Beavers in Scotland

A Report to the Scottish Government

Scottish Natural Heritage
Dualchas Nàdair na h-Alba
All of nature for all of Scotland
Nàdar air fad airson Alba air fad

Beavers in Scotland:
A report to the Scottish Government

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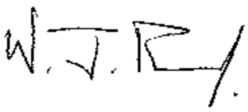
Foreword

Beavers in Scotland

I am delighted to present this report to Scottish Ministers. It is the culmination of many years of dedicated research, investigation and discussion.

The report draws on 20 years of work on beavers in Scotland, as well as experience from elsewhere in Europe and North America. It provides a comprehensive summary of existing knowledge and offers four future scenarios for beavers in Scotland for Ministers to consider. It covers a wide range of topics from beaver ecology and genetics, to beaver interactions with farming, forestry, and fisheries.

The reintroduction of a species, absent for many centuries, is a very significant decision for any Government to take. To support the decision-making process we have produced this comprehensive report providing one of the most thorough assessments ever done for a species reintroduction proposal.



Ian Ross
Chair
Scottish Natural Heritage
June 2015

Commission from Scottish Ministers to SNH, January 2014

Advice on the future of beavers in Scotland

SNH should deliver a report to Scottish Ministers by the end of May 2015 summarising our current knowledge about beavers and setting out a series of scenarios for the future of beavers in Scotland.

The report should present a summary of existing knowledge about the likely impact of beavers living in the wild in Scotland. This summary would draw on the information gathered in Scotland from the Scottish Beaver Trial in Knapdale, the Tayside Beaver Study Group, the Beaver-Salmonid Working Group, and other projects and academic papers, as well as experience from elsewhere in the world.

The scenarios in the report should be developed in an open and inclusive way with a range of interested stakeholders from the National Species Reintroduction Forum and other beaver-focused groups. They should set out the risks and benefits of each approach, and any management approaches to help mitigate the risk and/or maximise any benefits.

The report should show clear links between the evidence base and the risks and benefits in the scenarios.

The report should seek to describe possible ways forward to inform Ministers' considerations of the issues rather than make specific recommendations.

The report should be published.

Contents

Summary

Background

- This report been requested by the Scottish Government, and is designed to support the Minister for Environment, Climate Change and Land Reform in making a decision on the future of beavers in Scotland
- The report provides assessments of the interactions beavers may have on the natural and human environments, examines legal and beaver management issues, and presents a number of future scenarios for beavers in Scotland
- The issues surrounding beaver reintroduction to Scotland have been the subject of intense investigation and discussion over the last 20 years. This report draws on work and experience generated through SNH-commissioned projects, the Scottish Beaver Trial, the Tayside Beaver Study Group, the Beaver-Salmonid Working Group, the National Species Reintroduction Forum and a range of other studies from Scotland and abroad
- Assessing the need for beaver reintroduction has a legal basis, in particular the 'Habitats Directive'. This requires EU Member States to study the desirability of reintroducing certain species, such as Eurasian beaver. The potential for beaver reintroduction to contribute to the aims of the '2020 Challenge for Scotland's Biodiversity' is a further consideration
- At the current time there are two wild populations of beavers present in Scotland on a 'trial' basis, at Knapdale in Argyll and in Tayside. Any decision would need to consider their future, as well as the desirability or not of any further reintroductions

Beavers and the natural environment

- Beavers are widely considered to be 'ecosystem engineers', which means they have a large impact on habitats and species through the alterations they make to the physical environment
- Beaver activity is largely restricted to freshwater and associated riparian habitats, in particular where broadleaved woodland is present. Substantial areas of these habitats occur across much of Scotland, and these would be able to support a viable population of beavers. Other habitats in Scotland would generally be unaffected by the presence of beavers
- Experience from Scotland and abroad has demonstrated that, overall, beavers have a very positive influence on biodiversity. Their ability to modify the environment means that beavers not only create new habitats but also increase habitat diversity at the catchment scale. Their impacts are dynamic and change across space and time
- The mechanisms by which beavers change environments and affect biodiversity include creating ponds and wetlands, altering sediment transport processes, importing woody debris into aquatic environments, creating important habitat features such as standing dead wood, creating coppiced stands and unique vegetation structures, and creating successional stages such as beaver meadows
- Many species benefit from these changes, others are disadvantaged at local scales. However, the latter species may colonise new habitat created by beavers or their remaining habitat may be improved, resulting in neutral effects or overall benefits at the catchment/wider scale
- Some species and habitats of high conservation importance have the potential to be adversely affected by beavers. This is especially the case where they are isolated and in close proximity to riparian areas, and where ecological continuity could be affected. There may be localised losses of riparian stands of aspen and Atlantic hazel, and their associated species. The regeneration of other tree species felled by beavers may also be hindered where deer are abundant. There may be potential benefits of beaver presence for migratory salmonids, but there may also be possible adverse impacts, especially on the spring stock component of Atlantic salmon
- There is now a greater understanding of the genetic backgrounds of beavers across Europe and in Scotland, including risks to genetic health that may arise from inbreeding, which will assist in the development of any future reintroduction and reinforcement planning
- Habitat mapping and population modelling tools have been developed that will assist in any future monitoring and management planning

Beavers and the human environment

- Beavers can provide a range of ecosystem services. These include 'provisioning ecosystem services' such as increased ground water storage, 'regulation and maintenance ecosystem services' such as flow stabilisation and flood prevention, and 'cultural ecosystem services' that relate to people's recreational, educational and spiritual interactions with the environment. They can act as agents of natural change and restoration. These all contribute to human wellbeing and have socio-economic impacts
- Socio-economic assessments have been undertaken at Knapdale and Tayside, and a range of recent, and potential future, costs and benefits have been identified
- Public consultation and surveys carried out over the last 17 years have demonstrated overall public support for beaver reintroduction, although concerns have been more evident amongst some land use sectors
- Beaver activities that may affect land use, such as agriculture and forestry, include burrowing and canal construction, damming of smaller water courses, blocking of culverts, direct foraging of crops, and felling of trees of commercial value. The extent and significance of the resultant impacts will depend on local conditions. Concerns will tend to be greatest in areas where beaver activities affect intensive agriculture. However, beavers may also contribute positively to land use objectives relating to the improvement of the health and wellbeing of people, and aspirations for a high-quality, robust and adaptable environment
- The damming, burrowing and tree felling activities of beavers can also impact on a range of infrastructure including roads and tracks, culverts, weirs, sluices, fish passes, flood banks and other river structures, canals and water treatment plants. There is also the potential

for beavers to affect ornamental gardens, ponds and sites of historic value
- The impact of beaver activity on some native species such as pike, roach and perch, for which recreational fisheries exist in Scotland, are likely to be relatively modest. However there remain uncertainties over the impacts of beavers on migratory salmonids, and the potential implications for fisheries
- Animals used for the SBT were quarantined and screened before, and monitored after, release, and there was a programme of public health monitoring at Knapdale. A sample of Tayside beavers were also tested for a range of parasites and diseases, and no evidence was found of pathogens that may cause an increased health risk to humans, livestock and other wildlife
- Beavers could be involved in the transfer and hosting of diseases and parasites with public health and animal health significance. Consultations with key public health authorities should be undertaken during the planning stages of any translocation. Health assessments and pathogen screening of beavers are regarded as key requirements prior to release. Post-release monitoring may also be required in some cases

Beaver management and legal issues

- It is assumed that beavers, if reintroduced to Scotland, would be given full legal protection as a European Protected Species under the Habitats Regulations. There may be a need to produce a Strategic Environmental Assessment as part of a decision on the future of beavers in Scotland
- Management of beavers and their impacts will involve the interaction of a number of different pieces of legislation. Any release of beavers in Scotland presently requires a licence from SNH
- Beavers now occur in over 25 European countries. Techniques for the effective management of beavers and beaver impacts are well developed across Europe and North America, providing a range of beaver management options and experiences upon which to draw
- A large number of techniques have been developed in response to legal constraints and a wider social interest in minimising non-lethal wildlife management solutions. Many management techniques are unlikely to require a licence, but some would. There would need to be a regulatory regime in Scotland which is balanced, proportionate and legally compliant
- The appropriate management of beavers and their impacts will inevitably change over time. Once reintroduced into a river system, beavers will eventually spread to occupy most of the suitable habitats throughout that catchment. If this is undesirable the only management solution to limit beavers to particular areas, especially in the longer term, is through a constant, consistent process of removal via trapping or culling
- The creation and restoration of riparian ‘buffer zones’, and the identification of existing ones, could be an additional and effective way of planning beaver management on a more long-term basis and providing wider environmental benefits

Future scenarios and a management strategy

- Four potential scenarios for the future of beavers in Scotland are presented. These range from the full removal of beavers to the widespread reintroduction of beavers across Scotland. The scenarios are broad and a number of sub-options are possible. Few of the scenarios are discrete, so scenarios may be combined and there is the potential to change between different scenarios over time. There is a range of risks and benefits associated with each scenario; no scenario is risk or cost free
- Scottish and European species management experience has shown the value of producing and adopting a pragmatic and responsive management strategy at an early stage in any reintroduction process. This would help alleviate land owner, land manager and public concerns that potential impacts may be unmanageable and to establish clear parameters for intervention
- Best practice, such as that set out in the Scottish Code for Conservation Translocations, would suggest that a management strategy should be developed in collaboration with stakeholders
- Any management strategy would set out the wider and longer term aims and objectives of the beaver scenario concerned. It would include realistic timescales (e.g. five years for immediate actions, but taking into account longer term goals). Further details on what a management strategy might need to address are presented in the report. They include issues such as the need to; take account of the Scottish Code for Conservation Translocations for any reintroduction; provide clear guidance on management options; identify sources of advice and support for land managers; develop a research and monitoring programme; identify measures to reduce escapes from captive collections; look for opportunities for beaver reintroduction and management to be set within the wider aims of long-term land use planning, the ecosystem approach and habitat restoration in a multi-functional landscape

Chapter 1
Introduction and background

The issues surrounding beaver reintroduction to Scotland have been the subject of intense investigation and discussion over the last 20 years. During this time there have been numerous research projects, hundreds of media articles and broadcasts, and many public debates on the topic. As a result, it has influenced wider thinking on the reintroduction and management of other species, and the value of ensuring that both biological and socio-economic issues are integrated into the planning of conservation and wildlife management projects.

Why has the potential reintroduction of beavers created so much interest? Firstly, the Scottish Beaver Trial at Knapdale was the first time that a government-approved release of a former native mammal species into the wild had been attempted anywhere in the UK. It has been a historic project which has generated national and international attention. Secondly, the beaver itself has a fascinating and unique natural history, the only species apart from humans that can intentionally modify its environment by building structures. Thirdly, this very ability can also bring many wider environmental benefits, including to other habitats and species, but it can also bring it into conflict with land managers and others when damage is caused.

What is this report for and why is it needed?

This report is being produced following the completion of the Scottish Beaver Trial, the work of the Tayside Beaver Study Group and a number of other projects and initiatives (Chapter 2)[1]. It has been requested by the Scottish Government, and is designed to support the Minister for Environment, Climate Change and Land Reform in making a decision on the future of beavers in Scotland. As things stand, there are two wild populations of beavers present on a 'trial' basis, at Knapdale in Argyll and in Tayside, and any decision would need to consider their future, as well as the desirability or not of any further reintroductions.

The report summarises the significant amount of Scottish and international work and experience on beavers. It provides assessments of the interactions beavers may have on the natural and human environments, examines legal and beaver management issues, and presents a number of future scenarios for beavers in Scotland. It does not go into details but points readers to appropriate sources, many of which were produced in Scotland.

Assessing the need for beaver reintroduction has a legal basis. The key legal driver has been Council Directive 92/43/EEC of 21 May 1992 on the conservation of natural habitats and of wild fauna and flora, better known as the 'Habitats Directive'. Article 22 of this directive states that EU Member States should:

'…study the desirability of re-introducing species in Annex IV that are native to their territory where this might contribute to their conservation, provided that an investigation, also taking into account experience in other Member States or elsewhere, has established that such re-introduction contributes effectively to re-establishing these species at a favourable conservation status and that it takes place only after proper consultation of the public concerned.'

The Eurasian, or European, beaver *Castor fiber* (Figure 1.1) is one of the species listed in Annex IV, so this report summarises and assesses the 'desirability' of its reintroduction.

There are also other international legal instruments which refer to reintroductions in a more general sense, such as the 'Bern Convention' of 1979 and the Convention on Biological Diversity (1992), and these are described elsewhere[2].

All of this should be considered in the context of the 2020 Challenge for Scotland's Biodiversity, a strategy launched by the Scottish Government in 2013 to protect and restore Scotland's biodiversity, in response to the Aichi Targets set by the United Nations Convention on Biological Diversity. It aims to:

- Protect and restore biodiversity on land and in our seas, and to support healthier ecosystems
- Connect people with the natural world, for their health and wellbeing and to involve them more in decisions about their environment
- Maximise the benefits for Scotland of a diverse natural environment and the services it provides, contributing to sustainable economic growth

Figure 1.1
Eurasian beaver.
© Laurie Campbell

Beavers in Europe

The Eurasian beaver inhabits riparian broadleaf woodland or scrub bordering fresh standing waters or slow-moving watercourses. It occurs from western Europe eastwards to the Chinese–Mongolian border region. At the beginning of the twentieth century there were thought to be only around 1,200 animals surviving in eight populations[3]. Three discrete western European populations survived: in southern Norway, on the Elbe in Germany and on the Rhone in France. In the east, small populations persisted in Belarus, Russia, Ukraine, Mongolia and China. The twentieth century marked a dramatic turnaround. As a result of changes in wildlife legislation, management practices and enhancements, translocations/reintroductions and natural recolonisation, the total population is now estimated to be a minimum of one million animals in at least 25 European countries[4], although this is heavily weighted towards eastern and northern Europe. As of 2008 there were 678 SACs (Special Areas of Conservation) within 10 EU Member States where the European beaver was recorded as a Habitats Directive Annex II interest (an increase from 85 SACs in four EU Member States in January 2002)[5]. This represents one of the most strikingly successful conservation feats for a European vertebrate.

Beavers in Scotland and Britain

The fossil record indicates that the species was living in Britain two million years ago, 1.3–1.5 million years before the first humans. Initial work[6, 7] found that the Eurasian beaver appeared to have been widespread throughout Britain, including Scotland. Some palaeontological and archaeological remains, together with written historical information, suggest that it was present here until the early sixteenth century – the last Scottish record is mentioned in the 1526 'Cronikils of Scotland' and refers to beavers as being abundant in the Loch Ness area. More recently, evidence has been found that beavers may have been present well into the late eighteenth century in England[8]. The cause of this loss to Scotland, as elsewhere across Europe, is believed to have been unsustainable levels of hunting for the valuable beaver pelts, and to a lesser extent for castoreum and meat. These causes are unlikely to be a problem for any new reintroduction. Habitat loss is thought to have been a relatively minor and localised factor.

SNH started investigating the feasibility and desirability of reintroducing beaver to Scotland in 1995, as part of its 'Species Action Programme'. A number of reviews and assessments were run during the 1990s, culminating in a national consultation in 1998[9]. As a result, a trial reintroduction was proposed, and approved by the SNH Board in 2000. Shortly afterwards, Knapdale Forest in mid-Argyll, an area owned and managed by Forestry Commission Scotland (FCS), was identified as a potential release site. A licence application to permit this was eventually turned down by the Scottish Executive (as the Scottish Government was then known).

However, beavers were included within the Species Action Framework launched in 2007 by SNH, and shortly afterwards a licence application was submitted by the Scottish Wildlife Trust (SWT) and Royal Zoological Society of Scotland (RZSS) to undertake the 'Scottish Beaver Trial', a trial reintroduction at Knapdale. Permission was granted by the Scottish Government, and animals were released in 2009, followed by five years of monitoring (Figure 1.2). In the meantime, occasional

Figure 1.2
The first ever formal release of beavers into the wild in Britain took place at Knapdale in May 2009.
© Lorne Gill/SNH/2020VISION

records were received of beavers in the Tay catchment. These were thought to have originated as unauthorised escapes from animal collections, and possible deliberate releases. Initial attempts to capture and rehouse the beavers stopped when it became apparent that the numbers were far higher than originally estimated, and in 2012 the Scottish Government decided to 'tolerate' and monitor their presence on a temporary basis.

Beavers have also been placed in a number of private, large enclosures across Britain, and allowed to live under 'semi-wild' conditions. They include sites on Tayside, Inverness-shire, the Cotswolds, Kent and Devon. Animals have also been reported living in the wild from one site in mid-Wales and at least five sites in southern England, although there is little information on their origin, numbers and viability[10]. The Devon Wildlife Trust was issued with a licence by Natural England in January 2015 to allow the monitoring of a small breeding population, which originated from unknown sources, of beavers on the River Otter in Devon for a five-year trial period.

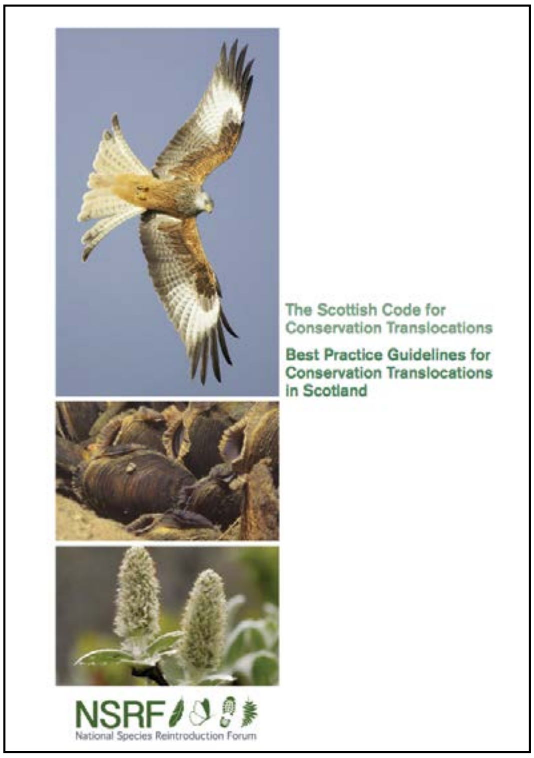
Conservation translocations and Scotland

Although the projects investigating the issues surrounding beaver reintroduction have gained a lot of attention, there have been many other projects involving reintroduction and other types of conservation translocation in Scotland. More recently, many of these were done through the Species Action Framework, and included species such as woolly willow *Salix lanata*, pine hoverfly *Blera fallax*, freshwater pearl mussel *Margaritifera margaritifera*, vendace *Coregonus albula* and white-tailed eagle *Haliaeetus albicilla*. The biological and socio-economic challenges that these types of projects bring resulted in the establishment of the National Species Reintroduction Forum in 2009. This forum is chaired by SNH and has a membership representing a range of stakeholders from the land use, conservation and science sectors. It is a unique group and has an advisory role to contribute to broad-scale, strategic issues relating to species reintroductions and other types of conservation translocations in Scotland.

One of the key recent outputs of the forum has been the Scottish Code for Conservation Translocations and the accompanying 'Best Practice Guidelines for Conservation Translocations in Scotland', launched by the Minister for Environment and Climate Change in July 2014 (Figure 1.3). The Code and Best Practice Guidelines are believed to the first of their type anywhere in the world. They set out when conservation translocations may be appropriate and the types of situations in which they may benefit or cause problems to wildlife, people and the environment. They are based on the International Union for the Conservation of Nature's Guidelines for Reintroductions and Other Conservation Translocations[11] but they provide a special focus on both Scottish socio-economic and biological issues. The significant involvement and approval of 26 different members of the National Species Reintroduction Forum also means that they represent an approach that has been agreed across a wide range of conservation and land use organisations.

The experiences gained during 20 years of examining beaver reintroduction helped to influence the approach that was agreed and set out in the Code and Best Practice Guidelines. In turn, they will also be applied in assessing any new beaver conservation translocation proposals, if the decision is made to allow beavers to remain in Scotland.

Figure 1.3
The Scottish Code for Conservation Translocations produced by the National Species Reintroduction Forum.



Chapter 2
Sources of information

This chapter describes the main sources of Scottish and international information which have been used to underpin the report. It includes the two field-based studies of wild-living beavers at Knapdale and Tayside. Further information can be found in the chapter on beavers in the Species Action Framework Handbook[1].

Figure 2.1
Knapdale forest, mid-Argyll.
© Martin Gaywood/ SNH

SNH-commissioned projects

A number of reviews and other studies were commissioned by SNH before permission was sought to undertake a trial reintroduction. These included literature reviews and the collation of information provided by specialists on the European and, to a lesser extent, the North American experience with beavers:

- Assessment of the historical evidence of beaver occurrence, and causes of extinction, in Scotland[2, 3]
- Identification of the most appropriate source of beavers for any Scottish reintroduction[4]
- Development of beaver habitat survey protocols[5]
- Identification of potential beaver habitats, and prediction of population patterns, at the national and local scales[6–8]
- Review of beaver dam-building and hydrology[9]
- Review of beavers and fish/fisheries[10]
- Review of beavers and woodland habitats[11]
- National consultation – an assessment of public desirability[12]

These helped to identify some of the potential risks and benefits of beaver presence in Scotland. More recently, some of this work has been updated and developed, and new studies have been organised by SNH:

- Identification of potential beaver habitats, and prediction of population patterns, at the national and local scales[13, 14]
- Review of beavers and fish/fisheries[15, 16]
- Review of beavers and biodiversity[17]
- Review of beavers and management[18]
- Review of the European experience in applying derogations for protected reintroduced species, including beaver[19]

All of the above SNH-commissioned reports are available to view on the SNH website.

The Scottish Beaver Trial

The Scottish Beaver Trial (SBT) has been the central beaver-related project. It was managed by the SWT and RZSS, with the FCS acting as host partners. The aims of the SBT were set out in the original licence application, namely to undertake a scientifically monitored trial reintroduction of the Eurasian beaver to Knapdale for a five-year period in order to:

- Study the ecology and biology of the Eurasian beaver in the Scottish environment
- Assess the effects of beaver activities on the natural and socio-economic environments
- Generate information during the proposed trial release that will inform a potential further release of beavers at other sites with different habitat characteristics
- Determine the extent and impact of any increased tourism generated through the presence of beavers
- Explore the environmental education opportunities that may arise from the trial itself and the scope for a wider programme should the trial be successful

The licence application also set out a range of criteria to help measure the success of the SBT. Appendix 1 describes these criteria in further detail, together with an assessment by SNH on how they were met.

Full details on how Knapdale was identified as a release site, the SBT local consultations, the licence application process, the project management and organisational roles, resourcing, practicalities associated with the translocations (capture, holding, transport, quarantine and screening, release), the management of the animals, and the education and visitor interpretation programme are described elsewhere[1, 20] (Figures 2.1-2.4).

There were a number of conditions associated with the SBT licence, a key one of which set out SNH's role in coordinating a monitoring programme for the SBT (Figure 2.5). To ensure that the process was independent, SWT and RZSS did not contribute to the scientific design, interpretation and reporting, but were involved in discussions relating to the practical application of work on the ground and undertook some of the data collection. SNH worked in direct partnership with a range of organisations leading on various natural heritage issues:

- Beaver ecology – with the University of Oxford
- Riparian mammals – with the University of Oxford
- Fish ecology – with the Argyll Fisheries Trust
- Dragonflies and damselflies – with the British Dragonfly Society
- Woodland habitat – with the James Hutton Institute
- Loch ecology/aquatic plants – with the University of Stirling
- River habitat – with the University of Stirling
- Hydrology – with the University of Stirling
- Socio-economics – with Scotland's Rural College

Other independent organisations led on issues outside SNH's specialist remit:

- Beaver health – led by the Royal (Dick) School of Veterinary Studies
- Water chemistry – led by the Scottish Environment Protection Agency
- Public health – led by Argyll and Bute Council
- Scheduled monuments – led by Historic Scotland

The final outputs of these monitoring projects are available on the SNH website and are referred to frequently throughout this report.

Figure 2.2 The Scottish Beaver Trial. © Lorne Gill/SNH

Figure 2.3 One of the first animals ready for release at Knapdale, 27 May 2009. © Martin Gaywood/SNH

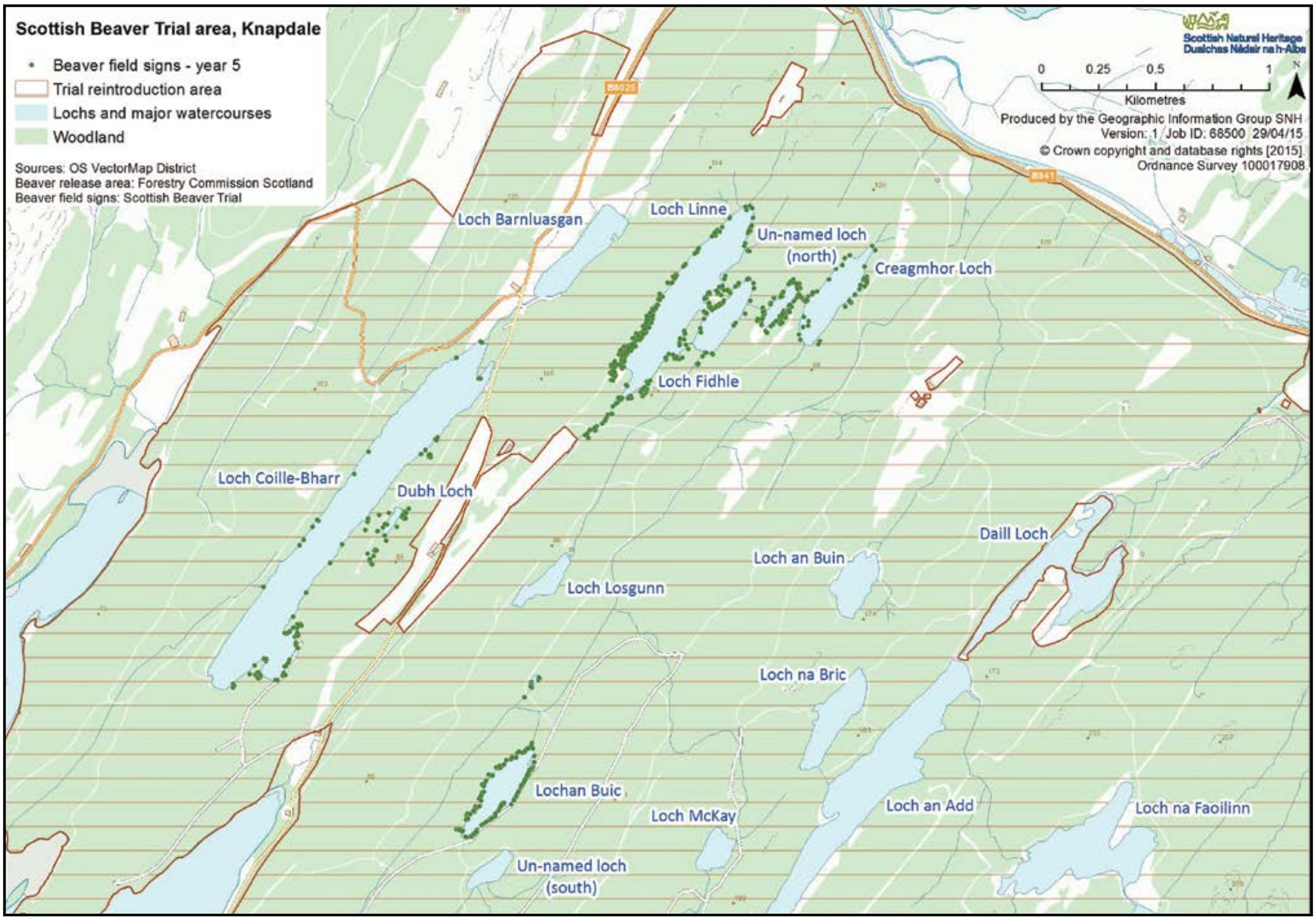


Figure 2.4
Map of the SBT area at Knapdale. The location of beaver field signs from the fifth year of monitoring shows where most beaver activity has been concentrated.

The Tayside Beaver Study Group

The Tayside Beaver Study Group (TBSG) was established in 2012 by SNH in response to a decision by the Minister for Environment and Climate Change to tolerate the unlicensed beaver population on Tayside (specifically the River Tay and Earn catchments). The Minister decided that the Tayside beaver population should be allowed to remain in place and be subject to appropriate study for the duration of the official SBT in Knapdale.

The TBSG was chaired by the SNH Area Manager for Tayside and Grampian. It comprised a range of partners: the National Farmers Union of Scotland, RZSS, Scottish Environmental Protection Agency, the Scottish Government, SNH, Scottish Land and Estates, Scottish Wild Beaver Group, SWT, Tay District Salmon Fisheries Board and the Confederation of Forest Industries.

The group had two principal aims:

– To gather information about the Tayside beavers and monitor impacts on local wildlife and land uses in the area
– To help identify a variety of means to resolve any conflicts between beavers and land uses in the area, provide advice and practical help to land owners at a local level, and consider how these means could be used more widely in the future

The information gathered from Tayside was designed to complement information from the SBT and elsewhere. Key activities carried out during the monitoring period included:

– Gathering information on the health and genetic status of the population
– Understanding breeding success to aid with population modelling
– Recording impacts on land use
– Investigating and trialling methods to minimise negative impacts
– Establishing the current and future requirements for advice

The work of the group did not extend to the study of the ecological effects of the beaver population, including any ecosystem services/dis-services that may have resulted from their presence.

A part-time project officer was employed from April 2013 until December 2014 to progress and coordinate these activities.

The final outputs of these projects, including a final TBSG report[21], are available via the TBSG website, and are referred to frequently throughout this report. In addition, a separate socio-economic study commissioned by SNH[22] is available from the SNH website.

The Beaver–Salmonid Working Group

The Beaver–Salmonid Working Group (BSWG) was established in 2009 as a sub-group of the National Species Reintroduction Forum, to consider the potential impacts of beaver activity on salmonids (Atlantic salmon and brown trout). The BSWG comprised representatives from:

- Association of Salmon Fishery Boards*
- Marine Scotland*
- National Museums of Scotland*
- Scottish Government*
- Scottish Environmental Protection Agency
- SNH*
- Tay District Salmon Fisheries Board
- University of Southampton
  (* original full members of the BSWG at its inception)

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 habitats 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

To take this forward, the BSWG 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. The final report of the BSWG is available from the SNH website[23]. Particular reference is made to the BSWG report in the fish and fisheries sections of this report.

Other sources of information

SNH holds a literature database listing over 2,500 publications which describe various studies on beavers, beaver interactions with the natural and human environment, and other related issues. Many of these are referred to in this report, with a focus on European sources, although many North American studies are also referred to where relevant. This report also draws on discussions that SNH staff have held with specialists based in other countries.

A range of other projects and initiatives have also been taking place in Scotland. These include PhD studies involving field-based studies at Scottish sites where there are enclosed and wild-living beavers[24, 25]. A number of studies have been undertaken on veterinary considerations in beaver translocations and husbandry, partly based on the Scottish experience[26]. The RZSS has led on a multi-partner project examining beaver genetic issues[27].

There have also been preliminary feasibility studies examining the potential for beaver reintroduction to both England[28] and Wales[29].

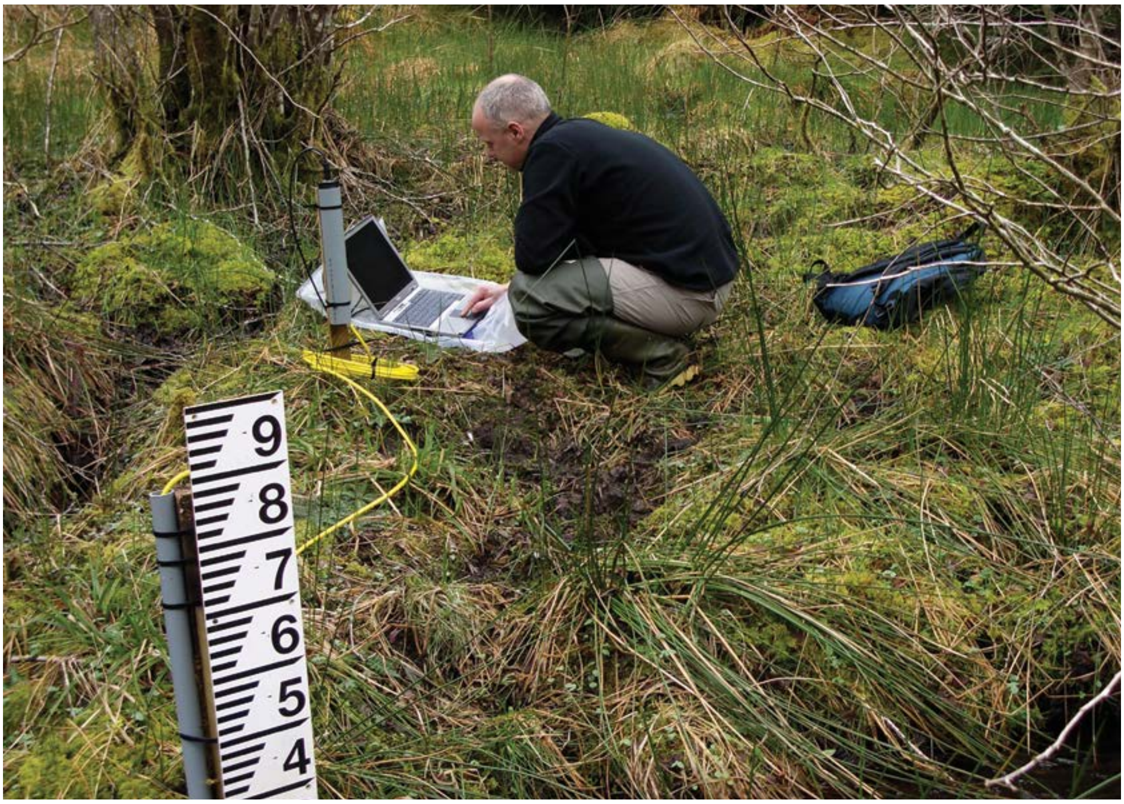


Figure 2.5 An independent monitoring programme was set up for the SBT, coordinated by SNH. © Martin Gaywood/ SNH

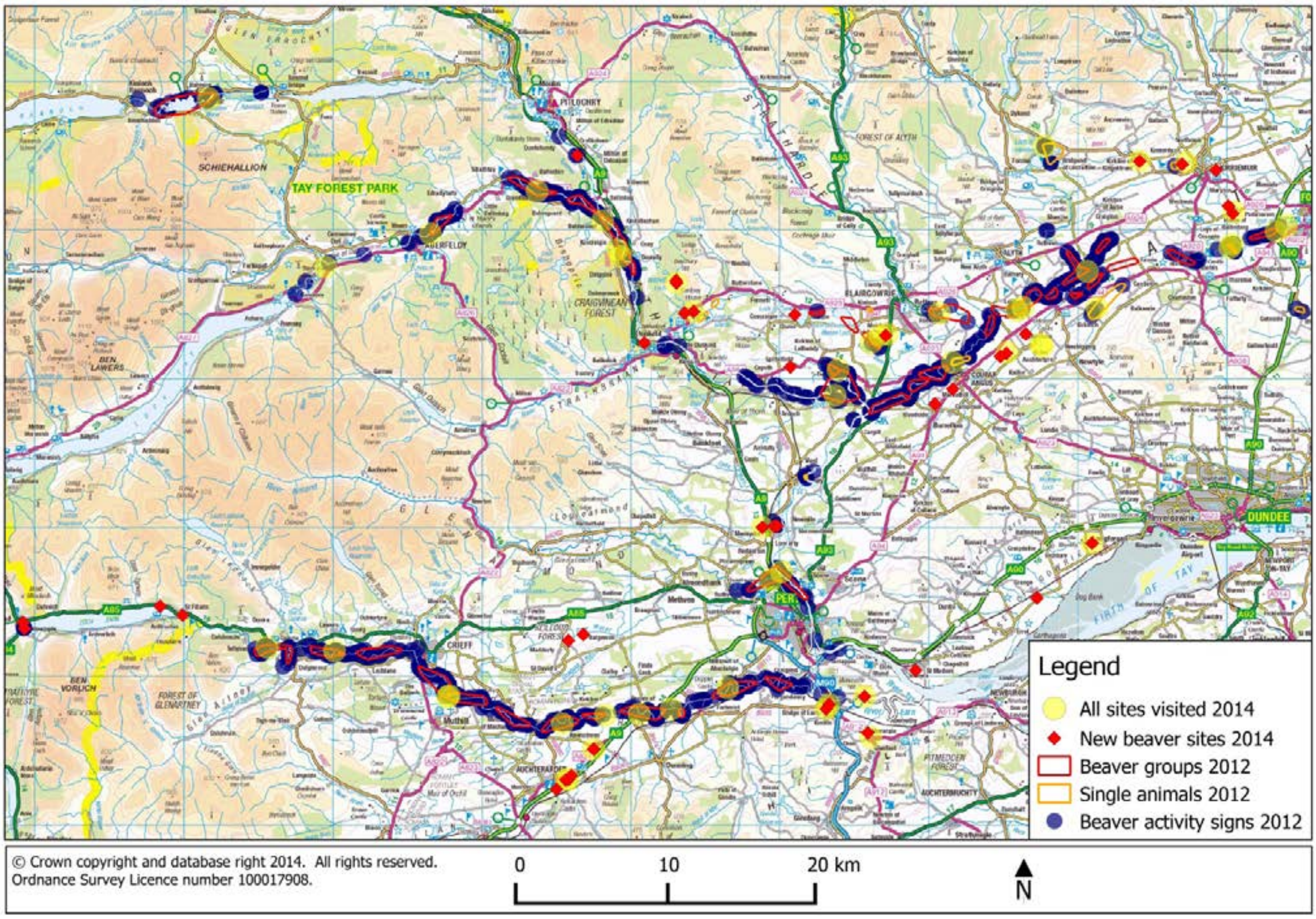


Figure 2.6
Beaver distribution map for Tayside. It is based on data from the 2012 survey, and further records from 2014[21].

