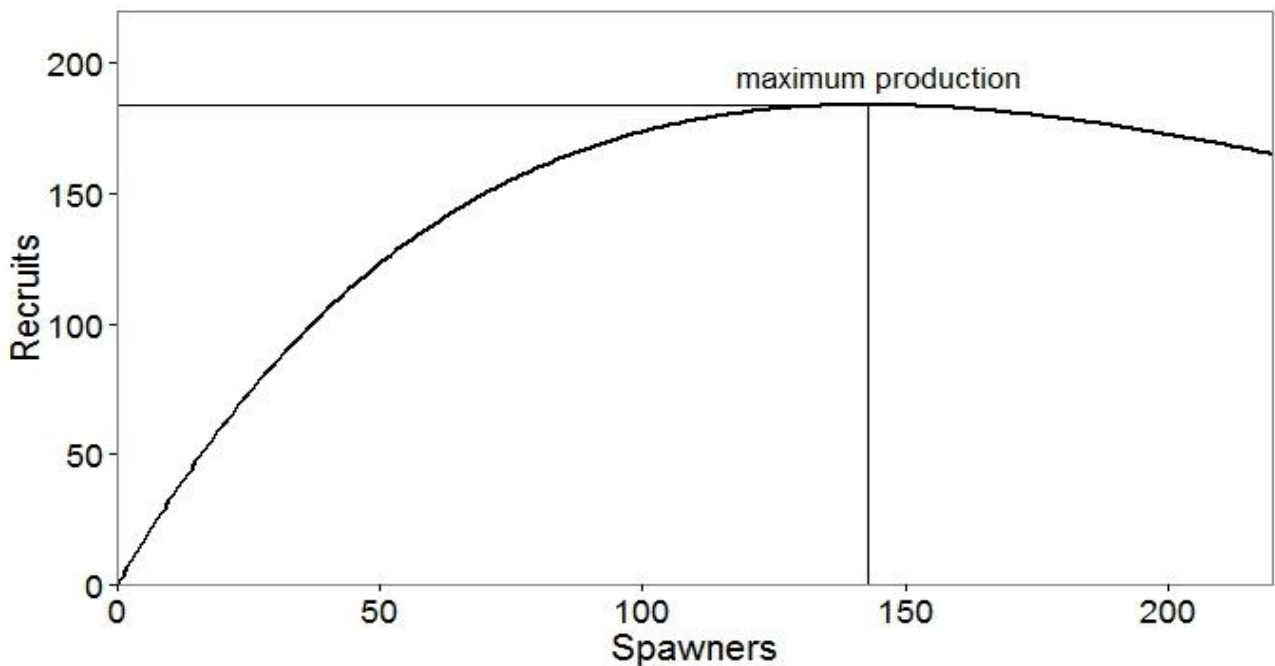


Figure 6. Idealised stock recruitment relationship between the number of successfully breeding adult salmon (spawners) and the number of smolts subsequently produced (recruits). In practice, data are widely scattered around such a theoretical curve. The maximum production (maximum number of recruits) is shown along with a theoretical number of spawning adult fish required to obtain that maximum production.

Summary of population responses

Considering the overall life-cycle of salmon, and the complex combination of factors that determine the relationship between adult spawners and subsequent production of recruits, four particularly important features are of clear relevance to potential interactions with beavers:

Enrichment of food supply and physical habitat, where such factors were limiting production, will be beneficial and increase the production of recruits.

Limitation in the number of spawning salmon to the extent that the population moves down the rising limb of the stock recruitment curve reduces smolt production and increases risk of extinction.

The population includes a number of cohorts at any point of time, typically in Scotland, up to four in fresh water and two at sea. This provides resilience to survive a number of years of no spawning due to obstruction to spawner migration, albeit with temporarily reduced smolt production.

Any reduction in salmon smolt output (recruits) would be expected to result in a largely proportionate reduction in the number of returning adults.

3.5 Fish migration movements and connectivity among life-cycle stages

Salmon and trout move through rivers at different points of their life cycle, including upstream spawning migration and seaward movements after spawning, within-river juvenile movement between habitats, and downstream (smolt) emigration to the sea. Hindrance to adult spawning migration is the most commonly cited negative effect of beavers on fish (including salmonids) (Kemp *et al.*, 2012), with the location and integrity of beaver dams and autumn stream flow interacting to determine the uppermost extent of spawning in any year in Catamaran Brook, New Brunswick (Mitchell & Cunjack, 2007) and Brierly Brook, Nova Scotia (Taylor *et al.*, 2010). In Scotland the occurrence of high flows during salmonid spring and autumn migration periods will vary by year and between regions with generally greater rainfall in western regions compared to the east coast. The potential for obstruction to movement may relate inversely with discharge.

Beaver colonies can often exist without creating dams. The period during which dams may persist can vary enormously, and dams may be rapidly replaced following their loss in floods. The density of functional dams in a river landscape is expected to vary with season and flow regime and the range of specific physical conditions under which beavers may be capable of constructing dams has been described using a variety of metrics, including stream gradient, stream order, stream power, depth, width and valley shape (see section 1.3).

3.5.1 Adult spawning migration

Adult salmon migrate into rivers throughout the year in many parts of Scotland whereas Sea trout tend to migrate into rivers predominantly in summer months. Trout and salmon undertake spawning migrations predominantly during the autumn and winter months. They may remain in wide, deep reaches, such as main stems, or adjoining rivers (Stewart *et al.*, 2006) before migrating to smaller rivers and tributary burns close to spawning sites in autumn. Accessibility of spawning burns to salmonid fish depends on characteristics of water flow and degree of physical obstruction (reviewed by Thorstad *et al.* 2007). Small tributary streams commonly

provide important spawning and rearing habitat for salmon and trout and it is known that for salmon it is important that fish gain full access to the upper reaches of streams in order to maximise breeding success (Hay, 1989). Mature trout can also undertake considerable within-river migrations driven by feeding and breeding requirements. As these fish may commonly utilise small streams (see section 1.7), the interaction of dams and trout movement requires further research.

Fish access to spawning habitat upstream of beaver dams is highly variable depending on dam integrity and the magnitude and occurrence of high water flow events (Mitchell & Cunjack, 2007; Taylor *et al.*, 2010). In these studies, North American beaver dams fully prevented upstream passage in some years, and had no detectable effect in others. In Catamaran Brook, New Brunswick, a particular beaver dam in one year was believed to limit spawning distribution, and may have resulted in a subsequent reduction in survival, and an increase in emigration of salmon fry hatched below this dam in the following year (Cunjack & Therrien, 1998). Juvenile trout and salmon parr in a small Norwegian stream were found above 4 dams ranging from a height of 0.5m to 1.6m, although the authors acknowledge that these individuals may be the progeny of adult salmonids that spawned upstream of the dams, or that these juveniles negotiated the dams themselves (Halley & Lamberg, 2001). Even if fish are able to pass in-stream structures such as beaver dams, these may cause delays, expenditure of additional energy and increased predation risk. The potential and scope for beaver dams to delay salmonid migration has not been investigated in detail.

While tagging and monitoring of individual fish in the context of beaver dam passage has received considerable attention for adult trout species in Utah, U.S.A (native Bonneville cutthroat trout *Oncorhynchus clarkii* (Richardson), non-native brown trout and non-native brook charr *Salvelinus fontinalis* (Mitchill), in Lokteff *et al.*, 2013) and for juvenile salmonids in Alaska (chinook *O.tshawytscha* (Walbaum) and coho *O. kisutch* (Walbaum), in Malison *et al.* (2014), there are currently no comparable data for salmonids available in a European context. A recent one-year study has been conducted in Lithuanian trout streams in a region of high beaver population density. The authors have suggested that based on electrofishing data and redd counting, beaver dams cause hindrance to trout movements in some cases (Kesminas *et al.*, 2013). However, habitat characteristics of Lithuanian streams tend to be different to those of Scotland.

3.5.2 Juvenile fish movement

Movement soon after hatching in juveniles is predominantly downstream and generally at a scale of a few hundreds of metres (Einum *et al.*, 2011). These young fish may move through the gravel and may negotiate beaver dams, although it is not clear whether passage through beaver ponds would have associated mortality risk and hence be avoided (e.g. due to accumulations of fish-eating trout). At the subsequent parr stages, in some populations home ranges may extend over hundreds of metres, and it is not clear how easily these fish may negotiate beaver dams. Parr may also migrate during spawning to find females, in relocating to find overwintering habitat, and in migrating out of tributary streams in autumn. These small fish are adept at finding routes through gravel and it would not be surprising if some dams are passable.

3.5.3 Downstream smolt movement

Salmon and trout smolts migrate from rivers during spring. The majority of smolts running in any given year are expected to reach salt water generally between March and June. Given the wide range of beaver dam structures and habitats throughout Scotland, it would not be surprising if there was substantial variation in their passability to smolts. Although not in the context of beavers, a recent study in the Tweed Catchment concluded that sea trout smolts can be impeded by small overflowing concrete weirs, and that these hindrances are increased during periods of extreme low flow (Gauld *et al.* 2013). This study found that predation, thought to be predominantly from terrestrial and avian predators, was higher in a year of low flows (19% survival rate)

compared to a year with no extremely low flows (45% survival rate). Beaver dams are far more porous and dynamic than concrete weirs, but the extent to which smolts can pass through or over these natural structures remains unclear, particularly during low flow conditions. As stated above, the possible implications of any delays to smolt migration arising from beaver dams are unclear.

3.5.4 Human land use

With the Scottish riverine landscape currently in a largely semi-natural state, the balance of interactions will be influenced by the degree of degradation. For example, weirs, fish passes, and culverts constitute structures against which beavers can engineer dams in certain circumstances, and any construction in such circumstances has the potential to exacerbate fish passage constraints (see section 4.6). Channel modifications or incisions may also reduce lateral connectivity with the river floodplain (Kemp *et al.* 2012), requiring beavers to construct larger dams in order to raise water levels to inundate the floodplain and gain access to food resources (Taylor *et al.*, 2010). Flow regulation, hydro-damming or water extraction may also alter the natural flow regime, and may influence the natural cycle of beaver dam reduction or destruction in floods.

Summary of potential effects relating to fish access

Beavers are capable of constructing and maintaining dams only in specific circumstances. In streams where culverts, weirs and fish passes are present in direct proximity to beaver dams, fish passage constraints are likely to be exacerbated. It is difficult to quantify the impact of beaver dams on the movement of juvenile salmonids. Beaver dams could obstruct or delay both emigration of smolts and spawning migrations of adults in some circumstances, particularly where low flows persist. In seasons characterised by high flows fish passage concerns at beaver dams may be reduced.

3.6 Spawning substrate availability

Salmon and trout generally spawn in gravel/cobble substrates at the tail of pools with low intrusion of fine organic sediments for spawning (Armstrong *et al.* 2003). The surface area of beaver ponds is determined by dam height, stream gradient and channel shape (e.g. Fuller & Peckarsky, 2011). Therefore, the area of a pond from a dam would tend to be larger at lower gradients. Dams may have both positive and negative effects. The conversion of shallow, fast-flowing water to slower, deeper water in beaver ponds may impound and locally reduce spawning habitat in some circumstances (Collen & Gibson, 2001; Kemp *et al.* 2012). Conversely, in catchments where siltation acts to limit spawning habitat suitability, beaver dams could act as natural filters capable of improving substrate suitability. Such benefits are more likely to be realised in lowland agricultural areas in Scotland. However, potential impacts arising from beaver ponds on spawning are likely to be of a greater magnitude in such areas because of lower gradient. In some Scottish streams suitable spawning areas may be rare, such as the Girnock Burn on the upper Aberdeenshire River Dee. Hence, in some situations although impoundments and inundation may be localised, they could have significant impact.

Summary of potential effects relating to spawning substrate

There is the potential for beaver dams to act as sediment traps, making downstream habitat more suitable for salmonids in agricultural regions. There is also the potential for a reduction in spawning and juvenile salmon habitat, resulting from the localised conversion of shallow, fast-flowing water to slower, deeper water, and sediment deposition. There is a clear need to monitor potential losses and gains in spawning habitat, particularly where such habitat is limited.

3.7 Competition and predation

Competitive interactions between trout and salmon mean that these species may occupy different micro-habitats within the same river or stream. Presence of beaver dams may result in changes to the composition of in-stream habitat to favour one species over another.

In Scotland, Atlantic salmon co-occur across much of their range with brown trout, (see section 1.7). These species differ in their morphology such that salmon have adapted to life in swift waters, whereas brown trout are dominant in pools (Armstrong, 2010). Both species are threatened by invasive fish species, notably the European minnow, and the northern pike. Minnow are small shoaling cyprinid fish that occupy pools and hence exert competition on salmon and trout (Museth *et al.*, 2007). Pike are predatory fish that also generally inhabit slower flowing areas and can have devastating consequences for salmon, particularly through consumption of smolts on their downstream emigration to sea (Kekalainen *et al.*, 2008).

In a recent three –year study of Polish mountain streams (Bylak *et al.*, 2014) found significant differences in fish species composition in beaver ponds compared to nearby stream sections. Trout fry and spawning habitats were found upstream of impoundments with minnow and stone loach recorded at higher densities in ponds.

There may be benefits for salmon through additional pool habitat, with the extent of any such effect requiring further investigation, as there is conflicting evidence that trout and salmon of similar size can co-exist in pools with benefits to salmon (Hojesjo *et al.* 2010). Overall, there is little information regarding salmon in slow-flowing deep habitats to enable quantification of these interactions (Armstrong & Nislow, 2006).

Although beavers do not eat fish, in Scotland juvenile salmonids are eaten by a range of species, including pike, otter *Lutra lutra* L., heron *Ardea cinerea* L., goosander *Mergus merganser* L., red-breasted merganser *Mergus serrator* L. and cormorant *Phalacrocorax carbo* (L.) (Gowans *et al.* 2003). An increase in pool habitats may favour trout over salmon and increase habitat for minnows, pike and other competitors and predators. The risk of increased fish predation in beaver ponds has been cited as a concern (Collen & Gibson, 2001). This may be particularly relevant in relation to downstream smolt migration. In some circumstances smolts may be subject to increased predation from species such as pike which favour slow flowing water, and may have to negotiate a series of predator-occupied ponds during their migration to sea. Kemp *et al.* (2012) also noted that cover from bird and mammal predators may also be provided by large woody debris or increased water depth within beaver ponds. However, it is not currently clear how this would apply to Scottish streams.

Summary of effects related to competition and predation

Beaver mediated changes in habitat composition from riffle to pool habitat may favour trout at the expense of salmon by creating additional habitat for larger trout. It is difficult to predict the effects of beaver ponds on the complex interactions between salmonid fish, and other fish, bird or mammal predators. The possibility of increased predation, or conversely the potential for ponds to provide cover against predators, warrants further research.

3.8 Productivity

The age of a beaver pond is a factor which governs the productivity of aquatic organisms including salmonids in North America (Malison *et al.* 2014), and a range of fish species in Poland (Bylak *et al.* 2014). As the beaver pond ages, resultant salmonid productivity can increase in the first 2-4 years after dam construction, before declining thereafter (Peterson, 1951; Hale, 1966). In New Brunswick, in a newly constructed beaver pond, age-2 Atlantic salmon parr exhibited faster summer growth rates in body length and mass than those above or below the pond (Sigourney *et al.*, 2006). A recent study in Alaska concluded that beaver pond age was a major driver of habitat use by juvenile coho and chinook salmon (Malison *et al.* 2014). In a study of Polish mountain streams Bylak *et al.*

(2014) found significant changes in fish species composition in beaver ponds associated with pond ageing, which were unfavourable for stream-dwelling Siberian bullhead, but resulted in trout of double average length compared to those from stream areas.

Within beaver ponds, the ecosystem processes by which primary production, invertebrate biomass, presence of fish species and fish productivity evolve over seasonal and annual timescales warrants further investigation in Scotland. While newly created impoundments may be beneficial for salmonid fish production, long-standing ponds or abandoned sites may be detrimental. Elevated growth opportunity may be a function of low fish density in ponds, and may not translate to an improved rate of survival.

The only study to assess the impact of Eurasian beavers on salmon and sea trout at a watershed-scale concluded that in a Norwegian river system, out of 51 tributaries used by sea trout for spawning, 18% of these were also used by salmon. 29% of the 51 tributaries with spawning sea trout and 67% of the tributaries with spawning salmon had intermittently been occupied by beavers. Five dams were functioning in the catchment during autumn 2003, with the density of beaver colonies on the main river ten times that found in tributaries. Therefore, the majority of salmon production in this particular catchment was unaffected by beavers (Parker & Ronning 2007). Knowledge of the distribution of trout in Scotland is limited compared to that of salmon, and the occurrence of salmon habitat in tributaries in Scotland (see chapter 2) is proportionately greater than this particular Norwegian system.

The presence of beaver dams has been reported to cause changes in the availability of potentially limiting nutrients by several chemical and biochemical processes (Naiman *et al.*, 1994). Breakdown of flooded terrestrial vegetation would release nutrients that could be taken up by invertebrates, increasing the food supply for juvenile fish. The presence of beaver ponds would increase freshwater residence time in upland areas potentially with corresponding increases in nutrient flux and invertebrate biomass. Effectively, beaver activities may accelerate the flow of nutrients from vegetation to the aquatic community (Naiman *et al.*, 1994). However, the sustainability of this process depends on complex processes which allow sufficient nutrients for growth of micro-organisms and for plant regeneration. This requirement may not be met in nutrient poor Scottish upland systems as pools may act as nutrient sinks (Willby *et al.* 2014) and hence deplete nutrients in riffle habitats used by juvenile salmonids.

Nutrients in streams encourage the growth of in-stream algae and plants, but only if there is sufficient light. Beavers may increase light levels by cropping bankside trees. This could increase in-stream primary productivity potentially leading to increased production of some groups of invertebrates. Beaver activity can result in a general increase in the abundance and diversity of herbaceous wetland plants, and can influence biogeochemical processes of watersheds because of the creation of ponds (Kemp *et al.* 2012). Detrimental effects on water quality within and below beaver ponds have been described with reduction in dissolved oxygen the most frequently cited negative response (Kemp *et al.* 2012). The deposition and retention of sediment and organic material can increase acidity within beaver ponds over time, but conversely the trapping of such organic-rich sediment may reduce overall stream acidity levels (Kemp *et al.* 2012). The latter would be positive for salmonids where low pH is a limiting factor (e.g. south-west Scotland or parts of the Cairngorms), but would have little effect in alkaline systems (Collen & Gibson, 2001). Assessing effects on water chemistry is highly complex and will be dependent on local circumstances and whether pre-beaver hydrochemistry conditions were limiting to fish production.

Salmon feeding in fresh water has been extensively studied, providing the general conclusion that juveniles are largely flexible and opportunistic in response to local environmental conditions (Johansen *et al.* 2010). Aquatic invertebrates provide the main food source for many fish species including salmonids. Whilst there may be an increase in overall invertebrate biomass, it is unclear how this change in invertebrate community structure and

biomass may benefit particular species of fish. Beaver ponds are likely to support an increased biomass of large invertebrates (reviewed by Collen & Gibson, 2001). (Hering *et al.* 2001) reviewed the effects of beaver activity on invertebrate community assemblages in Central European mountain streams, concluding that (for prey known to be relevant to salmon) it is likely that mayfly, blackfly and midge abundance will increase, whereas stonefly and caddisfly abundance will decrease.

Juvenile salmonids require some form of physical cover within streams and such cover can be provided by coarse substrate, stream margins or encroaching bankside vegetation. In terms of salmonids, woody debris may provide cover, maintenance of substrate heterogeneity and increased invertebrate production. Woody debris can provide valuable cover and can also act as a filter of fine sediment. Woody debris has the highest value in streams where other forms of cover are lacking (for example where there is a fine substrate and no in-stream vegetation). In-stream cover is commonly provided within beaver impoundments by the dam and other large woody debris, food cache material and aquatic vegetation, and cover can also be provided by food cache stores in running water not associated with a dam. It is important to note that some fishery managers in Scotland are trialling the input of woody structures into streams, with the aim of enhancing cover and substrate diversity.

Summary of effects related to productivity

At catchment-scales, beaver-salmonid interactions may be governed by the relative importance and use of small streams by trout in comparison with salmon.

The ecosystem processes by which fish productivity in beaver ponds can evolve over seasonal and annual timescales warrants further investigation in Scotland. While newly created impoundments may be beneficial for salmonid fish production, long-standing ponds or abandoned sites may be detrimental.

The presence of beaver dams may boost the availability of nutrients, although these processes may not be beneficial in nutrient poor upland streams. Beavers may increase light levels by cropping bankside trees and this could increase in-stream primary productivity.

Whilst there may be an increase in overall invertebrate biomass, it is unclear how this change in invertebrate community structure and biomass may benefit particular species of fish. Additional in-stream cover resulting from the activities of beavers may be beneficial in some circumstances.

3.9 Climate and the riparian zone

3.9.1 Climate and river flow

The impact of changing climate on the interaction between fish and beavers may be speculated. With summer air temperatures in Scotland expected to rise by 1.5-2.5°C over the next century (Solomon *et al.* 2007), these increases are of increasing concern for salmonids (Todd *et al.* 2011). Extreme weather will become more common over this period, leading to a projected increase in seasonal amplitude of flow regime, with the potential for extended drought periods (Bates *et al.* 2008). Winter precipitation is likely to increase by 10-20% across much of the salmon's range with uncertainty remaining around projected changes in summer precipitation in the UK.

Beaver dams can stabilise flow in some cases by increasing water residence time within catchments, elevating water tables and by decreasing the amplitude of the flow regime (Finnigan & Marshall, 1997; Kemp *et al.* 2012). In drought periods this flow stabilisation could potentially benefit fish populations (Kemp *et al.* 2012) as described in North America (Cook, 1940; Knudsen 1962) and Sweden (Hagglund & Sjoberg, 1999). The magnitude of these potential benefits (in the Scottish context) will be governed in part by the density of functioning dams in any particular catchment. While these aspects of beaver activity may be negligible in the current climate, in future, flow stabilisation, elevation of water tables and flood/drought refuge will become increasingly relevant.

3.9.2 Temperature and riparian regeneration

Stream temperature has an important influence on living organisms and the aquatic system (Caissie, 2006) with temperature conditions affecting fish during the entire freshwater phase of their life cycle (Elliot, 1991). Beaver induced alterations to stream temperature occur through two broad mechanisms: By changing the surface area and depth through damming Fuller & Peckarsky, (2011), and by changing the level of direct sunlight reaching the stream through riparian coppicing (Cook 1940). Theoretically, beaver-induced increases in water temperature may be beneficial in cool areas where fish production is temperature limited, but increases in temperature would reduce fish production if it exceeds the thermal optimum of a particular species (Kemp *et al.* 2012). Juvenile salmon growth rates are typically constrained outside temperatures of 4.9-26.7 °C, with the optimum being 16-20°C (Elliot & Hurley, 2003; Jonsson *et al.* 2001). For trout, growth can occur between 3.5°C and 19.5°C, with maximum growth at 13°C (Solomon & Lightfoot, 2008).