Chapter 3
Beavers and their interactions with the natural environment

This chapter summarises what is known about the ecology of beavers, their genetics, where beavers might occur in Scotland in the future and how they interact, or might interact, with a range of habitats and species. It does not provide detailed and comprehensive reviews of these topics, as these are available elsewhere and are referred to in the text.

Each section on the interaction of beavers with habitats and species is structured in the same way. They start with an overview of the topic concerned, setting out the information available, in particular from European and North American studies. The ecology of the North American species of beaver is so similar to that of the Eurasian species that it makes sense to refer to studies involving the former, especially where information on the latter is limited. There are then summaries of the Scottish experience, drawing on field- and desk-based studies that have been carried out over the last 20 years. These are followed by assessments of the potential future implications for Knapdale and Tayside for the species group or habitat concerned if beavers are allowed to remain. Inevitably these involve a degree of uncertainty, but they are based on the research and experience gained to date and the expert judgement of specialists. Finally, the potential future implications of a wider beaver reintroduction to Scotland are assessed. These include assessments for habitats and species of European importance (i.e. those listed on Annex I, II or IV of the Habitats Directive, plus some examples of specific bird species of conservation importance).

At the end of each habitat and species section is a table that summarises potential interactions with beavers. The same standard beaver activities, and mechanisms that cause change, are listed in each table. Summaries of the potential positive and negative effects that these beaver activities and mechanisms may have on Scottish habitats and species are provided. In some cases the information is lacking, so it is not possible to make a judgement on what the effect will be. The effects are not weighted, so the influence of each effect may differ greatly. It may be possible to counteract negative effects and promote positive effects through appropriate targeted management.

3.1 Beaver ecology

This section provides a brief summary of beaver ecology. It reviews how the SBT beaver population at Knapdale has established and performed, and provides comparisons with the beaver population on Tayside (where there are comparable data). Reference is also made to ecological information from beaver populations in other European countries. The potential for beavers to establish in Scotland, and key factors that might affect their performance and management, are assessed.

The SBT was designed to be practical, reversible and of an appropriate duration as a trial, and thus was necessarily small (in terms of population size) and relatively short (in terms of duration). For an animal which typically lives for 7–8 years, the demographic information is inevitably limited. Four family groups were established to assess how a trial population would settle and how the beavers would adapt to, and affect, their surroundings. The trial was not designed to establish a self-sustaining reintroduction. Hence, the parameters derived must be viewed with caution as they may not be representative of a larger population.

The Tayside beaver population has stemmed from the unlicensed release or escape of beavers. The nature of the releases and associated lack of baseline data pose additional challenges to assessing the performance of this introduced population. However, recent monitoring of the Tayside population has highlighted some differences from the Knapdale population.

Eurasian and North American beaver

Beavers are semi-aquatic rodents. The two species, Eurasian and North American, are remarkably similar and are indistinguishable without close examination[1]. The North American beaver was introduced in Finland before the two species were described as separate. Eurasian and North American beavers have different numbers of chromosomes and have not been recorded interbreeding under natural conditions. Eurasian beavers are medium-sized mammals, averaging 18 kg in weight, and live for an average of 7–8 years[2].

Beaver colonies and territories

Beavers form lifetime pairs, with a pair defending a strict territory against unrelated intruders. Beaver colonies are made of family groups, typically consisting of an adult pair, and a number of kits (young under one year of age) and sub-adults. A study in Norway showed an average colony size of 3.8 individuals (range 1–7), with an average composition of 54% adults, 26% yearlings and 19% kits[3]. The size of territories is often measured by the length of water bank utilised and is quite variable[4]. In Telemark, Norway, the mean territory size was estimated at 4 km, while in Biesbosch, the Netherlands, the mean territory size was 12.8 km. Scent marking by beavers identifies their territories, and this often occurs on scent mounds, which are regularly remarked[1, 5]. Territories are rarely permanent. Beavers are strict herbivores, and their preferred food sources slowly deplete over time. Therefore beavers may leave a territory for a number of years, and will not recolonise the area until enough suitable food has regenerated.

In the final year of the SBT the four beaver families occupied six lochs, totalling an area of 367 ha. The families that set up territories largely continued to occupy the lochs and sections of the connecting waterways on which they were released. The area of loch occupied per beaver family ranged from 4.3 to 34.6 ha, largely dictated by loch size. The length of water's edge used by a beaver family ranged from 1.8 to 4.7 km. The density of beaver families was on average 0.2 per kilometre (or one beaver family per 5 km) of water bank edge. Despite some minor shifts, territories remained largely stable. The scarcity of scent-marking behaviour at Knapdale suggests that beaver families were not encountering one another frequently and, in the absence of neighbours, established home ranges in the immediately available habitat.

A 2012 survey in Tayside found 25 lodges, and 38-39 active beaver territories were estimated to be present[6]. This averaged out to 0.14–0.15 beaver family groups per kilometre of waterway on the sections of river where they occur. The mean length of waterway covered by each beaver group was 2.9 km (± 1.5 km). This study used the presence of scent marks and the distribution of other signs of recent beaver activity to help delineate the number of family groups. Boundaries of territories were determined by identifying where field signs ceased, unless there was another explanation for an absence of field signs such as a lack of suitable habitat. In contrast to Knapdale, the Tayside survey detected 67 scent mounds and 14 scent sites, representing 4% of all the field signs recorded. The River Earn and the rivers in the Isla catchments (particularly Dean Water) exhibited the greatest density of beaver groups, while the Rivers Tummel and Tay had the lowest density. Group territories on tributaries of the River Isla (excluding the Ericht) were the smallest (mean 1.5–1.6 km linear length) while group territories on the Rivers Isla itself, the Earn and the Tay were all of a similar larger size (mean 3.4–3.8 km linear length), although it was noted that differences in survey methods may have influenced these estimates. These findings support the suggestion that territory size can shrink but can still support a family group in higher density populations.

Territory size in Norway and the Netherlands was positively related to the proportion of deciduous habitat, which it was hypothesised was associated with the slow renewal rate of woody plants[5]. The patterns observed at Knapdale suggest that, at least for low-density reintroduced populations, home range size is largely influenced by the size and shape of water bodies. It is probably reasonable to assume that pairs of beavers will, for the most part, settle on the loch on which they are released, until higher population densities are achieved. Release site fidelity may be different on rivers, where there may be less distinct natural boundaries along the waterbody to influence exploration.

Feeding and habitat

Beavers are strict herbivores and feed on a wide variety of plant species, including aquatic and terrestrial herbaceous and woody vegetation (see sections 3.4.1 and 3.4.3). Smaller stems, less than 0.1 m in diameter, are often preferred[7–9]. However, larger stems (up to 0.2 m) may still be commonly utilised[10], and the use of trees of more than 1 m diameter has been recorded[11]. The presence

Figures 3.1 and 3.2
Most woody stems taken by beavers are less than 0.1 m diameter, but larger trees may be felled.
© Lorne Gill/SNH, © Martin Gaywood/SNH

of beavers is often easily identified by the chiselled stumps of felled trees (Figures 3.1 and 3.2). Other signs include feeding stations, often close to watercourses where beavers sit to feed, and foraging trails, which are regularly used pathways which beavers use for movement and dragging branches back to the water (Figure 3.3). Foraging trails may be developed into beaver canals. These structures extend the watercourse into the surrounding land, allowing beavers to forage further from a watercourse (Figure 3.4).

To help survive the winter beavers may also create food caches. A beaver food cache is a collection of branches either anchored into the bed of a watercourse or entangled within a waterlogged raft. Food caches are a useful food source for beavers, and help sustain them through the winter months. However, the creation of food caches seems to be dependent on the severity of winters, as in some populations not all beavers will build food caches[12]. Although food caches have been observed in both Tayside and Knapdale[6, 13], it is not clear how frequent this behaviour will be in the Scottish context.

The habitats occupied in Knapdale were largely broadleaf woodland, with birch, oak and hazel stands. The wider release area included conifer plantations as well as bogs, marshes, fens, heath and scrub[14]. The most dominant species was downy birch, and woodland types were used approximately in proportion to their availability. The feeding preferences and woodland impacts are examined in more detail in section 3.4.1 and the consequent implications for lichens are discussed in section 3.4.4.

Beavers are semi-aquatic and are reliant on water to escape from any potential predators. Because of this they feed only in close proximity to watercourses (section 3.2.1). At Knapdale, field signs (mostly felled or gnawed trees or branches) were predominantly located within 20 m of the water's edge, with occasional signs up to 50 m from the water's edge. There was no evidence of any progressive spread of field signs over the period of the trial and there were no apparent seasonal patterns in use of habitat or space. This is supported by international experience, which shows that the great majority of beaver activity is in close proximity to the watercourse[15–18]. Hence, it seems likely that the spread of beaver habitat use (and thus impact) away from aquatic habitats is very limited. This is supported by the woodland monitoring at Knapdale that showed increased use of non-preferred resources nearer the water over time, rather than use of preferred resources at increasing distances from the water[14].

Beaver structures

Lodges and burrows

Beavers live in lodges and/or burrows. Lodges are often highly visible structures made from cut branches, logs and mud (Figures 3.5 and 3.6)[1]. Burrows are often inconspicuous with underwater entrances. The two may be combined in a bank lodge, which is a burrow with further reinforcement and insulation provided above with a structure of logs and branches. Each pair of beavers at Knapdale built one to three lodges, resulting in a total of

Figure 3.3
Beaver trail at Knapdale.
© Lorne Gill/SNH

Figure 3.4
Beavers will dig canals. This one at a Dutch reintroduction site, has been dug in a pond that is drying up, and leads to a bank lodge.
© Martin Gaywood/SNH

seven. A second lodge was sometimes built on a second loch, and sometimes at the opposite end of the same loch. In addition, all beaver pairs/families dug one or two burrows that were located away from the lodge. Burrows appeared to be used as more temporary structures.

In Poland, it was noted that single beavers often lived in burrows, and that lodges were usually associated with reproduction[19]. All beavers at Knapdale were released as mature pairs, which may have explained why lodges were immediately built on the release lochs. A number of 'attempted' burrows were also recorded, particularly in the first two years of the trial, and these probably represented the start of lodge-building or temporary burrows.

Dams

Beaver dams are built from a variety of logs, branches, grass, mud and stones (Figures 3.7-3.9). The majority are less than 1.5 m in height, ranging from 0.2 m in height and 0.3 m in length, up to 3 m in height and more than 100 m in length, although the latter are exceptional cases[1, 45]. They are built to retain water, create feeding areas, provide safe refuge (and keep the lodge entrance under water) and facilitate travel and movement of logs and branches[1]. Dams were built at five main locations, on three lochs, during the SBT, although an additional one has recently been recorded on another loch. Dam- and canal-building was variable among families/lochs, and canal-building was also variable between years. These observations are consistent with other studies.

Although there is an extensive literature describing dam-building by beavers, it is not always predictable where or in what physical conditions beavers will build dams. One detailed study in Sweden reported that the mean width of streams on which beavers built dams was 2.5 m, up to a maximum of 6 m, and the mean water depth downstream of dams was 0.36 m (range 0.10–0.85 m)[20]. In some situations, beavers will not build dams at all, in others they may build dams at variable densities, with higher densities in smaller backwaters and side channels. In Bavaria 19% of beaver colonies have been recorded building dams. Reintroduced beavers in the Morava River basin in the Czech Republic did not build dams at all, because water levels were stable and the channel was too wide to dam[22]. Within beaver territories that build dams, the density of dams will also vary, with reports ranging from 0.14 dams per kilometre up to 19 dams per kilometre[20, 45]. Dam-building by beavers in the Tay catchment was initially minimal, with only three of an estimated 38–39 occupied territories having dams[6]. However, dam-building has now been reported at at least nine sites[21]. Management and mitigation options for dams and canals are discussed further in Chapter 5.

Dams may have a range of effects on the surrounding environment and nature of the watercourse (see section 3.4.3). In Knapdale, dam-building on Dubh Loch increased the water level dramatically, which in turn had a large impact on the ecology of the loch. For example, large amounts of benthic peat floated to the surface of the loch, a clear illustration of how changes to water levels can have indirect and dramatic physical impacts[23].

Figures 3.5 and 3.6
Beaver lodge at Tayside (top) and Knapdale (bottom). The former is 1.5 m high.

Figures 3.7 and 3.8
Beaver dams, such as these from Knapdale (top) and the Danish reintroduction site at Klosterheden (bottom), vary in size and construction.

Owing to either siltation or dam failure, beaver ponds are often temporary. After a beaver pond has returned to a terrestrial state, a beaver meadow may be created, which can persist for many decades. However, a pond may also develop into other states such as emergent wetland, bogs or forested wetland, which may remain stable for centuries[24, 25].

Population characteristics

Birth rate

Eurasian beavers give birth to between one and six kits per year, with an average of around 2.7 kits[26]. Between one and three kits per breeding pair were produced in each year of the SBT during which they could have been expected to breed. The proportion of females breeding was high, and the average litter size of breeding pairs ranged from 1 to 1.7 kits per year. This is comparable to the donor population in Norway.

After the first year, the young are described as sub-adults, and they often disperse to find their own territory at around two years old. Family groups in Knapdale varied in their composition from year to year, and were largely composed of an adult pair (with the exception of a single male on one loch at the end of the trial) plus one or more kits and sub-adults. The Dubh Loch family was the largest, with two adult females, a male and, in 2012, one sub-adult and three kits. The parentage of these kits is unverified as they subsequently disappeared, but may have resulted from a father–daughter pairing. The adult pairs on Lochan Buic and Creagmhor Loch swapped (males) at some point in 2011. Such changes in family dynamics are not unknown in beavers, perhaps where individuals are older and/or pairings are not successful in producing young[27].

Lodge counts conducted on the Tay catchment in 2013 and 2014 suggested an average litter size of 1.9 (±1.1), with a range in litter size of one to four and most lodges producing two or three kits. Kits were produced at 83% and 88% of lodges observed (at 11 and 18 lodges, respectively[39]). Hence, there may be differences in the performance of the two populations. This may be because Knapdale is a small, short-term population that may be significantly influenced by chance events. However, differences may also have arisen because of the different sites, habitats and provenances of the Knapdale and Tayside beavers (Norway and probably Bavaria, respectively). It is not possible to separate these factors from the data available.

Death rate

Beaver mortality may be caused by a wide range of factors, such as predation, disease, hard winters and old age. The majority of studies on mortality rates come from North America. Annual mortality for all age classes has been estimated at 27–30%; however, mortality seems to be much higher in kits and sub-adults than in adults[1, 28, 29].

Predators of beavers in Europe include wolves *Canis lupus* and lynx *Lynx lynx*, but also, less commonly, red foxes *Vulpes vulpes*, pine martens *Martes martes* and American mink *Neovison vison*[30–35]. In Latvia, the beaver is the most important prey species for wolves in the summer months, making up 36% of wolf diet by biomass[36]. Otter species rarely prey on beavers. A study in North America showed that beavers were present in only 5 of 1,140 river otter *Lutra canadensis* scats studied (0.4%)[37]. Beaver kit predation by raptors has been reported, including by white-tailed sea eagles *Haliaeetus albicilla*, golden eagles *Aquila chrysaetos* and goshawks *Accipiter gentilis*[35].

A total of 16 beavers were released in five families during the SBT. Four of the five beaver families settled on the lochs on which they were released. Three deaths (all males) were recorded during the first year of the trial, and five animals went missing (in years 1, 2 and 4). Eight of the released beavers were known to be alive at the end of the trial. A total of 14 wild-born beavers were recorded over four breeding seasons. Two kits are known to have been predated and a further eight went missing and almost certainly died. One (or two) of the wild-born kits were present at the end of the trial. Survival estimates for the trial population are very variable depending on how the missing animals are treated (ranging from about 0.4 to 0.7, with confidence limits of 0.2 and 1, respectively). However, mortality of adult beavers appeared to be low in comparison with reintroductions elsewhere in Europe.

Kit survival at Knapdale was also low in comparison with levels reported at the donor population in Norway. In some years kit loss was 100% and about 71% for the duration of the trial. The reasons for kit losses are not fully known, but two kits were found that had been predated. This may become a long-term trend or the high kit loss may simply have been the result of a few poor years. For example, 52% of kits less than six months old died in a study of a healthy population in Newfoundland[28].

The Knapdale beaver population was therefore stable, but did not increase over the period of the trial. A number of sub-adult beavers are thought to have dispersed from the trial site, but, owing to the timings and locations, are not thought to have resulted in any pairings outside it. The trial produced some information on the proportion of sub-adults that leave their family group and at what age this occurs, but was not able to accurately report dispersal distances or describe dispersal movements despite intensive searching[38].

The Tayside beaver population was estimated to comprise 38–39 beaver occupied territories in 2012[6]. It has not been possible to calculate the population growth rate of the Tayside population because its founder population size and the timing of its release remains unknown. Neither has it been possible to reconstruct beaver dispersal distances from the Tayside population, because the locations of the original releases are also not known. However, the present number, the age classes present and their distribution indicate that new pairings have established in the wild[39]. The presence of sub-adults and yearlings was found to be 67% at six active lodges observed in 2013, and 78% at nine active lodges observed in 2014, which suggests higher levels of kit survival than in Knapdale.

Population expansion

The average dispersal distance of beavers in established populations on the Elbe, Germany, was 26 km, and in Switzerland most beavers dispersed 10–20 km from their natal site, but occasionally travelled up to 120 km[40].

Predicting the dispersal of beavers from a release site is obviously an important consideration if a decision is made to formally reintroduce beavers to Scotland. Translocated beavers may stay at the release site, as was broadly the case in Knapdale. This is more likely if release sites are carefully selected and appropriate release methods used. However, average dispersal distances of between 4 and 18 km have been recorded for animals following translocation (with 390 km recorded in one North American example)[1]. Section 3.2 looks at this in more detail and models population growth and dispersal based on a range of literature sources[41].

Population range expansion has been observed following a number of reintroductions across Europe. Rates of expansion have been recorded of between 1.5 and 19.7 km per year[42, 43]. Population growth has also been recorded at a range of rates between 5% and 34% per year[44–48]. Following reintroduction, population range expansion occurs first with a lag in density increase[22, 42, 49]. Hence, the literature suggests that beavers usually undergo an expansion in range before increasing in density. Therefore, if numbers increased sufficiently in Scotland, they might eventually occupy the available territories before increasing in density, but then approach an equilibrium, presumably through density-dependent effects. In Sweden, a beaver population reached a high density and then plateaued in numbers 25 years after colonisation[50].

Figure 3.9
Beaver dam at Dubh Loch, Knapdale.

3.2 Potential beaver habitat and population

The beaver woodland datasets

It is useful to predict where potential habitat exists for beavers in Scotland, and to use this to estimate potential future beaver distribution. Work has therefore been done, using Geographic Information System (GIS) tools, to provide this information. This will help to identify where beavers may have effects on particular ecological and socio-economic factors.

Identifying the habitat requirements of beavers and using these parameters to predict their future distribution has been attempted before[1,2]. Beavers may utilise particular habitats, in particular riparian, broadleaf woodland, which provides a key source of food and materials for building structures (see section 3.4.1). They will also use aquatic vegetation as a food resource, although this could not be used in our model because of the lack of a nation-wide dataset. This work built on previous investigations of the extent of potential beaver woodland in Scotland[3].

GIS tools were used to create datasets of suitable beaver woodland across Scotland. The datasets were then used in a variety of overlapping analyses, described in later sections of this report, to predict where beavers may potentially interact with certain species or land use issues[4]. They were also used in the production of a revised beaver population model to help predict how beaver populations may grow and expand from their current locations (described below). A full methodology, including a description of the limitations of this approach, has been published[5].

Potential beaver woodland

The criteria used for previous woodland outputs for Scotland were reviewed and revised to take into account recent beaver ecological research[4]. Furthermore, baseline geographical data (watercourses and woodland) have

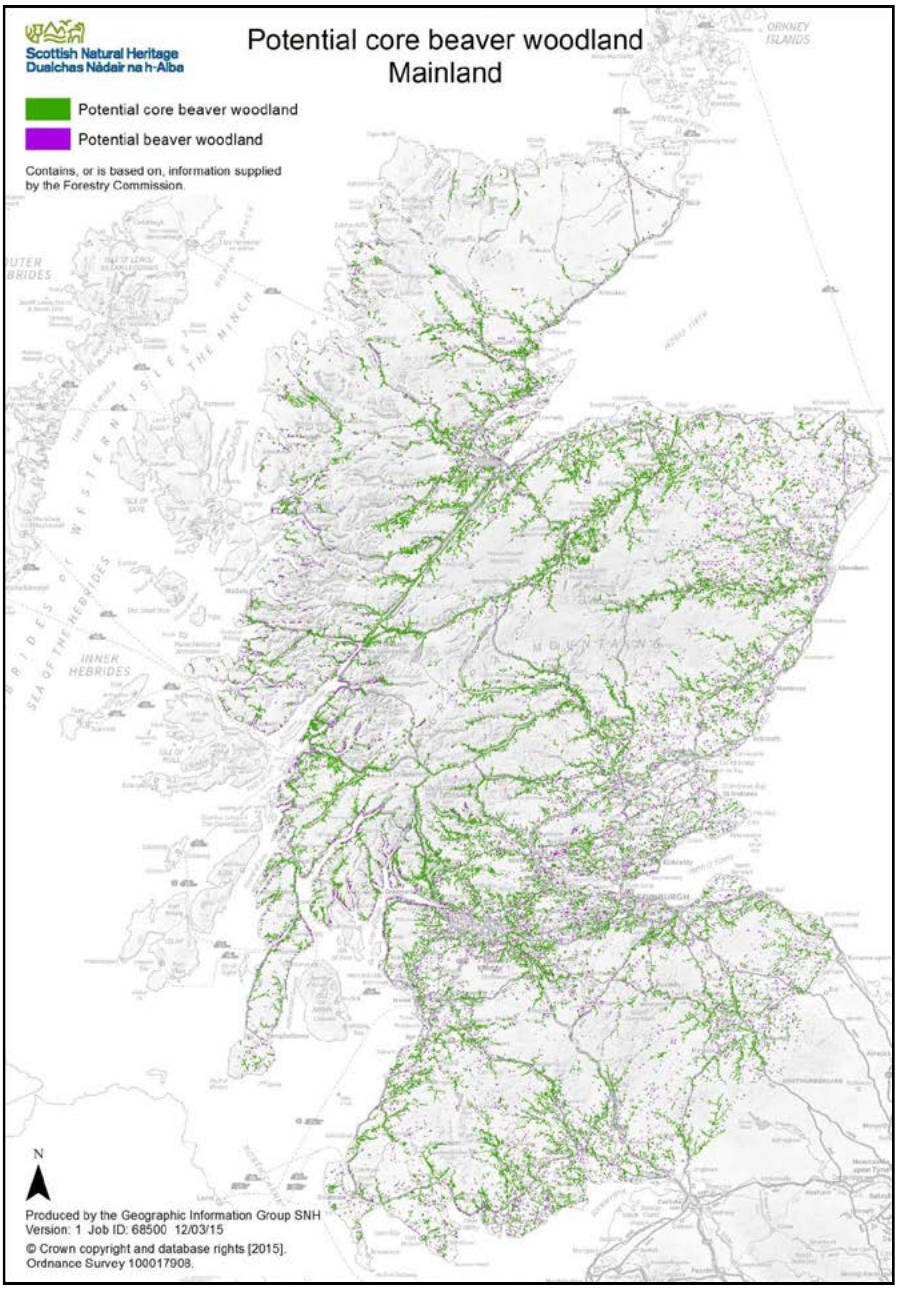


Figure 3.10
Potential core beaver woodland in mainland Scotland, showing further areas of 'potential beaver woodland'.

Table 3.1
The top 10 river catchments with the most core beaver woodland area. The smallest catchment is the River Leven (79,566 ha) and the largest the River Tay (498,705 ha). The numbers in brackets show the rank of the catchment if these 10 catchments were ordered by the density of woodland present. Catchments with less, but potentially denser, core woodland areas are not presented.

Catchment name	Potential core beaver woodland area (ha)
River Spey	7,086 (3)
River Tay	6,996 (9)
River Dee (Grampian)	4,421 (5)
River Tweed	3,875 (10)
River Ness	3,670 (6)
River Clyde	3,364 (7)
River Leven/Loch Lomond	2,650 (1)
River Forth	2,649 (2)
River Lochy	2,184 (8)
River Beauly	2,182 (4)

improved in accuracy and coverage since previous versions of the beaver habitat map were produced. Potential beaver woodland can be identified by the following characteristics:

- Broadleaf woodland and shrub – the main predictor of the presence or absence of beavers is the availability of food, in particular the abundance of suitable woodland[6, 7]. Hence, the datasets used categories of broadleaf woodland, shrub and native pinewood taken from the National Forest Inventory (NFI) and Native Woodland Survey of Scotland (NWSS)
- Within 50 m of freshwater edge – beavers prefer to feed in close proximity to water. In Denmark, 95% of foraging was within 5 m of the water's edge[8]. As the distance from the water increases, the amount of beaver foraging declines[9]. Evidence from the literature shows a variety of maximum foraging distances, including an extreme case of a record of a North American beaver felling a tree 238 m from a watercourse[10]. However, the great majority of activity will be constrained to within 50 m of a watercourse[6, 11, 12], and this matches observations recorded during the Scottish Beaver Trial[13]
- Streams with less than 15% gradient – higher gradient streams are known to be sub-optimal habitat for beavers. Although stream gradient has a gradual rather than absolute effect on beaver presence, evidence shows that stream gradients greater than 15% are very unlikely to be occupied by beavers[2, 14, 15]
- Not in tidal sections – beavers are only rarely seen in salt/tidal water and do not establish territories in such habitats[16]. Hence, coastal and tidal sections of rivers were excluded from the dataset

Using these parameters, a dataset of 'potential beaver woodland' was created, which identified all woodland that could potentially be used by beavers in Scotland. The resulting map (Figure 3.10) identified 120,390 ha of potential woodland on the mainland.

Potential core beaver woodland

The 'potential core beaver woodland' dataset is a refinement of the 'potential beaver woodland' dataset described above. Beavers require a certain area of suitable woodland to set up a territory. The potential beaver woodland dataset contains all woodland that could be utilised by beavers, but many of these are small, isolated patches.

The minimum amount of woodland needed for a beaver to establish a long-term territory was estimated based on the literature[17]. Any suitable woodland that could not be part of approximately 1.9 km of woodland within a 4 km territory (measured by river bank length) was rejected. If a small woodland patch was isolated, and could not form part of beaver territory with sufficient woodland, it was not included in the core beaver woodland dataset.

The potential core beaver woodland map consists of 57,309 polygons, covering 105,586 ha of suitable woodland (Figure 3.10). It is anticipated that beavers would be more likely to set up long-term territories in proximity to these areas of potential core beaver woodland.

A previous mapping exercise identified four catchments as key woodland areas for beavers: Lomond, Tay, Spey and Ness[3]. Our analysis showed that the catchments with the most core beaver woodland were the Tay and Spey (Table 3.1). A number of catchments in close proximity also have a high abundance of core woodland, such as the Lochy, Ness and Beauly catchments. Analysing which catchments have the most core woodland is useful, but is biased by the size of the catchment. For instance, the River Tweed has high total amounts of woodland, but it is more sparsely distributed.

The potential core beaver woodland map attempts to predict which woodland fragments would be utilised as part of a territory. To test this prediction, the 2012 Tayside beaver survey data were used[18]. The potential core beaver woodland dataset was created using an estimated minimum territory size of 4 km of bank, which equates to 2 km of watercourse length. Therefore, assuming the centre of a territory is within a core woodland patch, a beaver territory may extend 1 km upstream and downstream from these patches. All beaver signs that were within this area were identified as being predicted by the dataset. It was found that 82% of feeding signs and 84% of territory signs (e.g. burrows, dams, lodges and scent mounds) were predicted by the map. In particular, 91% of scent mounds were predicted[5]. This is relevant as the abundance of scent mounds is likely to be correlated with the quality of a territory and the length of beaver occupancy[19]. These results suggest that the dataset does seem to be a useful tool in predicting long-term beaver territories.

There are a number of limitations to these datasets and the associated maps. Many other parameters have the potential to affect the ability of beavers to utilise woodland, such as the steepness of river banks. However, they were not used here because either there was not a clear consensus in the literature or they could not be derived accurately enough at a national scale. In addition, in some specific areas of Tayside the map was a poor predictor of beaver signs. This was primarily thought to be due to thin strips of woodland along watercourses that were too narrow to be picked up within the baseline woodland datasets. So, whilst the map should provide a good overview of beaver woodland at the national scale, particular care is needed when using the datasets to examine local patterns. If necessary, the potential beaver woodland datasets can be refined at a regional or local scale to address some of these limitations.

Areas where dam-building by beavers is less likely

It would be useful to predict where beavers may build dams in Scotland, assuming any reintroduction. However, key ecological measures which might help predict dam sites (e.g. stream depth) are not currently available in national geospatial datasets. Therefore, it was decided that a reliable dataset could not be produced at the present time, and, instead, a dataset was created to predict where beavers are unlikely to dam. Areas not identified by this dataset contain watercourses where the potential for dam-building is unknown.

Building dams is a high-cost activity for beavers. For this exercise it was assumed that beavers would justify the investment in building and maintaining a dam only where resources exist to sustain a beaver territory. Hence, watercourses not adjacent to potential core beaver woodland were identified as being less likely dam sites.

Beavers cannot build dams where the flow rate of a stream is too great. The larger a watercourse, the more likely a dam will get washed away during flooding. This is why the great majority of beaver dams are found on smaller watercourses less than 6 m in width[20, 21]. Hence, all watercourses greater than 6 m in width were also identified as being unlikely dam sites.

Figure 3.11
River Tweed catchment, showing sections where dam-building by beavers is less likely.