A review of the effect of forested riparian zones on stream temperature is available elsewhere (Moore *et al.* 2005). Much of the riparian tree cover which would have been present in the ancient Scottish landscape has been lost, with a resultant reduction in river shade. Excessive riparian woodland can also be damaging to salmonids, through shading out light and hence reducing in-stream primary productivity. In such instances where broad-leafed riparian woodland exists (rather than coniferous riparian woodland), beaver activity may be advantageous. Riparian tree cover also provides shade, capable of reducing peak summer stream temperatures, with recent analysis showing that extension of broadleaf riparian forests into upland headwater streams represents one potential measure for mitigating climate change impacts on salmonids (Garner *et al.*, 2014; Hrachowitz *et al.*, 2010; Malcolm *et al.*, 2008). Fishery managers and conservation organisations are now implementing broadleaf tree-planting schemes and facilitating natural regeneration through herbivore exclusion. The purpose of this is to provide dappled shade, with a view to mitigating expected future increases in stream temperatures. Such schemes warrant particular attention and until woodland becomes fully established, should be protected from beaver activity.

In areas where riparian trees are established, the influence of beaver activity may in some cases enhance riparian regeneration rates (Donkor, 2007; Fryxell, 2001). However, in the scenario that riparian livestock or deer grazing pressure is excessive, natural regeneration after beaver cropping may be suppressed (Marshall *et al.*,

2013). In Scotland and in the presence of moderate roe deer grazing pressure rapid regeneration of willow and aspen after felling by beavers has been observed (Jones *et al.*, 2009). Iason *et al.* (2014) provide a synthesis of woodland monitoring undertaken to date at Knapdale.

Summary of effects related to climate and the riparian zone

Climate change presents an increasing challenge to salmonids. The effects of beaver activity on stream temperature, flow stabilisation and flow refuge, warrant further research.

The activities of beavers are in some cases cited as a factor capable of enhancing the rate and extent of riparian regeneration processes.

Riparian tree planting schemes warrant particular attention, and until woodland becomes fully established, should be protected from beaver activity.

3.10 Conclusion

There are a range of processes associated with the presence of beavers that may interact with Scotland's fish communities, and rather than considering these in isolation, it is important to view these dynamic interactions together within the aquatic system. For example, in Atlantic salmon these effects can be expected to change the relationship between the number of successfully breeding adults, and the number of smolts subsequently produced, such that any increases in production through food enrichment, change in temperature and provision of critical limiting habitat may increase the maximum productive potential. However, negative effects, such as obstruction to migration, increased risk of predation, or competition, may reduce the productive potential of streams for salmon, and hence cause an actual reduction in the number of smolts produced in any given year. In practice, there is inadequate information to determine the net response at catchment scales, and it can be expected that there will be local variations in the balance between, and relative magnitude of, these positive and negative impacts. However, it is clear that as a swift water migratory species, salmon will be more susceptible to negative effects than many other resident salmonids. In the specific case of spring salmon, which generally utilise upland, nutrient poor streams, it is likely that the potential for obstruction to migration will outweigh potential positives (as these are unlikely to be realised in such nutrient poor upland areas). There is a need to collect the necessary information in the range of habitat contexts in Scotland in which salmon and beavers would be likely to coexist (see Chapter 5). The magnitude of maximum potential beaver-salmon overlap is expected to vary within and between catchments (see Chapter 2).

Should the Minister decide to proceed with a licensed reintroduction programme, monitoring of streams, and active management will be necessary. Based on the information available, the extent to which management will be required cannot be predicted, perhaps with the exception of instances whereby beaver dams are constructed upon human infrastructure such as culverts, where the need for intervention is pronounced. In the current interim period before a scientific consensus is reached and accepted, a precautionary approach to management is suggested, given the present concern around salmon population status.

4. MANAGEMENT OF INTERACTIONS

4.1 Introduction

This chapter defines beaver-salmonid monitoring and management, its legal implications, applicability, practicality, and approximate cost. It also makes the case for the management of beaver dams and potentially of beavers in the context of fisheries conservation. Using limited experience from Europe and North America applied to the Scottish context, and given the potential overlap between beavers and salmon in the minor rivers and tributaries (chapter 2), monitoring alone (prior to any potential management action) can be expected to constitute a significant expense. A review of beaver management will be available as part of the package of information provided to the Minister for Environment, Climate Change & Land Reform in May 2015 (Campbell-Palmer *et al.* 2015).

While the focus of this chapter is on the potential management costs which may arise from beaver presence, the potential socio-economic or ecosystem services provided by beaver activity must also be kept in mind. Further, although for the majority of this chapter management infers the act of mitigating a problem, beaver-salmonid management in other regions with differing fish communities from Scotland (such as western North America) may alternatively be defined as actively harnessing beaver activity to improve habitat heterogeneity (Pollock *et al.*, 2007, 2014). However, for the purposes of this chapter, the scope is limited to regions in which beavers (*Castor* spp.) and Atlantic salmon co-exist. From experience in eastern North America and Eurasia, the majority of general beaver management takes place as a result of beaver-human conflict. Beaver-salmonid management intervention is different in that it is undertaken as a result of actual or perceived species-species conflict. With the low density of natural predators in much of Europe, beaver populations are known to grow until the availability of habitat and food supply is limiting, and to mitigate impacts on agriculture and infrastructure, a range of general beaver management techniques have been utilised (Nolet & Rosell, 1998). For example, in North America notches can be created in dams to improve fish passage Taylor *et al.* (2010), culverts can be protected from damming through the installation of a protective fence, and the regular use of beaver scent and predator odours are believed to help influence colonisation (Engelhart & Muller-Schwarze, 1995). Translocation of problem beavers is common in some countries and culling of beavers is also undertaken under licence where applicable, although culling (or translocation) is often a temporary solution to human-beaver conflicts, as other beavers can re-occupy vacant territories (Nolet & Rosell, 1998).

Although beaver foraging activity may occur up to 100m from water, the majority (95%) occurs within 5m in Denmark Elmeros *et al.*, (2003) or at Knapdale in Scotland the majority of activity is recorded within 10m (Iason *et al.*, 2014). European beaver management experts recommend the proactive measure of maintain a functioning riparian vegetation strip, which acts to physically separate the majority of beaver activity from human activity (Nolet & Rosell, 1998).

This chapter does not set out to prescribe when and where management intervention is required. Rather, based on the evolving literature base (chapter 3), a case by case assessment is necessary. Prior to undertaking management intervention, there are a number of important considerations, including legislation. While the inevitable focus is on the potential management costs, the potential ecosystem services provided by beaver presence must also be kept in mind. These will result in socio-economic benefits (Moran & Lewis, 2014) which are relevant to the wider community, including those involved in fisheries. They are often more difficult to measure but will not be insignificant. These ecosystem services may reduce the need and costs of current management programs involved in the regulation and maintenance of waterways. For instance, beaver may reduce diffuse pollution by increasing pollutant storage and also by increasing sediment retention. They may also help with the mediation of flows by stabilising stream flow, and by reducing the size of floods. Beaver may

also help to restore watercourses by improving sinuosity, restoring incised streams, and promoting the recruitment of some water demanding tree species such as willow and alder. Finally, there are the wider cultural benefits caused by an increase in riparian biodiversity and possible sightings of charismatic mammal, which will benefit all those who use and enjoy riparian areas for recreation.

4.2 Legal considerations

4.2.1 European designations

Legal considerations associated with species and habitat protection are major factors in modern nature conservation. For example, Atlantic salmon is a qualifying species in 17 riverine Special Areas of Conservation (SACs) in Scotland (see chapter 1). The Salmon and Freshwater Fisheries (Consolidation) (Scotland) Act 2003 contains a number of provisions in relation to the maintenance of free passage for migratory fish.

The Eurasian beaver is listed under the Habitats Directive Annex IV, providing the species special protection (Article 12) through prohibitive and preventative measures, with suitable monitoring and enforcement strategies required to be administered at a national level (Pillai *et al.* 2012). The species is also listed under Annex II, enabling the designation of SACs for beaver as a qualifying feature. Annex IV prohibits the deliberate capture or killing of beavers, further to disturbance, deterioration or destruction of breeding or resting sites (Habitats Directive, Article 12 (1)). This legislation is transposed into UK/Scottish legislation via the Habitats Regulations, although at the present time Eurasian beaver is not listed as a 'European Protected Species' (EPS) in Scotland. However it is anticipated that beaver would become an EPS if the Minister gives approval for the formal reintroduction of the species. There are no legal exceptions to these provisions without formal licensed permission.

Certain conditions are required in order for a species licence (for example to allow culling, translocation or dam removal) to be granted under the Habitats Regulations, where "no satisfactory alternatives" are shown to exist. In considering appropriate measures (of relevance to maintaining stream access to salmonids for example), it is difficult to interpret what may be deemed a "satisfactory alternative" (Pillai *et al.* 2012). For example, a "satisfactory alternative" to culling may be dam notching or removal because where a dam does not conceal a beaver breeding or resting site, it is thought that notching or complete removal would be permissible without a licence (see Figure 7), although it is up to the licensing authority (SNH) to make a judgement on how this will be interpreted.

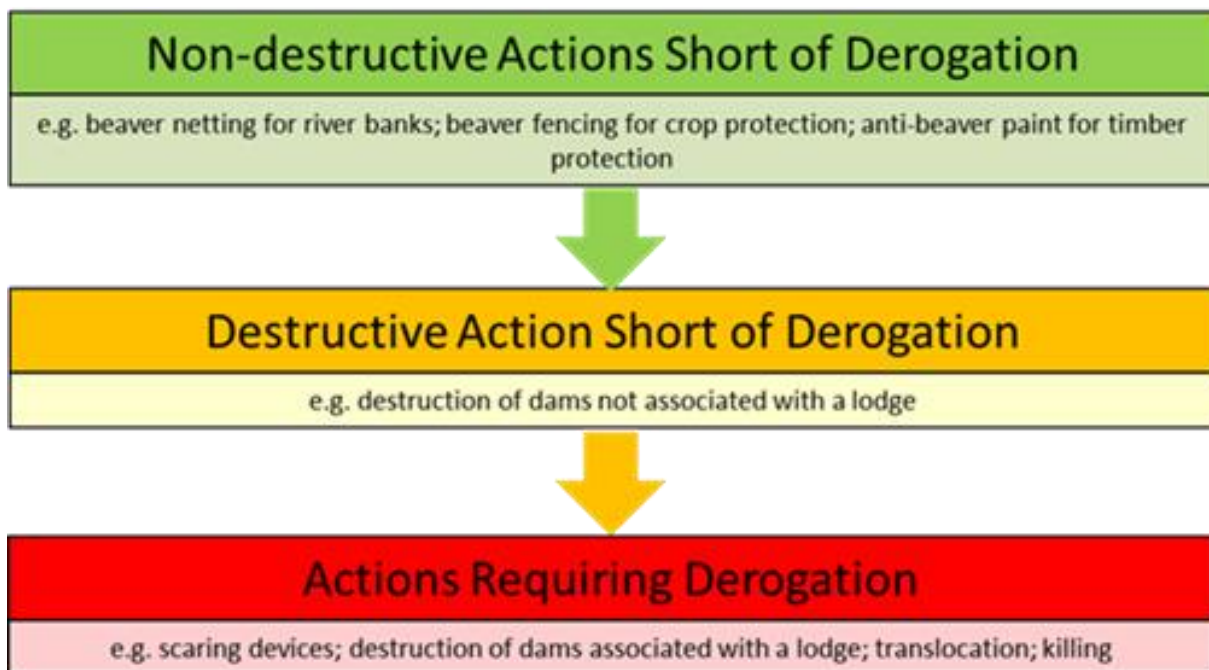


Figure 7: Beaver management actions and derogation (licence) requirements under The Habitats Regulations (Source: Pillai *et al.* 2012). Note that these are the views of the authors, and not necessarily those of the relevant licensing authority (SNH).

It is likely that the following types of actions may require a species licence (although SNH would ultimately decide).

- Beaver exclusion
- Modification of beaver structures associated with a breeding or resting site
- Beaver removal, including culling
- Other technological mitigation such as electronic scaring devices

A species licence may be issued under the Habitats Regulations for the following five purposes:

- In the interest of protecting wild fauna and flora and conserving natural habitats;
- To prevent serious damage, in particular to crops, livestock, forests, fisheries and water, and other types of property;
- In the interests of public health and public safety, or for other imperative reasons of overriding public interest, including those of a social or economic nature and beneficial consequences of primary importance for the environment;
- For the purpose of research and education, of repopulating and re-introducing these species and for the breeding operations necessary for these purposes, including the artificial propagation of plants;
- To allow, under strictly supervised conditions, on a selective basis and to a limited extent, the taking or keeping of certain specimens of the species listed in Annex IV in limited numbers specified by the competent national authorities.

Pillai & Heptinstall (2013) report that any measures featuring the capture or killing of beaver are required to be “selective”, “limited” and “strictly supervised” by relevant national authorities. One specific issue which has been raised is in the case of 13% of beaver lodges in Sweden (Hartman & Tornlov, 2006), where a beaver dam serves to elevate water levels to conceal the entrance to the beaver lodge or burrow. The legislation may be interpreted to suggest that interference in this situation would be an offence. Consideration of beaver welfare is required as sudden exposure of the lodge or burrow entrance can result in a potential increased risk of predation for the beavers, which has been shown to result in increased movement of beaver colonies, body weight loss (Smith & Paterson, 1991), and in some cases starvation (Wilsson, 1971). The approach applied to beaver management and licensing considerations in Bavaria is described in Pillai *et al.* (2012). SNH will be providing further advice on these legal considerations in due course.

4.2.2 Interim advice to landowners and managers in Tayside

The Tayside Beaver Study Group have provided information based on legal advice received by SNH and current best practice in beaver management from Europe. This information was designed to inform the management of beavers and beaver activity during the interim period before the Ministerial decision in 2015. Further information can be found on the Tayside Beaver Study Group website¹.

4.2.3 Interim management of beaver dams in Scotland

SEPA have recently published a regulatory position on the management of beaver dam structures². This guidance relates primarily to the notching or removal of beaver dams, and the installation of flow devices. The Water Environment (Controlled Activities) (Scotland) Regulations 2011 (CAR) practical guide sets out SEPA’s policy with respect to authorisation requirements specific to that legislation. Within SEPA’s recent position statement on the management of beaver structures, of particular relevance to beaver-salmonid management considerations are the following points:

¹ <http://taysidebeaverstudygroup.org.uk/legal-situation/4573245812>

² http://www.sepa.org.uk/system_pages/search.aspx?q=management%20of%20beaver%20dam%20structures

- The breaching or partial removal or complete removal of a beaver dam in a watercourse using hand tools and/or ropes and grapnels is not subject to a requirement for prior authorisation by SEPA under the CAR Regulations. Any work in or around watercourses must be completed without causing pollution, such as the escape of silty water downstream (e.g. silt trapped behind a beaver dam).
- Work to breach or remove beaver dams in artificial drainage channels is not subject to a requirement for prior authorisation by SEPA under the CAR Regulations.
- Where management of beaver structures will be undertaken using machinery in the water environment, this may be done without prior authorisation from SEPA, if undertaken in accordance with the conditions of CAR GBR 9.
- Where a flow device will be installed using boulders to secure any ancillary fencing, this may be done without prior authorisation from SEPA, if undertaken in accordance with the conditions of CAR GBR14. For any other approach, consult with SEPA to determine the regulatory requirements.
- For any other proposed activity not covered by the points above, SEPA must be consulted to determine the regulatory requirements.

Removal or notching of dam structures, using hand tools, is not subject to a requirement for prior authorisation by SEPA under CAR. Importantly, any work must be completed without causing the escape of silty water trapped behind a beaver dam downstream. In order to achieve this in practice, dams should be breached with care such that the water level in the pond does not drop rapidly. Where a sequence of dams is to be breached or removed, consideration should be given to breaching dams sequentially to prevent the build-up of sediment and water behind remaining dams. It should be noted that the length of time taken to ease or remove a dam, or a series of dams, in such a manner, has clear implications on the resources required to undertake such management action.

Although the regulations set out above by SEPA do not require authorisation for dam removal with hand tools, permission for a controlled activity under CAR does not confer or imply permission under any other legislation that may apply outside the control of SEPA. If beavers are to be formally reintroduced, the relevant regulator for beavers would have to be consulted prior to undertaking work that may require additional licensing under the Habitats Regulations as described above (section 4.2.1).

4.3 Review of management approaches in Europe

Beavers and salmon co-exist in a number of European countries including Norway, Sweden, Finland, Denmark, France, and to an extent in the Baltic States. Beaver-salmonid management intervention appears currently to be rare or non-existent, and on the European Commission website there is currently no evidence available to suggest that licenses have been provided in a EU context. In a Lithuanian publication, in the face of rapidly increasing beaver populations, to maintain the brown trout fishery, the annual removal of all beaver dams in middle and lower reaches of these streams is recommended. It is also recommended that dams in the upper reaches of streams are subject to targeted removal during the autumn trout migration (Kesminas *et al.*, 2013). Lithuania has a derogation from the Habitats Directive, relaxing species protection measures specifically in relation to beaver.

In Scandinavia, there does not appear to be such documented evidence of beaver management in the context of salmonids. In a review of general beaver management in Norway, (Parker & Rosell, 2003) cite the success of their model as being in part due to the fact that Norwegians have been managing beavers for more than 150

years, whereas most European countries who have recently reintroduced beavers currently have little experience. In Norway beaver harvest quotas are determined by regional game boards and then divided among landowners, with few non-lethal methods of management deployed, and the majority of beavers shot by hunters in spring for recreation and for meat. Beaver management presents little cost to the public, with hunting gaining popularity and giving income to landowners. Although the Norwegian legal context is different to that of EU states, Parker & Rosell (2003) present a useful beaver management model founded upon (1) an increased understanding of the beaver's ecological role, (2) the gradual progression from a nuisance to prized game species, and (3) the straightforward means available to control animals. Norway is not within the EU and consequently the Habitats Directive does not apply. The lethal control of beavers is probably likely to be more widely accepted in Norway than would be the case in Scotland due to the strength of the hunting culture in Norway.

4.4 Review of management approaches in eastern North America

In eastern North America management of beavers in the context of fisheries is undertaken in some catchments, primarily during, or immediately prior to the peak autumn salmonid migration. Based on our consideration of the limited literature and experience available online, evidence of management action targeted specifically at the spring smolt migration is not available. Although there may be legal, social, environmental and biological differences between Scotland and eastern North America (see section 3.3) leading to a particular management approach, which will not be directly applicable to Scotland, it is still relevant to review these techniques, as they occur in areas where beavers and salmonid habitats overlap. Of particular concern is the potential for increased hindrance to fish migration caused when beavers construct dams on, or adjacent to human infrastructure, such as weirs, culverts and fish passes (see section 4.5). Beavers can be discouraged from damming culverts by protective fencing where necessary, but it is important to stress that these modifications are themselves known to block fish passage, if not regularly maintained and rigorously designed. Although a consensus on techniques for maintaining fish passage around culverts with beaver dams has not been reached, progress is currently being made in the U.S.A (Figure 8). In the below diagram, the culvert fence is constructed to encourage beavers from damming away from the culvert mouth.

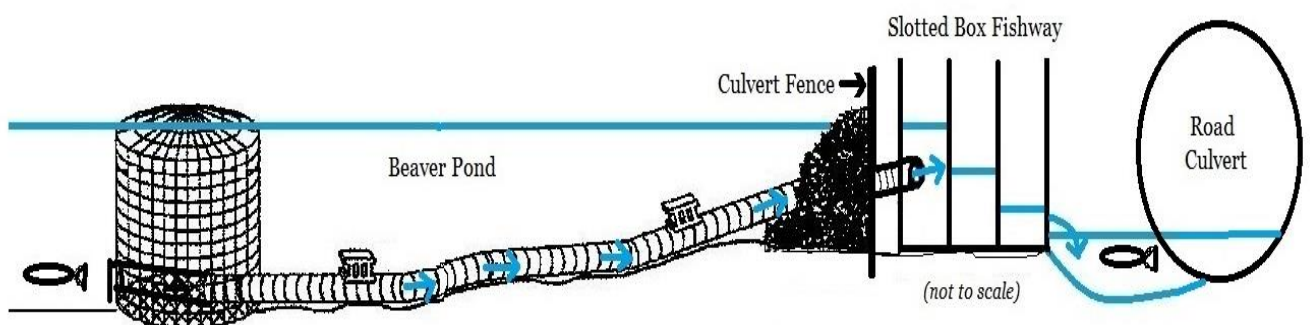


Figure 8: "Snohomish" possible solution for protecting culverts from beaver damming, and providing fish passage. Source: Mike Callahan³

³ <http://www.beaversolutions.com/>.

4.4.1 Nova Scotia, Canada

In a study of the influence of rainfall and beaver dams on the upstream movement of spawning salmon in a recently restored Nova Scotian stream, the authors state: "*In the short-term, notching beaver dams during the spawning season may be a useful practice for habitat managers trying to restore salmon populations in low-gradient streams. It is labour-intensive, however, and impractical for more than a few dams. Even with notching, the dams remain an impediment to migration. A long-term solution requires the removal of beavers or ensuring high flows during the spawning season*" (Taylor *et al.* 2010). In this case, it is suggested that the negative effects of beavers can be traced back to the historical degradation of this stream by humans, a situation which may also be expected in some areas of Scotland. In this stream in two seasons characterised by low flows, the authors tested dam notching with hand tools as an approach to aid fish passage in autumn, by regular removal of 0.25-0.5m² of material from the dam.

4.4.2 Miramichi Salmon Association (MSA) (Canada)

MSA is responsible for the conservation of Atlantic salmon in the Miramichi catchment, New Brunswick, Canada. As a result of a drop in the price of beaver pelts, leading to a reduction in beaver trapping effort, since 2006 beaver dam mitigation has taken place during the adult salmon spawning period. No dam mitigation occurs during the spring smolt run as high flows provide downstream passage. In 2011 for example, surveys were undertaken on foot and by canoe, with dam locations recorded, and a total of 88 dams subsequently removed or notched, further to the culling of 15 beavers (Reid, 2011). A smaller number of 20 dams was removed or notched in 2012, because this particular season featured high water levels, destroying most beaver dams and allowing salmon access to the entire watershed (Ginson, 2012). In 2013 additional government funding enabled a more detailed survey by plane. In total 112 dams (including abandoned dams) on 22 tributaries were notched or removed, including seven dams on the intensively studied Catamaran Brook (Mitchell & Cunjack, 2007). However, in 2013 salmon redds were observed upstream of several dams where human intervention did not occur, leading MSA to review their approach in light of this evidence (Parker, 2013). The 2014 report is not yet available online.