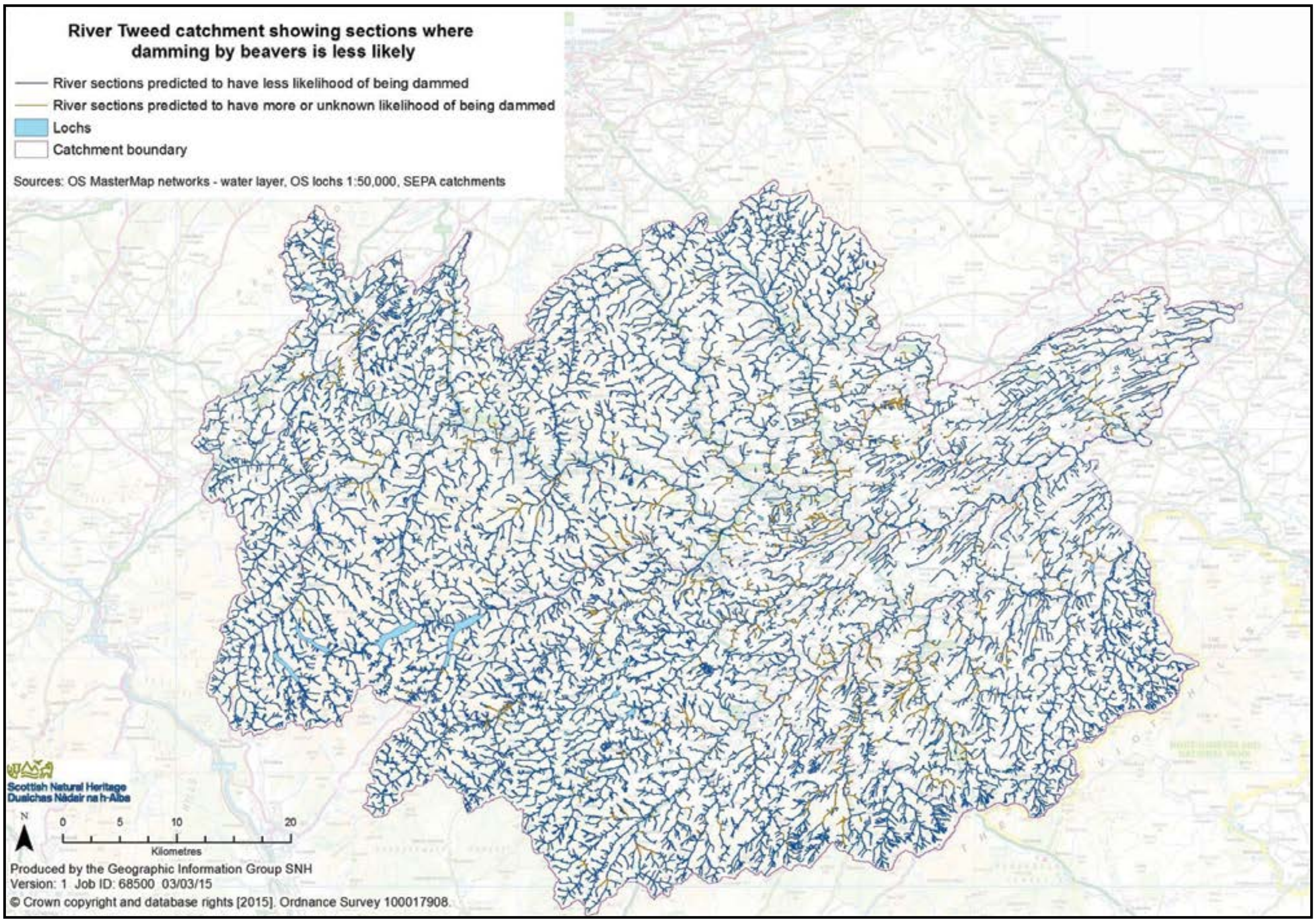
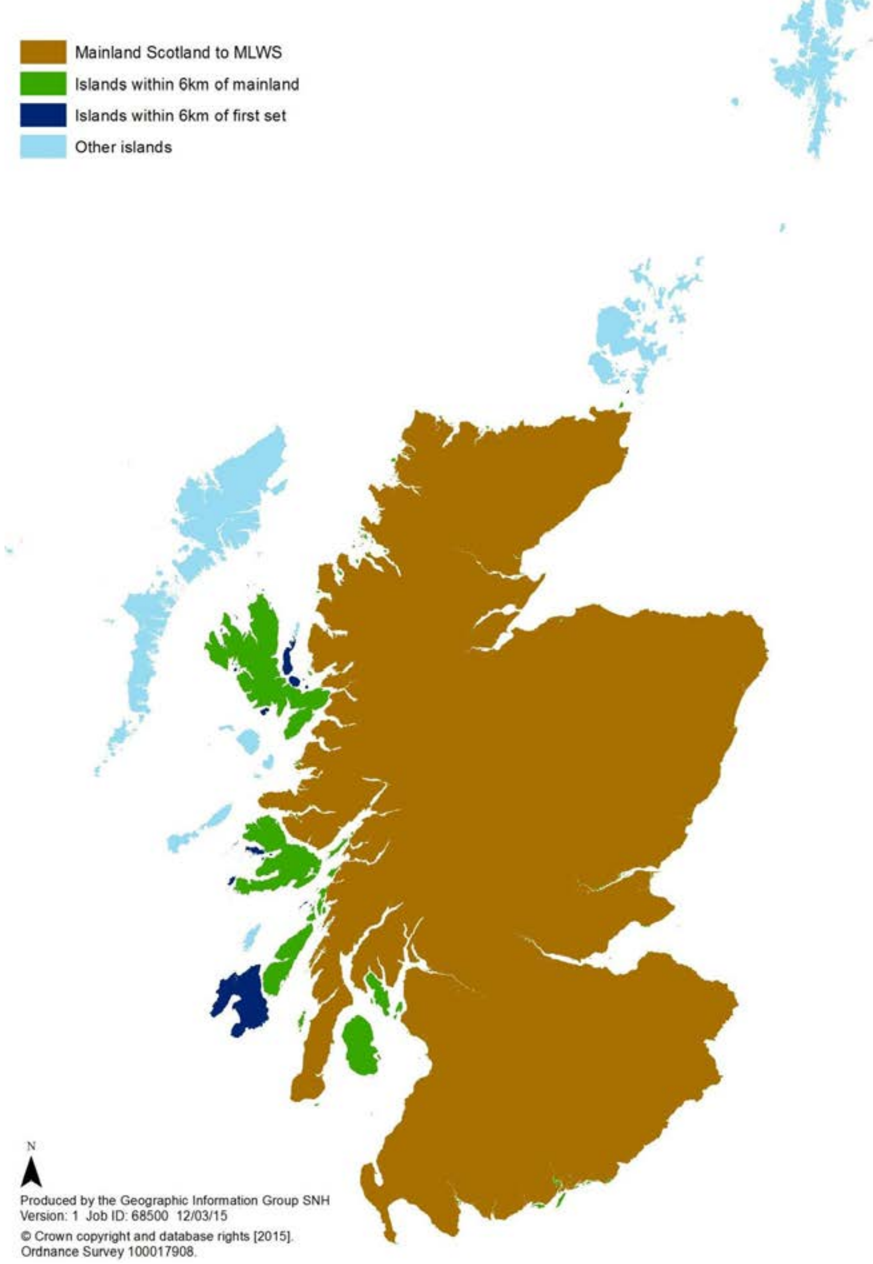


Figure 3.12
Islands potentially reachable by beavers.



Using these parameters, it was estimated that a minimum of 87% of watercourse length on mainland Scotland is less likely to be a dam site for beavers[5]. An example is the River Tweed catchment (the Scotland component) where a minimum of 90% of watercourse length was identified as being less likely dam sites for beavers (Figure 3.11). This tool could be applied in the future to help guide decisions on beaver reintroduction and management.

Islands potentially reachable by beavers

It is uncertain which islands beavers may be able to colonise from the Scottish mainland. Beavers do not permanently utilise marine waters; however, there is some evidence of beavers dispersing along coastal stretches[16]. Beaver dispersal along coastlines has been observed both in Denmark[22] and at Knapdale where felled trees were found on Shuna, an island that probably requires an offshore swim of 0.9–1.5 km[23]. There are also records of North American beavers colonising islands up to 6 km offshore[5, 24]. It is not known to what extent beavers will use islands as stepping stones for further island colonisation. For instance, there is very limited information to suggest whether beavers will continue swimming to other islands if they first come to an island with no suitable habitat. There is also no information on the extent that coastal currents and tidal regimes can impact on beaver movements through marine waters.

Despite these limitations, and based on the information that is available, a dataset was produced which identified and mapped islands within 6 km of the mainland (Figure 3.12). An additional 2,486 ha of potential core beaver woodland occurs on these islands (primarily Skye, Mull, Jura, Arran and Bute). Islands that are within a further 6 km of the first set were also identified to illustrate how beavers may possibly utilise islands as stepping stones. A further 553 ha of potential core beaver woodland occurs on the second set of islands[5].

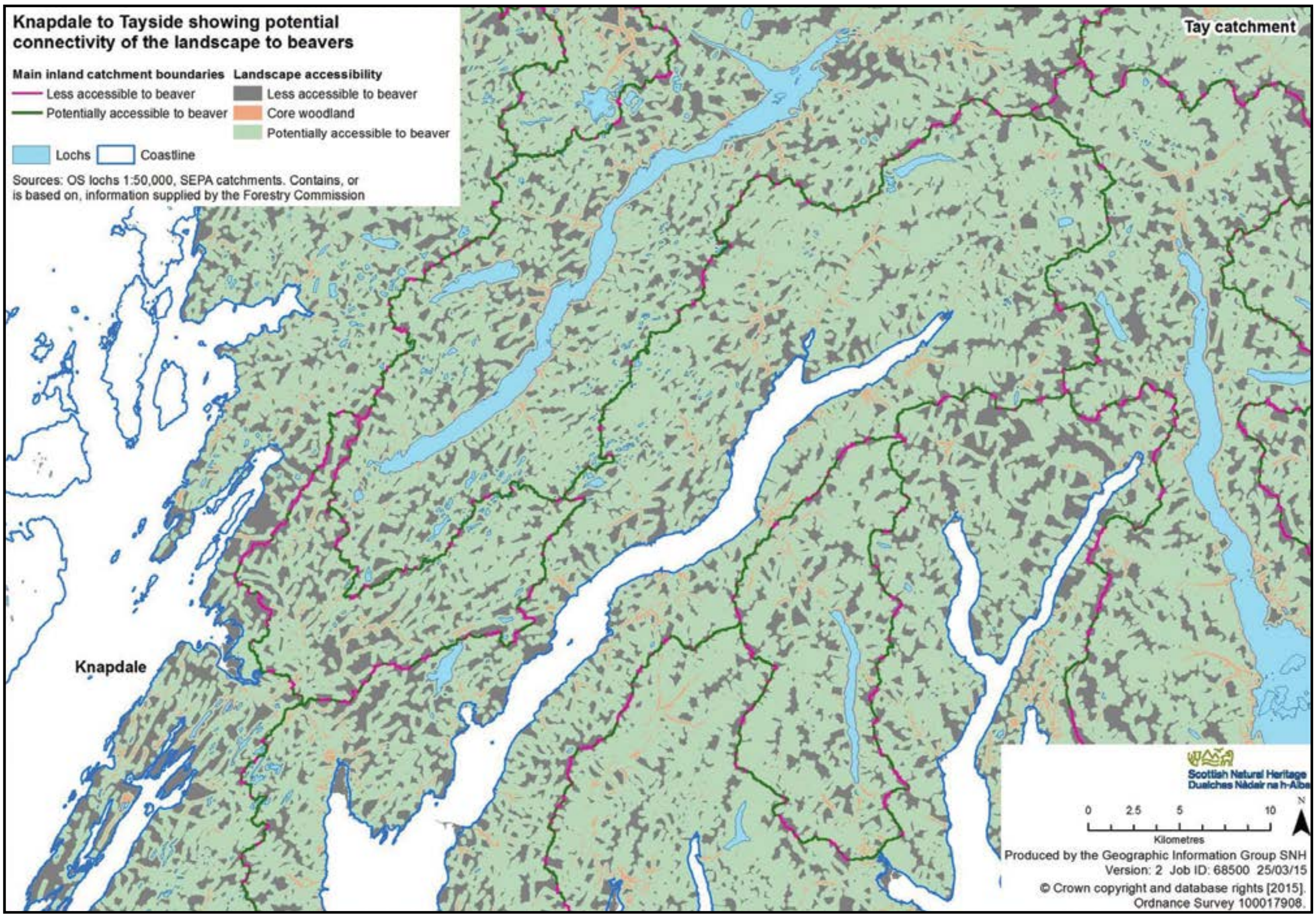


Figure 3.13
Knapdale to Tayside, showing potential connectivity of the landscape to beavers.

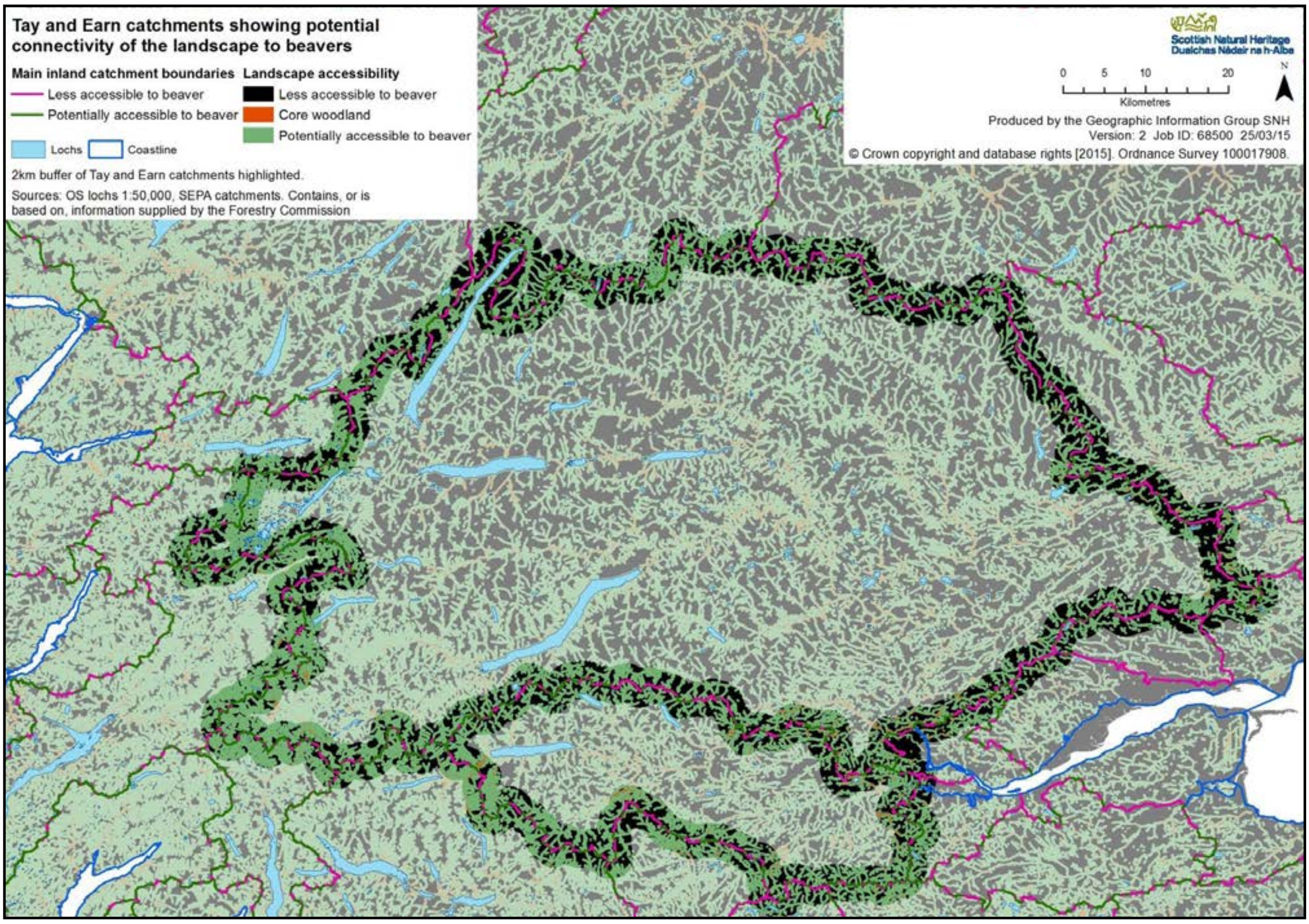
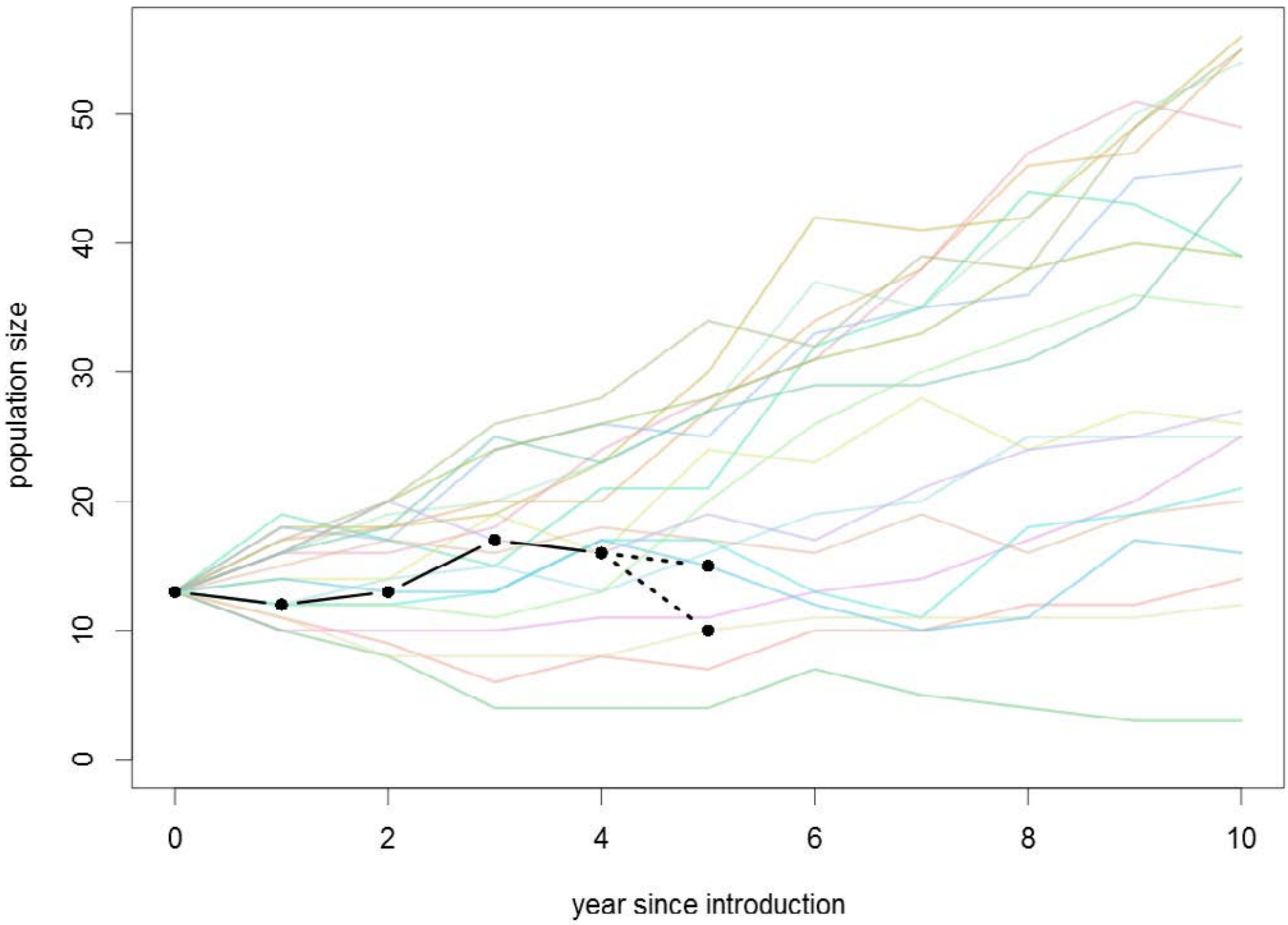


Figure 3.14
Tay and Earn catchments, showing potential connectivity of the landscape to beavers.

Figure 3.15
Comparison of the 20 Knapdale replicate simulations with the actual population size reported at Knapdale (total adults and juveniles). The last point does not include kits born in 2014; the lower point is the known population of adults and sub-adults, the upper is the known population augmented with an estimate of five kits (the same as born in 2013)[30].



Watercourse network

A dataset of the overland connectivity between river catchments was produced to provide indicative information on the ability of beavers to colonise and spread. Beavers generally disperse along watercourses and only occasionally over land. The overland or coastal dispersal required to move between river catchments can severely slow the range expansion of beavers in some situations[16, 25, 26].

A threshold of approximately 300 m was set on the maximum overland dispersal distance for beavers, based on the limited ecological literature. This distance was reduced in the dataset depending on the presence of urban areas or very steep slopes[5]. There is little published literature about overland dispersal distances and factors that affect them, although a similar dispersal distance was proposed in a separate study[27].

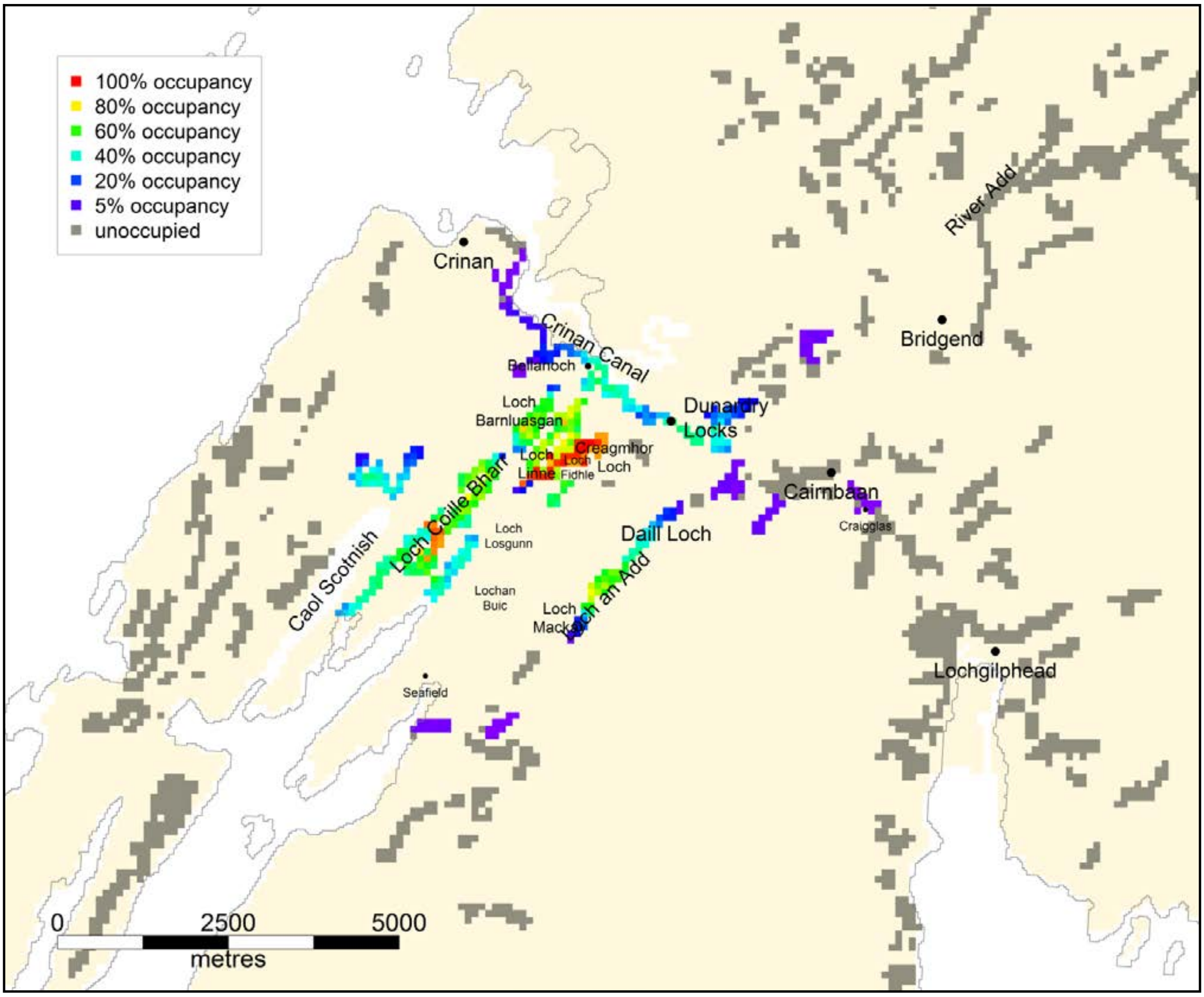
The potential overland connectivity between catchments was mapped using the above parameters (Figure 3.13 and 3.14). The interconnectivity between catchments is high, which suggests that beavers should be able find multiple overland routes into other catchments when dispersing. This is a long-term prediction of the ability of beavers to move between catchments, which should be considered in parallel with the more short-term predictions of beaver range expansion. Scotland has a high number and density of wetlands and watercourses[28] along which beavers may disperse. There is also the potential for beavers to colonise by moving down rivers into marine waters, along coasts and up into adjacent catchments, which this dataset does not cover.

Population modelling

A previous exercise modelling beaver reintroduction success showed that as long as beavers were released into the large habitat patches available in Scotland, then reintroduction success was likely[29]. Two further models have been developed more recently for different purposes, and designed to answer different questions.

The first modelling approach used the population parameters observed at Knapdale during the SBT, and is set out in the beaver ecological monitoring report[23]. It described a population viability analysis (PVA) of the Knapdale population, using life history parameters derived from the scientific trial[23]. The PVA predicted the likely fate of the Knapdale population on the assumption that the life histories of the beavers there remained the same as has been observed over the last five years, and also modelled the effects of reinforcement (i.e. releasing more beavers) to assess the future viability of a reintroduced population at Knapdale. This involved the theoretical release of up to 20 more animals (10 pairs) released over one to five

Figure 3.16
Population density map of beaver reintroduction in Knapdale by 2039, with population reinforcement. The intensity of colours indicates the persistence of beavers, where red is occupancy in all years in all replicates and purple is occupancy in one year in one replicate[30].



years, and modelled over 30 years with 1,000 iterations. This highlighted that in the absence of any improvement in reproductive success (from that observed, see section 3.1) the population size is likely to decline as soon as supplementation stops.

A second modelling approach was also developed, involving a process-based spatial model to examine more closely the factors driving colonisation in a released beaver population[30]. This provided a simulation model of beaver populations, and used life history parameters derived from the literature to generate its predictions[30]. It can be used to simulate population dynamics of beaver populations at any site for which a habitat suitability map is available, and so could be a useful tool for planning reintroduction and management in the future. It was applied at Knapdale and used to determine whether the results observed during the scientific trial could have resulted from chance events (termed 'stochastic variation') around beaver life history parameters. Details of this second model are described below.

Modelling methodology

The process-based spatial model was based on a previous model[31]. The model took into account life history parameters taken from the scientific literature, and the potential core beaver woodland map of mainland Scotland provided the spatial reference for the model. The full details and methods can be found in the published report[30].

Current status of Scottish populations

The model was tested against the SBT data from Knapdale. The population growth observed at Knapdale fell within the variation in output produced by the model (Figure 3.15). Four out of the 20 replicate model runs had populations that were similar or worse than the numbers at Knapdale, and the mortality and fecundity of modelled beavers in these model runs were comparable to data from the Knapdale population after six years. Of these four replicates, three eventually expanded into a healthy population of beavers, and one went extinct in year 18 of the simulation.

Population growth and range expansion with and without reinforcement

The model predicts that the Knapdale population will expand, assuming that average population parameters are appropriate for Knapdale and that the poor values for kit mortality observed in the SBT are the result of chance events rather than an unknown feature of the Knapdale environment or the beavers released there. Without reinforcement the population is estimated to reach a mean of 90 beavers by 2039 (30 years after establishment). The maximum beaver population from the model was 165, although the population went extinct in one out of the 20 model runs.

The Knapdale population was meant as a trial population, not a founder population. The population is predicted to fare much better when there is reinforcement. With further releases of five pairs of animals, there were no model runs where the population went extinct, and the estimated population size in 2039 is 153 beavers in 27 families. A notable prediction of the model is that within this timeframe the beavers at Knapdale are not predicted to expand far into neighbouring catchments (Figure 3.16).

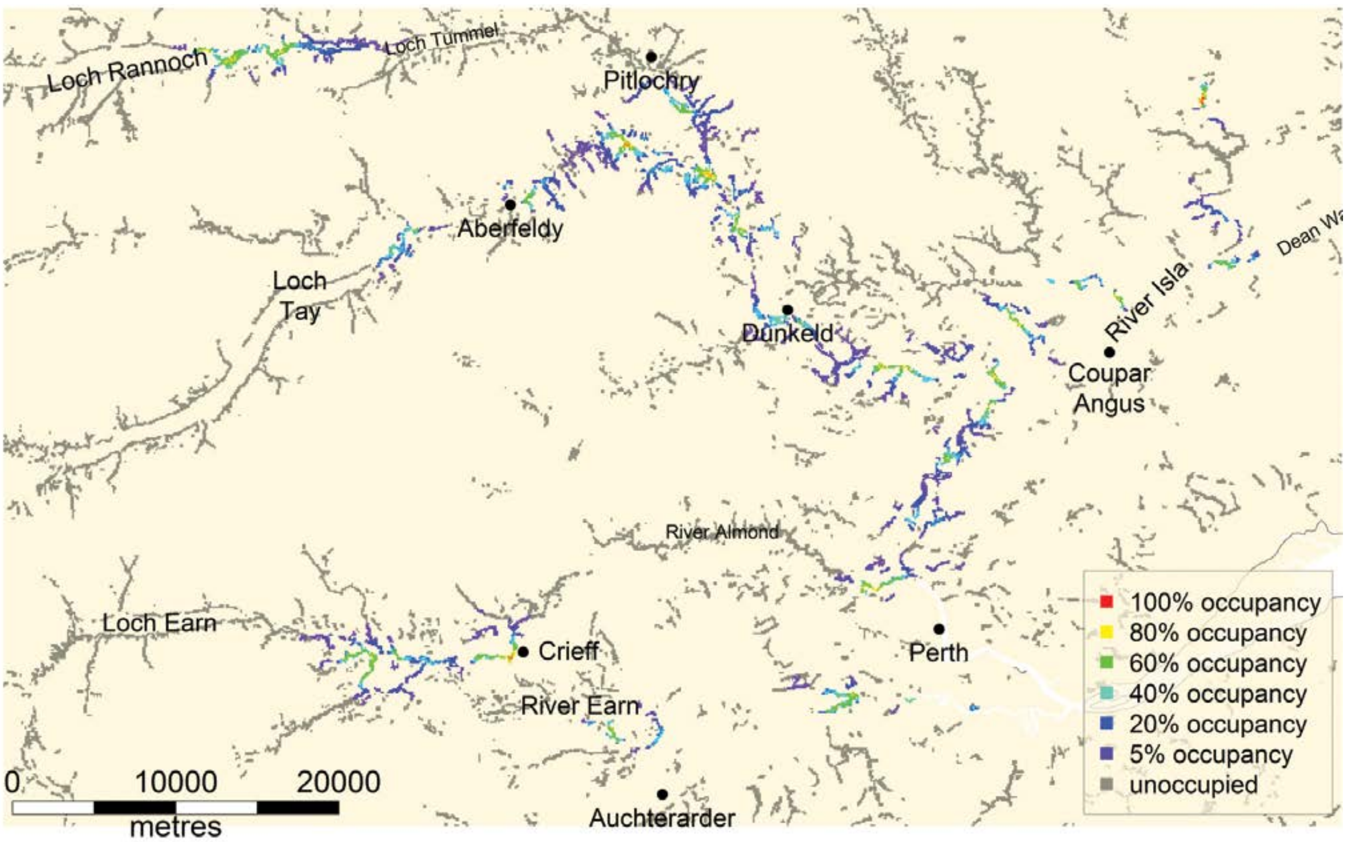
The population of beavers within the Tay and Earn catchments was, in 2012, predicted to be 146 individuals. The modelling predicts this population to expand to a mean of 771 beavers in 160 families by 2042, assuming no human interference. The population density map (Figure 3.17) suggests that beavers tend to expand along the river catchments where they are already established. It is possible that the founder population at Tayside consisted of several separate releases in different geographical locations, either at the same time or in a staggered introduction. Much of the modelled range expansion, therefore, is infilling, since the early spatial population pattern was discontinuous. There remains plenty of additional habitat in the greater Tay region, and the population will probably continue to grow at a similar rate into the medium term.

These models predict that a viable beaver population will become established on Tayside, and, if there is reinforcement, at Knapdale. Beavers are not predicted to expand far from their current catchments over the next two or three decades. The two populations are not predicted to link in the near future without assistance.

As with any model, caution has to be taken over how the predictions are interpreted. There are a number of limitations to the model[30]. In particular, these include the imperfect nature of the woodland map, the lack of Scotland-specific life-history parameters for beavers, and the limitations in modelling dispersal. For example, the model assumes new pairs form only when one beaver randomly locates a territory occupied by a single animal, rather than reflecting how individuals may actively search for a mate. In addition, the model does not account for the long-distance dispersal events sometimes seen in wild beaver populations.

However, the models do provide useful tools to provide estimates of predicted beaver population growth and range expansion, which could be useful in predicting the viability and success of any further releases that may occur.

Figure 3.17
Population density map of beaver reintroduction in Tayside by 2042. The intensity of colours indicates the persistence of beavers, where red is occupancy in all years in all replicates and purple is occupancy in one year in one replicate[30].



3.3 Beaver genetics

Genetics and conservation translocations

Determining the most appropriate or best genetic composition of a founder population of an animal or plant is of great importance to the success of any reintroduction. The conservation translocation guidelines produced by the International Union for the Conservation of Nature (IUCN) has an extensive section on the selection of founders, as does the Scottish Code for Conservation Translocations[1, 2]. The selection of founders is often complex because a number of competing factors must be considered. These include the balance between inbreeding and outbreeding depression, the local adaptation of founder individuals to their release site and the ability of the population to evolve and adapt to future changing environments:

- *Inbreeding depression* may affect individual survival and population growth and make a population more susceptible to disease[3]. Ensuring that a founder population is sufficiently genetically diverse is crucial to reintroduction success
- *Outbreeding depression* occurs when individuals from two dissimilar genetic lineages are combined. Although each population may be well adapted, when combined, fitness may be lost due to a lack of specialisation and genetic incompatibilities[4]

A starting point for reintroductions is to find individuals closest in type (genotype and phenotype) to the population that was lost. This aims to increase the probability that individuals will be well adapted to their release site, helping to increase reintroduction success. It also helps to ensure that the reintroduced population will fulfil the same ecosystem roles as the lost population.

Genetic diversity also needs to be maintained, so that a population can adapt to future environmental change, such as climate change, and future pressures, such as novel disease exposure[5, 6]. Although sustaining these evolutionary processes is an important long-term consideration, it can also be addressed at later stages through population reinforcement.

Low genetic diversity can arise from a variety of potential causes, and can occur due to 'sampling a source population with low genetic diversity, biased sampling of a single source population, genetic bottlenecks in the translocation process, and unequal survival, establishment and reproductive output in the destination area'[1].

The current status of extant populations is a further consideration. The action may help to conserve the genetic identity of extant populations, in line with the aspiration for the conservation of biodiversity at all 'levels' set out in the Convention on Biological Diversity. For instance, through the reintroduction decisions we make, should a new population of an already existing genotype be created, to help conserve that particular genotype?

Genetics of the Eurasian beaver

The Eurasian beaver went through a recent bottleneck caused by hunting pressure. Eight relict populations survived and were previously assigned tentative sub-species status. Although they are no longer considered a sub-species, the names are now used to identify the relict populations, also known as the 'fur trade refugia'. The three western relict populations were named as:

- *Castor fiber fiber* – Southern Norway
- *Castor fiber galliae* – Rhone, France
- *Castor fiber albicus* – Elbe, Germany

The five names from the eastern relict populations of Belarus, Russia, Ukraine, Mongolia and China are:

- *Castor fiber belorussicus* – Pripet, Belarus/Ukraine/Russia
- *Castor fiber osteuropaeus* – Voronezh, Russia
- *Castor fiber pohlei* – Ob catchment, Russia
- *Castor fiber birulai* – Mongolia/China border
- *Castor fiber tuvinicus* – Russia, near Mongolian border

There is some evidence for differences between these different populations: some may be distinguishable based on morphological features[7]. In addition, geographical isolation of these populations may have led to differences in chemical communication. For instance, experimental evidence shows that *C. f. fiber* respond differently to chemical secretions from their own population than from *C. f. albicus*[8].

Recent genetic work has identified two major mitochondrial DNA (mtDNA) lineages: a western 'evolutionarily significant unit' (ESU) made up of the Norwegian, French and German relict populations, and an eastern ESU made up of the other five relict populations[9]. This suggested that during the last ice age at least two refugia existed for the species. Genetic diversity is higher within the eastern ESU than the western, and differences between previously proposed sub-species may have arisen entirely due to the relict population bottleneck caused by hunting. Importantly, they show low overall genetic diversity within the Eurasian beaver. This is supported by earlier work which showed a monomorphic major histocompatibility complex (MHC), the region of the DNA which encodes for the immune system[10].

More recent work has investigated the division between western and eastern ESUs. An investigation of the composition of individuals across Switzerland, Luxembourg, Belgium and Germany (including Bavaria) showed that, of 235 individuals studied, only one had the eastern ESU haplotype[11]. Further work has also supported the hypothesis that there are western and eastern clades, and that the previously proposed subspecies groups are a result of relict populations created by hunting pressure. Recent investigations also confirm that genetic diversity within Eurasian beaver is low in comparison to that prior to human influence, and that the western clade has lower diversity than the eastern clade[12].

The most recent evidence shows that the split between the eastern and western ESU may not be well resolved, as a new haplotype found in all *C. f. osteuropaeus* individuals (from central Russia) grouped with the western ESU[13]. Five genetic clusters were identified, which were highly likely to have been accentuated by the population bottleneck and genetic drift within relict populations:

- Norway
- France
- Albicus (from Hesse in Germany, previously the Elbe population)
- Eastern Europe
- Central Eurasia

Previous reintroduction proposals and approaches

The provenance of beavers used for reintroduction projects across Europe has not always been regarded as a significant factor in decision-making. Consequently, some mixed genetic forms of beavers were released in the west (Germany, Switzerland, Belgium), and some mixed forms of beaver were released in the east (e.g. Poland and Romania). In 1935, the North American beaver was judged suitable for release in places such as Finland, where a population of over 10,000 animals now exists, with the threat of it expanding into Sweden and Russia. The Eurasian and North American species do not appear to hybridise under natural conditions. More recently, however, and with the advent of the IUCN Guidelines for Reintroductions (first published in 1998, revised in 2013[1]), the provenance and distinctiveness of the relict populations have been given more careful consideration in reintroduction projects, for example both Denmark and the Netherlands used pure *C. f. albicus* for their reintroductions in the 1990s[14].