4.5 Human influence and infrastructure

Much of the present riverine landscape in Scotland could be considered to be semi-natural, caused by factors such as habitat connectivity fragmentation from in-stream infrastructure (section 4.4), or channel degradation leading to a loss of lateral water connectivity with river floodplains during floods (Kemp *et al.* 2012). Therefore, beaver-salmonid interactions may not unfold in an entirely natural manner as was the case in an impacted Nova Scotian stream where channel degradation and low flow was thought to necessitate beavers to construct larger dams than normal to gain access to riparian food resources (Taylor *et al.* 2010). As discussed previously, beavers commonly utilise 'pinch points' to begin dam construction, including that of weirs, culverts and fish passes.

To gain an approximation of the occurrence of these features within Scottish catchments, three Fisheries Trusts were invited to provide information on the number of culverts, weirs and fish passes within their catchments. The Tweed Foundation is currently aware of 14 weirs and four culverts within the minor river (tributary) reaches which contain potential beaver habitat (see Figure 4 c). In the whole River Awe (Loch Awe) catchment there are over 100 recorded man-made obstructions to fish passage including 27 culverts and three weirs. Further GIS mapping analysis would be required to determine which of these would fall within potential beaver woodland and salmon habitat. In the North Esk catchment human infrastructure in streams is less prevalent with no major concerns reported for the purposes of this exercise. Further to this brief qualitative assessment, it is suggested that a future exercise be undertaken to add the river infrastructure locations reported here to the maps provided in chapter 2. This could form part of a cost-benefit analysis prior to a decision on the licensed reintroduction of beavers in any particular catchment.

The recent experience of the Tay District Salmon Fishery Board (TDSFB) is pertinent, where in two particular locations in late-summer 2013 and 2014 a beaver colony on the Shochie Burn constructed a dam on a man-made fish pass (Figure 9). Subsequently, after an electronic fish counting device was reinstalled on another fish pass downstream, beaver damming activity compromised salmonid passage, and the operation of the fish counter. Dam removal over a number of weeks was required at the upper fish pass and on a daily basis at the fish counter in order to ensure free passage. Ultimately, the resources required to undertake this work have proven to be disproportionately high and the fish counter has now been removed. The work involved amounted to a day's work per week at an approximate cost of £100 per week, and this does not take into account the operational cost of diverting resources away from other priorities. It is also pertinent to highlight that the fish pass is located in a Perthshire village and there was evidence that local inhabitants were feeding the beavers with sweet potatoes. This suggests that where beaver management may be required, it may not be deemed appropriate and may be resisted locally.



Figure 9: Beaver dam constructed on the Shochie Burn fish pass before removal by Tay District Salmon Fishery Board (Tay District Salmon Fisheries Board, 2013).

4.6 Monitoring requirements and costs

In order to assess where, when and if management interventions are required, streams must firstly be surveyed prior to know fish migration periods. Based on the mapping work undertaken (chapter 2), the potential for beaver-salmon overlap and hence potential for interactions is likely to vary considerably between and within catchments. For example, in the Conon catchment (with the smallest proportion of potential maximum beaver salmon overlap in minor rivers out of the six catchments studied), up to 11.5km of stream length in tributaries may require surveying. It is important to note that this length does not take into account transit time between areas of potential beaver-salmon habitat, which could be inaccessible by road.

In order to provide a broad estimate of the cost of monitoring small tributary streams to determine the presence/absence of beaver dams, a small number of Fisheries Trusts were invited to provide cost estimates of the total stream length that they would expect one staff member to survey in any given day, and to provide a cost estimate for this work. On average respondents estimated that 8km of stream (range 5-15km) could be surveyed in one day, costing an average of £400 per day.

Another possible issue, which would need to be considered and monitored by fishery managers, is the potential for beaver ponds to present opportunities for the illegal taking of salmonids, now recognised in Scotland as a

wildlife crime. Poachers often take advantage of adult salmonids being delayed in their upstream migration, such as may occur below beaver dams, particularly in low-flow conditions.

4.7 Management scenarios and costs

4.7.1 Importance of timescales

In designing and implementing a future beaver-salmonid management plan, the spring and autumn migration periods are of particular importance in relation to fish passage and urgent management action may be deemed necessary during this time. Therefore, if fishery managers wish to survey a particular catchment for beaver dams, it is important that this is undertaken prior to the likely smolt (or adult) migration period. If management action is deemed necessary, the relevant licensing authority should be cognisant of the small optimal time window in which salmon smolts or returning adults require free passage. An appreciation of the beaver's natal timescales (or indeed the breeding season of any other species in the aquatic or riparian system), is required prior to undertaking any beaver dam management. The most important period for beaver natal welfare is thought to be between April and September in Scotland, with particular consideration advised to reduce the welfare risk to dependent beaver young (kits), which may be present in the lodge, but not seen. It should be noted that the early part of this period may overlap with the downstream smolt migrations of salmonid fish, and with the adult spawning migration in September. It is therefore vital that all stakeholders are provided with clear guidance on beaver dam management.

4.7.2 Dam notching

This section and section 4.7.3 are based on the assumption that intervention is deemed necessary for one of the reasons discussed in chapter 3, and that legal permission (if required) has been granted. If a dam is notched by removing the recommended 0.25-0.5m² of woody material (Taylor *et al.* 2010), this process can be expected to take around 30 minutes for two members of staff. It is recommended that the water level in the pond is drawn down slowly to avoid sediment release, sudden dam collapse or excessive adverse impacts on biota including rapid displacement of habitat, stranding, or death of salmonids as described in Niles *et al.* (2013). This will also help ensure compliance with the guidance provided by SEPA, relating to minimising the escape of sediment (see section 4.2.3). It can be estimated that a maximum of 10 dams could be notched carefully in this manner in any one day. Based on a team of two staff members, a rough estimate of the cost of this work for one day would be £800. This cost estimate should be considered indicative, rather than conclusive as it is dependent on variables such as ease of access, terrain and beaver dam integrity.

4.7.3 Dam removal

If notching is found not to provide suitable fish access, dam removal may be an alternate mitigation technique, subject to legal considerations. It is recommended that dam removal is undertaken slowly to avoid adverse impacts on biota (including salmonids) as described above (4.7.2). Such removal should ordinarily be undertaken using hand tools, subject to compliance with the SEPA regulations set out in section 4.2.3.

Based on experience from North America, during dam removal a maximum draw down of the water level in the pond of 0.2m per hour is recommended. A study of dams in Sweden, (Hartman & Tornlov, 2006) found that the average raising of the water level as a result of dam construction was 0.46m (SD: 0.21, range: 0.1–1.0m, n=48). Assuming that these findings are reflected in the Scottish landscape, if fisheries managers aim to draw down water levels by 0.2m per hour, theoretically this process may take about 2 hours (range 0.5 hours – five hours). Dam removal should be undertaken in a sensitive manner on a site-by-site basis, and using these broad estimations, two or three dams would be expected to be removed per day by a two person team, at a cost of approximately £800.

4.7.4 Monitoring of management effectiveness

If the decision is taken for intervention management, monitoring of its effectiveness will be required to underpin a policy of flexible and adaptive management. Further research into techniques, their applicability, efficiency, effectiveness, and cost is required. Further, research and monitoring over multiple years will also be required to identify clear criteria to define when the management of dams is necessary in Scotland, and when it is not. It is important that local fisheries management bodies and public bodies maintain and make available a record of beaver-salmonid interactions within particular catchments, along with any management action undertaken, such as is currently being compiled for other land uses in Tayside by the TBSG, for example. Such monitoring carries with it clear resource requirements and it is important that new resources are made available to fisheries managers.

4.7.5 Cost scenarios

Over annual timescales, hindrance to migration (see section 3.4) and the subsequent potential requirement for management (Ginson, 2012) will vary significantly based on river flow levels alone. Furthermore, the density of dams constructed by Eurasian beavers is variable with one dam for every 14.3km of stream reported in a Norwegian study (Parker & Ronning, 2007), while in Poland (Zurowski, 1989) reported 24 dams in a 1.3km reach. After a detailed assessment of the comparability of these studies to the Scottish landscape it may be possible to estimate the number of dams that may occur in a similar landscape.

The scenario of ten dams being notched may cost up to £800. If in the scenario that ten of these dams are large and are required to be completely removed for whatever reason, it may cost up to £4000 (five days work for a two-person team). The length of small tributary streams, which may provide suitable beaver woodland in the Tay or Tweed catchments for example, is far higher than the Conon catchment (11.5km, see chapter 2). Therefore, potential management cost may be proportionately greater. Conversely, in terms of positive interactions with salmonids, the aquatic community and ecosystem services, catchments such as this with a greater coverage of suitable riparian woodland in tributaries may be capable of supporting a proportionately higher number of beaver colonies.

4.8 Conclusion

Recognising that there will be socioeconomic and ecosystem service benefits, there is a clear consensus that the development of a management strategy should be a fundamental prerequisite of any decision to licence the reintroduction of beavers. Kemp *et al.* (2012) make clear that the balance between costs and benefits of beaver activity when viewed from a fisheries perspective will vary locally determined by vulnerable stages in fish life-history. Localized impacts of beaver dams on fish passage and spawning habitat, while potentially negligible from the perspective of the long-term dynamics of healthy populations, may impose additional pressures on populations that are already stressed as a result of anthropogenic factors. In such cases it is likely that management of beaver dams and possibly of beavers will be necessary from the perspective of fisheries conservation. While legal considerations may stipulate the strict protection of beaver dams or beavers, there may also be a need to issue a licence for the sole purpose of allowing salmonid fish access in the event that there is an overriding public interest.

Over annual timescales the potential requirement for management will vary significantly based on river flow levels alone, and it is entirely possible that no management intervention may be necessary within entire catchments. All management actions should be undertaken carefully with consideration of the potential detrimental impact of management action in itself on salmonids and other species of European conservation importance. A particular focus for fisheries managers may be areas in which the riparian landscape is semi-natural, such as where habitat connectivity is fragmented by in-stream infrastructure including culverts and weirs, or where lateral water connectivity with river floodplains is lost (Kemp *et al.* 2012). It is recommended that a detailed assessment of the extent of such infrastructure should be undertaken as part of a cost-benefit

analysis prior to the licensed reintroduction of beavers in any catchment. It is also important that further consideration be given about where the burden of any additional monitoring and management obligations should rest, including how such obligations will be resourced in future.

There appears to be an absence of consensus available with regard to beaver management in relation to salmonid (and in particular Atlantic salmon) fisheries. However, prior to any licensed reintroductions a management plan is required. In practice this would take place after the Ministerial decision in May 2015, and once it was more clear which future beaver reintroduction scenario is most appropriate. This plan should include provisions relevant to fisheries conservation, based on information included in this report. This plan should be flexible and adaptive, and should be developed through engagement with a range of stakeholders including wild fisheries interests and nature conservation interests, prior to any licensed reintroductions in Scotland.

5. FURTHER RESEARCH RECOMMENDATIONS

5.1 Introduction

This chapter suggests research priorities that may improve understanding of beaver induced changes to the river landscape, and the interaction of these changes with aquatic species, in particular salmonids. In recognising that the main remit of this report is salmonids, the aim of this chapter is also to discuss possible research requirements on beaver influence on the wider aquatic system, including consideration of species of conservation interest such as eel, lamprey species and freshwater pearl mussel (see sections 1.8 and 3.2).

Salmonids have, in general terms, received extensive scientific interest in Europe and North America. Eurasian beaver ecology and management has also received increasing attention in recent decades, with some of this research specifically designed to underpin reintroduction considerations in other European countries including Scotland. Beaver-salmonid interactions have not received sufficient attention, especially in Europe (Kemp *et al.* 2012). The BSWG has considered what they have identified as current research requirements, although these may change in the light of changing circumstance.

5.2 Current research

In an evolving field, the BSWG are aware of a number of research programmes that are currently taking place, and will assist in improving our knowledge of beaver-fish interactions (Table 3). In addition, MSS and the BSWG have conducted preliminary research into beaver-trout interactions in a Perthshire stream, and Argyll Fisheries Trust has been monitoring fish populations at Knapdale as part of The Scottish Beaver Trial (Argyll Fisheries Trust, 2010; Kettle-White *et al.*, 2011, in prep.).

Start date	Organisation, lead(s) and summary	End date
May 2014	<i>NINA/Marie Curie Norwegian Research Fellowship – Rachel Malison- 'Do beavers negatively affect the Atlantic salmon and sea trout resource?'</i>	Circa 2016
July 2014	<i>University of Southampton/SNH PhD- Rob Needham - Quantifying structural and hydrodynamic properties of beaver dams and their impact on the movement of migratory fish.</i>	Circa 2017
November 2014	<i>Marine Scotland Science / Cromarty Firth Fisheries Trust - Simon McKelvey, John Armstrong –Can Atlantic salmon navigate pipes, within the context of beaver dam flow devices.</i>	-

5.3 Further research

Without the immediate collection of baseline information in Scotland, the following suggested research topics will be more difficult to address in the future.

Other Species of Conservation Importance:

- Interactions between beavers and eel, lamprey species and freshwater pearl mussel

Salmonid fish movement:***Upstream passage of adults***

- Potential for hindrance where beaver dams are constructed adjacent to weirs, culverts, fish passes or other human infrastructure
- Potential for constructing fish bypasses in these situations
- Characteristics and stability/longevity of dam structures
- Predictability of dam characteristics during spawning runs
- Response of beavers to dam decay or destruction in autumn
- Relationship between passability and fish size, temperature, flow, dam height, pool depth, overhang, porosity, water flow characteristics, stage of dam construction/ beaver colony occupation
- Behaviour of fish at dams, and quantification of delay

Upstream passage of juvenile salmonids

- Porosity of dams as a function of fish size, discharge, temperature

Downstream passage of juveniles

- Stability of dam structures
- Predictability of dam characteristics during smolt runs
- Response of beavers to dam decay or destruction in spring
- Relationship between passability and fish size, temperature, flow, dam height, porosity, water flow characteristics, stage of dam construction
- Quantification of delay

Consequences of delay in migration

- Energy loss due to delay
- Costs to missing ideal spawning/smolt migration times
- Increase in mortality risk (particularly predation)
- Changes in juvenile production
- Population level cost of mortality
- Changes in juvenile production
- Adult density-dependent compensation
- Reduction in genetic diversity (small populations)

Change in in-stream habitat:

- Beaver dam associated changes in spawning substrate availability for salmonids
- Effects on salmonid communities out-with beaver ponds, due to changes in large woody debris for example
- Cover from large woody debris and water depth
- Thermal change from pooling: increased thermal refuge, temperature change
- Ponding-
- Competition dynamics between salmon, trout and other species
- Increased predation risk
- Decreased energy costs and density dependant competition (affects growth)
- Invertebrate dynamics

- Sediment/flow changes
- Change in flow/gravel niche for spawning
- Sediment cleaning below dams
- Change in hydrology- ground water/surface water ratio (impact on eggs)
- Influence of this habitat change on food resources for juvenile salmonids

Change in bankside habitat:

- Change in vegetation and coppicing
- Interactions with other herbivores
- Related effects on temperature
- Influence of this habitat change on food resources for juvenile salmonids

Systems approach and integration across scales:

- Quantification of the effect of beaver presence on migratory salmonid populations at a watershed scale
- Changes in fish production associated with pond age
- Catchment scale effects related to distribution of dams
- Individual-population scaling up of local dam effects
- Beaver dam influence on fish access dynamics over multiple years
- Importance of juvenile salmonid inter-cohort dynamics and resilience

6. CONCLUSION

Information and experience on beaver-salmonid interactions in the specific context of the native fish communities in Scotland has been reviewed. There are a range of impacts that beaver activity may have on Atlantic salmon, trout, and the aquatic and riparian environment. The overall effect on fish populations will depend on the balance between, and relative magnitude of these impacts. As these interactions are likely to vary over time, and between catchments, and indeed between tributaries within catchments, it is not possible to predict the overall impact of beaver activity on salmonid fish (or other species of conservation importance) with certainty. Beaver activity is likely to be of particular conservation concern to spring salmon which utilise nutrient poor upland streams.

To help inform the Minister's decision on whether to proceed with a licensed reintroduction programme under any of the possible scenarios set out by SNH, the BSWG would make the following recommendations:

Beaver-salmonid management strategy

The development of a management strategy should be a fundamental prerequisite of any decision to license the reintroduction of beavers. This should guide when work should be carried out; the situations where management may be justified; and what type of interventions can be made. The strategy should be developed, in full consultation with stakeholders from the fisheries management sector, as well as a range of other sectors, and should consider the following:

1. Experience from abroad, and more recently on Tayside, has demonstrated that human infrastructure such as weirs, fish passes and culverts can be particularly susceptible to blockage by beaver activity. A detailed assessment of the location and relative importance of such infrastructure to fisheries should be undertaken as part of a cost-benefit analysis prior to any licensed reintroduction of beavers. In the event that beaver dams are constructed upon or adjacent to such human infrastructure, it is likely that these 'pinch points' that will be a particular concern for fishery managers, and management intervention may be required.
2. The strategy should allow a range of management interventions to be undertaken ranging from immediate action to longer term intervention (subject to legal considerations). Beaver presence alone should not be a trigger for action. Where management of dams or beavers is required for the conservation of fish species, the management mechanism should be quick, simple and efficient. It is envisaged that such management may be necessary in advance of key fish migration periods during spring and/or autumn.
3. Beaver-salmonid interactions (and indeed wider interactions with other fish species) in Scotland should be managed in a flexible and adaptive manner, so that management can take account of new scientific evidence. Management in the medium and long term will need to respond to changes in beaver population density and distribution.
4. Where management action is deemed necessary, it should not be compromised, for example through the prevention of access to land to remove dams.
5. Under the imperative of ensuring free passage of migratory fish, this strategy should recognise the dynamic nature of beaver dams and the resources required in assessing such structures on multiple occasions and at both high and low river flows. It should also set out the criteria by which relocation or lethal control of beavers would be appropriate for the conservation of fish or protection of fisheries. One scenario could be to ensure free passage of fish at weirs, fish passes or culverts.

6. During principal (upstream and downstream) migration periods characterised by low flows or drought beaver dams may have a greater potential to hinder fish movements. In migration windows characterised by extreme high flows beaver dams are, in the majority of cases, less likely to present a complete barrier to fish movement. If key migration periods are coincident with low flow conditions then fishery managers may require additional resource to deal urgently with beaver dams that prevent the free passage of fish. Potential additional resource requirements are to be highlighted in this strategy, further to options for funding sources.

7. Monitoring and management interventions will carry with them resource implications, and therefore it is vital that such resources are committed, over the medium to long term, to the relevant management authority. In the absence of such a commitment, and given the uncertainties surrounding the effects of beavers on salmonid fish and the aquatic system, it is difficult to see how beaver reintroductions to Scotland could be supported by the salmonid fisheries management sector.

8. There are no natural predators of adult beavers, and in Scotland the density of beaver dams at a catchment scale is partly influenced by beaver population size. In the event that beaver populations become widespread and are at high density, proactive management may be necessary. This should be clearly stated at the outset of any formal reintroduction in Scotland.

9. All bodies involved in a beaver management strategy should work in co-ordination with fishery managers to ensure that rigorously controlled reintroductions are conducted in a manner that is cognisant of the conservation status of fish species, resource implications and the requirement for on-going monitoring and management.

10. In terms of general beaver management, European experts recommend the re-establishment or maintenance of a riparian vegetation strip as a proactive and long-term measure by which to separate beaver activity within the riparian zone, from human activity out-with this riparian zone. In the scenario that beavers are to be reintroduced, the BSWG support this recommendation in the dual contexts of; (1) minimising general beaver-human land use conflict, and (2) salmonid conservation. It is recognised that there could be wider socioeconomic and ecosystem service benefits that will result from the presence of beavers. There are also benefits of beaver presence to salmonids, and these may be realised particularly where management options are available.

Legal considerations

11. We would anticipate that some beaver dam management intervention may be permissible without the need for a licence. For interventions that will require a licence, it is important that both the licence application - and the decision to issue or reject - is made in good time to allow permitted action to take place. This is particularly important if it is thought that the conservation status of another EU species of community interest may be impacted, and especially if pressures are placed upon particular fish life-cycle stages or vulnerable population groups (such as spring salmon).

12. The management of beaver dams or populations is likely to be complicated and could be constrained by the requirements of the EU Habitats Directive. Therefore, clarity is required as to the timescale under which beavers in Scotland might be considered a European Protected Species under the Habitats Regulations, and when this species may be included as a qualifying feature within existing, or new, SACs. Further, land users in Scotland (including fisheries managers) require, from the relevant authorities, a criterion upon which to determine when a beaver dam is likely to be associated with a beaver breeding or resting site, and when it is not. Ideally this information should be available prior to any licensed reintroduction of beavers.

Research requirements

13. There is a clear need for further research to inform our understanding of the impacts of the activities of reintroduced beaver on the aquatic system and in particular on salmonids in Scotland. A list of suggested research is set out in Chapter 5. It is important that resources are made available to begin addressing these. It is possible that, because beaver populations are well established in other areas of Europe, research at these locations may inform our view of long-term beaver interactions in Scotland. Nevertheless, the collection of baseline information on beaver-salmonid interactions in Scotland should be an immediate priority.

Release of unlicensed animals

14. It is crucial that the IUCN Guidelines on Conservation Translocations IUCN/SSC, (2013) are followed and that any licensed reintroduction of species to Scotland is in accordance with the Scottish Code for Conservation Translocations (National Species Reintroduction Forum, 2014). Internationally recognised best practice was clearly not applied in the Tayside situation, and so serious consideration should be given over how appropriate it would be to add beaver as a qualifying feature to the Tayside SAC, and any precedents a decision may set.

15. Whilst these beaver populations present an opportunity for further research, albeit currently with an absence of baseline information, they also present an opportunity to trial beaver-salmonid management approaches including in some cases the translocation or removal of beavers from the wild. Scottish Ministers should have adequate powers to ensure that wild animals, kept in private collections, are managed responsibly as a licensed condition of ownership. All animals should be chipped, and material which will enable the genetic identification of animals should be securely stored. The health status of all animals, including disease testing should be adequately monitored, and the quality of holding structures should also be tightly controlled to ensure that the risk of escape is eliminated.

7. CITATIONS and ACKNOWLEDGEMENTS

7.1 Citations

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*Indicates original full members of the BSWG at its inception.

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Marine Scotland (MS)*

National Museums of Scotland (NMS) *

Scottish Government (SG)*

Scottish Environmental Protection Agency (SEPA)

Scottish Natural Heritage (SNH) *

Tay District Salmon Fisheries Board (TDSFB)

University of Southampton

It is important to understand that the views expressed in this report are not necessarily representative of the wider views of the individual organisations involved.

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<i>Duncan Halley</i>	<i>(Norwegian Institute for Nature Research).</i>
<i>Alex Parker</i>	<i>(Miramichi Salmon Association)</i>
<i>Simon Jones</i>	<i>(Scottish Wildlife Trust/Scottish Beaver Trial)</i>
<i>Barry Taylor</i>	<i>(St. Francis Xavier University)</i>
<i>Rick Cunjack</i>	<i>(University of New Brunswick)</i>
<i>Ronald Campbell</i>	<i>(Tweed Foundation)</i>
<i>Marshall Halliday</i>	<i>(Esk Rivers Trust)</i>
<i>Brian Shaw</i>	<i>(Ayrshire Rivers Trust)</i>
<i>Simon McKelvey</i>	<i>(Cromarty Firth Fisheries Trust)</i>
<i>Alan Kettle-White</i>	<i>(Argyll Fisheries Trust)</i>

We apologise for the omission of anyone who is not hereby acknowledged.