SNH started to investigate the desirability and feasibility of reintroducing beavers to Scotland in the 1990s. The IUCN Guidelines for Reintroduction were applied. As part of this process, work was commissioned to identify appropriate source populations for any future beaver reintroduction. A morphometric study was done, involving measurements taken from 388 beaver skulls. This allowed a comparison of fossil British beavers with those from the three geographically closest relict populations (Norway, France and Germany), whose ancestors may have colonised Britain at the end of the last ice age. A molecular study was not feasible given the limitation of the techniques available at the time. The analyses suggested that fossil British beavers were morphologically closest to the relict Norwegian *C. f. fiber* population[7].

SNH therefore recommended that beavers from the Norwegian population be used for any beaver reintroduction project in Scotland. Although it is not possible to know how the behaviour or physiology of Norwegian beavers compared with those of the extinct British/Scottish populations, a judgement was made based on the morphometric study, also taking into account that animals from Norway were likely to be relatively well adapted to the environmental conditions of Scotland.

It has been proposed that *C. f. galliae* (Rhone relict population) or *C. f. albicus* (Elbe relict population) should be used for southern British reintroductions ‘as they are adapted for lowland habitat’, whilst recognising that Norwegian *C. f. fiber* was suitable for Scotland as it was more likely ‘to be adapted to the prevailing harsher climate and habitat’[15]. It has also been argued that the origin for British beavers was probably a mixture of Scandinavian, French and German populations, and unlikely to have been a single colonisation event. One study suggested three options for future releases: the use of western-form animals from a single relict population; the use of the western form of beaver but from a mixture of two or three of the relict populations; and the use of a mixture of beavers from populations of the eastern and western forms. The last was described as an ‘informed’ exception to the IUCN Guidelines for Reintroduction[16]. Another study argued that the mixing of eastern and western forms was not appropriate, and that more genetic evidence is needed before a decision should be made[17].

Most recently, three criteria have been presented for choosing founder individuals[13]:

- To select individuals with low levels of inbreeding and high combined genetic diversity
- Conversely, to ascertain that the introduced combination of animals is not likely to suffer outbreeding depression
- To select the most similar individuals to those historically present

The risks of inbreeding depression are now considered much greater than the risks of outbreeding depression, as mixed-stock populations have been successful in Germany and Switzerland. In addition, it is believed that a founder population should not be sourced from a single unmixed population and that, because of historical mixing of western and eastern ESUs, either could be used. Finally, a recent study suggested that the ‘“ideal” world scenario is to take animals from a genetically diverse source that is also closely related to the original population. The final choice must balance the need for genetic diversity against phylogenetic fit’[13].

Genetic status of the current wild British populations

The SBT was the first licensed release of beavers into unenclosed, ‘wild’ conditions in Britain. The licence application submitted by the RZSS and the SWT for the release of beavers at Knapdale proposed that, on the basis of work undertaken up to that point, Norwegian *C. f. fiber* animals should be used. This precautionary approach was accepted and a licence was issued in May 2008.

Analysis of the current Knapdale population has confirmed that all are *C. f. fiber*[18]. The Norwegian source population has low levels of genetic diversity, as has been seen with all populations from the western ESU. Heterozygosity and allelic richness at Knapdale are both slightly lower than in the Norwegian source population[18], and further reinforcement from Norway will not improve this above Norwegian levels.

The Tayside beaver population is likely to have arisen through either captive escapes or unlicensed releases. Genetic analysis of this population has shown that founder individuals were most likely to have originated from Bavaria, Germany. Heterozygosity and allelic richness are both comparable to the mixed Bavarian source population and are favourable in comparison with other Eurasian beaver populations[18].

There is a population of Eurasian beaver currently licensed to remain on the River Otter in south-west England for a trial period, with a decision on their long-term status expected in 2020. The source and genetic origin of these individuals are currently unknown.

A formal, planned release is also currently being considered in Wales.

Summary of current thinking

SNH has consulted with a number of genetics and conservation specialists to try and develop a consensus on the relevant considerations and their implications, based on the most recent research. These are set out below.

General issues

- There is no convincing genetic evidence to support the original classification of eight sub-species that was based on the remnant isolated populations that remained after cessation of the fur trade – the so-called 'fur trade refugia'
- Genetic evidence suggests that these eight historical groupings collapse into two genetic groupings that correspond to an east–west Eurasian split, with the divide situated in Poland
- There is evidence of some historical mixing across this east–west boundary, and current mixed populations appear to be successful
- The current Norwegian and Swedish beaver population of *C. f. fiber* is extensive and consists of over 170,000 individuals (the Danish reintroduction used *C. f. albicus*). There is no pressing need to establish a 'genetically pure' Scandinavian beaver conservation resource elsewhere.

Inbreeding

- The genetic diversity within populations of the Eurasian beaver today is low. This reflects previous hunting to near-extinction and the extensive reduction in size of individual populations. This creates two potential problems: inbreeding depression, which means decreased genetic viability and fitness of individuals in contemporary conditions, and a lack of adaptive potential, which means constraints on populations to further adapt genetically to new pressures such as emerging diseases or environmental change

Outbreeding

- Outbreeding depression resulting in reduced fitness or viability can occur when highly divergent lineages are mixed. The apparent viability of populations with mixed eastern/western ancestry (such as in Bavaria) suggests that either there is little, if any, detectable reproductive isolation or genetic incompatibilities between these two genetic groups or outbreeding depression has already occurred but natural selection has eliminated unfit individuals

Local adaptation

- It is not possible to identify which precise combination of beaver genes is ideal for long-term survival of the beaver populations in Britain, based on the available genetic and morphological data (they inform only on population relatedness). A reasonable assumption is that the beavers that are most closely related to those previously found in Britain will be the best adapted. For some morphological traits, historical Scottish beavers seem to have been most similar to those from Norway, although it is unclear whether this is due to genetic or environmental factors, or a combination of both. The survival of both Norwegian and Bavarian beavers has been successful in Scotland so far, and they have adapted to a range of environments

Future implications for beaver reintroduction in Scotland and the rest of Britain

- Outbreeding depression and inbreeding are conflicting concerns
- In the light of the evidence, problems arising from inbreeding are viewed as the greater challenge to the viability of introduced beaver populations to Scotland/Britain
- The risks of outbreeding depression are considered low if currently mixed populations and/or a mixture of different populations from the western lineage are used as donors
- *Inbreeding* – individuals from genetic clusters, source populations and areas that have not been previously used in British releases are preferred, and hence close relatives of beavers already present are not preferred. Founder populations should be as large as possible and sourced from a diverse range of genetic sources (populations and families)
- *Outbreeding* – supplementing existing populations with pure eastern individuals should be avoided. There is no strong reason to source from the 'pure' eastern

populations, and new mixing of eastern and western populations would be the situation where the risk of outbreeding depression (and associated animal welfare issues) would be highest. There is no strong genetic argument either for or against using individuals with already mixed western/eastern genes
- *Local adaptation* – in Britain, it remains preferable to release animals that are most likely to resemble the extinct population genetically, so western European stock is preferred
- *Future genetic management* – an increased number of wild founders is preferred to ensure genetic diversity. However, it is critical that any future releases (including within-country relocations) should be planned, co-ordinated, licensed and managed

If the decision is made to allow further releases of beavers in Scotland, then the above considerations will be incorporated into any beaver management strategy (see Chapter 6). This would include reviewing the Knapdale and Tayside populations, and identifying the appropriate provenance of animals which might be required for any reinforcement.

3.4 Interactions with habitats and species

3.4.1 Woodland

Overview

The main mechanisms by which beavers affect woodland are tree-felling for food and construction, and flooding. They generally avoid conifers, but will use most native broadleaved tree species that occur in Scotland, and other non-native broadleaved trees.

Where numbers of other herbivores are high, the impacts of beavers may be exacerbated if subsequent browsing of regrowth by other herbivores prevents coppice regrowth and tree regeneration. Hence, careful management of deer and livestock in areas colonised by beavers will maximise the likelihood of an overall positive impact of beavers on woodland ecosystems.

These mechanisms can lead to a range of impacts on woodland.

Woodland structure

In general, beavers prefer smaller stems, less than 0.1 m in diameter, but will take much larger ones as well. When choosing material for construction, stem size may be more important than species[1]. Most broadleaved trees can regrow from cut stumps, but the vitality of the regrowth varies with species and the age of the tree.

Since beavers select a tree according to its stem size, and as younger trees generally produce more, stronger, regrowth shoots than older trees, a younger age profile is likely to develop over time, with a loss of both older stems and older growth riparian woodland communities. If a large proportion of the woodland is affected then ecological continuity could be interrupted, particularly with impacts on lichens and other species characteristic of older stems.

Most felling is within 10 m of the water's edge and, because beavers are usually considered to be central place foragers, impacts vary along watercourses according to distance from lodges[2–4]. The impact of beavers may therefore be patchy, leading to greater structural diversity along the length of watercourses.

Felling large trees opens the canopy, allowing more light to reach the ground, and allowing regeneration from seed, which could potentially lead to increased structural diversity in even-aged woodland.

Where browsing from other herbivores is high, regrowth may be prevented, and this could lead to a reduction in structural diversity and ultimately loss of woodland cover.

Species composition

Beaver have a clear preference for some tree species over others, in particular aspen *Populus tremula* and willow *Salix* spp. These species generally resprout rapidly[5], and beavers seem to avoid young aspen regrowth[6, 7]. However, young shoots are very attractive to deer, and the combined impact may lead to the loss of beaver-preferred species. In some cases, aspen might be lost from parts of the core beaver habitat, where near-permanent beaver presence prevents substantial regrowth[8, 9].

More generally, although beavers often use species according to their abundance, they may also preferentially select less common species in order to fulfil their need for a diverse diet[10]. This could lead to reduced species diversity, which might be exacerbated by differences in the responses of tree species to beaver browsing and the preference of deer for different species. Willow and ash *Fraxinus excelsior* produce stronger shoots than alder *Alnus glutinosa* or birch *Betula pubescens*, but are also more attractive to deer.

Inundation of woodland will lead to the death of trees of many species, but could promote the growth of others, especially willow, which can grow well even in standing water.

Figure 3.18
Monitoring of woodland at Knapdale included the use of tags on individual trees.
© Lorne Gill/SNH

Figures 3.19 and 3.20
Photographs taken from the same woodland monitoring point at Knapdale showing the results of beaver activity - November 2009 on the left, November 2012 on the right.
© James Hutton Institute/SNH

Figures 3.21 and 3.22
Photographs taken from the same woodland monitoring point at Knapdale showing the results of beaver activity - November 2009 on the left, November 2012 on the right.
© James Hutton Institute/SNH

Dead wood

Although tree-felling by beavers could lead to increased fallen dead wood in some areas, much of the material is removed for food and construction, some of which falls in, or is placed in, water bodies (see section 3.4.3).

In flooded areas, the death of trees which are unable to cope with increased water levels will lead to an increase in standing dead wood, which is generally present at only low levels in British woods. Such areas may become hotspots for dead wood biodiversity (see, for example, sections 3.4.6 and 3.4.9).

Scottish experience

There was an intensive woodland monitoring programme at Knapdale (Figure 3.18), and therefore this forms the main source of information currently available for Scotland, and is reported below. No equivalent work was done in Tayside.

Woodland structure

After four and a half years at Knapdale, and across the whole trial area, 8.6% of trees within 30 m of the loch shores had been gnawed or felled, mostly within 10 m of the water's edge (Figures 3.19-3.25). The impacts of beavers diminished strongly with distance from the water's edge. Beavers had also affected trees in nearly half (47%) of 108 monitored plots, gnawing or felling 16% of all the trees[3]. The overall proportion of trees used in riparian zones across the whole trial area was lower, because the plots were deliberately located in specific areas within the riparian zone which were expected to be used by beavers.

The tree species preferred most by beavers also produce the most vigorous regrowth, especially willow and ash (almost no aspen occurs at Knapdale) (Figure 3.25). However, this was heavily browsed by deer, which will affect the success of regeneration. In the final year of monitoring, about 70% of young shoots were browsed by deer. Frost damage killed a high proportion of new

Figures 3.23 and 3.24
Photographs taken from the same woodland monitoring point at Knapdale showing the results of beaver activity - November 2010 on the left, November 2013 on the right.

shoots during the first two winters of the trial, which were especially cold.

The woodland is more open, with a grassier ground flora, than before beavers were released.

Species composition

Beavers showed strong preferences for willow, ash, rowan and hazel, but avoided alder. They browsed almost half the willow in the sampling plots in the first four years, and their use of hazel increased greatly in the last two years. They used birch slightly less than expected from its abundance, but it still comprised the majority of trees felled, as it is by far the most abundant tree species in the area.

Increased grazing of non-woody terrestrial species by beavers, particularly bracken *Pteridium aquilinum* and purple moor grass *Molinia caerulea*, was recorded over the trial period[11].

Dead wood

Most of the felled trees were removed for construction, caching or eating elsewhere, or consumed on the spot by beavers. Despite this, there has been some increase in fallen dead wood in the areas most heavily used by beavers.

Potential future implications for Knapdale and Tayside

As stated above, information was collated from Knapdale on beaver effects on woodland, but not from Tayside, and so it is possible to give more information on future implications for the former site. However, the assessment of potential beaver woodland across Scotland identified the Tay catchment as having almost 7,000 ha of potential core beaver woodland, the highest for any catchment in Scotland apart from the Spey which has about the same[12] (section 3.2). To some extent this is not surprising, as it is also the largest catchment area in Scotland by some considerable margin (500,000 ha, followed by the Scottish part of the Tweed, of about 380,000 ha). Woodland connectivity is relatively good, and if beavers were to remain on Tayside then it is anticipated that in the long term a significant proportion would eventually be colonised. Similarly, at Knapdale the population is expected to expand and use additional areas of riparian woodland, although there may be limited colonisation outside Knapdale Forest over the medium term of 30 years, even with reinforcement[13] (see section 3.2).

Woodland structure

The future structure of riparian woodland at Knapdale will depend on the amount of regrowth from beaver stumps and the level of browsing on the regrowth from both deer and beavers[5]. If the woodland continues to become more open, with a grassier ground flora, it is likely to attract higher numbers of red *Cervus elaphus* and sika deer *C. nippon*, which are primarily 'grazing' rather than 'browsing' herbivores, potentially exacerbating the impact of beavers on the vegetation. Similar impacts are likely in Tayside.

Increased use of bracken and purple moor grass by beavers could increase niches for tree regeneration, although it is unlikely that large areas of these species occur within the core beaver habitat.

Species composition

In Knapdale, willow is the only one of the abundant tree species close to the water edge to have been significantly

Figure 3.25
New regrowth on a rowan at Knapdale, after being felled by beavers. Young shoots were frequently browsed by deer.
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Figure 3.26
Aspen woodland at the Muir of Dinnet National Nature Reserve.
© Lorne Gill/SNH

depleted in the monitoring plots. If this continues, beavers would be expected to forage initially on willows in currently less-utilised areas and to then increase their use of less-preferred species.

The greater use of hazel *Corylus avellana* in the two latter years of this study suggests that this species may ultimately become less abundant, depending on the impact of deer on the regrowth. Alternatively, smaller younger shoots may predominate, with a loss of older stems.

Impacts on Tayside woodlands will depend on their composition.

Dead wood

A general reduction in older dead wood in riparian zones is likely, as the woodland becomes dominated by younger trees, and ultimately this may lead to reduced biodiversity and ecological functioning of the decomposer food chain, although in Knapdale beaver activity was also associated with an increase in the amounts of smaller fallen dead wood litter. In flooded areas, standing dead wood is likely to increase in the short to medium term, as few species of tree can withstand prolonged inundation. Such areas may become hotspots for dead wood biodiversity.

Where there is an increase in dead wood, forestry managers have noted that fallen trees and material might cause future impacts on human access for recreation or woodland management.

Habitats of European importance at Knapdale

The Taynish and Knapdale SAC is designated for 'Old sessile oak woods with *Ilex* and *Blechnum* in the British Isles' (91A0). Beavers are unlikely to affect the majority of this woodland type, as only 15.1% overlaps with the core beaver habitat (described in section 3.2) within the SAC. Beaver impact in itself would not be considered damaging, as it generally gives rise to a change in structure rather than a loss of woodland, although there may be some loss of woodland canopy (or a change to a wetter woodland type) in inundated areas, as has occurred around the Dubh Loch. Unless such areas are very large, they would generally be viewed as an increase in integral open space habitat, rather than loss of woodland as such. However, in the absence of deer control, it is likely that the areas close to the loch shores will become more open with a grassier ground flora and, over time, this could lead to a deterioration in the condition of the qualifying woodland habitat. Conversely, increasing deer control is likely to result in greater regeneration from felled stumps and the development of a denser understorey. This would be considered to be within the normal range of variation for the habitat, although it could lead to a reduction in more light-demanding ground flora or epiphytic species, particularly lichens.

Potential future implications of wider reintroductions in Scotland

The impact of beavers on woodlands will depend on the tree species composition, so any attempt to predict likely impacts will need to take account of this. High levels of impact can be expected on preferred species in riparian areas and, depending on the abundance of other herbivores, might result in changes in tree species composition, possibly from species less tolerant to browsing towards more browsing-resilient ones or those less likely to be browsed. For example, in the Knapdale trial, birch resprouted poorly, whereas willow and ash produced much stronger shoots. However, the latter species are attractive to deer, so long-term success will be related to deer browsing pressure on regrowth. Alder resprouted poorly but was also much less likely to be felled by beavers in the first place.

Where woodland is fairly continuous, as it is at Knapdale, the impact of beavers is likely to be patchy. However, if the landscape contains smaller areas of broadleaf woodland, especially if this is largely riparian, then beaver activity is likely to be heavily focused on these patches if they are large enough to sustain beaver territories. Very small, isolated woodland patches may be used far less.

An important predictor of the future localised impact of beavers, in any colonisation, is where they choose to site their lodges/burrows, the basis for which is unclear. However, it is possible to predict, with some level of certainty, which areas of woodland may provide core beaver habitat (section 3.2) within which beavers may establish territories.

In summary, beavers are selective foragers that are likely to affect woodland species composition, age structure and ecological functioning. These effects are likely to occur largely within 30 m of the water's edge, and be strongly concentrated within 10 m of the loch shore[3], but may have a large impact in this area. In parts of Scotland, riparian woodland may be the only woodland within a landscape, and impacts of beavers will be particularly notable in such areas. Regeneration of the woodlands from the beaver-affected trees is dependent upon the tree species' propensity for resprouting, and will depend upon the density of the deer species present and the browsing pressures they exert on tree regrowth.

If the decision is made to reintroduce beavers to Scotland, vulnerable habitats and species, such as alluvial forests, Atlantic hazelwood and aspen (Figure 3.26), would need to be closely monitored, especially where they are isolated and in close proximity to riparian areas. This is particularly important because of the variety of associated vulnerable species which depend on ecological continuity, such as lichen communities on Atlantic hazelwood (see section 3.4.4 for a more detailed consideration of lichens and bryophytes).

Whilst woodland regeneration is possible at low to medium deer densities, at the high deer densities currently experienced in much of Scotland regeneration could be significantly affected in the absence of appropriate management measures. Although beavers affect only a fairly narrow corridor along watercourses, as the beaver population grows deer density may have to be reduced to medium or low levels to avoid detrimental effects on riparian woodland. It is important to remember that it is not only the habitats themselves that may be affected, but all species dependent upon them, such as lichens in Atlantic hazelwood.

Rhododendron maximum, a parent of the invasive complex hybrid *Rhododendron ponticum*, has been shown to be a preferred food choice[18]. No impacts on rhododendron were seen in the Knapdale trial area, but most had already been removed by FCS prior to the trial. Since rhododendron regrowth is vigorous, and avoided by other browsing animals, if beavers were to use this species they might maintain it in a juvenile form but would be unlikely to exert a controlling influence.

Habitats of European importance

The following sets out the potential impacts on specific woodland habitats which are qualifying features of SACs. GIS-based measures of predicted potential overlap with beaver core habitat (described in section 3.2) are provided.

Alluvial forests with Alnus glutinosa *and* Fraxinus excelsior - There is a high likelihood that beavers will interact with this habitat based on levels of predicted potential overlap. Any interaction with beavers is likely to have a large impact.

GIS analysis suggests there would be an extensive overlap between predicted beaver core woodland (section 3.2) and alluvial forest SACs. Within non-coastal alluvial forest SACs (Conon Islands, Mound Alderwoods, Shingle Islands, Urquhart Bay Wood) up to 69% of the total woodland area may form part of core beaver habitat. Hence, a large proportion may be heavily affected by beaver activity.

Beavers would have an impact on this habitat due to their herbivory of willow and alder. Although the latter is not a preferred species, it may still make up a significant proportion of a beaver's diet, especially where it is dominant. Beaver herbivory is unlikely to cause the extirpation of any species from these areas, but is likely to shift the relative abundance of these species. However, flooded areas behind beaver dams are likely to be colonised by willows, which are tolerant of standing water, so beavers may create alluvial forest habitat in other areas.

Tilio-Acerion *forests of slopes, screes and ravines* - There is a low likelihood that beavers will interact with this habitat based on levels of predicted potential overlap. Any interaction with beavers is likely to have a large impact.

In some areas there is likely to be an extensive overlap between predicted beaver core habitat and SACs. However, this woodland type exists on steep, unstable slopes, and hence the affected area is likely to be confined to the lower fringes of such woods. Of the species common in this habitat in Scotland, ash and sycamore are preferred species, whilst elm is non-preferred[14].

Bog woodland - There is a medium likelihood that beavers will interact with this habitat based on levels of predicted potential overlap. Any interaction with beavers is likely to have a low level of impact.

There is likely to be some overlap between bog woodland SACs and predicted beaver core habitat. Bog woodland is usually dominated by pine, which is unlikely to be significantly affected by beaver herbivory. Alternatively, bog woodland may be restored, or more habitat created, due to beaver impoundment[15].

Caledonian forest - There is a low likelihood that beavers will interact with this habitat based on levels of predicted potential overlap. Any interaction with beavers is likely to have some impact.

The abundance of birch in riparian Caledonian forest may be reduced, shifting species composition towards increased dominance by pine. Although this would be viewed as a negative impact, the impact will be localised to riparian areas of Caledonian forest and will not affect the broad distribution of the habitat.

Old sessile oak woods with Ilex *and* Blechnum *in the British Isles* - There is a low likelihood that beavers will interact with this habitat based on levels of predicted potential overlap. Any interaction with beavers is likely to have a large impact.

There is likely to be some overlap between oak woodland SACs and predicted beaver habitat. The habitat is dominated by oak and birch, both preferred species which will be affected by beaver activity. However, the habitat area is extensive, and hence the affected area is likely to be relatively small.

Other habitats of conservation importance

The following woodland types are not qualifying features of SACs, but are of conservation importance.

Atlantic hazelwood - There is a high likelihood that beavers will interact with this habitat based on levels of predicted potential overlap. Any interaction with beavers is likely to have a large impact.

The potential overlap between Atlantic woodland dominated by hazel (where it is greater than 80% of the canopy) and potential beaver core habitat is likely to be in the region of 27% (Table 3.2). As hazel is a preferred species, beavers may have a large impact within the zone of overlap. In particular, the ecological continuity of lichen communities may be affected in small patches of Atlantic hazelwood (section 3.4.4).

European aspen - There is a high likelihood that beavers will interact with this species based on levels of predicted potential overlap. Any interaction with beavers is likely to have a large impact.

In the longer term, beavers may cause the local loss of aspen in areas of core beaver habitat, at least of mature trees rather than suckers (i.e. where beaver presence is likely to be longer term, preventing substantial regrowth)[8, 9]. The interaction may be especially damaging in riparian areas of high deer density, as browsing by deer on aspen regrowth is high. In other areas, aspen regrowth after beaver herbivory can be vigorous[5], and in a juvenile form that beavers tend to avoid[7]. Beavers may also increase the dispersal, and, hence, distribution, of aspen by releasing branches into watercourses that may subsequently act as propagules[17].

Across Scotland, 42% of woodland with 25% or more aspen in the canopy is likely to overlap with potential beaver woodland (Table 3.3). Similar levels of overlap are seen in the potential core beaver woodland (37–41% overlap), the areas which are likely to be most heavily affected by beavers. However, the overlap with the well-surveyed and important Strathspey aspen woodland is less extensive, with 18% (58 ha) overlapping with core beaver habitat. Ultimately, beavers may have a large impact on this species and the interaction would need to be closely monitored and managed. See sections 3.4.4 and 3.4.6 for a consideration of impacts on biodiversity associated with aspen.

Table 3.2
Predicted overlap of all and core potential beaver habitat with Atlantic hazelwood[16]. Values are provided for three thresholds of hazel as a percentage of the woodland canopy within a Native Woodland Survey for Scotland woodland polygon.

Hazel in canopy (%)	Total area (ha)	Overlap with potential beaver woodland (ha (%))	Overlap with potential core beaver woodland (ha (%))
≥ 25%	7,207	2,215 (31%)	1,796 (25%)
≥ 50%	2,660	753 (28%)	544 (20%)
≥ 80%	934	252 (27%)	176 (19%)

Table 3.3
Predicted overlap of all and core potential beaver habitat with aspen woodland. Values are provided for three thresholds of aspen as a percentage of the woodland canopy within a Native Woodland Survey of Scotland woodland polygon.

Aspen in canopy (%)	Total area (ha)	Overlap with potential beaver woodland (ha (%))	Overlap with potential core beaver woodland (ha (%))
≥ 25%	568.5	240.0 (42%)	209.2 (37%)
≥ 50%	119	49.7 (42%)	47.3 (40%)
≥ 80%	30.8	12.9 (42%)	12.7 (41%)

Table 3.4
Summary of potential interactions between beavers and woodland. At some sites appropriate management may be needed to counteract negative effects and promote positive effects. Note that the significance of any individual effect may be far higher or lower than that of other effects.

Activity	Mechanism	Positive effects	Negative effects	Notes
Felling	Change in riparian woodland: Opening of woodland canopy and increased patchiness	– Most felling is within 10 m of the water's edge. Beavers are central place foragers, so impacts also vary along watercourses according to distance from lodges. The impact of beavers may therefore be patchy, leading to greater structural diversity along the length of watercourses – Felling large trees opens the canopy, allowing more light to reach the ground and allowing regeneration from seed, which could lead to increased structural diversity in even-aged woodland	– Where woodland is already very open, the impact of beavers could lead to localised loss of woodland cover, especially where levels of deer browsing are high, and could prevent regeneration from seed	
Felling	Change in riparian woodland: Change in relative abundance of different tree species		– Young shoots are very attractive to deer, and the combined impact may lead to loss of preferred species. In some cases, aspen could be lost from parts of the core beaver habitat, where near-permanent beaver presence prevents substantial regrowth – Beaver may preferentially select less common species in order to fulfil their need for a diverse diet. This could lead to reduced species diversity, which might be exacerbated by differences in the responses of tree species to beaver browsing	Beavers have a clear preference for some tree species, particularly aspen and willow. These species generally resprout rapidly, and beavers seem to avoid young aspen regrowth
Felling	Change in riparian woodland: Change in age classes of trees		– Where browsing from other herbivores is high, regrowth may be prevented, and this could lead to a reduction in structural diversity and ultimately loss of woodland cover – Since beavers select according to stem size, and as younger trees generally produce more and stronger shoots than older ones, a younger age profile is likely to develop over time, with a loss of older trees and of climax riparian woodland communities. If a large proportion of the woodland is affected then ecological continuity could be interrupted within the riparian zone	Most broadleaved tree species can regrow from cut stumps, but the vitality of the regrowth varies with species and age. In Knapdale, ash and willow were found to produce stronger shoots than birch and alder

Activity	Mechanism	Positive effects	Negative effects	Notes
Felling	Change in riparian woodland: Amount/diversity of fallen dead wood on woodland floor	– Tree-felling by beavers could lead to increased fallen dead wood in some areas, although much of the material is removed for food and construction		
Felling and constructions	Changes in amount/ diversity of woody material in watercourses			
Feeding	Feeding on specific terrestrial herbaceous and aquatic plant species			
Dams/pond creation	Change from lotic to lentic habitat			
Dams/pond creation	Change in hydrological processes on riparian and downstream habitat	– Inundation of woodland could promote the growth of some species, especially willow, which can grow well even in standing water. Bog woodland may be restored or more habitat created	– If a large proportion of an area of woodland is inundated, and willow is unable to regenerate, loss of woodland cover could be considered a negative impact	This might be positive/ negative or neutral depending on the area, tree species and regeneration
Dams/pond creation	Changes in water quality downstream			
Dams/pond creation	Change in standing dead wood resulting from inundation of trees	– Death of trees which are unable to cope with the water levels will lead to an increase in standing dead wood, which is generally present at only low levels in British woods	– Inundation of woodland will lead to the death of trees of certain species	This might be positive/ negative or neutral depending on the area, tree species, regeneration and the pre-existing biodiversity value of the inundated woodland
Dams/pond creation	Longer term successional changes after dam abandonment, e.g. beaver meadows	– In previously homogeneous woods, this increase in integral open space would add diversity and improve the habitat for some species groups, e.g. the adults of dead wood invertebrates often require nectar sources	– In fragmented woodland, this loss of woodland cover would be considered a negative impact	This might be positive/ negative or neutral depending on the pre-existing woodland structure
Dams/pond creation	Impacts on movement of species			
Other constructions	Creation of lodges, burrows, canals, etc.			
Other				
Indirect habitat creation/ restoration initiatives as a result of beaver presence	Beavers used to promote opportunities for riparian and freshwater habitat creation/ restoration	– Any riparian woodland restoration programme would aim to increase the abundance of this much reduced habitat, and of particular preferred species, such as aspen		

3.4.2. Freshwater – Standing waters

Overview

The effects of beavers on standing water habitats and associated wetlands are mainly related to dam-building and herbivory (Figures 3.27 and 3.28). Throughout this section a particular focus is given to aquatic plants and plant communities, as they are key indicators associated with standing water habitats.

Effects of dam-building activities

The effects of beavers on plants have been linked to changes occurring as a consequence of modification of habitat[1]. Numerous studies have looked at the ecological effects of beaver dam-building around pond–wetland complexes and on streams[2, 3]. However, there is less information on the effects of beaver activity on more discrete, existing, larger lake environments. Beavers tend not to dam in water bodies more than 0.85 m deep and 6 m wide[4], which means that dam-building does not tend to occur within lakes, but it may occur at the outflow and inflow streams.

Pond–wetland complexes inhabited by beavers represent a variety of habitats, which exhibit different stages of colonisation by biota, and therefore support a diversity of species. The diversity of plant species present in beaver ponds has been found to increase with time[5]. Beaver activity also increases the number of invertebrate taxa present in ecosystems[6]. Dam-building in stream systems introduces environments that provide habitat for invertebrates associated with standing waters.

Flooding of terrestrial environments results in the creation of wetland habitats adjacent to fully aquatic environments, increasing the number of niches associated with the standing water. Increased plant and invertebrate species richness supports other components of standing water/wetland systems, for example birds[7, 8], bats[9], amphibians[10] and fish[11] (described in more detail in the following sections). Where ponds are formed as a result of dam-building on stream systems, there may be an overall biodiversity gain, and downstream lotic (i.e. running water) habitats may benefit from better water quality with the dams creating sediment traps[12], although there may also be localised losses in stream biota.

Effects of foraging activities

Research has been carried out on the terrestrial food preferences of beavers, but also on grazing in aquatic habitats[13, 14]. Aquatic plants have been found to constitute a considerable proportion of beaver diet, though the degree of reliance on such plants varies with time of year and differs between sites[15].

In North America, beavers have been known to have both positive and negative effects on the abundance of invasive plant species[1, 16, 17]. Although much of the literature relates to terrestrial rather than aquatic plants, parrot's feather *Myriophyllum aquaticum* and *Elodea* pondweeds, which are aquatic invasive non-native species present in Scotland, have been found to be highly preferred food species for beavers elsewhere[1, 18].

Foraging by beavers affects existing habitat not only in terms of removal of preferred plant species, but also through deposition of harvested plant material. Such material includes food for consumption during winter, but also discarded matter. Food caches are stored in slow-moving waters and have been linked with positive effects on biodiversity. Compared with existing sand and gravel substrates, a higher abundance of macroinvertebrates, fish and amphibians has been found to be associated with beaver lodges and wood caches in lakes in Ontario[19] and, in general, woody debris is considered beneficial for invertebrates and fish in lakes[2].

Figures 3.27 and 3.28
Herbivory and dam-building are the main ways through which beavers can affect standing waters.
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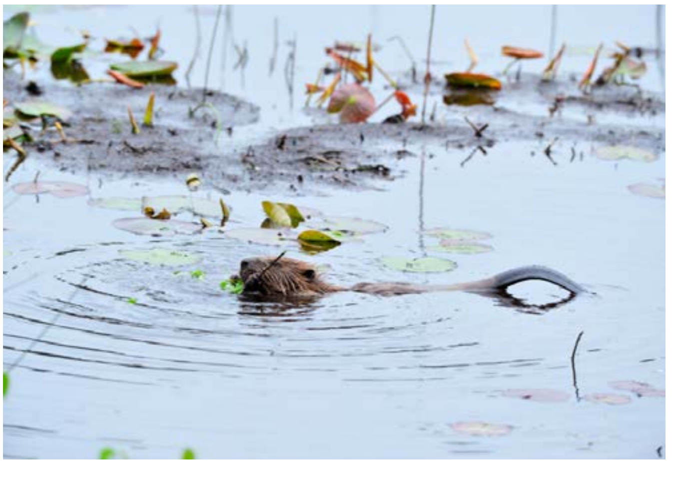

Table 3.5
Field signs recorded during macrophyte surveys (2009–13) indicating the patterns of herbivory or foraging across the eight lochs lying within four existing beaver territories[2]. The size of circle reflects the extent or frequency of observation of associated field signs: large symbols (widespread and/or commonly observed), medium symbols (local and/or occasionally observed), small symbols (very local and/or rarely observed).

	Dubh	Coille-Bharr	Linne	Fidhle	Creagmhor	Un-named North	Buic	Un-named South
Nymphaea alba White water lily	medium	medium	small	small	small	medium	medium	small
Cladium mariscus Saw sedge	small		small	large	large		large	
Schoenoplectus lacustris Common club-rush		small	large	large	medium			
Equisetum fluviatile Water horsetail	medium	medium	small		small	small	medium	small
Carex rostrata Bottle sedge	medium	small	small	small	small	small	small	small
Menyanthes trifoliata Bogbean	small	small						
Phragmites australis Common reed		small					small	
Sparganium erectum Branched burr reed	small			small				
Potamogeton natans Broad-leaved pondweed					small			
Carex paniculata Tussock sedge	small							

Scottish experience

The SBT in Knapdale provided a unique opportunity to assess the effects of beavers living in the wild on loch ecology in a Scottish environment. The monitoring study involved the collection of pre-release data and detailed work on the effects of beavers on standing water plant communities.

In Dubh Loch, there was a marked and sustained water level rise as a consequence of dam-building, but aquatic vegetation lost through submersion or herbivory was largely replaced by rapid colonisation of newly flooded areas, and the number and diversity of plant species increased (Figures 3.29–3.39). Invertebrates rapidly colonised the newly flooded areas, with composition of the community changing with time. The majority of invertebrates found in newly inundated areas were non-biting midge and water boatman larvae. Water beetle diversity increased from the baseline, with *Agabus* species (predatory beetles) and Hydroporinae (diving beetles) becoming more dominant over 2011–13 (see section 3.4.6).