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9. APPENDICES

Appendix 1:

A mapping study of the overlap of potential Eurasian beaver (*Castor fiber*) habitat and Atlantic salmon (*Salmo salar*) distribution in Scotland

John D. Armstrong, Hilary L. Anderson, Sean L. Dugan¹, Ross Gardiner

Marine Scotland Science, Freshwater Fisheries Laboratory, Faskally, Pitlochry, PH16 5LB, UK

¹Beaver Salmonid Working Group

Abstract

Atlantic salmon are both a species of conservation importance listed under the EC Habitats Directive and the target of important Scottish rural fisheries. Scottish Government is considering the possibility of formally reintroducing the Eurasian beaver. In assessing the option, it is important to consider possible positive and negative effects of beavers on salmon. An important first requirement is to establish whether there would be substantial overlap of potential beaver habitat and known Atlantic salmon distribution. This issue was addressed using a Geographic Information System (GIS) to compare the current known distribution of Atlantic salmon in six river catchments with predicted beaver distributions should these animals be reintroduced and use all available suitable habitat. At the full catchment scale in the six rivers (Awe, Ayr, Conon, North Esk, Tay and Tweed), the percentage wetted area of salmon habitat likely to occur in proximity to potential beaver habitat (termed *percentage overlap*) ranged from 47-73%. In all six rivers the percentage overlap was greatest in major rivers (predominantly main stems) >10m in width (54-87%). In minor rivers <10m in width, that is predominantly tributaries, overlap ranged from 15% to 59%. Results of the mapping exercise are discussed in relation to understanding possible positive and negative effects of beavers on Atlantic salmon. While the figures presented here estimate the percentage spatial overlap in distributions of these species, impacts of beavers would likely extend further upstream and downstream of this physical overlap. Thus, in interpreting the findings of this study, the influence of beavers on salmon populations throughout moorland streams above beaver dams is identified as being a particular risk to weak salmon populations, whereas benefits of the presence of beavers might be accrued in other areas downstream.

1. Introduction

Eurasian beaver, *Castor fiber*, are large semi-aquatic mammals that use trees and herbs as food and also material for maintaining lodges and damming rivers under certain circumstances

(Kitchener, 2001). Atlantic salmon, *Salmo salar* L., use rivers for development of eggs and early growth before a majority of the population migrates to sea as smolts and subsequently returns to spawn (Mills, 1991). Salmon are an iconic component of Scotland's cultural and natural resources and have a high conservation status, being listed under the EC Habitat Directive, as well as supporting high value fisheries. Beavers occurred in Scotland's ancient landscape but have been extinct since about 1600 (Raye, 2014). In the intervening years, the nature of that landscape and the character of river ecosystems have changed substantially. Against this backdrop, the Scottish Government is currently assessing the likely consequences of allowing beavers to re-colonise (Gaywood, 2014). This assessment includes a consideration of potential interactions between beavers, fish and fisheries with particular focus on Atlantic salmon.

Beavers radically change the characteristics of riverine habitats and influence a range of physical and chemical processes, many of which may have either or both positive and negative effects on fish communities and populations (Collen & Gibson, 2001, Kemp *et al.*, 2012). The overall net impact (positive or negative) can be expected to vary depending on the species of fish involved and the local environment in which they live. Atlantic salmon are highly migratory swift-water specialists (Armstrong, 2010). As such they could be expected to be more negatively affected than many other fish species by obstructions from damming activities and change from fast-flowing riffle to pool habitat. However, they may also benefit from local presence of beavers if these animals increase food supply, the availability of cover from predators, and/or quantity of suitable local habitat (Kemp *et al.*, 2012). The potential extent of these possible positive factors depends largely on the overlap that can be expected between salmon and beavers. By contrast, where damming hinders fish migration, the negative effects of this obstruction may extend for the entire area upstream.

A basic requirement in determining where potential interactions may occur is to estimate the spatial overlap between the expected range of beavers and the distribution of salmon. This study uses a geographic information system (GIS) approach to consider potential spatial overlap in six river catchments that cover much of Scotland's geographical and hydrological diversity: the Rivers Awe, Ayr, Conon, North Esk, Tay and Tweed (Fig.1). Salmon distribution is that recorded in recent years, whereas potential beaver distribution is based on predictions of suitable habitat, defined as existing broadleaf and mixed broadleaf woodland within 200m of freshwater habitats including rivers and wetlands, but excluding high gradient streams, tidal areas and land above 400m in elevation. The data are also considered as a comparison of larger and smaller river reaches, taking a 10-m width cut-off. This approach provides an estimate of how the area of overlap may differ between major rivers (predominantly main stems) and minor rivers (predominantly tributaries).

2. Methods

GIS was used to determine the percentage of river habitat known to be currently occupied by Atlantic salmon that would be predicted to be used by beavers should they extend to their full potential range. Salmon distribution data, provided by Marine Scotland Science (MSS) and last updated in 2008, includes the spatial range over which juvenile salmon have been detected in Scotland. Potential beaver habitat distribution data, produced, using the methodology of Webb *et al.* (1997), and provided by Scottish Natural Heritage (SNH), includes habitat types and topographies known to be used by the mammals in other European countries. The data set includes a wide range of habitat types, including small groups of trees and scrubland, including willow and alder. Hence, it emphasises the widest area of habitat likely to be used by beavers rather than only those areas that might sustain territories over long periods of time and hence encourage production of dams.

2.1 Datasets

Salmon distribution was compiled initially by Gardiner & Egglisshaw (1986) and updated in 2008 with more recent data from surveys conducted by Marine Scotland Science and Fisheries Trusts. The updated salmon distribution data were incorporated in the Centre for Ecology and Hydrology (CEH) 1:50,000 Digital River Network (DRN) as a Scotland-wide line dataset. This information was transferred to Ordnance Survey MasterMap (OSMM) to create area-based polygon data for each catchment and subsequently split twice. Firstly to separate lochs and rivers, locations were identified using Scottish Environment Protection Agency (SEPA) loch coding in the CEH DRN and Ordnance Survey 1:10,000 data as a guide. Secondly, river polygons were split based on SEPA 1:50,000 stream width data, into two river types: those areas below and equal to, and those above 10m in width.

Potential beaver habitat distribution data were produced by SNH (August 2011) from fresh water, woodland and Ordnance Survey datasets as listed below, using a methodology based on earlier studies (Webb *et al.*, 1997). Suitable beaver woodland was compiled from areas with existing broadleaved and mixed broadleaved woodland (Highland Birchwood's Scottish Semi-Natural Woodland Inventory - SSNWI - and Forestry Commission's National Inventory for Woodlands and Trees - NIWT), lying within 200m of suitable water or wetland habitat. Tidal areas were excluded as were areas above 400m, and stream reaches of greater than 2% gradient using a slope analysis of OS 1:50,000 Panorama Digital Terrain Model (DTM) data.

Catchment boundaries for the Rivers Awe, Ayr, Conon, North Esk, Tay and Tweed were extracted from data produced by SEPA from CEH 1:50,000 DTM data. For the study, the Tay catchment excluded the River Earn and the Tweed catchment included the River Whiteadder. Since SNH potential beaver habitat datasets did not extend into England, the Tweed catchment boundary was restricted to the area within Scotland, using OS Panorama 1:50,000 data at the Scottish Border.

2.2 Salmon and beaver distribution overlap

Salmon rivers data were required in polygon format to quantify the area of potential overlap. The salmon rivers DRN (line) dataset contains no area information, and processing used salmon rivers OSMM (polygon) data, extended with OSMM line data where necessary. With the potential beaver habitat datasets restricted to areas below 400m in elevation, salmon distribution polygons were checked against OS Profile 1:10,000 contour lines and salmon river sections above 400m altitude, which occurred only on the North Esk and Tay, were excluded.

To calculate the area of salmon rivers in proximity to potential beaver habitat at a catchment scale, suitable beaver woodland was “buffered” by 50m and the total area and percentage of salmon rivers within this buffer zone was calculated. Secondly, using the salmon river type categories (section 2.1), this overlap methodology was repeated to provide area values and percentages specific to each river category.

The method of analysis limited overlap to a 50m buffer zone, which was the smallest scale applicable given data resolution. Salmon lochs were also excluded, predominantly as the large surface area of lochs relative to that of rivers was found to exert a disproportionately large influence on species overlap figures. Further, as beavers would likely use the perimeter of lochs and would not be capable of creating dams across lochs, beaver-salmon interactions would likely be limited relative to the area of lochs.

2.3 Data limitations

A number of assumptions and approximations were required in view of data limitations. SEPA catchment boundaries are held separately for the Rivers Tweed and Whiteadder and for the Tay and Earn since the Whiteadder enters the Tweed below the tidal limit as does the Earn in the Tay estuary. Areas considered were for the Tweed including the Whiteadder and the Tay excluding the Earn.

SNH potential beaver habitat data exclude the Tweed in England. Consequently a boundary was produced for the Tweed within Scotland and figures for the Tweed relate to the Scottish part only.

OS MasterMap data for fresh water are held as both polygons and lines, depending on river width and scale of data capture. Line data occur mainly in upper river sections, usually where stream width is less than 5m, but may also denote field ditches in lower catchment areas. Consequently, the data for some of the upper tributaries are in line format only, with no width or area information.

An accurate area can therefore be calculated for river and loch sections held as polygons but not for those river sections available only as lines. In the absence of width information for upper tributaries and following investigation of suitable buffer widths, an area was created for line sections by producing 4m total width polygon buffers on the lines.

OS Mastermap freshwater polygon data contains no separation between lochs and rivers or between larger rivers and any smaller tributaries. Where salmon distribution included lochs, breakpoints were required to separate loch polygons from the rivers flowing in or out of them. These were determined using a combination of SEPA loch coding in the CEH DRN, Ordnance Survey data (section 2.1) and best judgement.

SEPA river width data were used to assist in determining the breakpoint between minor tributaries and major tributaries or main-stem categories. All streams where width values were consistently recorded as being less than 10m were categorised as minor tributaries. In certain areas, width data values were limited, and as such breakpoints were determined using best judgement and OS 1:10,000 raster data.

3. Results

For maps and tables see chapter 2.

The distribution patterns of potential beaver and known salmon habitat and the degree of overlap at whole-catchment and major and minor river-scales are summarised in Table 1. At the catchment scale in the six rivers (Awe, Ayr, Conon, North Esk, Tay and Tweed), the percentage wetted area of known salmon distribution likely to occur in proximity to potential beaver habitat (termed *percentage overlap*) ranged from 47-73%. In all six rivers, the degree of overlap in the habitat distributions was greatest in major rivers (predominantly main stems) >10m in width, ranging from 54 to 87%. The highest percentage overlap in the River North Esk reflected the extensive woodland close to major rivers in this catchment. In minor rivers <10m in width, that is predominantly tributaries, percentage overlap ranged from 15% to 59%. In each case the higher or lower percentage values reflect the extent to which both major and minor rivers are currently accessible to salmon, and feature broadleaf riparian woodland. For example, percentage overlap is particularly low on the River Conon minor rivers due in part to limited accessibility to salmon and in part to comparatively low levels of suitable beaver woodland. Conversely, minor rivers of the River Tay feature relatively more suitable beaver woodland compared to the other catchments studied, resulting in a high overlap percentage.