Beaver activity had a clear and measurable impact on aquatic plant communities in some of the lochs that were monitored in Knapdale[2]. The greatest effects were on plant cover, with species richness being little affected. In general, the number of plant species recorded in the lochs increased, especially in lochs occupied by beavers, but there are insufficient data to discern whether such increases were caused by beavers. However, at the highest level of beaver occupancy, a significant negative effect on plant cover was detected. This effect was distinguished from background variation in plant cover only after a number of years of high-level occupancy[2].

Four plant species were particularly affected by grazing, with two species showing significant reduction

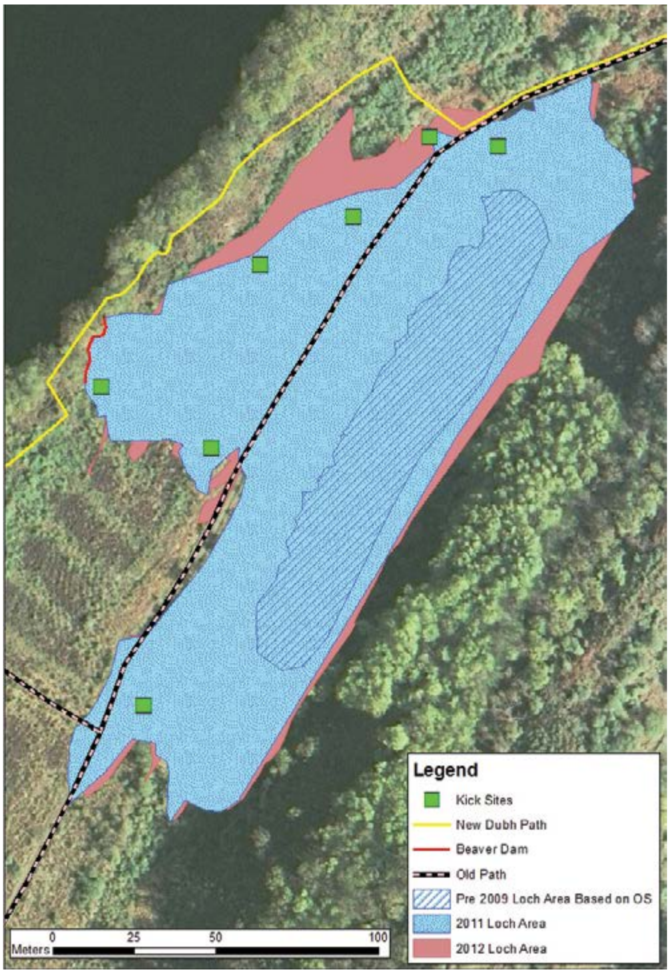

Figure 3.29
The outline of Dubh Loch, Knapdale, in May 2011 and 2012, relative to the outline according to Ordnance Survey data and 2005 aerial photography.
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Figures 3.30 and 3.31
Changes at Dubh Loch – fixed-point photography of the southern end of Dubh Loch showing the vegetation present in September 2008 (left) and September 2011 (right).

Figure 3.32
Changes at Dubh Loch – new loch edge being colonised by aquatic plants, 2014.

Figure 3.33
Changes at Dubh Loch – vigorous growth of common water-starwort *Callitriche stagnalis*, lesser spearwort *Ranunculus flammula* and rushes *Juncus* spp. on mud of inundated zone exposed during May 2013.

Figure 3.34
Changes at Dubh Loch – scale of colonisation by broad-leaved pondweed *Potamogeton natans* beneath former birch woodland, 2013.

Figure 3.35
Changes at Dubh Loch – dense stands of broad-leaved pondweed and white water lily with drowned birch trees in the background, 2013.

Figures 3.36 and 3.37
Benthic peat that had surfaced in Dubh Loch as a result of beaver dam-building, at various stages of colonisation (mainly by bottle sedge *Carex rostrata* and rushes), in September 2011 (left) and September 2012 (right).
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Figure 3.38
Dubh Loch in May 2014, showing unshaded open water following dieback of birch trees in the area inundated by the beaver dam. The open water in the lower left of the picture was the original area of the loch. Loch Coille-Bharr is in the background.
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Figure 3.39
A closer view of Dubh Loch in May 2014, showing dieback of birch trees in the area inundated by the beaver dam.
© Martin Gaywood/SNH

in cover. Saw sedge *Cladium mariscus* was grazed heavily and there was a considerable decrease in its population. Detailed studies of the effects on white water lily *Nymphaea alba* showed that beavers selected larger leaves of lilies in shallow water near to the shore. Although removal of lily pads within grazed areas was considerable, the decrease in lilies was limited to 0.38–1.23% over the entire resource[20]. This species also incurred losses in areas of raised water levels, but it may have benefited by expanding into areas no longer supporting saw sedge[2]. There was considerable grazing on common club-rush *Schoenoplectus lacustris*, leading to large declines in lochs with a high level of beaver occupancy. Grazing of water horsetail *Equisetum fluviatile* in one loch led to a noticeable decline in the cover of this species. Other plant species showed little change[2]. Table 3.5 illustrates the effects of beavers on a number of plant species, as indicated by field signs. These results were consistent with results from other parts of the surveys.

No adverse effects were found on the submerged plant assemblages that are designated as part of the Taynish and Knapdale Woods Special Area of Conservation (SAC) feature of 'clear water lochs with aquatic vegetation and poor to moderate nutrient levels'. Preferred food plant species were edge/emergent and floating-leaved, rather than submerged species. Although consumption of water lobelia *Lobelia dortmanna* and lake quillwort *Isoetes lacustris* by beavers in Norway has been documented[14,] no evidence of feeding on such submerged isoetid species was found in the Knapdale study. There was some uprooting of isoetid plant species that represent part of the feature of interest, but this occurred as a result of removal of other species for consumption, rather than because the isoetids were used by the beavers, and loss of these plants was not considerable[2]. Dubh Loch, which was particularly affected by dam-building, does not constitute part of the SAC feature of interest, so the shift from aquatic to mire species was not an issue from this perspective.

Caches of woody material were observed only in close proximity to beaver lodges. However, woody debris resulting from beaver activity was recorded at the shoreline in a number of lochs, with some of it collecting in areas occupied by isoetid plants, particularly shoreweed *Littorella uniflora*. This species grows along the shoreline, whereas water lobelia and lake quillwort grow only in completely submerged habitat. Such woody debris may increase the complexity of habitat and replace shelter lost as a consequence of the removal of common club-rush, though it may also cause adverse effects for macrophytes in shallow areas during strong winds[2].

Although the work at Knapdale was unique in Scotland in terms of monitoring beavers in the wild, studies have also been undertaken in an enclosure at the Bamff estate in Perthshire, where beavers were released in 2002. Monitoring carried out from 2003 to 2012 revealed that there were considerable increases in macrophyte diversity and changes in the species present, these occurring as a result of persistent, selective feeding by beavers on preferred species such as iris *Iris pseudacorus*. Of note at Bamff was the considerable consumption of rhizomes of bogbean *Menyanthes trifoliata*, this species not having been targeted to such an extent in Knapdale[21, 22].

At Bamff, the presence of lodges, caches and woody waste material resulted in an increase in the species richness, diversity and abundance of macroinvertebrates in the beaver ponds, and 30% of all species collected were found only in sites affected by beavers[21].

The Tayside beaver survey of 2012 estimated that there were about 38-39 beaver territories present[23]. The presence of beavers was recorded at Lochs Clunie and Marlee, with individual beavers noted at Loch of the Lowes and Butterstone Loch. Beavers are known to be continuing to use Loch of the Lowes. These four lochs are constituent water bodies of the Dunkeld–Blairgowrie Lochs SAC, a site designated for the quality of its standing water habitat and vascular plants, the latter including the European Protected Species slender naiad *Najas flexilis*.

The 2012 survey also recorded beaver activity close to the large water bodies of Loch Tay and Loch Rannoch[23], and by 2014 beaver activity was also noted at the east and west ends of Loch Earn[24]. Loch Rannoch and Loch Tay fall within the River Tay SAC.

Beaver activity was recorded at Loch of Lintrathen, which is hydrologically connected to the River Isla, a water body where beavers have also been recorded. A similar record exists for Loch of Kinnordy, which lies between Loch of Lintrathen and Forfar Loch. It appears likely that the latter water body was colonised from the Dean Water, a number of beaver records having been made on that tributary of the River Isla. Loch of Lintrathen and Loch of Kinnordy are designated as SSSIs for their standing water features of interest.

In Forfar Loch, beavers have been transporting parts of trees and feeding on plants near the outflow, where there is a reedbed. In the past, this area was cleared annually by local personnel to prevent a back-up of water and flooding elsewhere on and around the site. As a result of this increase in beaver activity, including swimming and dragging material through the reeds, there has been a reduction in the density of the reedbed, and the development of a more diverse habitat. This has reduced the amount of effort required by personnel to clear the outflow area[24].

Beavers have also built a dam on a large pond in the Tayside area. The dam was removed a number of times, as a risk of flooding upstream was identified. However, the beavers always rebuilt the dam. A flow device is now in place (see Chapter 5) to allow sufficient drainage to avoid flooding and to ensure that there is water of a suitable depth for the beavers, of approximately 0.8 to 1.0 m[24].

Detailed ecological studies of the potential effects of beavers on water bodies in Tayside have not been carried out because baseline data are not available on pre-release conditions[24], apart from at the site at Bamff.

Potential future implications for Knapdale and Tayside

A summary of the potential effects of beavers in the lochs monitored at Knapdale, based on observations to date, is presented in Table 3.6. It is possible that similar effects would occur at other lochs in the Knapdale or Tayside areas, should beavers occupy them. Post-release monitoring at Knapdale has been carried out over only five years, so further effects may be observed in the longer term. Since the main monitoring programme was completed, a new dam has been built at the outflow of Un-named Loch (South).

In cases of loch water level rises occurring as a result of dam-building, it may take 10 years or more for vegetation to adjust, should water remain at that level[2]. The effects of dam-building at Dubh Loch are likely to be long-lasting, and if the beavers were to leave the site a return to previous conditions may take several decades. It may be that beavers will use this water body less if the vegetation is no longer adequate to feed them. Where only small or temporary rises in water levels resulted from dam-building (at Knapdale this occurred in Un-named Loch (North), and Lochs Linne and Fidhle), vegetation did not show a directional change. Monitoring over longer periods may be required to detect any trend.

During the SBT it was noted that, increasingly, beavers were feeding on terrestrial plant species such as bracken and purple moor grass. This trend may continue, particularly if beavers have consumed large quantities of aquatic or wetland plants for which they have a preference[2]. The continuation of tree-felling, alteration of riparian areas and further creation of woody debris would be likely[2]. Beavers will start to colonise different locations in the Knapdale area (see section 3.2). A pond to the north of Lochan Buic has been used by beavers on occasion, and may be further modified in the future. Activity around Un-named Loch (South) started to increase after the end of the trial, and will probably continue. Beavers have also moved into Loch Barnluasgan and built a lodge since the trial ended. To date, Loch McKay and Loch Losgunn have not been used by beavers, but they represent potentially suitable habitat for beavers, although the diversity and abundance of trees close to these water bodies is limited. The predictive population model (section 3.2) indicates that beavers are also likely to move into the Crinan Canal feeder lochs to the south-east, such as Loch na Bric, Loch an Add, Loch Daill and Lochan Duin, although water fluctuations can be significant and the extent of aquatic vegetation and riparian habitat is variable[25]. Lochan

Table 3.6
Summary of potential effects of beavers on standing waters at Knapdale, based on observations to date[2].

Potential effect	Main loch locations	Classification	Basis for interpretation
Grazing and foraging on saw sedge	Buic, Creagmhor, Fidhle	Negative	Uncommon species subject to almost complete loss in several lochs. Very limited evidence of recolonisation. Populations present in other sites and not universally depleted
Grazing on common club-rush or water horsetail	Fidhle, Linne	Neutral	Common species, present elsewhere in Knapdale, and small residual populations in lochs affected, so there is potential for rapid re-establishment. Possible loss of hydraulic refuge for some aquatic biota
Grazing and foraging on white water lily	Buic, Dubh, Coille-Bharr, Un-named (North)	Neutral	Common species, losses small and sustainable. Little evidence of compensatory growth or expansion of understorey species due to high level of dominance. Possibility of greater utilisation in future if preferred foods exhausted
Uprooting of isoetids	Buic, Coille-Bharr	Neutral	Losses trivial in relation to other forms of disturbance. Apparently collateral damage from feeding on common club-rush or white water lily and no evidence that isoetids are specifically targeted
Major water level rise	Dubh	Positive	Promotes fine to medium-scale heterogeneity. Rapid recolonisation by macrophytes and invertebrates. Generates novel habitat conditions and niches for early colonists
Minor or temporary water level rise	Fidhle, Linne, Un-named (North)	Neutral-positive (taxa dependent)	Reversible shift in relative abundance of more moisture-tolerant species. Possible niche for scarce species associated with fluctuating water levels
Removal of tree shade	Linne, Coille-Bharr, Creagmhor, Buic, Dubh	Neutral	Potential to increase diversity of understorey vegetation or increase aquatic vegetation if resulting habitat is suitable. Increased risk of desiccation of bryophytes associated with high shade and humidity. Multivariate effects preclude assessment
Accumulation of woody debris	Coille-Bharr, Linne, Buic, Creagmhor	Neutral-positive (taxa dependent)	No clear effect on aquatic vegetation. May lead to erosional losses but also likely to increase complexity of littoral habitat for other aquatic biota
Changes in water chemistry	Dubh, Un-named (North)	Uncertain	Potential for increase in dissolved organic carbon (DOC) in smallest lochs with raised water levels. May reduce macrophyte growth but insufficient evidence from water quality monitoring
Spread of Canadian pondweed	Dubh	Negative	First record for Dubh Loch in May 2014 at a dam, although impossible to state categorically that spread to this waterbody was due to beavers

Duin may be the most suitable site for beavers, as there is extensive aquatic vegetation and less evidence of water fluctuation[26]. Lochan Taynish, which is 5 km to the south-west of Loch Coille-Bharr and outside Knapdale, has plentiful aquatic and woody vegetation and may be colonised in time[2].

Few dams were constructed on streams during the SBT (section 3.4.3) but, in time, should territories already be established on many of the lochs and/or numbers of trees of preferred size and species near to lochs be reduced, this may become more common and new ponds may be created[2].

On Tayside it would seem likely that beavers will continue to explore potential loch habitat that is close to areas already colonised and find further suitable habitat through following lines of hydrological connectivity. Beavers will probably colonise the area around all five lochs of the Dunkeld–Blairgowrie SAC: Lochs Craiglush, Butterstone, Clunie and Marlee and Loch of the Lowes. Beavers have also been recorded on the Lunan Burn to the south-east of Loch Marlee and on the Rivers Isla and Ericht. Therefore, colonisation of Fingask Loch, White Loch, Hare Myre and Stormont Loch, which are all bordered by potential core beaver woodland, may be expected in the short to medium term. Black Loch and Monk Myre are not surrounded by core beaver woodland, but are close enough to the other lochs to be within the same beaver territories.

Some core potential beaver woodland is present at Loch of Lintrathen and Forfar Loch, where some activity has already been recorded. Forfar Loch is located to the west of Forfar, and to the east are Loch Fithie, Balgavies Loch and Rescobie Loch, which all have potential core beaver woodland. Beavers may find these water bodies in the short to medium term.

Drumore Loch is some distance from any current recorded beaver sites, but is hydrologically connected to the Black Water and is close to the headwaters of the Alrick Burn. These two running waters flow into the River Earn and River Isla respectively, so, in time, beavers would be expected to disperse to Drumore Loch. However, the site does not have potential core beaver woodland, which suggests that the habitat quality may be poor for beavers, although this would need to be confirmed by more detailed checks on the ground.

There have been signs of beaver activity close to Loch Tay and Loch Rannoch, so beavers may travel westwards along these lochs to other water bodies. There is potential core beaver woodland along Loch Tay itself and some around Loch Rannoch. To the south-west of Loch Tay there is a potential core beaver woodland around Loch Iubhair and Loch Dochart. Although there are lochs to the west of Loch Rannoch, a combination of lack of woodland and low plant productivity in water bodies may discourage beavers from colonising these areas, at least on a longer term basis.

In the River Earn catchment, beavers have reached the western end of Loch Earn. From there, they may go on to sites such as Loch Voil, Loch Lubnaig, Loch Venachar, Loch Achray and Loch Katrine, all of which are in proximity to potential core beaver woodland. Lochan Lairig Cheile may be accessed via Glen Ogle, although potential core beaver woodland along that route is limited.

Most of the lochs of the River Tay catchment area mentioned above have conservation and/or biodiversity interests, including SSSI standing water or wetland features of interest, and records of slender naiad. Any current and future beaver effects on these lochs will be site specific, and as yet detailed monitoring has not taken place.

Potential future implications of wider reintroductions in Scotland

The potential future implications of wider reintroductions of beavers in Scotland will be site specific, depending on the characteristics of the individual sites inhabited, the desirability of dam-building in these locations and the beavers' food preferences.

Physical and water quality considerations

It has been reported that beavers may not tolerate excessive and unnatural water-level fluctuations[27]. This suggests that they are less likely to inhabit lochs where water levels are significantly affected by activities such as power generation and abstraction for potable supply.

Beaver dams have been documented as leading to more stable water levels. Whilst this would be expected to provide stable conditions suitable for submerged plants, such as water lobelia *Lobelia dortmanna*, there are also plants that are reliant on exposure of substrate, for example pillwort *Pilularia globulifera*.

Building of dams increases the depth of water in a waterbody. This results in not only the creation of new aquatic habitat, but also the potential loss of habitat in deeper water due to light limitation. Increasing water depth also results in an increase in the volume of the loch, which increases its dilution capacity, but also increases the time the loch will take to flush. A longer flushing rate results in a longer retention time for nutrients and phytoplankton, this potentially having adverse effects on water quality in lochs that are enriched. However, beaver activity may also have a mitigative result, as in the case of Forfar Loch, where restriction of the reedbed may result in the restoration of free-flushing of the water body.

In Tayside, 32 dams were recorded between September 2013 and November 2014. The maximum height of the dams was 0.75 m[24]. An increase in water level that such dams would bring would not be large in absolute terms and in many water bodies this would be expected to fall within the natural variation. However, the water levels in the Knapdale lochs are likely to fluctuate by less than 0.5 m in the year, and in shallow waterbodies, such as Dubh Loch, where the surrounding land is relatively flat, the effects of increases in water level may be considerable[2, 28]. When the dam was first built at Dubh Loch the water level increased by a maximum of 1.1 m[28, 29]. However, by May 2014, the water level had decreased by 0.25 m compared with that present in May 2011 and 2012. As the level was close to the top of the dam, this suggested that the construction material had settled and that the height of the dam had not been maintained by the beavers[2].

Inundation of terrestrial habitats may result in increases in nutrient levels and decreases in dissolved oxygen in the water column, as a consequence of decay of terrestrial plant matter and leaching of nutrients from soils. In low-nutrient environments, this may have minor effects.

However, in situations where the inundated soil has been fertilised, as in the case of arable land, this may result in a considerable increase in nutrient loading to the water column.

Flooding of terrestrial habitats may also result in an increase in water colour, as a consequence of increased input of humic substances from peaty soils. Increased water colour may decrease maximum depth of colonisation by aquatic plants. However, if shading of standing waters were to be reduced by beavers felling trees, increased light availability could stimulate further growth of aquatic plants, particularly in edge habitats[2].

In Tayside, erosion has been found to occur as a consequence of beavers burrowing into river- and floodbanks, and water diverting around dams[24]. Increased erosion of banks of inflow streams and lochs may increase sedimentation within standing waters, with the potential to adversely affect water and substrate quality. As in the case of inundation of terrestrial environments, difficulties are less likely to occur in low-nutrient environments with little and unintensive land use. When the construction of dams results in the formation of ponds on inflow streams, these may attenuate flows and reduce the loadings of pollutants entering the loch downstream, as was noted in the interception of a slurry spill by beaver ponds in Devon[30]. Depending on the nature of the material being trapped in beaver ponds, the water may become more acidic, whilst stream acidity may decrease[31]. However, should beaver ponds become enriched, the water may become less acidic. Ponds and wetland complexes created by beavers may also act as pollutant sinks and buffer against the effects of drought[32].

Direct implications for aquatic plants

The diet of beavers depends on the palatability and nutritional content of different plant species and the availability of preferred species[15]. However, the plants that beavers eat and where and when they eat them are not easily predicted, and all beavers would not be expected to eat the same species, to the same extent. An example of such unpredictability is the consumption of saw sedge at Knapdale. As this species is rare in Scandinavia[33], it is unlikely that the Norwegian beavers released had encountered it previously[2], so they could not have had a known preference for it. It is possible only to highlight that, in general, grazing pressure is likely to be on rhizomatous species, particularly during summer[2]. The preferred species consumed at Knapdale were all rhizomatous. They were also edge/emergent and floating-leaved plants linked more with shallower waters closer to the lochs' edges rather than submerged, deeper water habitats, although common club-rush was harvested to a depth of 2.5 m as shown by the lengths of the severed stems[2].

A number of different types of loch exist in Scotland, ranging from unproductive dystrophic and oligotrophic waterbodies to moderately productive mesotrophic lochs and productive eutrophic lochs. It might be expected that beavers would be more likely to prefer the richer water bodies with more abundant vegetation, but the nature of the catchment area immediately surrounding standing waters of low productivity is likely to be important. Where, for example, an unproductive loch is small, shallow and easily dammable, and the surrounding vegetation is adequate to support the beavers, it may be that the presence of abundant aquatic vegetation is less important. Similarly, proximity or connectivity to other waterbodies may increase the suitability of any individual loch or pond.

All of the species on which the beavers have been feeding at Knapdale are common and grow throughout Scotland, with the exception of saw sedge. Saw sedge is not rare, but is uncommon in Great Britain. Although beavers may adversely affect the abundance of this species in sites where it co-occurs with beavers, beavers are unlikely to affect the status of this species in Great Britain[2]. Saw sedge grows in swamps adjacent to lochs and ponds, beside streams, and in tall-herb fens and open fen carr[34], so there is a range of potential habitats for the species. In Scotland, the distribution of saw sedge is skewed to the western coast and islands[34].

Germination trials (which involved replicating conditions expected to allow saw sedge to grow) were unsuccessful using material from Knapdale[2]. It was concluded that the seedbank in the Knapdale lochs is small and that the plant spreads vegetatively. As flowering was noted at low frequency, this conclusion is supported, although a study in East Anglia did not find seedlings and was unable to encourage seeds to germinate[35, 36]. The reliance of this species on the rhizome means that its removal will cause depletion of the species in sites where beavers co-occur. However, the preference for saw sedge at Knapdale may in part have been related to limited availability of emergent species such as branched bur-reed, reedmace *Typha latifolia*, iris and bogbean, on which beavers have been observed to feed elsewhere[2].

Invasive non-native plant species may also be affected by beavers. Those most commonly found in lochs in Scotland are Nuttall's pondweed *Elodea nuttallii* and Canadian pondweed *Elodea canadensis*. As beavers may consume *Elodea* species, there is a possibility that cover of *Elodea* species would decrease in lochs where beavers and *Elodea* co-occur. However, this would depend on the availability of other food species. If beavers were to feed on *Elodea* species, there is also a possibility that dispersal of these plants would increase, as damage may create numerous smaller fragments which may then grow into new plants. In addition, mud and plant material may be used by beavers as part of dam and lodge construction. This behaviour may affect the spread of *Elodea* species[2].

Habitats of European importance

There are five types of standing water qualifying features for SACs in Scotland. They are listed here, with a short summary of how potential core beaver woodland habitat (described in section 3.2) overlaps with the SACs.

Hard oligo-mesotrophic waters with benthic vegetation of Chara *species* – two out of three SACs have very low levels of associated core beaver woodland.

Natural dystrophic lakes and ponds – all six SACs have very low levels of core beaver woodland.

Natural eutrophic lakes with Magnopotamion or Hydrocharition-type vegetation – Loch Achnacloich is the only one of five SACs with core beaver woodland. Suitable woodland is abundant around Loch Achnacloich.

Oligotrophic to mesotrophic standing waters with Littorelletea uniflorae *and/or of the* Isoteo-Nanojuncetea – four out of 13 SACs have associated core beaver woodland, with suitable woodland in abundance around Loch Ruthven, Loch Ussie and, in particular, Muir of Dinnet.

Oligotrophic waters containing very few minerals of sandy plains: Littorelletalia uniflorae – the only SAC is on the Western Isles, which are not predicted to be colonised by beaver.

This simple assessment does not highlight sites where beaver presence may occur upstream, and could therefore have an effect on the downstream standing water habitats. Also, it does not cover standing waters with these habitats types that occur in the wider countryside. As noted earlier, it is difficult to give a general prediction on the effects beavers may have on different sites if they are ever colonised. Any assessment would need to be done on a site-by-site basis.

Beavers are also likely to have some level of interaction with a range of wetland/bog habitats which may also be qualifying features for SACs. However, this may happen at only a relatively small number of sites. An initial analysis suggests that the vast majority of sites are in areas where beavers are unlikely to build dams (based on the methodology set out in section 3.2)[3, 37]. At those sites where dam-building might occur, there would be localised changes in hydrology, which could be positive in conservation terms.

Species of European importance

Slender naiad *Najas flexilis* (listed in Annexes II and IV of the Habitats Directive) – there is a high likelihood of interaction of beaver with slender naiad at some sites based on levels of potential overlap[3]. Although beavers are already present at the Dunkeld–Blairgowrie SAC, the monitoring of the effects of beaver on slender naiad at the site would be difficult. First, it has not been possible to find slender naiad in the lochs of this site in recent years. Second, it may be difficult to identify specific effects of beavers in waterbodies that already have pressures of diffuse pollution and invasive non-native species acting on the submerged plant communities.

Although it is impossible to know what effects beavers might have on slender naiad without monitoring data, it should be noted that the plant has been recorded at 54 lochs since 1980 (there are a further 16 records which are historical or where the data are deficient). A considerable number of the lochs that support it are in the Outer Hebrides, with a few on Colonsay, Coll, Islay and Mull, and therefore in locations distant to mainland Scotland and often without potential beaver woodland habitat. These sites would not be, or are unlikely to be, colonised by beavers.

However, the Dunkeld–Blairgowrie Lochs, White Loch, Fingask Loch, Loch nan Gad, Tangy Loch, Loch Kindar, Lake of Menteith and Loch Bhada Dharaich, all of which are mainland lochs that support slender naiad, may be colonised by beavers in the longer term. There is evidence that other mainland sites (Monk Myre, Lindores Loch, Loch Flemington and Loch Monzievaird) all supported slender naiad in the past, but presently, environmental conditions are believed to be unsuitable for this species at these locations. Based on the work carried out in Knapdale, the beavers appeared to prefer to eat rhizomatous edge/emergent or floating-leaved plant species. Slender naiad is a submerged, annual species that spreads by seed and has no rhizome. Although these factors may mean that the risk to slender naiad is reduced, in cases of co-occurrence it is possible that there could be negative effects, should water levels rise and new habitat at appropriate depth be unsuitable for growth or if water quality were to be adversely affected, for example through increased water colour or nutrient concentrations. However it should be noted that slender naiad has been found in abundance in recently abandoned beaver ponds in North America[38].

Floating water-plantain *Luronium natans* (listed in Annexes II and IV of the Habitats Directive) – based on potential overlap, there is a medium likelihood of interaction with floating water-plantain[3]. However, this species occurs at a very limited number of sites (and therefore reduces the likelihood of co-occurrence) and is outside its natural range in Scotland.

Table 3.7
Summary of potential interactions between beavers and standing waters. At some sites appropriate management may be needed to counteract negative effects and promote positive effects. Note that the significance of any individual effect may be far higher or lower than that of other effects.

Activity	Mechanism	Positive effects	Negative effects	Notes
Felling	Change in riparian woodland: Opening of woodland canopy and increased patchiness	– Increased light levels may increase the maximum depth of colonisation by aquatic plants in lochs		
Felling	Change in riparian woodland: Change in relative abundance of different tree species			
Felling	Change in riparian woodland: Change in age classes of trees			
Felling	Change in riparian woodland: Amount/diversity of fallen dead wood on woodland floor			
Felling and constructions	Changes in amount/ diversity of woody material in watercourses	– Complexity of habitat is likely to increase with an increase in woody material within standing waters – Abundance and diversity of aquatic invertebrates, fish and amphibians may increase as a result of caches, woody debris, etc.	– Woody debris may adversely affect plants in shallow water during strong winds, although this is likely to be a localised and minor effect overall	
Feeding	Feeding on specific terrestrial herbaceous and aquatic plant species	– Selective consumption of edge/emergent plants may lead to colonisation of habitat by submerged species – There is a possibility that some invasive non-native species may be consumed – Clearance of vegetation that is acting as a barrier to water flow may restore flushing rates in standing waters and prevent backing-up and consequent flooding	– Preferential selection of uncommon species, such as saw sedge, may lead to localised losses at individual sites – Negative effects on the area covered by aquatic plants may occur in lochs after a number of years of high occupancy by beavers – Beavers may spread invasive non-native plant species by increasing fragmentation and incorporating plant material in lodges	Consumption of common species, such as bogbean, white water lily, common club-rush and water horsetail, may have localised effects, but neutral effects overall Incidental uprooting of isoetids when beavers are foraging for other species is not likely to have a considerable effect
Dams/pond creation	Change from lotic to lentic habitat	– Creation of pond-wetland systems may improve the quality of water flowing into lochs, thereby improving the water quality of standing waters – Numbers of invertebrate and plant species are likely to increase with the presence of both lotic and lentic environments, rather than the presence of running water habitat only	– Localised losses of lotic species where lentic habitat is created are likely – Considerable change in the balance of lotic and lentic species is possible at the catchment scale, if there are high densities of new ponds	

Activity	Mechanism	Positive effects	Negative effects	Notes
Dams/pond creation	Change in hydrological processes on riparian and downstream habitat	– Creation of ponds and wetlands in loch catchment areas may protect lochs from the effects of drought – Hydrological alterations may restore natural connectivity in wetland-loch systems – Creation of ponds and wetlands in loch catchments is likely to increase the number of species present – Water level rise in standing waters would be expected to increase the area of standing water habitat – Water level rise increases the volumes of standing waters, and greater volume may improve the capacity of a loch for dilution of nutrients and phytoplankton	– Flooding of terrestrial land upstream/adjacent to lochs may result in deterioration of water quality through decay of vegetation and leaching of nutrients from soils – Flooding of peaty soils may result in an increase in the concentration of humic substances in the water of lochs, thereby causing a decrease in light penetration – With loch water level increases, there is a potential for loss of plant habitat in deeper water because of light limitation – With increasing loch volume, water retention time increases, flushing rate decreases and nutrients and phytoplankton are retained for longer within the loch	Problems resulting from leaching of nutrients from soils are more likely in catchment areas that are fertilised The significance of increasing levels of humic substances or dissolved organic carbon has not been quantified and would be site specific Areas of habitat lost with increasing water depth may not be replaced if new areas of substrate at suitable depths are smaller or are unsuitable for plant growth Volume and flushing rate are variables that have considerable influence on the effects of nutrient loadings in lochs. Effects of alteration of these factors by beavers are unknown and would be site specific. In effect, reduction in flushing rate may offset increase in volume
Dams/pond creation	Changes in water quality downstream	– Creation of ponds on inflow waters may lead to improvement in the quality of water in the receiving waterbody through attenuation of flow, sedimentation of solids and assimilation of nutrients within the ponds	– Creation of ponds on inflow waters may lead to deterioration of water quality of loch inflows through changes in pH, a decrease in dissolved oxygen levels, a build-up of pollutants and disturbance within the ponds	Build-up of pollutants within created ponds would be a consequence of upstream land use rather than of beaver activity, so overall the effects of beavers may be neutral/positive
Dams/pond creation	Change in standing dead wood resulting from inundation of trees			
Dams/pond creation	Longer term successional changes after dam abandonment, e.g. beaver meadows			
Dams/pond creation	Impacts on movement of species			
Other constructions	Creation of lodges, burrows, canals, etc.	– Beaver lodges and other constructions may be beneficial to macroinvertebrates and other aquatic species, and canals may encourage hydrological connectivity	– Digging of canals and burrows may result in deposition of soil in downstream standing waters	
Other				
Indirect habitat creation/ restoration initiatives as a result of beaver presence	Beavers used to promote opportunities for riparian and freshwater habitat creation/ restoration	– Restoration of riparian habitat, for example by extending 'buffer zones' along the edges of watercourses, is likely to result in improvements to water quality of standing waters, and therefore to habitat		

3.4.3 Freshwater – Running waters

Overview

In those parts of the world where beavers are more prevalent, numerous studies of their effects on hydrology (the study of the occurrence, distribution and movement of water), fluvial geomorphology (the study of the physical process and forms that occur in streams and rivers) and river habitat have been conducted. Changes in the processes that occur in streams and rivers – and therefore the shape and position of them – are initiated by changes in the supply of sediment and water. The physical nature of the habitat found in running waters is therefore affected by changes in the quantity of water or sediment moving along them. Beaver activity, for example dam-building, has the potential to not only modify the supply of water and sediment, but also increase the supply of wood that may initiate channel change by deflecting flow and changing the patterns of erosion and deposition. The scale and nature of these changes and the fate of the wood will depend upon the relative size of the wood and the watercourse and the location of the wood in the river network[1, 2].

Hydrology

Beaver dams will impede the flow (quantity and velocity) of water in a channel. The extent to which they do will depend upon their height and porosity and the frequency at which they occur. Beaver dams therefore increase the in-channel storage of water. When dams extend beyond the channel, floodplain storage will also increase. One study[3] concluded that abandoned beaver ponds played a role in increasing channel retention, and that changes in in-channel storage resulting from beaver dams were a positive aspect of beaver activity. By increasing the amount of water stored in a channel or on a floodplain the effects of prolonged periods of dry weather may be lessened. Some of the findings of a recent literature review[4] include that beaver dams moderate stream flow, increase surface water and riparian groundwater storage, regulate hyporheic flows (i.e. flows in the groundwater–surface water mixing zone, which is now known to be important for the maintenance of running water habitat) and enhance evapotranspiration rates (i.e. the evaporation of water from plants and the earth's surface).

By slowing flow, and therefore reducing the speed at which intercepted precipitation passes through a catchment, beaver dams can increase the length of time taken for a flood to reach its peak and reduce the height of the peak. Beaver activity may therefore result in the development of natural flood defences. Investigations of the effects of dams on flow have been undertaken in North America and Europe. Following the reintroduction of Eurasian beaver to Belgium, one study[5] investigated some of the effects of their dams on hydrology. It indicated a significant lowering of peak flow downstream of dams, an increase in the length of interval between major floods, and an increase in the depth of low flows. Another study in Glacier National Park, Montana[6], found that North American beaver dams reduced the velocity and quantity of water emerging downstream of them and that older dams had a greater effect than newer ones.

Modifications to stream hydrology as a result of beaver activity are unlikely to be solely in response to dam building. In-channel accumulations of wood are a feature of many naturally functioning river systems, and wood derived from beaver activity is likely to increase both the total amount of material available and the incidence of accumulations. Investigations into the effects of accumulations of coarse wood in streams in the New Forest[7] showed an increase in the amount of time taken for water to pass through a channel.

Localised changes in the connectivity between channels and their riparian zone and floodplains are likely, including 'alternating patches of high and low water table'[8]. Beaver canals may increase channel–floodplain connectivity including via the connection of previously discrete floodplain water bodies with a stream or river.