Details of the salmon and beaver distributions in the six catchments are illustrated in Figure 2(a) – 2(f). From examination of the distributions it is evident that suitable beaver woodland is generally well dispersed throughout the major river reaches, while patterns of distribution are more variable

in minor rivers. In many cases the distribution of salmon extends above the treeline to open moorland areas with no woodland, though in some cases suitable beaver habitat exists.

4. Discussion

The present study clearly demonstrates that a wide overlap currently exists between potential beaver habitat and known salmon distribution: in the order of 47-73% across six rivers of varied geographic location and topology. There was a consistent trend of more beaver-salmon habitat overlap in major than minor rivers. This variation largely reflected differences in the extent of riparian tree cover, and the prediction of little colonisation by beavers into steeper gradient streams at higher altitudes.

4.1 Biases in estimates

Any model of beaver distribution is speculative because the way that the animals actually use the Scottish landscape would only become clear should they be formally reintroduced and permitted to colonise suitable habitat. However, given assumptions, suitability of rivers for beavers can be estimated from knowledge of habitat use (Allen, 1983) and applied effectively using GIS (Anderson & Bonner, 2014) to predict the range of the animals. The putative suitable beaver woodland dataset used in this project is based on known parameters for the Eurasian beaver in a European context. However there are several potential biases. In practice, beaver distribution would be variable over time because colonies commonly abandon ponds before re-establishing years later (Pullen, 1971). This phenomenon would introduce a positive bias in the overlap estimates. The suitable beaver woodland dataset presently does not include woodland close to streams of greater than 2% gradient. Eurasian beavers have been observed to exist on stream gradients of up to 2.5% (Schulte, 1989), and North American beavers may use streams of up to a 6% gradient (Pollock *et al.*, 2014). This factor may have resulted in systematic underestimation. Further, in future decades overlap will likely increase as riverine tree planting schemes generate bankside woodland in upland areas. Conversely, although beaver foraging activity may occur up to 100m from water, in Denmark for example, the majority (95%) occurs within 5m (Elmeros *et al.*, 2003). Therefore, the beaver dataset, derived using a 200m buffer, may generate a systematic overestimate. Understanding of the present distribution of salmon is obtained from extensive field survey work, and can be expected to provide a good coverage of the distribution of salmon as of 2008. However, salmon distribution will change, for example as man-made barriers are removed. In view of these uncertainties the results should be considered indicative of the predicted general, rather than precise, level of overlap.

4.2 Scottish salmon populations: status and structuring

The relevance of overlap in salmon and beaver distributions can be understood through consideration of the state of salmon populations in Scotland and the mechanisms by which the two species may interact. The overall strength of the Scottish salmon stock (all populations combined) has declined markedly in the last fifty years due to increased mortality at sea (Anon, 2014). A reduction in international and coastal net fisheries has generally offset this change at the whole-Scotland scale to maintain or increase stocks entering rivers to support rod fisheries and provide a spawning escapement. However, little scope remains for further such compensation. Furthermore, serious reductions in populations have occurred at more local scales. Atlantic salmon are geographically structured within the larger rivers into genetically distinct groups with significantly different phenotypes (Stewart *et al.*, 2006). Those salmon from upstream tributaries tend to leave and return earlier in the year and support a “spring fishery” which is both highly valued for sport and at highest conservation risk. There is evidence that some such populations have approached a level that is sufficiently low that further reduction in spawning will have a direct effect on the numbers of emigrants they produce and hence the next generation of returning adults (Anon, 2014; Jonsson *et al.*, 1998). Salmon are protected at the local sub-stock level within SACs under the EC Habitats Directive. Hence, there would evidently be a need to manage any adverse effects of beavers on spring salmon. If mortality of salmon on the high seas increases further, then it is likely that adverse effects of beaver dams will exacerbate the situation across a wider range of tributaries and river main stem areas as summer and autumn stocks decline. Furthermore, reduction in the condition and fecundity of salmon due to high seas warming (Todd *et al.*, 2008) can be expected to lead to an increase in the number of returning fish needed to attain a conservation limit.

4.3 Key interactions between Atlantic salmon, the fish community and the thermal, physical and chemical environment

Given the precarious state of some Atlantic salmon populations, it would be particularly welcome if presence of beavers resulted in overall beneficial effects. In reviewing effects of beavers on fish, Kemp *et al.* (2012) highlighted that generally a greater number of positive than negative factors had been identified and demonstrated. However, such a general assessment does not inform on likely effects of beavers on individual fish species in specific contexts. The Scottish native fish communities are of relatively low diversity compared with others in Europe due to isolation in the last Ice Age (Maitland & Campbell, 1992). In Scotland, Atlantic salmon co-occur across much of their range with the closely related brown trout, *Salmo trutta* L.. These two species differ in their morphology such that salmon have adapted to life in swift waters, whereas brown trout are dominant in pools (Armstrong, 2010). Both species are threatened by invasive fish species, notably the European minnow, *Phoxinus phoxinus* L and the northern pike, *Esox Lucius* L. Minnow are small shoaling cyprinid fish that occupy pools and may filter out food and hence exert competition on salmon and trout (Museth *et al.*, 2007). Pike are predatory fish that also generally inhabit slower flowing areas and can have devastating consequences for salmon populations, particularly through consumption of smolts on their downstream emigration to sea (Kekalainen *et al.*, 2008).

An increase in pool habitats may favour trout over salmon and increase habitat for minnows, pike and other competitors and predators. However, there may also be benefits for salmon of additional pool habitat, at least in some situations. For example, the interaction between trout and salmon is complex. The presence of trout may reduce dominance hierarchies among salmon of similar size (Höjesjö *et al.*, 2010) with possible growth benefits for subordinate individuals. There is indeed some evidence of relatively fast summer growth among salmon parr in a beaver pond (Sigourney *et al.*, 2006), although this has not been demonstrated on fish communities of Scotland. Pools may also modulate thermal properties of the water, with possible positive or negative consequences, depending on how the local temperature relates to optima and lethal levels for trout and salmon (Elliott & Hurley, 1997; Elliott, 1994). Beaver ponds may constitute nutrient sinks (Wilby *et al.*, 2014) which may be beneficial in agricultural areas. However, this process may result in the stripping out of chemicals (Danell, 1996) that are essential for growth of salmon in the faster-flowing reaches they occupy in upland areas (Williams *et al.*, 2009).

An increase in large woody debris due to beaver activities may benefit young salmon by increasing the availability of good foraging and hiding areas (Nislow *et al.*, 1999). The importance of this effect in Scotland is unknown and would depend on local habitat structure and on which size-specific habitats limit overall production of salmon (Armstrong & Nislow, 2006).

Bankside tree cover affects light and temperature in streams (Malcolm *et al.*, 2008; Finstad *et al.*, 2010). In some circumstances a reduction in vegetation cover due to beaver activity would increase light and temperature, and thereby increase production at primary levels and up into higher trophic levels including salmon (Kemp *et al.*, 2012). In other cases, reduction in the tree canopy could increase temperature above the optimum for growth (about 16°C for salmon) with negative consequences. Indeed, in exposed upland moorland areas, daytime summer temperatures may already far exceed these optimal levels. Contemporary management of salmon involves modelling geographic variation in temperature regimes to guide the plantation of riparian vegetation specifically to protect against anticipated elevation in temperature if climate change continues. Clearly, beaver activities would need to be incorporated into such assessments and management plans.

It is evident that there is a complex range of mechanisms relating to light, temperature, nutrients, water depth and in-stream cover via which beavers may affect production of salmon. In some situations the balance may be positive (for example where competing fish and still water predators are absent) and in others they may be negative (for example where summer stream temperatures are high and pike are abundant in pools). The mapping work is important because it shows that the potential for those positive effects that are not directly related to damming activity is greatest in larger rivers where the degree of overlap is most extensive.

4.4 Damming

A major clear potential negative effect of beavers is obstruction to migration of salmon due to damming, which is most likely to occur in relatively shallow and hence generally narrower tributary areas. Variation among tributaries in the area of overlap of distribution of salmon and beavers is not in itself relevant to the extent of such impacts since the whole area of tributary upstream may be affected by a dam. However, such overlap delimits the areas where obstructions would be most likely to be constructed should local conditions be suitable. In the context of identifying locations where dams would be built, it may in the future be useful to refine mapping procedures to identify core habitat in which beavers would be most likely to establish territories (Webb *et al.*, 1997). However, in the absence of maps of water depths and channel morphology it is in any case not currently feasible to apply GIS meaningfully to predict likely dam locations.

It is well established that man-made dams and weirs may affect survival and energetics of salmon moving upstream (Gowans *et al.*, 2003) and downstream (Gauld *et al.*, 2013) even if those structures are passable. It is also clear that beaver dams in some contexts may be impassable and that the occurrence, stability and abilities of salmon to pass beaver dams would be likely to vary greatly depending on local geomorphological and hydrological conditions, which would influence river discharge characteristics (Mitchell & Cunjak, 2007). It seems likely that there would be strong interactions between beavers and man-made structures in rivers. For example, fish passes and culverts constitute structures against which beavers can engineer dams; furthermore, regulated hydro rivers may lack the seasonal high flows that would otherwise displace dams.

4.5 Population responses to beaver-induced impacts

There are often more adult salmon spawning than are required to replenish a stream. Reduction in the number of upstream migrating salmon would be of concern only if it brought the spawning stock below a critical level termed the conservation limit. Below this level, there is little scope for compensation from density-dependent processes and a reduction in smolt production would be expected, although the preceding and subsequent couple of cohorts may be enhanced as a consequence of a single weak year class (Einum *et al.*, 2011; Gurney *et al.*, 2008). Regardless of the year class strength, reduction in numbers of emigrating smolts due to obstruction of downstream migration would be likely to have a direct proportionate effect on returning adults since mortality at sea is thought to be density independent (Jonsson *et al.*, 1998). Although dams may have these immediate negative effects, populations of salmon would also have substantial resilience to becoming extinct due to damming because in Scotland there may typically be two to four cohorts in fresh water and two at sea at any time. Hence, a tributary population might recover from several consecutive missing year classes in the scenario that beaver damming fully prevented upstream passage. If a tributary population is eliminated then it would likely be replaced over time should damming subside, but possibly with a loss of the locally-adapted gene pool and

hence lower productive potential. Such change has conservation implication through reduction in genetic diversity.

4.6 General conclusions

Beavers are a natural component of Scotland's wildlife heritage that was lost due to man's activities. Atlantic salmon evolved with beavers over millennia and clearly the two species co-occurred in Scotland. There is little doubt that beavers can generally have overall positive effects on production of some species of salmonid fishes due to their role in engineering river habitats and influencing the chemical dynamics within the watercourse (Kemp *et al.*, 2012). However, their influence on Atlantic salmon is more ambiguous, because this species of fish is specialised for swift waters, which would be reduced by extensive beaver damming. Furthermore, Atlantic salmon is highly migratory and hence vulnerable to obstruction of free passage. As with beavers many years ago, Atlantic salmon may be threatened now by human activities, but in this case through the current general effects of climate change on the high seas (Todd *et al.*, 2008) combined with a range of local impacting factors. It is therefore by no means certain that salmon across their range can tolerate negative effects of beavers in the way that once they could. It is likely that beavers would need to be managed to avoid negative effects and if done so carefully then any positive effects may be harnessed for the good of salmon. In this regard, the mapping work in this study provides a foundation for planning effective management strategies and can usefully be extended more widely. If beavers expand their range in Scotland and more is understood of their detailed biology in this new landscape, then GIS might usefully be applied to predict damming points (Dryburgh, 2009). GIS might also be used to estimate the linear extent of tributaries in which dams might be constructed as an aid to management surveys for identifying and breaching beaver dams to protect spring salmon in upper river tributaries.

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