Figure 3.40
Woody material input to stream prior to beaver dam-building, Bamff Estate, near Alyth, Tayside.
© Nigel Willby/University of Stirling

Figure 3.41
Beaver dams, such as this one at Kosterheden, Denmark, may get washed away during heavy spates.
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Figures 3.42 – 3.44
Dam on inflow to Loch Fidhle, Knapdale, May 2013 (upper left). The stream habitat is shown in 2008 prior to dam construction (upper right), and from the same vantage point in 2012 after dam construction (lower right).
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Geomorphology

Beaver dams will not only attenuate flow but also impede the movement of sediment. As the ability or 'competence' of a flow to transport sediment decreases, fine material will begin to fall out of suspension and coarser material will come to a stop. These interruptions to sediment transport will happen upstream of beaver dams where flowing water enters a ponded reach. Work in Glacier National Park[6, 9] showed that beaver ponds clearly trapped sediment and that the depth and volume of sediment substantially increased with dam age. In the Republic of Tatarstan, Russia, three beaver dams stopped 4,250 tonnes of particles in the Sumka River during a period of flooding in 2001[10].

The dissipation of energy associated with flows slowed by beaver activity will result in increased channel stability[8], i.e. less erosion and deposition and therefore less lateral and vertical movement of the channel. Undammed reaches in systems affected by beaver activity are likely to become more geomorphologically complex[8].

Changes in geomorphological processes, and therefore channel shape and position, are also likely to occur in response to increased amounts of in-channel wood (Figure 3.40) derived from beaver activity. Pieces of wood may coalesce and have a significant effect. Smaller accumulations or single large pieces may also instigate changes to both channel cross-section shape and the lateral movement of the channel by increasing channel roughness, and therefore altering patterns of erosion and deposition.

Habitat

The construction of beaver dams and ponds introduces many additional habitats to river reaches, resulting in a substantial increase in habitat diversity, the spatial complexity of the habitat mosaic and the overall resilience of river and riparian ecosystems to disturbances[11]. The hydrological and geomorphological effects of beaver activity will alter the amount of lotic (running water), lentic (still water) and wetland habitat supported by a stream or river. These alterations will affect the composition of some aquatic communities, for example the diversity of lentic and lotic habitat-dwelling invertebrate species may change. The system is dynamic, with dams eventually degrading due to abandonment and/or heavy spates (Figure 3.41).

The sediment accumulating in the ponded reaches upstream of beaver dams will be sorted, with larger particles being deposited at the head and finer material in the main body[8]. A change in the composition of bed material downstream of dams is also likely to occur as a result of sediment being retained behind dams. These changes will increase habitat diversity.

The retention of organic and mineral matter by beaver dams is likely to improve downstream water clarity and quality. The flushing of fine and sorting of coarse sediment in reaches between ponds may also occur. These effects may be beneficial for fish-spawning habitat and have provided a rationale for beaver reintroduction into degraded, incising river systems in the USA[11]. Changes in the aquatic invertebrate community composition are also

Figure 3.45
Secondary dam on outflow from Loch Linne, Knapdale, September 2009.
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Figure 3.46
Dam on Dubh Loch, Knapdale, May 2014.
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likely in response to changes in flow, sediment and food availability (section 3.4.6).

Beaver activity in streams will increase habitat diversity, notably in watercourses that have been managed. It has been demonstrated that beavers enhance habitat availability, heterogeneity and connectivity[12]. In Scotland, as in many other parts of the world, streams and rivers have been modified by humans, for example straightened, widened and deepened, for a variety of reasons. This engineering has reduced the diversity of aquatic habitat, and therefore the species supported by it. Re-establishing the natural habitat complexity of running waters has been the focus of many restoration projects, including several that have been undertaken in Scotland in recent years (see the River Restoration Centre website*)*. Beaver activity can hasten the restoration of habitat mosaics, and their use as initiators of recovery has been explored[13, 14]. One study[15] concluded that in areas inhabited by beaver, the evolution of stream planform (i.e. the shape of the channel when viewed from above) is the result of not only physical variables but also biotic processes, for example beavers constructing dams.

Further implications of these types of changes on various species groups, in particular those of conservation significance, are described elsewhere in this chapter. A particular focus has been made on reviewing beaver interactions with fish[16, 17], summarised in section 3.4.7.

Scottish experience

Although beavers appeared to have explored much of the stream network in the Scottish Beaver Trial at Knapdale, they exploited little of the river and riparian resources available, and therefore had limited influence on the fluvial geomorphology and river habitat in the area during the five-year trial period. Dams were constructed where streams enter (Figures 3.42 – 3.44) or leave (Figure 3.45) lochs and the gradient was low and the flow sluggish. Three dams were built within approximately 200 m of the outflow from Loch Linne; one immediately downstream of Un-named Loch (North); one on the inflow to Loch Fidhle from Loch Losgunn; and one on the outflow from Dubh Loch immediately upstream of Loch Coille-Bharr. However, an analysis of the data collected during the trial indicated that little change in stream habitat occurred, and there was no evidence of a reach-scale beaver activity effect on physical habitat. For example, the rate of input of beaver-generated wood to the streams of Knapdale was small compared with the inputs through other natural processes, such as windthrow during storms.

However, these dams had some discernable effects on the hydrology of the lochs and the streams that flow from them. These included temporary increases in the storage of some larger lochs, the elevation and stabilisation of the water level in some small lochs, an increase in the dry weather flow in some streams, and a possible delay in the timing of peak stream flow. The most striking change to the hydrology of the trial area was a result of the dam (Fig. 3.46) on the outflow of the small lochan, Dubh Loch, which caused a rise in water level of over a metre and an increase in the loch's surface area from 0.38 to 1.66 ha.

Monitoring work[18] concluded that in comparison with other studies, the effects observed at Knapdale were subtle and that beavers had mostly minor effects on hydrology over the period of the trial. There were probably two major reasons for this. First, the low number of animals present, and the fact that the dams they constructed were, with the exception of the one on Dubh Loch, small, poorly sealed structures, and isolated rather than being closely grouped where reported effects tend to be more pronounced. Second, the Knapdale catchment naturally attenuates runoff due to its extensive forest cover and significant potential for storage in lochs and valley floor peats. Such circumstances will greatly moderate any additional effects of habitat engineering by beavers on hydrology. However, it is possible that, if beavers were to remain in Knapdale and the population was to grow, some family groups might become more active on the running waters and there may be increased dam-building activity.

The evidence gathered during the Knapdale trial suggests that the incidence of beaver dam-building will be low when populations are small and have ready access to well-vegetated standing waters. In agricultural settings, or where higher densities of animals occur and are required to exploit sub-optimal habitat, a higher level of habitat engineering and associated hydrological effects should be expected. Although detailed monitoring of aquatic systems was not undertaken on Tayside, the 2012 beaver survey[19] recorded seven intact or recently cleared dams, some of which had apparently led to agricultural land being flooded. The Tayside Beaver Study Group[20] reported that this had increased to 32 dams, recorded between September 2013 and November 2014.

Within the 3 ha enclosure of the Devon Beaver Project there is a solitary, intermittently defined stream. Within a week of releasing a pair of beavers, a new watercourse had been created and, within a year, eight large ponds.

Potential future implications for Knapdale and Tayside

The majority of Knapdale's running waters are narrow, single-thread channels and many of them appear to have been modified for land drainage, with limited use by migratory salmonids. Although Knapdale has been a suitable site to investigate certain beaver interactions, to date it has been of limited value in assessing river habitat in general and migratory fish habitat specifically. Beaver activity in running waters has been limited so far. However, if the population is reinforced, and the animals start to colonise Knapdale as described in section 3.2, then it seems likely that territories will start to be established along the running waters over the next decade or so. That is likely to result in more dam-building and other types of impacts along the running waters, with consequent wider effects as described above. Continued monitoring would allow some assessment to be made of the effects of beaver activity on hydrology, fluvial geomorphology and river habitat, although the effects of other natural processes and commercial forestry operations (e.g. increased runoff due to clear-felling, alterations to flow caused by ditch maintenance) would need to be teased out.

Potential future implications of wider reintroductions in Scotland

These can be summarised:

- Beaver dams will have some effect on the hydrology, fluvial geomorphology and in-stream and riparian habitat of Scotland's running waters
- The paucity of significant beaver activity in the running waters of the Scottish Beaver Trial area to date has meant that there is a limited understanding of the possible effects of beavers on the hydrology, geomorphology and habitat of Scottish streams and rivers. However, continued monitoring would allow assessments to be made should the Knapdale population begin using the running waters of the area. The research opportunities afforded by the presence of beavers on Tayside might add to our understanding of the possible effects
- The Knapdale experience suggests that in situations where beavers are released onto lochs with high-quality habitat, territories are established initially in the immediate vicinity of the lochs, and colonisation of interconnecting running waters may not necessarily occur in the short term
- By restricting flow, and therefore storing water upstream of them, beaver dams may help to combat some of the effects associated with periods of low flow, i.e. they may help to ensure that aquatic habitat is maintained through prolonged periods of dry weather
- Changes in flow, and therefore energy, will result in changes in erosion and deposition and, in turn, changes to the cross-section and planform of rivers and streams. The significance of this will depend upon the setting
- The ponding of water upstream of beaver dams will lead to localised changes to in-stream and riparian habitat and increased habitat heterogeneity
- Beaver dams will have some effect on sediment transport processes and are likely to lead to localised changes in both the upstream and downstream composition of bed sediment. Locally reduced velocities could result in some particles that may previously have been moved downstream being deposited upstream of dams and the composition of bed sediment downstream would therefore be altered. The significance of this will depend upon the setting, for example it might result in changes in the quality of salmon or lamprey-spawning habitat
- The slowing of flow and storage of water resulting from beaver activity could have local, perhaps wider, flood defence benefits and would accord with natural flood management aspirations currently being discussed in Scotland
- Most of the scientific literature has a reach-scale focus. There appears to be relatively little information about catchment-scale effects

Habitat of European importance

The River Tweed is the only SAC in Scotland with a riverine habitat qualifying feature.

Water courses of plain to montane levels with the Ranuculion fluitantis *and* Callitricho-Batrachion *vegetation* – there is a high likelihood that beavers will interact with this habitat based on levels of predicted potential overlap. Any interaction with beavers is likely to have a small to medium impact, with much of the relevant plant communities occurring in sections which will not be dammed by beavers (at least 90% of the entire SAC is unlikely to be dammed by beavers).

Table 3.8
Summary of potential interactions between beavers and running waters. At some sites, appropriate management may be needed to counteract negative effects and promote positive effects. Note that the significance of any individual effect may be far higher or lower than that of other effects.

Activity	Mechanism	Positive effects	Negative effects	Notes
Felling	Change in riparian woodland: Opening of woodland canopy and increased patchiness	– Development of diverse riparian understorey, and therefore increase in habitat diversity and species richness – Increase in amount of light reaching watercourses, and therefore: - increase in diversity of in-stream habitat provided by aquatic plants - increase in geomorphological change initiated by the presence of plants (and therefore increase in habitat diversity) - stabilisation of banks and reduction in erosion due to binding effect of bank and riparian species	– Reduction in shading, and therefore a potential increase in thermal stress upon some species such as fish	
Felling	Change in riparian woodland: Change in relative abundance of different tree species		– Possible reduction in type of food preferred by some aquatic invertebrates, and therefore possible indirect effects upon species such as fish – Possible reduction of deep-rooted species that bind bank material, and therefore possible increase in erosion	
Felling	Change in riparian woodland: Change in age classes of trees	– Possible eventual reduction in the size of wood entering watercourse, and therefore a change in the nature and scale of geomorphological change initiated	– Possible eventual reduction in size of wood entering watercourse, and therefore change in in-stream habitat structure provided and nature and scale of geomorphological change initiated	
Felling	Change in riparian woodland: Amount/diversity of fallen dead wood on woodland floor	– Greater source of wood available to be entrained by overbank flows, and therefore possible increase in habitat diversity and likelihood of wood jams in streams and rivers		
Felling and constructions	Changes in amount/ diversity of woody material in watercourses	– Increased number of wood jams, resulting in: attenuation of flow and - lowering of downstream flood risk - greater geomorphological, hydraulic and habitat diversity - improvements in water quality as fines settle in areas of slower flow	– Increased number of wood jams, so a possibility of localised floodplain inundation and impacts on land use	

Activity	Mechanism	Positive effects	Negative effects	Notes
Feeding	Feeding on specific terrestrial herbaceous and aquatic plant species	– Change in nature and scale of geomorphological change initiated by the presence of vegetation	– Change in nature and scale of geomorphological change initiated by the presence of vegetation	
Dams/pond creation	Change from lotic to lentic habitat	– Increase in habitat diversity – Increased flood storage, and therefore decrease in downstream flooding – Improvements in base flow during periods of low precipitation due to increased water storage	– Increased fish predation opportunities – Smothering of bed sediment upstream of dams resulting in change in habitat quality – Reduction in turbulence upstream of dam, so decrease in rate of water oxygenation	
Dams/pond creation	Change in hydrological processes on riparian and downstream habitat	– Increased habitat and species diversity	– Increased flooding of riparian zone and beyond, so potential impacts on land use	
Dams/pond creation	Changes in water quality downstream	– Reduction in the amount of fine material deposited on bed sediment, and therefore habitat, e.g. spawning redds, maintained – Reduction in rate of sediment movement, and therefore the speed at which it leaves streams and rivers		
Dams/pond creation	Change in standing dead wood resulting from inundation of trees			
Dams/pond creation	Longer term successional changes after dam abandonment, e.g. beaver meadows	– Reconnection of streams and rivers with floodplains, and therefore lateral extension of river corridors – Increased habitat and species diversity – Improvements in natural flood management		
Dams/pond creation	Impacts on movement of species		– Dams are a possible impediment to migratory fish – Increased fish predation opportunities	
Other constructions	Creation of lodges, burrows, canals, etc.	– Expansion in amount of aquatic habitat and attendant increase in habitat and species diversity and abundance		
Other				
Indirect habitat creation/ restoration initiatives as a result of beaver presence	Beavers used to promote opportunities for riparian and freshwater habitat creation/ restoration	– Beavers may be used to promote river restoration projects (as well as contributing to low-cost restoration through their own activities)		

3.4.4 Bryophytes, fungi and lichens

Overview

Bryophytes (mosses and liverworts), fungi and lichens are diverse groups of organisms that make up a large proportion of Scotland's biodiversity. Over 1,500 species of lichen occur in Scotland and the Scottish Biodiversity List includes 210 species of bryophyte, 207 fungi and 486 lichens. The majority of these species will never be affected by beavers because their habitat occurs mainly or entirely outside potential beaver habitat. However, Scotland is an internationally recognised hotspot for biodiversity associated with oceanic woodland. In particular, many species of bryophyte and lichen have the majority or all of their European population in Scottish woodlands (example species and maps are presented elsewhere[1]). Since beavers directly affect trees – and therefore woodland structure, continuity and composition – their effect on woodland oceanic bryophytes and lichens is highlighted here. Fungi are less well known in terms of their distribution and conservation status. However, they provide key ecosystem services, so are considered here in terms of the mechanisms by which beavers may affect them.

When considering the overall impact of beavers on bryophytes, lichens and fungi, it is important to consider the scale of assessment. For example, most of these species respond to small-scale habitat variation as much as, if not more than, broad habitat variation. This means it is necessary to consider the impact of beavers not only on broad habitats, but also on the occurrence of small-scale habitats such as dead wood, boulders within woodland and deeply fissured bark on old trees. The biodiversity benefits of beavers should also consider the national and international impact of beavers as well as local impacts. It is important to compare local species losses and gains against each species' wider distribution. For example, negative local impacts on the globally restricted oceanic bryophytes and lichens referred to above should not be compared like-for-like with positive local impacts on species that have much wider global distributions.

The diversity of bryophytes, lichens and fungi makes it difficult to make general statements about the potential impact of beavers. It is possible, however, to identify the main mechanisms by which beavers may affect these species (Table 3.9).

Figures 3.47-3.49
Atlantic hazel supports two globally restricted communities of lichens, one on smooth stems (left) and another on rough stems (upper right). Beaver activity can result in the local loss of these communities (lower right). See the SBT monitoring report for further details[1].
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Loss of old woodland micro-habitats and habitat continuity

Species diversity is positively correlated with micro-habitat diversity[2]. Old woodland supports a wider range of micro-habitats and associated species than young woodland. Beaver activity is likely to result in localised loss of old woodland micro-habitats through medium- to long-term loss of old trees (section 3.4.1). This will result in medium- to long-term localised loss of old woodland species. Species associated with young tree micro-habitats may increase in abundance, but these are much more common and widespread in Scotland.

Many old woodland species are poor recolonisers[3]. Micro-habitats associated with old woodland may also take many years to recover. This may result in local extinction of old woodland species, or species associated with old trees, many of which have their core European populations in Scotland.

A more detailed description of the importance of micro-habitat diversity and temporal habitat continuity is provided in the SBT monitoring report on lichens[1].

Gains and losses in riparian woodland extent and suitability for bryophytes, lichens and fungi

The reintroduction of beavers may be accompanied by incentives to promote riparian woodland restoration and creation. This indirect effect may create future habitat for bryophytes, lichens and fungi. However, there may be localised losses of old woodland supporting bryophytes, lichens and fungi of conservation concern in the long term if beaver-felled trees do not regenerate due to over-browsing by deer. Areas of woodland habitat for these species may also be lost due to flooding, although many species associated with dead wood will benefit in the short to medium term in such circumstances.

Beavers are likely to increase the area of wet woodland. Wet woodland supports a different range of species from dry woodland. For example, there will be an increase in mycorrhizal fungi associated with wet woodland trees (e.g. aldercaps) and a decrease in species associated with dry woodland.

Moisture-loving species, such as bog mosses[4], and scarce species associated with damp, wet wood may increase (Swedish pouchwort *Calypogeia suecica* and Heller's notchwort *Anastrophyllum hellerianum* are examples of nationally scarce liverworts associated with damp dead wood - Scotland has an international responsibility for the conservation of such oceanic species). Epiphytic species associated with moisture-intolerant trees may decline if these tree species are lost.

Species vary in their requirements for light and shelter. The more open canopy that would be created by beaver activity will favour species of bryophyte and lichen that require higher light levels but that can withstand exposure. Species that tolerate lower light levels and require shelter to maintain high humidity are likely to be negatively affected. Woodland floor features such as boulders and dead wood are particularly important habitats for mosses and liverworts. An increase in the cover of vascular plants and large, robust bryophyte cover in areas opened up by beavers may have a negative impact on smaller and less competitive woodland floor bryophytes through increased competition.

Many species of bryophyte, lichen and fungus are associated with specific tree species. Medium- to long-term loss of mature trees of species preferred by beaver may result in the loss of a suite of associated species. For example, mature aspen, a preferred food source for beavers, supports a diverse community of lichens and bryophytes in central Scotland. These associated species may suffer localised extinction within areas colonised by beavers.

Dead wood

Beavers may increase the quantity and variety of dead wood, at least in the short to medium term. Many bryophytes, lichens and fungi are associated with dead wood[5–7], either as a substrate or, in the case of fungi, as a food source. The long-term impacts of beaver on dead wood habitat are less clear. Depending on beaver colonisation patterns at the landscape scale, there may be fewer large trees in the future to supply large-volume dead wood. Many species of lichen, bryophyte and fungus have strong associations with large-volume dead wood[8, 9] and standing dead wood supports a number of threatened lichens. Standing deadwood supports lichens classed as 'vulnerable' by the IUCN, such as the forked hair-lichen *Bryoria furcellata* which is on the Scottish Biodiversity List.

Historical perspective

The Scottish landscape has changed significantly since the national extinction of beavers several hundred years ago. In this time, habitats have been subject to disturbance through often drastic changes in land use (e.g. conversion to conifer plantations). Hence, many areas, such as Knapdale, have suffered severe habitat reduction, and ancient woodland lichen, bryophyte and fungus populations could be described as remnants, only now beginning to recover. Beavers have the potential to reintroduce a further source of habitat disturbance, albeit one that occurred as a natural component of the landscape in the past. Whether habitats, particularly those that support ancient woodland species, have the resilience to withstand additional disturbance should be a key consideration when interpreting the information available on the effects of beavers.

Scottish context

There are no significant studies from other countries on the specific impact of beavers on bryophytes, lichens or fungi. It is possible to interpret studies on habitat structure and diversity which would affect these species, but this does not add significantly to the evidence acquired from the SBT.

Beavers are known to fell large, mature aspen trees in Sweden in order to strip their nutrient-rich bark as a food source[1]. This may have serious implications for the continuity of aspen and for species that depend upon mature trees[2]. While aspen and associated species were not studied within the SBT (due to very few aspen being present), some parts of Scotland contain relatively high densities of aspen.

So far it is possible to predict the impact of beavers based only on information from the SBT at Knapdale.

Monitoring here focused on the impact on lichens because of the relatively large overlap of important lichen habitat (Atlantic hazel woodland) with potential beaver habitat[1]. To the best of our knowledge, this is the first specific monitoring to assess the impact of beavers on lichens. Although the Tayside beaver population is much larger than the SBT population, its impact on lichens, bryophytes and fungi has not yet been assessed. The key conclusions from the SBT in relation to lichens are:

- Beavers have the potential to negatively affect nationally and internationally restricted lichen populations by reducing areas of woodland with ancient woodland characteristics or by breaking the ecological continuity of important lichen micro-habitats. However, the risk varies greatly between habitat types, mainly due to differential overlap with beaver habitat. The risk to most lichen habitats is low while the risk to others, particularly Atlantic hazel woodland, is high (Figures 3.47-3.49). Further information on the importance of Atlantic hazel woodland for lichens is provided in the SBT monitoring report[1]
- Detailed monitoring of Atlantic hazel habitat within the Knapdale SBT area has demonstrated relatively high impacts that may eventually result in the permanent or temporary localised loss of a globally restricted lichen habitat. The impact was restricted to a maximum of about 60 m from a loch and within woodland on gentler, less bouldery slopes. Within this utilised zone, 24.4% of stems had been felled, affecting just over half of the stools. There was no observable impact on lichens beyond areas where felling had occurred. Within the SBT five-year monitoring period, only 8% of the SAC's area of Atlantic hazel had been affected. Most felled stems supported oceanic lichen communities, including a number of species that are of national and/or international conservation concern
- Deer browsing of sun-shoots and frost damage may prevent the recovery of hazel stools. The former represents an important interaction between beavers and other herbivores that will require careful monitoring and management. Woodland monitoring concluded that it is not yet possible to ascertain definitively whether regeneration can ensure replacement of trees felled or damaged by beavers[1, 10]
- These impacts have to be considered against the fact that the majority of Atlantic hazel habitat within the SAC is unlikely ever to be affected by beavers
- So far, the SBT is not considered to have had an unacceptable adverse impact on the quality of SAC-qualifying woodland habitat (with lichens and bryophytes as typical species) within the Taynish and Knapdale SAC. However, it is recommended that the assessment should be reviewed periodically and that a management plan be developed should beavers remain within the site

Potential future implications for Knapdale and Tayside

Beavers are unlikely to ever affect many of the important lichen, bryophyte and fungus habitats within the Knapdale and Taynish Woods SACs because of a lack of overlap with suitable beaver habitat. However, within the areas utilised by beavers there will be a shift in the age composition of preferred tree species towards younger growth. Old-growth trees, while not in the preferred size range, may be extirpated over the long term within the riparian zones. This will have subsequent impacts on lichens, bryophytes and fungi associated with climax riparian woodland communities.

Atlantic hazel woodland is a particularly important habitat for lichens at Knapdale because it supports a wide range of species, many of which have their main European populations in western Scotland (Figures 3.47-3.49). Further monitoring over a longer period of time is required to clarify uncertainties as to the long-term impact on Atlantic hazel habitat. Particular attention should be given to impacts on the internationally restricted *Graphidion* and *Lobarion* lichen communities. There is a moderate risk that hazel stems supporting such species of conservation concern will be felled and that this could result in local extinctions. Since the end of the official monitoring period, beavers have colonised Loch Barnluasgan, which is adjacent to the largest area of Atlantic hazel woodland within the site. This will require careful monitoring if beavers remain here, and it may be necessary to consider fencing off this woodland if impacts are as extensive as elsewhere on the site.

The potential main, future implications and recommendations at Knapdale can be summarised:

- Impact of beaver on local Atlantic hazelwood lichen habitat (potential negative impact) - There may be local loss of this lichen habitat, so further monitoring of hazel to determine whether the lichen habitat can persist in the long term around beaver-occupied lochs would be required, with a particular emphasis on the temporal continuity of young and old stems and interaction with deer browsing. There would be a need to refine thresholds to inform when beaver management should be triggered to protect SAC qualifying features
- Recent beaver colonisation of Loch Barnluasgan (potential negative impact) - Monitor the large stand of hazel to the north-east of the loch. If extensive beaver impact looks likely, instigate appropriate beaver management such as fencing
- Impact of beaver and deer management (unknown impact) - Under-grazing can reduce the quality of woodland for bryophytes and lichens due to shading caused by increased vascular plant undergrowth height and climbers such as ivy. The impact of any management that reduces or excludes grazing, for example fencing or deer culling, should be monitored to ensure that lichen and bryophyte habitat is maintained
- Non-beaver-related pressures (potential positive impact) - Management to address pressures that affect beaver habitat quality may benefit lichen, bryophyte and fungus habitat quality, for example reinstatement of conifer plantations to broadleaf native woodland, rhododendron control and deer management to address over-grazing

Within the Tayside catchment, potential beaver habitat occurs within five Sites of Special Scientific Interest (SSSIs) that are noted for their woodland lichen assemblage (Glen Lyon Woods SSSI, Black Wood of Rannoch SSSI, Craighall Gorge SSSI, Milton Wood SSSI and Birks of Aberfeldy SSSI). The extent to which beaver activity could affect lichens varies between these sites depending on the distribution of the feature in relation to watercourses. As for Knapdale, monitoring will be required to detect whether beavers establish within the sites and, if they do, their impact should be assessed and appropriate management put in place. Tayside SSSIs noted for their fungus or bryophyte assemblages are unlikely to be affected by beavers.

Den of Airlie SSSI also occurs within the Tayside catchment and is noted for the protected aquatic river jelly-lichen *Collema dichotomum*. This lichen is sensitive to changes in water depth and sediment deposition, both of which could be affected by beavers, in positive or negative ways depending on where dams are created.

Beyond designated sites, many areas of high lichen and bryophyte importance in drier, eastern parts of Scotland, such as Tayside (and elsewhere should beavers spread further, for example Speyside, Morayshire, Aberdeenshire, east Sutherland and eastern Easterness), are typified by trees on riverbanks or low-lying strips of alluvial ground (often where rivers bend or at confluences). The main tree species supporting threatened lichens in such places is ash, but willow and hazel are also important. The potential impact on these tree species is discussed in section 3.4.1. It is recommended that catchment-level assessments are made to predict and plan for the impact that beavers may have on rare or threatened riparian tree-dependent species.

Potential future implications of wider reintroductions in Scotland

As within the SBT area, nationally many important areas and habitats for bryophytes, lichens and fungi will never be affected because they are mainly or entirely outside potential beaver habitat. However, there are some important exceptions.

At the national scale, potential beaver woodland (section 3.2) overlaps with 27% of Scotland's main Atlantic hazel resource (this falls to 19% if only core beaver habitat is considered). Given the uncertainty of the future of hazel within woodland utilised by beaver in the SBT, this is a significant proportion of an oceanic lichen habitat that has a restricted global range[11]. However, the impacts observed within the SBT should be scaled up only with caution, and wider monitoring over a longer period of time will be required to assess impacts.

Aspen is an important habitat for lichens, bryophytes and a number of rare fungi, particularly in the central Highlands where it is one of the few trees able to support species that require nutrient-rich bark[12]. Across Scotland, 42% of woodland containing more than 25% aspen overlaps with potential beaver woodland[13]. Three hundred and eighty species of lichen (and their associated fungal parasites) have been recorded from aspen. Britain is considered to have international responsibility for 42 of these species because of the relatively high proportion of their global population that occurs here[14]. The aspen bristle-moss *Orthotrichum gymnostomum* is a rare Scottish Biodiversity List priority species that grows only on mature aspen trees (Figure 3.50). Species diversity on aspen is related to a number of factors but tends to be higher in areas with historic woodland cover and continuity of a range of tree ages[15]. Large mature aspen trees are particularly important for a range of associated species. However, aspen is highly favoured by beavers and may be lost from core beaver habitat (Figure 3.51, and see section 3.4.1). More detail on the impact of beavers on aspen is provided in the recent biodiversity review[13]. There are uncertainties about how beavers will affect aspen, but, given the importance of this species as a substrate for a large number of associated species, careful monitoring and beaver management would be necessary in core aspen areas.

Figure 3.50
The rare aspen bristle-moss depends on the continuity of old aspen trees for its survival.
© Gordon Rothero

Figure 3.51
There is currently uncertainty about how beavers will affect current and future old aspen trees in Scotland, but as a preferred tree species, beavers will fell even large specimens to access the nutrient-rich bark, as seen here in Sweden.
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Other woodland lichen habitats, even those that were not considered at risk from beaver activity within the SBT, could clearly be affected by beavers to a greater or lesser extent. A wider assessment of these habitats is provided in the SBT monitoring report[1].

The wider woodland impacts described in section 3.4.1 of this report and the SBT woodland monitoring report[10] should be considered when examining the likelihood of local impacts, with particular attention being paid to the impacts on micro-habitat diversity and ecological continuity. The Tayside beaver population should also be used as a starting point to quantify beaver impact on lichen, bryophyte and fungus habitat in an eastern, riparian environment.

Wooded ravines in western Scotland are of national and international importance for their communities of water-loving oceanic bryophytes. The impact on bryophytes of modifications to water and sediment flow due to small-scale hydro developments has been considered in detail[16]. In some cases, permission for water abstraction by developers has been refused where the development would have affected an important watercourse for these species. Beavers will not have the same impact as hydro development, but they are likely to alter flows and sediment transport (see section 3.4.3) as well as affect trees that support many of the ravine species (see section 3.4.1). The current potential beaver woodland model (section 3.2) indicates that there will be an overlap with some of the most important watercourses. In many cases, this is likely to be an artefact of the current resolution of the model; however, further analysis and research will be required to ensure that beavers do not affect oceanic bryophyte habitat for the most important 'Category A' watercourses in Europe for these species[16].

The impact of beaver management options on bryophytes and lichens will require careful consideration. For example, fencing may not be an appropriate method to protect trees or shrubs that provide important lichen habitat. The long-term absence of grazing can be as damaging as over-grazing due to thicket regeneration and shading of light-demanding lichens and bryophytes.

Despite potential concerns about the impact on internationally restricted old woodland species, there may also be positive long-term benefits to these species, for example:

- Expansion of fluvial woodland to improve beaver habitat could result in an overall increase in old woodland habitat if beavers move about within the landscape and allow old-growth woodland to develop
- Management of deer to prevent over-grazing within beaver habitat will benefit the long-term continuity of bryophyte, lichen and fungal habitat by promoting woodland regeneration
- An increase in dead wood (but note that there is some uncertainty as to the impact beavers will have on important large-diameter dead wood, see section 3.4.1)

Beyond areas occupied by beavers, every effort should be made to ensure that woodland habitat is in good condition. This applies particularly to habitat that supports rare, internationally restricted or threatened bryophytes, lichens and fungi. By maintaining healthy populations of species that could be negatively affected by beavers within their core habitat range, the relative significance of such impacts will be reduced. The principal pressures on these species across Scotland are invasive non-native species (particularly rhododendron), air pollution and inappropriate grazing levels.

The principal policy, monitoring and analysis recommendations, as well as required actions, can be summarised:

- Promote the proactive expansion of aspen woodland, ensuring temporal continuity of young and old trees

- Promote the proactive expansion of Atlantic hazelwood lichen habitat in western Scotland
- Address existing pressures on priority bryophyte, lichen and fungus woodland habitat, e.g. rhododendron, under- or over-grazing
- Assess the relative impact on restricted compared with widespread species
- Assess the overlap between lichens, bryophytes and fungi of conservation concern, particularly those that depend on old trees, and potential beaver habitat prior to local reintroductions, and monitor and manage where appropriate
- Assess the overlap between potential beaver habitat and nationally/internationally important wooded oceanic ravine bryophyte habitat, and monitor and manage where appropriate
- Monitor impact on species of European importance (see below) and manage as required
- Research the impact of beaver control fencing on woodland lichen and bryophyte habitat quality, and produce guidance
- Research the long-term impact of beavers on large-volume dead-wood habitat

Species of European importance

Green shield-moss *Buxbaumia viridis* (listed in Annex II of the Habitats Directive) – there is a medium likelihood that beavers will interact with this species based on levels of potential overlap. Any interaction with beavers is likely to have some impact. This rare moss grows on large dead wood and other stable organic matter in humid woodland. As beavers are expected to increase the abundance of dead wood in riparian areas, and stabilise water regimes, they may increase the habitat for this species. However, beavers may also reduce the amount of shade along watercourses, and reduce the abundance of large dead wood in riparian areas over the long term. The interaction should be monitored.

Slender green feather-moss *Hamatocaulis vernicosus* (listed in Annex II of the Habitats Directive) – there is a low likelihood that beavers will interact with this species based on levels of potential overlap. Any interaction with beavers is likely to have some impact. Changes in the water regime within a catchment may alter the nature of the flushes on which slender green feather-moss survives. Alternatively, the stabilised water regime and increased water table may improve habitat. The interaction should be monitored.

Petalwort *Petalophyllum ralfsii* (listed in Annex II of the Habitats Directive) - there is a very low likelihood that beaver will interact with this species based on levels of potential overlap. It is only found in a single coastal location not associated with potential beaver woodland.

Table 3.9

Summary of potential interactions between beavers and bryophytes, fungi and lichens. At some sites appropriate management may be needed to counteract negative effects, and promote positive effects. Note that the significance of any individual effect may be far higher or lower than that of other effects.

Activity	Mechanism	Positive effects	Negative effects	Notes
Felling	Change in riparian woodland: Opening of woodland canopy and increased patchiness	– More open canopy due to beaver activity will favour tree-dwelling species of bryophytes and lichens that require higher levels of light but that can withstand some exposure	– Some tree-dwelling species that tolerate low levels of light and require shelter to maintain high humidity may be negatively affected as beavers create more open woodland – An increase in the cover of vascular plants and large, robust bryophyte cover in areas opened up by beavers may have a negative impact on smaller and less competitive woodland floor bryophytes through increased competition – Where browsing from other herbivores is high, tree regrowth may be prevented, and this could lead to a reduction in structural diversity and ultimately localised loss of areas of important lichen, bryophyte and fungus woodland habitat	
Felling	Change in riparian woodland: Change in relative abundance of different tree species		– Medium- to long-term loss of mature trees of species preferred by beaver, such as aspen, may result in loss of a suite of associated species – Mature trees on river banks are particularly important for lichens in eastern Scotland and support a number of rare or threatened species	
Felling	Change in riparian woodland: Change in age classes of trees		– Old trees provide habitat for a high diversity of bryophytes, lichens and fungi that do not occur in young woodland. Beavers may prevent trees from becoming old at local levels – Breaks in the temporal and spatial continuity of old woodland characteristic will have a negative impact on the many bryophytes, lichens and fungi that are poor dispersers and/or colonisers. There is a risk of local extinction for some species	Ecological, or micro-habitat, diversity and continuity are key requirements for many species for which Scotland holds internationally important populations[1]
Felling	Change in riparian woodland: Amount/diversity of fallen dead wood on woodland floor	– Many bryophytes, lichens and fungi are associated with dead wood, either as a substrate or, in the case of fungi, as a food source. Beavers may increase the amount of dead wood in some areas – Any increase in the diversity of dead wood (e.g. size, moisture content, exposure, tree species, orientation) is likely to increase the diversity of these species	– Beaver activity may result in fewer large trees in the future to supply large-volume dead wood. Many species of lichen, bryophyte and fungus have strong associations with large-volume dead wood. – Large standing dead wood supports a number of threatened lichens and bryophytes, some of which may become locally extinct	Much of the beaver-felled timber is removed for food and construction Positive impacts are likely to be greater in the short term as large-volume dead wood is created, but this benefit may be lost in the long term

Activity	Mechanism	Positive effects	Negative effects	Notes
Felling and constructions	Changes in amount/ diversity of woody material in watercourses			
Feeding	Feeding on specific terrestrial herbaceous and aquatic plant species			
Dams/pond creation	Change from lotic to lentic habitat			
Dams/pond creation	Change in hydrological processes on riparian and downstream habitat	– Wet woodland supports a different range of species from dry woodland. Some species of bryophyte and fungus will benefit	– Wet woodland supports a different range of species from dry woodland. Some species of bryophyte, lichen and fungus will decline or become locally extinct	There is overlap between potential core beaver habitat and watercourses identified as being internationally important for water-loving oceanic bryophytes. The impacts of beaver activity on hydrology with respect to these species is unknown but requires monitoring
Dams/pond creation	Changes in water quality downstream	– Possible positive impact on aquatic lichens, e.g. the protected river jelly-lichen, due to changes to sediment transport and water chemistry	– Possible negative impact on aquatic lichens, e.g. the protected river jelly-lichen, due to changes to sediment transport and water chemistry	Many effects are unknown
Dams/pond creation	Change in standing dead wood resulting from inundation of trees	– Standing dead wood, particularly when it has lost its bark, provides an important habitat for a number of lichen and fungus species. Beaver may locally increase standing dead wood in the short term in inundated areas		There is uncertainty about the long-term availability of standing dead wood once trees have died and decayed in an area. However, volumes may be maintained at the landscape scale as beavers abandon territories and colonise new areas
Dams/pond creation	Longer term successional changes after dam abandonment, e.g. beaver meadows			
Dams/pond creation	Impacts on movement of species			
Other constructions	Creation of lodges, burrows, canals, etc.			
Other	Beaver management		– Fencing to exclude beavers from sensitive habitat could result in deterioration of habitat for bryophytes and lichens due to under-grazing and subsequent shading by dense herbaceous or tree regeneration within exclosures	It should be possible to use fencing that does not exclude other grazers. Fence requirements will be habitat and site specific
Indirect habitat creation/ restoration initiatives as a result of beaver presence	Beavers used to promote opportunities for riparian and freshwater habitat creation/ restoration	– Any riparian woodland restoration programme is likely to benefit woodland bryophytes, lichens and fungi in the medium to long term		Rhododendron control and deer management in particular will benefit bryophytes and lichens These may be compensatory measures outside the range of beavers to improve habitat for species that will be negatively affected within beaver habitat

3.4.5 Terrestrial vascular plants

Overview

There are two main mechanisms through which beavers affect vascular plants: directly by being eaten and indirectly through successional habitat change (tree-felling, changes in water levels and changes in wave action). Habitat change is specifically addressed in this report in sections 3.4.1 to 3.4.3, impacts upon tree species in section 3.4.1 and impacts upon freshwater plant species in section 3.4.2. This assessment of the potential impacts of beavers on vascular plants is based on the recent biodiversity review[1].

Compared with the information available on indirect impacts caused by habitat change, there is relatively little information on direct impacts by beavers on vascular plants. Despite 60–80% of the North American beaver diet being reported as aquatic vegetation, much of the literature on beaver impacts on vascular plants is in connection with tree species[2]. At Knapdale, it was noted that the proportion of the beaver diet comprising plants other than trees is unknown, but is likely to be higher during the summer due to greater availability and nutritional quality of plant material[3].

The terrestrial vascular plants at greatest risk from direct impacts will tend to be species which occur in habitats close to waterbodies and watercourses.

In Norway, Eurasian beavers have been found to be strongly associated with deciduous trees[4–6]. It has been shown that the abundance of deciduous trees within 40 m of the river bank was a key determinant of beaver presence (or absence) in Norway[7]. Vascular plant species associated with woody shrubs and trees are therefore available for beavers to eat.

The importance of terrestrial open land for foraging is not clear. Land outside woodland has been recorded as part of the territory of Eurasian beavers in both the Netherlands and Norway[6]. Activity is generally constrained to within 50 m of a watercourse[3], with the majority much closer. In the Netherlands Eurasian beavers were found to forage mainly within 6 m of the water's edge[4]. Vascular plants in open areas are therefore potentially available for beavers to eat, but foraging might be predicted to be within a few metres of the water's edge.

The proportion of non-woody plants in beavers' diets varies according to the habitat in which the beavers live and the time of year.

Beavers have been considered to be opportunistic feeders, eating what is available. However, they do appear to be selective as regards their diet. One study found that Eurasian beavers mainly ate woody food in all seasons[8]. Bark and a small amount of roots of monocotyledonous plants were eaten in the winter. In the spring, woody food was eaten with a few herbs and roots. The summer diet was similar to the spring diet, but with more bark. The conclusion was that beavers select food according to the nutrients it provides. Where nutrients are lacking, beavers may target certain plant species in order to obtain sufficient quantities of essential nutrients. Yellow water lily *Nuphar lutea*, a relatively scarce plant in Scotland and eaten by beavers, is rich in sodium and phosphorus. In the Netherlands the large size of Eurasian beaver territories may be because beavers require sufficient sources of minerals during gestation[9].

Plant defence mechanisms are also important and might explain why captive North American beavers have been recorded eating more North American white water lily *Nuphar odorata* than expected[10]. Plant defences might also explain why, at some locations, beavers avoid non-woody plants[8].

Therefore, beavers will tend to feed on both woody and non-woody plants, targeting those species which are most nutritious and avoiding species with natural defences.

Habitat change influenced by beavers is a consequence of increased water inundation and herbivory. Colonisation by North American beavers and impacts upon shrubs can also be influenced by deer and livestock herbivory[11].

Flooding has significant impacts upon riparian vegetation as terrestrial habitat is converted to aquatic, lentic habitat. Initially, flooding will kill many tree species that become submerged. However, the shallow edges, characteristic of beaver ponds, encourage emergent vegetation[12, 13]. The hydrological gradient associated with the edge of beaver ponds increases vascular plant diversity and provides habitat characterised by saturated soils with an open canopy[14].

Plant biodiversity within beaver meadows is no greater than adjacent riparian communities. However, the community composition of these meadows is fundamentally different from other riparian ecosystems. Hence, the presence of beavers results in an increase in habitat heterogeneity, which may ultimately increase herbaceous plant species richness. One North American study recorded species richness increasing by 33% in the riparian zone at the landscape scale as a result of beaver activity[15].

Scottish experience

One SBT monitoring report provides information on beaver impacts on both aquatic and semi-aquatic plants at Knapdale, but not in detail upon terrestrial plant species[16]. A second SBT study investigated the gross changes in ground cover as a result of herbivory on woody trees and shrubs[3].

At Knapdale beavers were recorded feeding on terrestrial plant species, particularly bracken and purple moor grass. It was suggested that herbivory of terrestrial plant species might be expected to continue if the supply of preferred emergent plant species is exhausted[16]. The palatability of other terrestrial plant species is not recorded from other Scottish studies. Grasses and ferns were found to increase in cover, possibly as a consequence of opening the tree canopy. Changes in ground cover as a result of an increasingly open tree canopy may interact with other foraging species such as deer, leading to habitat change[3].

Potential future implications for Knapdale and Tayside

Any changes will be restricted to the riparian areas where beavers are most active, with the vast proportion of Knapdale and Tayside unaffected. Bracken and purple moor grass are widespread and abundant species, and will remain so should beavers continue to occupy Knapdale and Tayside.

Indirect impacts, caused by the felling of woody trees and shrubs, are likely to continue. Some terrestrial plant species might be expected to benefit in riparian habitat, whilst shade-loving species might decline. Terrestrial species which are associated with a high water table are expected to benefit from habitat creation by beavers.

Based on the experience in North America, and at Knapdale, interactions between beavers and other grazing and browsing animals will be important. It is likely that at both Knapdale and Tayside impacts caused by beavers will be influenced by local grazing pressures.

Potential future implications of wider reintroductions in Scotland

There is limited scientific information on the impacts of beavers on vascular plants (other than tree or shrub species), so it is possible to provide only a tentative prediction of possible future impacts.

Impacts through herbivory are most likely to affect terrestrial species within the foraging range of beavers, alongside ponds and streams. Some species currently growing in areas where beavers might change the habitat might be displaced. Other species will benefit from the creation of such habitat change.

The species most likely to be affected, either positively or negatively, by beavers are those which are already restricted in distribution and/or abundance, and which occur in potential beaver habitat close to waterbodies.

There is very little information on the palatability of herbaceous plants species which are rare in Scotland. However, species of European importance are listed below, with a short assessment of potential impact. Dock *Rumex* spp. has been reported as herbaceous species of pioneer and aquatic communities that Eurasian beavers eat during the summer season[17]. It is therefore possible that the Scottish dock *Rumex aquaticus*, a species identified on the Scottish Biodiversity List, might be palatable to beavers, and therefore at some direct risk. An assessment of the distribution of Scottish dock in relation to possible beaver occupancy would be required to predict impacts.

Generic conclusions regarding the possible impacts of beavers on vascular plant species are as follows:

- Beavers will lead to changing abundance and/or distribution of some vascular plant species in Scotland
- Some plant species will benefit, while others will be negatively affected
- Vascular plant diversity might increase locally due to habitat change associated with a resident population of beavers
- It appears highly unlikely that any plant species of European importance will be significantly affected by the re-establishment of beaver populations (see below)

Species of European importance

Marsh saxifrage *Saxifraga hirculus* (listed in Annexes II and IV of the Habitats Directive) – There is a very low likelihood that beavers will interact with this species; there is no overlap between predicted beaver habitat and the current marsh saxifrage distribution. Increased wetland areas resulting from beaver presence may include suitable habitat. Marsh saxifrage has not previously been reported as a food item of beavers, but this does not preclude the possibility.

Slender naiad *Najas flexilis* (listed in Annexes II and IV of the Habitats Directive) – an aquatic species (see section 3.4.2 for an assessment of likely impact).

Killarney fern *Vandenboschia speciosum* (listed in Annexes II and IV of the Habitats Directive) – this species occurs as two distinct stages in its life cycle: the sporophyte, which is the more recognisable 'fern' form; and the gametophyte, which resembles a filamentous alga or liverwort. The distribution of the two stages are different; the gametophyte extends to the north coast of mainland Scotland and the sporophyte is restricted to the south-west of Scotland. The sporophyte occurs at a very small number of locations and it is very unlikely that it will be affected by beavers. The gametophyte has been recorded from damp rock crevices in proximity to water, in addition to sites well away from open fresh water. There is a very small possibility that beavers could have an impact upon populations of the gametophyte based upon the potential habitat overlap and the known widespread distribution of the plant. Potential negative impacts would be caused by inundation of existing populations. Conversely, inundation by water might increase local humidity and make conditions more favourable for colonisation by the gametophyte. The proportion of gametophyte populations at risk is likely to be low and such losses are highly unlikely to result in unfavourable conservation status of the Killarney fern in Scotland.

Floating water-plantain *Luronium natans* (listed in Annexes II and IV of the Habitats Directive) – an aquatic species (see section 3.4.2 for an assessment of likely impact). This is a species native to the UK that occurs in Scotland, although outside its natural range.

Table 3.10

Summary of potential interactions between beavers and terrestrial vascular plants (see Table 3.4 for woody species and Table 3.7 for aquatic species). At some sites appropriate management may be needed to counteract negative effects, and promote positive effects. Note that the significance of any individual effect may be far higher or lower than that of other effects.

Activity	Mechanism	Positive effects	Negative effects	Notes
Felling	Change in riparian woodland: Opening of woodland canopy and increased patchiness	– Potential overall increased diversity at landscape scale due to increase in habitat heterogeneity – Increased localised diversity of species associated with an open canopy, e.g. grassland species	– Theoretical localised decrease in or loss of species which require lower light levels	Very little information regarding species impacts. See Table 3.4 for effects on woody species
Felling	Change in riparian woodland: Change in relative abundance of different tree species	– Increased localised diversity of species associated with an open canopy, e.g. grassland species	– Theoretical localised decrease in or loss of species which require lower light levels	Very little information on species impacts. See Table 3.4 for effects on woody species
Felling	Change in riparian woodland: Change in age classes of trees			See Table 3.4 for effects on woody species
Felling	Change in riparian woodland: Amount/diversity of fallen dead wood on woodland floor			
Felling and constructions	Changes in amount/ diversity of woody material in watercourses			
Feeding	Feeding on specific terrestrial herbaceous and aquatic plant species		– Potential localised decrease in or loss of palatable species	Direct impacts recorded for a very small number of species. Some species on the Scottish Biodiversity List could be adversely affected at local levels. A detailed assessment would be required to predict specific impacts. See Table 3.7 for effects on aquatic species
Dams/pond creation	Change from lotic to lentic habitat		– Potential localised decrease in or loss of riparian species, although opportunities for new riparian edge to be colonised	Indirect loss through water inundation not recorded, but theoretical. Loss might be balanced by displacement. See Table 3.7 for effects on aquatic species

Activity	Mechanism	Positive effects	Negative effects	Notes
Dams/pond creation	Change in hydrological processes on riparian and downstream habitat	– Species of wetland habitats likely to benefit at local levels	– Species which may be sensitive to wetter conditions may decrease or be lost at local levels	This might be positive/ negative or neutral, depending on the area and species concerned
Dams/pond creation	Changes in water quality downstream			
Dams/pond creation	Change in standing dead wood resulting from inundation of trees			
Dams/pond creation	Longer term successional changes after dam abandonment, e.g. beaver meadows	– Increased diversity of species associated with increased habitat heterogeneity		
Dams/pond creation	Impacts on movement of species			
Other constructions	Creation of lodges, burrows, canals, etc.			
Other				
Indirect habitat creation/ restoration initiatives as result of beaver presence	Beaver used to promote opportunities for riparian and freshwater habitat creation/ restoration	– Any riparian woodland and/or wetland restoration programme is likely to benefit many flowering plant species in the medium to long term. There will be increased diversity of species associated with increased habitat heterogeneity		

3.4.6 Invertebrates

Overview

The current literature suggests that the effects of beaver impoundments on aquatic invertebrates are mostly positive[1]. By building dams and digging small canals, beavers create and extend wetland micro-habitats that support many invertebrate taxa[2]. Beaver dams change the predominantly flowing character of aquatic ecosystems to a mixture of flowing and still conditions, which is of particular benefit to predatory invertebrates[3]. The wetland micro-habitat created by beavers attracts water beetle colonists[4] and several species of Odonata (dragonflies and damselflies), which are at the top of the food pyramid[5].

Studies in Germany have shown that the numbers of Odonata are significantly higher in beaver territories and dammed waters than in areas without beavers[6, 7]. In a river system where beavers had been established since 1981, 29 species of dragonflies were associated with beaver ponds and the surrounding wetland. In comparison, only four species were found in the streams. These figures are not surprising, as the number of dragonfly species that breed in flowing water is far fewer than those breeding in still waters. In North America, dragonflies have long been associated with newly created beaver ponds. In Virginia, 43 dragonfly and 23 damselfly species (a third of them on the state's rare species list) were found in the Laurel Fork recreation area, which consists of a series of river systems with beaver ponds. The majority of species were in beaver ponds and four were known from only beaver ponds or their vicinity. At one specific site of the study, the number of species of dragonflies fell from 61 to four when beavers abandoned it[8].

In Sweden, Dytiscidae (predatory diving beetles) and Corixidae (aquatic Hemiptera, or true bugs) are abundant and typical beaver pond fauna[9]. Studies in Canada[10] and Finland[11] showed that larval densities of Ephemeroptera (mayflies), Trichoptera (caddisflies) and Plecoptera (stoneflies) decreased in dammed river beds. In the USA, a site immediately downstream of a beaver dam exhibited lower Plecoptera and Trichoptera densities than upstream, but the densities of Diptera (true flies), Ephemeroptera and invertebrate predators in general were higher immediately downstream of the beaver dam[12].

Beaver herbivory on cottonwood trees in western USA caused an increase in shoot length, which subsequently led to an increase in sawfly (Hymenoptera: Symphyta) abundance[13]. In addition, the open canopy created by beavers allowed the white pine weevil *Pissodes strobi* to flourish where it had been absent previously even in the presence of its food source, the white pine *Pinus strobus*[14].

Scottish experience

As part of the licence conditions for the SBT at Knapdale, two species of Odonata, the hairy dragonfly *Brachytron*

Figure 3.52
Beautiful demoiselle damselfly.
© Lorne Gill

Figure 3.53
Outflow of Creagmhor Loch, Knapdale, a breeding site for hairy dragonfly. Note the floating vegetative detritus resulting from beaver activity.
© Pat Batty/British Dragonfly Society/SNH

pratense and the beautiful demoiselle *Calopteryx virgo* (Figure 3.52), were monitored over a five-year period. The hairy dragonfly breeds in six of the eight lochs used by beavers, and it is likely to breed in the other two lochs as well (Figure 3.53). Beavers had a significant impact on two favoured plants at the study sites, saw sedge and common club-rush[15], which are also associated with hairy dragonfly breeding sites[16–18]. However, there were no detectable effects of plant depletion on hairy dragonfly populations. There were some indications that the population of hairy dragonfly is falling at one of the water bodies, Dubh Loch, but it is difficult to be conclusive because of surveying difficulties, small population size and data variability. A time lag of five to six years is expected after the decrease in plant cover before any effect is shown on hairy dragonfly because of the relatively long rate of vegetation decay and time for larval development. Thus, the study period was too short to show the longer term effects of beaver activity on hairy dragonfly. To date, beavers have had a limited effect on the Knapdale burns[19] and any changes seen in beautiful demoiselle numbers have been mainly influenced by other factors. These include weather conditions, forestry operations and natural regeneration.

One site, Dubh Loch, experienced a marked rise in water level as a result of dam-building. In the resulting newly created habitats there was a sharp increase in the density of chironomid (midges) and Corixidae larvae. In addition, water beetle diversity increased in relation to baseline surveys[15].

Potential future implications for Knapdale and Tayside

The bulk of the evidence for the impact of beavers at Knapdale and Tayside refers to the two dragonfly species monitored since 2009, the hairy dragonfly and the beautiful demoiselle. Based on the survey results, some scenarios are possible.

For the hairy dragonfly:

- Negative – a significant reduction in floating macrophyte detritus because of grazing or rise of water level may reduce the size of breeding habitat. Dam-building has a long-term effect on vegetation cover, which could last for several decades even if beavers leave the site[15]
- Positive – the hairy dragonfly may adapt to using woody detritus, the volume of which is likely to increase[15], though to date there is no evidence for this. However, oviposition on dead wood has been witnessed in Knapdale

For the beautiful demoiselle*:*

- Negative – dam-building may reduce the amount of flowing water. However, from experiences elsewhere, beautiful demoiselle and other fast-water species such as the golden-ringed dragonfly *Cordulegaster boltonii* will continue to breed in the unaffected sections of watercourses[20, 21]. A few larvae of beautiful demoiselle have been found in beaver ponds, although they could have arrived by drift[20]

– Positive – beaver grazing is likely to open up scrub, allowing more sunlit areas, and create clearings through felling willow and birch. Thus, the negative effect of reducing the area of flowing water could be offset by the creation of sunlit sections

The beaver population is predicted to expand and colonise the catchments in the Knapdale area, particularly if there is reinforcement of the population (section 3.2). As space for territories becomes more limited, it is likely that beavers will utilise more stream habitat, with an expectation of increased dam-building. Dam-building may change the volume and character of stream sediments, change the chemical composition of the water and affect water temperature (section 3.4.3)[22, 23]. These are all factors that could alter the invertebrate community, but its specific composition would be very difficult to predict. Broadly, dam-building has been shown to result in greater retention of organic matter and increase in water temperature, with increased invertebrate abundance and diversity, but with differing effects on different invertebrate groups[1, 24]. It is therefore possible, for example, that the community of saproxylic feeders at Knapdale (species dependent on dead or decaying wood) may benefit from an increase in the abundance of standing and fallen dead wood, as described below. The opening of the woodland canopy, and the associated increase in ground cover and decrease in leaf litter[25], may also have a range of potential impacts.

The situation will be dynamic and will change over the long term. For example, as food resources are depleted at specific lochs, beavers may abandon them and move to others; the macrophyte vegetation community may then revert back to something similar to what it was before beaver release, although this may take decades for some species, such as saw sedge (section 3.4.2)[15].

Potential future implications of wider reintroductions in Scotland

The effects of beavers on aquatic invertebrates are considered generally positive because their activity (such as foraging and excavation of canals) markedly increases habitat heterogeneity and patchiness by the creation of canopy gaps, and generates wetland habitats through impoundment[3]. Structures built by beavers, such as dams, lodges and beaver meadows, also create novel colonising opportunities for different species groups. As a consequence, beaver ponds show greater abundance and diversity of aquatic invertebrates in relation to other wetland types[1, 2, 20].

However, beaver impoundments may affect water chemistry, nutrient composition, sediment load and temperature of downstream reaches, and these factors have variable consequences on different species groups[22]. For instance, water temperature affects the size of adult mayflies (Ephemeroptera) and has direct implications on their reproductive success[26]. Species from gravel micro-habitats and grazers may be negatively affected by sedimentation within the beaver pond. Caddisflies (Trichoptera) and stoneflies (Plecoptera) may also be negatively affected because they usually prefer fast-flowing waters, although stonefly abundance may return to normal levels some distance beyond impoundments[12].

Figure 3.54
Flooding, resulting from beaver damming, will kill trees and create standing deadwood habitat which can be used by many invertebrate species. This site is in Telemark, Norway.
© Martin Gaywood/SNH

Figure 3.55
Scotland is a European stronghold for freshwater pearl mussel.
© Sue Scott/SNH

The influence of a beaver impoundment on downstream ecosystems is expected to gradually dissipate with distance, thus species abundance and community assemblage may change along a gradient[3, 20, 27]. One study showed that the effects of a beaver impoundment on invertebrate assemblages were much reduced 100 m downstream[28], and another estimated that beaver dams affect crayfish assemblages up to 2 km downstream[29].

Beavers may increase the biodiversity of terrestrial invertebrates by increasing the volume of dead and decaying wood, which is the habitat of saproxylic species, particularly beetles[30–32]. Accumulation of woody debris in beaver ponds may be an important factor for water beetles because these materials offer both shelter from predatory fish and protection to water beetle prey. In deeper water, submerged debris may also sustain an invertebrate fauna dependent on algal biofilm that grows on wood[15]. Moreover, standing dead trees and semi-submerged wood resulting from flooding may create suitable breeding sites for several species groups[33], among them rare craneflies *Lipsothrix* spp. (Figure 3.54).

Beavers may have a negative impact on invertebrates that depend on vulnerable or scarce tree species, such as aspen. There are 14 moth species and 14 saproxylic flies that depend on aspen; the caterpillars of the dark bordered beauty *Epione vespertaria* feed on young suckers and the larvae of the rare aspen hoverfly *Hammerschmidtia ferruginea* live and feed under the bark of wet, decaying trees. The impact of beavers on the aspen hoverfly is twofold: felled young trees interrupt the succession process, ultimately reducing the availability of dead wood, and bark-stripping of larger trees already felled destroys the micro-habitat required by the fly.

Species of European importance

Freshwater pearl mussel *Margaritifera margaritifera* (listed in Annexes II and V of the Habitats Directive, Figure 3.55) – mussel habitat may be improved downstream owing to reduced water sediment load and the regulation of water flow[34], although there is the possibility that siltation immediately upstream of dams may be detrimental to mussels in those river sections, particularly juveniles. The impact of beavers on freshwater pearl mussel populations is therefore unclear, and is likely to vary locally. It has been estimated that for all populations on mainland Scotland surveyed prior to 2010, 92% are in locations less likely to be dammed[35]. The remaining 8% of the mussel populations are in locations where the ability of beavers to build a dam is unknown, but where it may be possible. Freshwater pearl mussels also require juvenile Atlantic salmon or brown trout to complete the early stages of their life cycle. Beavers could therefore also have an indirect effect, by affecting the species' fish host. Dam-building downstream of pearl mussel sites may have an impact if the dams impede the migration of salmonid hosts. Potential effects on salmonids are considered in section 3.4.7.

Whorl snails *Vertigo* spp. (listed in Annex II of the Habitats Directive) – based on a sample of records from Blair Atholl and the Black Isle, it is estimated that there is an overlap of less than 30% between potential beaver core woodland and the range of the round-mouthed whorl snail *Vertigo genesii* and Geyer's whorl snail *V. geyeri*[35]. This interaction is likely to negatively affect whorl snail populations because changes in the water regime may alter the nature of the flushes that are their habitats. Appropriate management planning and action would therefore be required in the event that beavers colonised areas where these species occur. Potential beaver habitat does not overlap with the narrow-mouthed whorl snail *V. angustior* and there is unlikely to be any interaction or impact.

Marsh fritillary butterfly *Euphydryas aurinia* (listed in Annex II of the Habitats Directive) – there is a low likelihood that beaver will interact with this species based on levels of potential overlap, with no overlap between predicted beaver woodland and the recorded marsh fritillary distribution. Any interaction with beaver is likely to have a low impact.

Table 3.11
Summary of potential interactions between beavers and invertebrates. At some sites appropriate management may be needed to counteract negative effects, and promote positive effects. Note that the significance of any individual effect may be far higher or lower than that of other effects.

Activity	Mechanism	Positive effects	Negative effects	Notes
Felling	Change in riparian woodland: Opening of woodland canopy and increased patchiness	– If scrub is removed as a result of beaver grazing, clearings will be created, which is favourable to some invertebrates, such as some sun-loving dragonfly and butterfly species – Overall positive effects on diversity at landscape scale since beaver activity markedly increases habitat heterogeneity and patchiness through the creation of canopy gaps, etc. – Increased light penetration may lead to increased production within streams, ponds and lochs. Increased primary productivity and temperature may increase production of aquatic macroinvertebrates	– May benefit species which can damage or kill tree species (e.g. white pine weevil in North America can benefit from open canopy created by beavers)	Limited information in the literature so there are many areas of uncertainty
Felling	Change in riparian woodland: Change in relative abundance of different tree species		– Bark-stripping of felled, larger aspen trees destroys the microhabitat required by the rare aspen hoverfly. Felled young aspen also interrupt the succession process and reduce the availability of dead wood. Fourteen moth species and 14 saproxylic flies also depend on aspen	See also Table 3.4 for beaver effects on aspen
Felling	Change in riparian woodland: Change in age classes of trees			
Felling	Change in riparian woodland: Amount/diversity of fallen dead wood on woodland floor	– Increase in the volume of dead and decaying wood will be beneficial to saproxylic species, particularly beetles		
Felling and constructions	Changes in amount/ diversity of woody material in watercourses	– Accumulation of woody debris may shelter water beetles from predatory fish and provide protection for water beetle prey species – In deeper water, submerged debris may sustain an invertebrate fauna dependent on the algal biofilm that grows on wood		
Feeding	Feeding on specific terrestrial herbaceous and aquatic plant species			

Activity	Mechanism	Positive effects	Negative effects	Notes
Dams/pond creation	Change from lotic to lentic habitat	– Overall positive effects on diversity at landscape scale since beaver activity markedly increases habitat heterogeneity and patchiness, with lentic and associated wetland habitat interspersed with lotic habitat – A change to localised lentic conditions is beneficial to some predatory groups such as Dytiscidae (predaceous diving beetles) and Corixidae (aquatic Hemiptera, or true bugs)	– A reduction in the volume of floating macrophyte detritus may reduce the size of breeding habitat for some dragonflies – Reducing the amount of flowing water may be negative for the beautiful demoiselle and other fast water species such as the golden-ringed dragonfly – Possible localised reduction in larval densities of Ephemeroptera (mayflies), Trichoptera (caddisflies) and Plecoptera (stoneflies) in ponds – A possible reduction in habitat suitability for juvenile freshwater pearl mussel in beaver ponds	
Dams/pond creation	Change in hydrological processes on riparian and downstream habitat			Likely to be a range of subtle effects, which will affect different species in different ways.
Dams/pond creation	Changes in water quality downstream	– Reduction in sediment loads resulting from filtering effect of dams, potentially improving downstream habitat quality for species such as freshwater pearl mussel		
Dams/pond creation	Change in standing dead wood resulting from inundation of trees	– Standing dead trees and semi-submerged wood may create suitable breeding sites for several species groups (among them the rare *Lipsothrix* spp. craneflies)		
Dams/pond creation	Longer term successional changes after dam abandonment e.g. beaver meadows			
Dams/pond creation	Impacts on movement of species		– Possible effect on freshwater pearl mussel if migration of salmonid hosts is affected by the presence of dams (see Table 3.14 for beaver effects on fish)	
Other constructions	Creation of lodges, burrows, canals etc.	– Beaver activity (creation of structures, foraging and excavation of canals) will increase habitat diversity (heterogeneity and patchiness)		
Other				
Indirect habitat creation/ restoration initiatives as result of beaver presence	Beaver used to promote opportunities for riparian and freshwater habitat creation/ restoration	– Any programme of riparian woodland/wetland restoration and creation is likely to benefit overall invertebrate diversity		

3.4.7 Fish

Overview

Scotland hosts a limited range of native freshwater fish species when compared with other parts of mainland UK and Europe. This relatively species-poor fish assemblage reflects the recent colonisation of Scottish fresh waters by fish following the end of the last ice age. A total of 42 species of freshwater fish have been recorded in Scotland, but not all of these are native. Those which are considered native and first entered Scottish freshwater environments from the sea include species such as Atlantic salmon *Salmo salar* (Figure 3.56), trout *Salmo trutta*, European eel *Anguilla anguilla*, brook lamprey *Lampetra planeri*, river lamprey *L. fluviatilis* and sea lamprey *Petromyzon marinus*, powan *Coregonus lavaretus*, Arctic charr *Salvelinus alpinus* and both three-spined *Gasterosteus aculeatus* and nine-spined *Pungitius pungitius* sticklebacks. Though not strictly 'freshwater species', sparling (smelt) *Osmerus eperlanus* and allis and twaite shads *Alosa alosa* and *A. fallax*, are also native and live as adults in estuaries and migrate into the lower reaches of rivers to spawn. One other native species which is thought to have invaded from the sea, the vendace *C. albula*, is now naturally extinct in Scotland, but has been re-established here using stock from northern England. Other freshwater species thought to be native to parts of Scotland, with a restricted, southern, natural distribution, are pike *Esox lucius*, roach *Rutilus rutilus*, perch *Perca fluviatilis*, minnow *Phoxinus phoxinus* and stone loach *Barbatula barbatula*.

Many other species have been introduced to Scotland from other parts of the UK where they are considered native. These include species which were introduced to some waters more than 100 years ago, such as grayling *Thymallus thymallus*, crucian carp *Carassius carassius*, tench *Tinca tinca*, common bream *Abramas brama* and chub *Leuciscus cephalus*, as well as species which have been introduced within the last 50 years, such as dace *L. leuciscus*, rudd *Scardinius erythrophthalmus*, barbel *Barbus barbus,* ruffe *Gymnocephalus cernuus* and bullhead *Cottus gobio*. Some waters in Scotland also host species which have been introduced from outside the UK. These species have largely been introduced for angling and include common carp *Cyprinus carpio*, brook charr *Salvelinus fontinalis* and rainbow trout *Oncorhynchus mykiss*. Fisheries for rainbow trout are widespread within Scotland and the number of carp angling venues has also increased in recent years.

Our native freshwater fish can be broadly separated into diadromous and freshwater-resident species. Fish which are diadromous (i.e. migrate between fresh water and the sea to complete their life cycle) include Atlantic salmon, trout (as sea trout), European eel, brook, river and sea lamprey, sparling and the shads. Those species that, in Scotland, are found only in fresh water are Arctic charr, powan, vendace, pike, roach, perch, minnow and stone loach. Three- and nine-spined sticklebacks can utilise both freshwater and marine habitats.

All species, regardless of whether they are diadromous or freshwater-resident, may undergo migrations at some period within their life history. These movements may be

Figures 3.56
Atlantic salmon.
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ontogenetic (e.g. based on life stage) changes in habitat use, or migrations may be undertaken to allow fish to fulfil a specific function, such as spawning. Some species, such as freshwater-resident trout, and in some cases Arctic charr, may undertake movements from lochs to riverine spawning areas. Others, such as pike, roach and perch, may undertake migrations to particular habitats within lochs or large rivers to spawn. The timing and location of these movements varies significantly between species.

This complex ecology means that many of our native fish species have the potential to interact with reintroduced Eurasian beavers and, in fact, these fish will have co-existed with beaver for millennia prior to their extinction in Scotland. Table 3.12 provides a summary of the perceived positive and negative impacts of beavers on fish derived from the published literature during a recent major review[1]. The scale and direction of impact of beavers on fish will differ according to the species concerned and its ecology.

Two SNH-commissioned reviews of the impacts of beaver on a variety of fish species have been carried out[1–3] and these, together with more recently published data, were considered by the BSWG[4].

Much of the published literature on the impacts of beavers on freshwater fish originates from North America and relates to the activities of the North American beaver. Far fewer data are available on the impact of Eurasian beavers on European fish species or fish communities. Some concern has been expressed about the extrapolation of data gathered relating to the impact of the North American beaver on fish to the European (or Scottish) situation, largely because of differences in habitat typology and dissimilarity in the range of species concerned, including salmonids. Regardless of these differences, the recent SNH review[1,3] and the BSWG concluded that, in general, issues such as the removal of riparian vegetation and tree cover; ponding; inundation and impacts on sediment transport as a result of beaver dam construction; and hydrological alterations and their influence on fish migration can be considered to be impacts common to both species.

Eurasian beavers co-exist with fish throughout their geographical range. However, in areas such as Denmark Finland, France, Norway and Sweden and some Baltic states, where beavers co-exist with high economic value species such as Atlantic salmon, there is surprisingly little published information relating to beaver–salmonid interactions. The information available has been reviewed within the BSWG report[4]. Data relating to other, non-salmonid, species are also limited. Table 3.13 provides an overview of those studies which have been undertaken within Europe across a range of species.

The conclusions reached in the available studies are mixed. This is also complicated by the fact that some of the data available come from areas where beavers have been reintroduced and management is varied. In Lithuania, where beavers were reintroduced in 1947, it has been recommended that beaver dams in the middle and lower reaches of trout-spawning streams should be removed to reduce impacts on spawning trout[10]. In Scandinavia, where Atlantic salmon and beaver are both native, beavers have been actively managed for centuries and there is little published evidence of negative impacts[11].

Scottish experience

Eurasian beaver would have co-existed with native fish fauna in Scotland for millennia before the former species was extirpated. The absence of Eurasian beaver from the Scottish fauna for the last 500 years means that, prior to the SBT, nothing was known about the impact of this species on Scottish freshwater fish. The range of interactions, positive as well as negative, could, however, be inferred from the published work available before the trial[12].

The introduction of Eurasian beavers to Knapdale in May 2009 provided the opportunity to study the impact of beavers on fish communities in that area within the five-year trial period. Although Knapdale was well suited to assessing the impact of beavers on a range of habitats and species, it was not an ideal place to study the impacts of beavers on fish because no anadromous fish (i.e. those that migrate from the sea as adults to fresh water to

Table 3.12
Summary of the perceived positive and negative impacts of beavers on fish[1].

Positive impacts	Negative impacts
Enhanced habitat availability/complexity	Barriers to fish movement
Enhanced over-wintering habitat	Reduced spawning habitat
Enhanced rearing habitat	Altered temperature regime
Provision of cover	Reduced oxygen levels
Enhanced diversity/species richness	Reduced habitat quality
Enhanced abundance/productivity	Altered flow regimes
Provision of habitat under low flows	Loss of cover
Provision of high flow refuge	Reduced productivity
Provision of temperature refuge	Reduced growth
Enhanced water quality	Abandonment of beaver settlements
Sediment trap	Reduced water quality
Enhanced invertebrate productivity	
Enhanced growth rates	
Enhanced fish condition	
Provision of fishing areas	

Table 3.13
Summary of the impact of European beavers on fish species reported from studies in Denmark[5], Sweden[6], Norway[7, 8], Estonia[9] and Lithuania[10].

Species	Overview
Atlantic salmon and sea trout	– Dam construction led to the loss of some spawning habitat due to the siltation of gravels. Juvenile Atlantic salmon were found above dams. Juvenile trout were found above dams, although these may have been resident fish. Authors state that while the hypothesis that beaver dams have had no impact on Atlantic salmon cannot be supported, neither can the view that fish are unable to negotiate beaver dams[7] – Beavers constructed five dams which had the potential to prevent access to spawning areas. While there is the potential to negatively affect upstream and downstream migration of Atlantic salmon and sea trout, the actual impact may be negligible due to the low frequency, small size and short lifetime of dams. The length affected was minor, but tree-felling resulted in a loss of shade over a greater area. There has been a simultaneous increase in beaver population size and Atlantic salmon catches over a 40-year period[8]
Trout	– Trout were more numerous in areas where beavers were absent, but trout were larger in beaver ponds than in riffles. Ponds provided a refuge for large brown trout during periods of low flow[6] – The presence of beavers is not considered to have a negative impact on the spawning habitat of brown trout, but restriction of the spawning migration of sea trout was considered an issue[5] – Dams proved to be a major obstacle to upstream colonisation[9] – Beaver dams in the middle and lower reaches of trout-spawning streams should be removed to reduce impacts on spawning trout[10]
Brook lamprey	– Dams are a complete barrier to brook lamprey, but they will not have an overall negative effect on this species[5]
European eel	– No negative effect of beavers on European eel. They are unaffected by dams[5]
Stickleback	– Dams are a complete barrier to sticklebacks, but this species will benefit from new pools developed by beavers[5] – Dams did not prove to be a major obstacle to upstream colonisation by nine-spined stickleback[9]
European minnow	– Minnows were more numerous in areas where beavers were present. Beaver ponds provided important spawning and rearing habitats for this species[6]
Roach	– Dams are a complete barrier to this species, but roach will benefit when new pools develop[5]

spawn) were present within the study area. Many of the streams within the site were already heavily modified and there was little beaver damming activity on streams within the site during the trial period. A substantial number of baseline data now exist for fish populations within stream environments at Knapdale[13–15]. Towards the end of the SBT, a limited time series of data (2012 and 2013) was available for two sites where beaver–fish interactions at dams could be studied. These are described in the SBT fish monitoring report[15].

These studies concluded that:

- Where tree-felling and dam-building had taken place, the fish community did not change. The fish community within the Knapdale study site was dominated by trout but also included smaller numbers of European eel, European minnow and three-spined stickleback
- On streams where no beaver activity was found, fish population and redd counts (counts of spawning nests) showed fish distribution and abundance in 2012 and 2013 similar to the baseline and follow-up surveys in 2008 and 2011
- The data collected by fish and redd surveys from within and outside the trial area (2008–2011) provide a baseline of information that may be used to assess future changes within Knapdale
- Two small dams on the burn between Loch Losgunn and Loch Fidhle do not appear to have affected fish spawning or juvenile recruitment upstream. Dam-building by beavers at the outflow of Loch Linne was initially managed to maintain existing water levels for the benefit of aquatic plants. To date, this activity does not appear to have affected the movement of brown trout from Loch Linne to their spawning and nursery habitat downstream
- Crucially, parallel studies on the impact of beavers on these habitats demonstrated that they had limited influence on the fluvial geomorphology and river habitat in the area during the trial period, and thus the quality of spawning substrates and other in-stream habitat for fish was maintained (see section 3.4.3)
- Fish utilised a wide range of habitats, some of which appear to have been already heavily modified by land use.

Fish populations may benefit from habitat improvement in streams which can influence the recruitment levels of young fish, but more data are required to determine whether beaver activity would deliver this
– If beavers are retained at Knapdale, and if more beaver activity takes place in stream habitats, future monitoring may be necessary to assess potential interactions, such as barriers to fish movement and loss of spawning habitat, and to inform management and mitigation

Assessing the impact of beavers on standing water fish populations within the Knapdale study area is difficult to achieve without corresponding baseline data. Section 3.4.2 describes the changes in loch level and macrophyte community structure which arose as a result of beaver activity within the five-year study period. Changes to the extent of tree cover, macrophyte distribution and water level may be beneficial to species such as three-spined stickleback, minnow and European eel. The impact of possible increased temperature on loch-dwelling trout is less clear, although the potential may exist for increased production of some macroinvertebrate taxa (see section 3.4.6), which could be prey for this species.

The presence of a substantial beaver population in Tayside, a major Atlantic salmon river and an SAC for that species was unknown at the start of the SBT. Beavers have recruited successfully and extended their range within the Rivers Tay, Earn, Isla and Ericht and Dean Water, Baikie Burn and Lunan Burn, with approximately 38-39 family groups located in the 2012 survey[16]. The BSWG noted that newly established populations such as this are not expected to produce the widespread ecosystem modifications which, for Eurasian beavers, would be predicted to occur at peak population density 11–34 years after initial colonisation[17, 18]. These (approximate) timescales should be borne in mind when considering the potential for beaver interactions with salmonids and the requirement for future management action.

Much of the beaver activity in Tayside has been restricted to small watercourses in the lower catchment. The small streams in these areas contribute to the output of Atlantic salmon and sea trout smolts in these areas and are an issue of concern[4]. Expansion of the beaver range to upland streams, which are particularly important for the spring Atlantic salmon stock component, may have to be carefully managed if this feature of the River Tay SAC is to remain in a favourable condition.

Potential future implications for Knapdale and Tayside

The post-release monitoring for the SBT ran from 2009 to 2014. From the perspective of assessing the impact of beavers on fish populations, five years is a short time period. The unpredictability of beaver activity meant that investigations into beaver–fish interactions at dams in the current study covered only the period 2011–2013. Some fish species vary greatly in the number of young produced from year to year, so changes seen in these studies may be a result of fish biological cycles rather than a response to beaver-induced environmental change. More data would need to be collected over a longer time period before definitive statements could be made.

Population models, maps of habitat suitability and expert judgement predict that an expanding beaver population will result in the colonisation of the small rivers upstream and downstream of the lochs where the main territories are situated at present over the short to medium term (section 3.2)[19]. The streams tend to be relatively narrow and shallow, and the creation of dams and increased beaver activity along river sections is expected. The impact on individual fish species and local populations is extremely difficult to predict for the reasons set out above. Impacts such as increased riparian tree-felling and exposure of the water to sunlight, increased amounts of woody material and other plant material present in the rivers, dam-building and related effects on geomorphology, river habitat and the movement of fish species, will all result in an overall change to the freshwater system. This may benefit some fish species, although the impact of dams on movement may have a particular impact on some species under certain conditions and at certain times of the year. Whilst it is acknowledged that the SBT was incapable of answering the key questions in relation to anadromous salmonids because they are absent, the abundance of baseline data (including habitat data) and the presence of trout mean that some further value can be gained from Knapdale if research and monitoring is allowed to continue and is adequately resourced.

In Tayside, where beavers are still extending their range, there is potential to use this site to learn more about the actual interactions between beavers and a range of fish species. Considerable attention has been given to the potential impact of beavers on commercially (and culturally) important species such as Atlantic salmon and trout, but Tayside also offers the opportunity to study the impact of beavers on a range of other fish (e.g. European eel, lamprey), invertebrates (e.g. freshwater pearl mussel) and other vertebrates (e.g. otter). All of these are conservation features within the River Tay SAC. The potential overlap between beaver habitat and Atlantic salmon is described in section 4.2. Dam-building activity will not occur in the downstream, wide and deep river sections of the Tay catchment, and indeed it is unlikely in much of the higher reaches where potential beaver habitat does not occur (section 4.2). However, dam-building and other beaver activity will continue to expand throughout the Tay catchment as the population increases and spreads (section 3.2). Impacts are expected to be complex, with variation in the positive and negative impacts for different species, across different sites and at different times. Overall, it seems likely that, even in the absence of human intervention, some species will not be affected, or may benefit, at the catchment scale. There are other species where the impacts are less clear, and this is particularly pertinent in relation to migratory species. Appropriate research and monitoring will help to identify impacts and inform management, which in turn can be designed to help mitigate any negative impacts and foster positive impacts.

It is widely accepted that high levels of marine mortality is the primary cause of the decline in Atlantic salmon populations across much of their range[20]. The long-term national decline in the spring stock component[21] means that the status of Atlantic salmon within the River Tay system is a key issue. As well as providing the opportunity to study the impact of beaver on fish and aquatic habitats, Tayside also offers the opportunity to develop and demonstrate effective management of the potential interactions. A key concern of the BSWG was that a beaver management plan should be developed which sets 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 (also see section 4.2).

Potential future implications of wider reintroductions in Scotland

The impact of beaver activity on the upstream and downstream migration of freshwater fish, and on the habitats on which they depend to complete their life cycles, is poorly understood. Attention has been focused on Atlantic salmon and trout because of their cultural and economic significance. Although this is understandable, it is essential that the impact of beaver activity on other fish species is also fully understood. These are important elements of Scottish biodiversity, and in some cases are notified features within sites designated for nature conservation or (in the case of Atlantic salmon and European eel fisheries management) subject to international agreement.

Despite the paucity of native freshwater fish species in Scotland, their diverse ecology would suggest that some species may benefit more than others from beaver-mediated habitat modification and habitat creation. Table 3.13 provides some examples of the ways in which some species, such as cyprinids and trout, may benefit from the creation of beaver ponds. Species such as pike, perch and European eel may also benefit, given their ability to utilise a wide range of running and standing water habitats. It also highlights which species, particularly migratory salmonids, may experience adverse impacts. Such studies are few and it is clear that a better understanding of the interactions between beaver activity and freshwater fish is necessary.

Species of European importance

Atlantic salmon (listed in Annexes II and V of the Habitats Directive) – there is a high likelihood that beavers will interact with this species, and that there will be some impact, both positive and negative. There is uncertainty over what the precise impacts will be. Overlap between potential beaver habitat and wetted area of Atlantic salmon habitat has been estimated at 47–73% in six study catchments[4]. Dam-building is unlikely to occur along 92% of SACs designated for Atlantic salmon (range of 85-100%), although dams which affect fish movement would have an impact on upstream sections. Further details are provided in section 4.2.

Brook, river and sea lamprey (brook and sea lamprey are listed in Annex II of the Habitats Directive and river lamprey in Annexes II and V) – there is a high likelihood that beavers will interact with these species, and that there will be some impact, both positive and negative. There is uncertainty over what the precise impacts will be. Dam-building is unlikely to occur along 91% of SACs designated for lampreys (range of 85-98%), although dams which limit fish movement would have an impact on upstream sections[22]. A Danish study predicted that there would be no significant impact of beaver on brook lamprey[5].

Allis and twaite shad (listed in Annexes II and V of the Habitats Directive) – there is a low likelihood that beavers will interact with this species. In Scotland, these anadromous species are mainly associated with the Solway Estuary.

Table 3.14

Summary of potential interactions between beavers and fish. At some sites appropriate management may be needed to counteract negative effects and promote positive effects. Note that the significance of any individual effect may be far higher or lower than that of other effects.

Activity	Mechanism	Positive effects	Negative effects	Notes
Felling	Change in riparian woodland: Opening of woodland canopy and increased patchiness	– Increased light penetration may lead to increased production within streams, ponds and lochs. Increased primary productivity and temperature may increase production of aquatic macroinvertebrate prey items for fish. This could lead to increased fish productivity and improved individual growth rates – Increased temperatures may favour the establishment of non-salmonid species which have a higher tolerance to lower dissolved oxygen concentrations (such as cyprinids and sticklebacks) – Increased light may lead to the establishment of macrophyte communities, creating complex habitats that offer shelter to some fish species (such as pike, perch, roach and sticklebacks) and their prey – Penetration of light to the riparian zone may result in the development of plant communities that will stabilise banks, reduce erosion and provide increased opportunities for greater terrestrial input of food items for fish	– Reduction in shading has the potential to increase water temperature and result in increased thermal stress upon some fish species, particularly salmonids – Increased temperatures may favour the establishment of fish species which may compete with, or predate, salmonids – Increased temperatures can contribute to reduced levels of dissolved oxygen in some circumstances. This may be unfavourable for some fish species (such as salmonids)	Tree-felling may also undo some of the extensive tree-planting restoration work that has taken place in some catchments (particularly the upper areas of catchments, which have little natural tree cover)
Felling	Change in riparian woodland: Change in relative abundance of different tree species	– Possible changes in the amount of allochthonous material derived from different sources (principally leaf litter), which may benefit some aquatic macroinvertebrates and potentially the fish which prey on them	– Possible reduction in type and quantity of allochthonous material (principally leaf litter) may lead to a reduction in aquatic macroinvertebrate community composition and production. This may negatively affect fish which prey on them – Possible reduction in the quantity of terrestrial (invertebrate) prey items that enter the aquatic environment as food for fish	

Activity	Mechanism	Positive effects	Negative effects	Notes
Felling	Change in riparian woodland: Change in age classes of trees	– Possible changes to tree age class in riparian or littoral areas may result in a more open canopy and increased light penetration, with consequent benefits for some species (see above)	– Loss of mature woodland may result in lesser quantities of allochthonous material entering waterbodies. This can affect macroinvertebrate production and therefore the production of fish – Possible reduction in size and quantity of large woody debris entering the watercourse in the longer term may affect in-stream habitat structure, and this may adversely affect some fish species – Possible changes to tree age class in riparian or littoral areas may result in a more open canopy and increased light penetration, with consequent negative effects for some species (see above)	Effects will depend on nature of changes, and the extent to which trees affected by beavers regrow. See Table 3.4.1 for beaver effects on woodland trees
Felling	Change in riparian woodland: Amount/diversity of fallen dead wood on woodland floor			
Felling and constructions	Changes in amount/ diversity of woody material in watercourses	– Greater quantities of large wood items in streams, rivers and lochs can result in increased habitat diversity and an increase in the availability of prey items and fish cover – Where large woody debris occurs, it may reduce the transport of sediment downstream	– The establishment of large log jams could hinder the in-stream movement of some fish species if they act as barriers – Depending on where woody items aggregate, such material can act as a barrier to movement or result in the loss of habitat – Where the quantity of large and small woody items is too great, this may result in blockages which may affect the transport of important gravels	
Feeding	Feeding on specific terrestrial herbaceous and aquatic plant species	– Changes to macrophyte community structure may favour some species of (non-salmonid) fish and their prey	– Decrease in macrophyte species in some lochs may have a negative impact on species that depend on them for food or shelter. Pike, for example, are often associated with macrophytes because they use these as cover when ambushing prey. Roach and perch may utilise macrophytes as cover from pike. Salmonids are rarely associated with macrophytes	See Table 3.7 for a summary of beaver effects on aquatic plants

Activity	Mechanism	Positive effects	Negative effects	Notes
Dams/pond creation	Change from lotic to lentic habitat	– Increase in habitat diversity, which may favour some fish species or fish life history (ontogenetic) stages. In some situations this may also result in an increase in species richness – of both fish and invertebrate prey items – Increased temperatures, changes in habitat availability and feeding opportunities in lentic habitats may result in increased individual growth rates, fish condition and overall production – Depending on depth and location, impoundments may offer a high-temperature refuge for some fish	– Increase in habitat diversity for fish may favour some species over others, or benefit only some life history stages (e.g. juvenile or adult fish) – Depending on location, the creation of lentic habitats may result in habitat loss for species which favour or dominate lotic habitats – Accumulation and smothering of bed sediment upstream of dams, and a reduction in habitat quality for some species (principally salmonids) – Reduction in turbulence (or mechanical mixing) may occur upstream of dams, resulting in a reduction in dissolved oxygen – Possibility of increased opportunities for fish predators (e.g. piscivorous birds, mammals such as otter, or man)	
Dams/pond creation	Change in hydrological processes on riparian and downstream habitat	– Reduction in the transport of fine material may improve the quality of spawning and rearing habitats downstream of any impoundment – Impoundments may create low- and high-flow refuges for fish – Flooding of riparian and wetland habitats can provide spawning opportunities for species such as pike and additional habitat for species such as European eel	– Changes in flow may result in sediment starvation in gravel spawning areas. This can affect both salmonids and spawning lamprey – A reduction in flow downstream of the structure may result in a reduced wetted width and a loss of juvenile fish habitat	
Dams/pond creation	Changes in water quality downstream	– Reduction in the amount of fine material deposited on the stream or riverbed downstream of the impoundment. This may result in an improvement in the quality of gravel spawning areas (downstream) for salmonids and lamprey – Accumulation of fine sediments may increase the volume of available habitat for lamprey ammocoetes		

Activity	Mechanism	Positive effects	Negative effects	Notes
Dams/pond creation	Change in standing dead wood resulting from inundation of trees			
Dams/pond creation	Longer term successional changes after dam abandonment e.g. beaver meadows			
Dams/pond creation	Impacts on movement of species		– Prevention of the free movement of fish to all habitats required during their life cycle. This is particularly relevant to key migration periods (such as spawning migrations), but also at other times – The scale of impact may be greater for species which have a limited ability to overcome in-stream obstacles (such as lamprey)	
Other constructions	Creation of lodges, burrows, canals etc.			
Other	Fisheries		– Beaver habitats (impoundments and flooded wetlands) may benefit North American signal crayfish, an invasive non-native species, if these are present within the catchment	
Indirect habitat creation/ restoration initiatives as result of beaver presence	Beaver used to promote opportunities for riparian and freshwater habitat creation/ restoration	– Presence of beaver may act as an incentive for greater investment, management and monitoring. This could include those related to the restoration and management of riparian woodland	– Beaver presence may impact on fish-related riparian woodland restoration activities that are currently under way	

3.4.8 Amphibians and reptiles

Overview

Beaver activity results in the creation of ponds and slow-moving water, the changing of water tables and development of wetland habitat[1], all of which will generally benefit Scottish amphibians.

Amphibians

Scotland has six native amphibian species:
- Frogs and toads (Anuran species) – common frog *Rana temporaria*, common toad *Bufo bufo* and natterjack toad *Epidalia calamita*
- Newts and salamanders (Caudatan species) – smooth newt *Lissotriton vulgaris*, palmate newt *Lessotriton helvetica* and great crested newt *Triturus vulgaris*

The great crested newt (Figure 3.57) and natterjack toad are European Protected Species. All six species are dependent on water for breeding sites and all prefer, or are dependent on, standing water. The natterjack toad is the least likely to interact with beavers, as it is associated with coastal dune or saltmarsh habitats in Scotland, which are not expected to be potential beaver habitat.

Dam-building on watercourses by beavers is the primary factor which will influence amphibians. Impoundment provides more standing water where flowing water was present before. The literature covering beavers' effects on amphibians is not large, although there are a number of published studies from North America[2–4.] Whilst these support the idea that beaver impoundments are beneficial to amphibians, they largely concern guilds of species which are not fully analogous to the Scottish situation, for example stream-living salamanders.

One study examined the impact of beaver reintroduction on a guild of amphibians in the European central highlands, including four of the Scottish species[5]. It found that beaver impoundments are important for all species, especially the common frog and palmate newt. Beaver ponds were compared with artificial ponds present before beaver reintroduction and it was concluded that artificial ponds acted as a surrogate for natural beaver ponds in their absence.

By reducing riparian tree cover, beaver activity can also raise the temperature of waterbodies by increasing insolation[1], a key factor in amphibian breeding success, particularly for great crested newts. Aquatic vegetation is important for cover for adult and larval amphibians and as egg-laying sites for newts. The effects of beaver presence on aquatic plants will vary between sites and are difficult to predict[6]. Creation of ponds and wetland habitat is expected to increase the invertebrate biota overall (section 3.4.6), and hence prey for all life stages of amphibians.

There is likely to be a benefit to amphibians, particularly anurans, where beaver dam-building changes the water table to induce wetland conditions. Newts, in the terrestrial phases of their annual cycle, favour damp rather than waterlogged habitats, such as leaf litter and friable dead wood. Hibernation sites are in damp habitats, and these would become unsuitable if they were waterlogged by beaver impoundments, although potential new sites may become available.

One negative aspect may be the presence of fish within these impoundments. Beaver ponds tend to be in-stream waterbodies rather than stand-alone ponds, isolated from fish colonisation. Great crested newts are particularly vulnerable to fish predation as their larvae are largely pelagic in habit, swimming in the water column to prey on species such as *Daphnia* and copepods[7]. The larvae of the smaller newt species, and tadpoles of anurans, are more benthic, so are less vulnerable to, although not immune from, fish predation. Flooding by impounding or canal-building could also open up isolated ponds to fish invasion. Interactions between beaver dams and fish are further described in section 3.4.7.

Figure 3.57
Great crested newt.
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One study reported evidence that great crested newts thrive in beaver ponds in continental Europe, although it also highlighted the need for fish-free conditions for great crested newt survival[8].

Reptiles

There are three terrestrial reptile species native to Scotland:

- Lizards – viviparous or common lizard *Zootoca vivipara* and slow worm *Anguis fragilis*
- Snake – adder *Vipera berus*

There is also some evidence of populations of grass snake *Natrix natrix* in Scotland, although it is not known whether any of these have arisen from natural sources rather than from escaped captives or releases.

Effects on the three known native species are likely to be incidental. Viviparous lizards and adders can persist in wetland habitats but they are sub-optimal for them. Beaver foraging thins out woodland canopy[9], which could lead to greater insolation of the woodland floor and a potential increase in microhabitats with thermoregulatory benefits to reptiles, depending on the pattern of regrowth and ground flora regeneration.

The grass snake could benefit from beaver activity as it often hunts in water, and frogs can be a major prey component. They are oviparous (they lay eggs) and lay eggs in piles of rotting vegetation, notably compost heaps, where increased temperatures speed up the development of the young. Detritus within beaver lodge structures can provide such conditions[10].

Several species of freshwater turtles (Chelonids) are invasive non-native species in Britain, such as the red-eared terrapin *Trachemys scripta elegans*. In the USA, these thrive in beaver impoundments, which provide standing water and basking sites on lodge or dam structures and other semi-submerged dead wood. As with grass snakes, it may be that lodge detritus would provide egg-laying sites, but it is doubtful whether they would provide the long periods of high temperatures (60 days at 28–30°C) needed for successful hatching.

Scottish experience

Amphibians and reptiles were not monitored specifically in the SBT, although impacts on some key habitats were monitored and the observations from these, and studies elsewhere, can be used to provide some tentative assessments of future implications. The monitoring of the Knapdale project and reports from Tayside point to an expected increase in wetland areas, habitat and aquatic vegetation heterogeneity and changes in canopy cover (sections 3.4.1 and 3.4.2).

Potential future implications for Knapdale and Tayside

The four common amphibians are present throughout both of these areas and they are expected to benefit from continued beaver presence. Great crested newt might also be expected to benefit, although fish presence may be an issue. There are a few historical great crested newt records from lowland Tayside, notably around Blairgowrie, but none of these has been confirmed in recent years. There is also Turflundie Woods SAC, for which great crested newt is a qualifying feature. There appears to be a more limited presence of great crested newt in the Knapdale area, although there is a single historical record in Kintyre, which has not been confirmed in recent years. The recorded presence was in a quarry site, so the habitat might not be suitable for beavers.

To date at Knapdale, some dams have been built at the outflows of existing standing waterbodies[11]. Over the next decade, if beavers remain at the site, it is anticipated they will start to colonise and dam running waters and create more standing waterbodies. The Tayside Beaver Study Group reported 32 dams as of November 2014[12], with further dams, and potential amphibian habitat, anticipated as the population expands.

Potential future implications of wider reintroductions in Scotland

In general, the spread of beavers would appear to be beneficial for amphibians in providing more pond habitat, especially in areas where the current stream gradients preclude standing water. Increased water tables may also create wet woodland or wetland habitat favourable to most amphibians. A proviso might be that the continued presence of fish in beaver impoundments may not be ideal for great crested newts, although there is evidence from continental Europe that they do exploit beaver-created habitats.

The situation for native reptiles is largely neutral. However, should the grass snake become more widespread in Scotland, either by natural colonisation in response to climate change, or by introductions, then it may benefit from beaver-created habitats.

Species of European importance

Great crested newt (listed in Annexes II and IV of the Habitats Directive) – there is a low likelihood that beavers will interact with this species in the three SACs for great crested newt in Scotland. Any interaction with beavers is likely to have a low, positive impact. Turflundie Woods SAC has no potential core beaver woodland. Luce Bay and Sands SAC, in Wigtownshire, is on an area of dune habitat, which is not considered to be potential beaver habitat, and the third, Burrow Head SAC in Wigtownshire, is an area of farmland with gorse scrub and rocky knolls well away from major watercourses and which is also not likely to support beavers. However in the wider countryside there is a high likelihood that beaver will interact with this species. The interaction with this species is likely to be broadly positive.

Natterjack toad (listed in Annex IV of the Habitats Directive) - there is no overlap between predicted beaver woodland and the primarily coastal distribution of natterjack toad in Scotland. There is therefore a low likelihood of interaction with this species. If any interaction was to occur, then beaver pond creation is likely to have a positive effect[13]. However, the high levels of invertebrate predators that depredate toad tadpoles may make some beaver ponds unsuitable[14].

Table 3.15
Summary of potential interactions between beavers, and amphibians and reptiles. At some sites appropriate management may be needed to counteract negative effects and promote positive effects. Note that the significance of any individual effect may be far higher or lower than that of other effects.

Activity	Mechanism	Positive effects	Negative effects	Notes
Felling	Change in riparian woodland: Opening of woodland canopy and increased patchiness	– Increased insolation of waterbodies will advance breeding times and accelerate maturation times in amphibians – Increased insolation will benefit reptiles through increased thermoregulatory opportunities		
Felling	Change in riparian woodland: Change in relative abundance of different tree species			
Felling	Change in riparian woodland: Change in age classes of trees			
Felling	Change in riparian woodland: Amount/diversity of fallen dead wood on woodland floor	– Increased fallen dead wood will provide additional foraging, resting and hibernation sites for amphibians and reptiles		
Felling and constructions	Changes in amount/ diversity of woody material in watercourses	– May benefit amphibian larvae by providing shelter and foraging habitat diversity, and through increasing abundance/ diversity of some invertebrate prey species		
Feeding	Feeding on specific terrestrial herbaceous and aquatic plant species	– Newts have plant species which they prefer to lay eggs on, so changes in plant composition may have some positive localised effects	– Newts have preferred plant species on which to lay eggs, so changes in plant composition may have some negative localised effects	
Dams/pond creation	Change from lotic to lentic habitat	– Increase in lotic habitat will benefit breeding amphibians	– Risk to great crested newt from fish predation where impoundments give access to fish predators	

Activity	Mechanism	Positive effects	Negative effects	Notes
Dams/pond creation	Change in hydrological processes on riparian and downstream habitat	– Increase in wetland habitat, and increasing habitat heterogeneity, will benefit amphibians overall	– Some risk of waterlogging of hibernacula	
Dams/pond creation	Changes in water quality downstream			Likely to be impacts on water quality of impoundments created downstream, which amphibians may use
Dams/pond creation	Change in standing dead wood resulting from inundation of trees			
Dams/pond creation	Longer term successional changes after dam abandonment, e.g. beaver meadows			
Dams/pond creation	Impacts on movement of species			
Other constructions	Creation of lodges, burrows, canals, etc.	– Lodge and dam structures will provide some benefit in providing shelter for amphibian larvae – Lodge and dam structures may provide shelter and breeding sites for grass snakes should they become established in Scotland	– Canals may provide access for fish to great crested newt breeding ponds	
Other			– Beaver impoundments and structures may provide a haven for invasive non-native terrapin species	
Indirect habitat creation/ restoration initiatives as result of beaver presence	Beaver used to promote opportunities for riparian and freshwater habitat creation/ restoration	– Presence of beavers may act as an incentive for greater investment, management and monitoring. This could include those related to the restoration and management of riparian woodland and wetland habitats, which would benefit amphibians		

3.4.9 Birds

Overview

The main mechanism for beavers influencing avian biodiversity is the increase in wetland areas available for nesting and feeding.

Overall, international studies show that beavers increase avian biodiversity in riparian areas by increasing the amount of slow-moving water and well-vegetated wetland habitat (Figure 3.58). Groups that respond best to increases in these habitats are waterfowl, herons and kingfishers.

The aquatic characteristics of beaver ponds, such as large shallow water areas with gradual edges, may be particularly important for a variety of species of waterfowl[1, 2]. The gradual edges of beaver ponds may be a key driver of high bird biodiversity, as they provide a structurally complex habitat that may improve nest concealment, reduce predation, increase food production and provide a diverse range of ecological niches[3, 4]. The interspersion of different vegetation types seems to be a key component of this habitat, which can provide cover for waterfowl in particular[3, 5].

The habitats created by beavers also provide a more abundant food supply for birds. Beaver impoundments tend to contain an abundant aquatic assemblage including a diverse range of macro-invertebrates which are an excellent food source for ducks[1, 2, 6, 7]. An increased abundance and diversity of fish and amphibians within beaver impoundments provides food for species such as grey heron *Ardea cinerea* and kingfisher *Alcedo atthis*[5, 8].

The ponds created by beaver dams often flood and kill trees in the riparian zone (Figures 3.38 and 3.54). This attracts woodpeckers, as standing dead wood is an important nesting and feeding habitat for them[9–11]. Woodpecker holes are also used by a range of secondary cavity-nesting species[12, 13]. Dead trees and snags are an important site for foraging and nesting raptors[14], which may also prey on beavers[15].

Beaver meadows support diverse grassland vegetation, which promotes bird biodiversity[16] and may be an essential source of habitat for grassland birds on a landscape scale[17]. In Canada, one study found that beaver meadows had higher levels of songbird biodiversity than all the adjacent riparian habitats[18].

Beavers may also encourage bird abundance in less obvious ways. Where ponds are covered with ice and snow for much of the winter, beaver physical activity causes the ice to melt earlier in the spring. This can bring benefits to wildfowl, for example beaver ponds have been shown to give Canada geese *Branta canadensis* access to an important habitat for an extended period[19].

Scottish experience

There is minimal information on the effects of beavers on birds in Scotland. SNH Site Condition Monitoring (SCM) of the 'Breeding Bird Assemblage' of the Knapdale Woods SSSI showed an increase in the number of breeding species between surveys undertaken in 2003 and 2013. However, this increase seems unlikely to be related to the presence of beavers in the SSSI. Monitoring of black-throated divers *Gavia arctica* in the Knapdale Woods SSSI and Special Protection Area (SPA) has shown a decline in occupancy by the birds. This is not related to beaver presence, as they have not been recorded in, and have not colonised, the lochs on which the divers nest.

Studies at Knapdale have shown that beavers create woodland with a more open canopy and a more diverse field layer. If deer grazing is controlled, regrowth from gnawed stumps should also increase the shrub layer. This is a similar effect to coppicing, a management technique that has been shown to be beneficial to a range of declining woodland bird species in England[20].

Dam creation at Dubh Loch has also increased the shallow water habitats available for nesting and feeding birds. Despite the lack of specific bird monitoring at Knapdale, it would appear that beavers have increased the diversity of the woodland structure and the amount of wetland habitat available for birds.

Potential future implications for Knapdale and Tayside

Based on the available evidence from the work undertaken at Knapdale and abroad, the overall effect of beavers on bird diversity is likely to be neutral to beneficial at Knapdale and Tayside.

Potential future implications of wider reintroductions in Scotland

As described above, the evidence for effects of beavers on birds in Scotland is extremely limited. However, given that beavers are known to create diverse habitats rich in structural complexity, it would be expected that their presence would result in greater avian diversity than may be expected from the existing remnant riparian habitats in Scotland.

Although there may be some negative impacts on woodland if tree regeneration is limited by deer grazing (section 3.4.1), the increase in the amount of standing water and wetland habitat is likely to improve the avian diversity of our riparian zones. If deer grazing is controlled, the increased structural diversity resulting from the cyclical coppicing and regrowth of riparian trees is likely to open niches for species not found in mature closed canopy woodland, for example tree pipits *Anthus trivialis*. The increased shrub layer resulting from the regeneration of tree stools will also create habitat for a range of insectivorous songbirds, particularly warblers.

Inundation of woodland, leading to the death of standing trees, would also create feeding and nesting opportunities for a range of bird species, including raptors and dead wood feeders such as woodpeckers (Figure 3.59) and nuthatch *Sitta europea*. The latter is a naturally colonising species in Scotland whose spread could be enhanced by the presence of beavers.

A wider reintroduction of beavers, particularly into the more agricultural landscapes of eastern Scotland, is therefore likely to result in some increases in the populations and range of native bird species associated with these riparian habitats.

The wetland conditions created by beavers may also assist the spread of invasive non-native species, such as mandarin duck *Aix galericulata*. This small duck has established seven small populations in Scotland from the

Borders to Inverness-shire. It is associated with deciduous woodland next to waterbodies, where it nests in natural cavities or nest boxes put up for other species. The closely related wood duck *A. sponsa* in North America has benefited throughout its range from the expanding North American beaver populations, which create an ideal forested wetland habitat for the ducks. It is therefore possible that increased populations of beavers in Scotland will also allow the small mandarin duck population to expand in numbers and range.

Examples of scarcer native species that may benefit include marsh harrier *Circus aeruginosus* and bearded tit *Panurus biarmicus*, which have populations currently concentrated in the Tay reedbeds. Others include:

- Woodcock *Scolopax rusticola* – woodcock breed in damp woodland and have shown a decline of 29% since 2003. Although the cause of this decline is unclear, one possible factor is the drying out of woodland[21]. The American woodcock *Scolopax minor* is known to use woodland around beaver ponds, and beavers may therefore benefit the Scottish breeding and wintering populations of woodcock
- Kingfisher – the kingfisher has a localised breeding range in Scotland as far north as the Moray Firth. One of the main factors controlling its distribution and population is severe winter weather. The presence of beavers will increase the amount of suitable slow-moving freshwater habitat for kingfishers to feed, and possibly keep areas ice-free for longer in the winter, allowing for better survival for the more northern populations
- Common crane *Grus grus* – cranes, thought to be of Scandinavian origin, nested in Scotland in 2012 and 2013. Cranes require large areas of shallow, wet and undisturbed vegetation to nest. Wet riparian areas with coppiced woodland and willow scrub may provide suitable nest sites for this recolonising species
- White-tailed eagle *Haliaeetus albicila* – reintroduced to the west coast of Scotland in the 1970s and 1980s, this has been primarily a coastal nesting species thus far. In much of Europe it is an inland, lowland nesting species that feeds extensively on wildfowl. An increase in lowland wetlands and their associated wildfowl populations may therefore assist in the recolonisation of Scotland by this species, for example in the east of Scotland following the recent successful reintroduction there
- Osprey *Pandion haliaetus* – an increase in the number of 'drowned' trees surrounded by wetlands is likely to increase the number of potential nest sites available to the expanding Scottish osprey population

Figure 3.58
A range of bird species, such as waterfowl, herons and kingfishers, will benefit from any increases in wetland and slow-moving water habitat that beavers may create.
© Lorne Gill/SNH

Figure 3.59
Great spotted woodpeckers *Dendrocopus major* are likely to be attracted to trees killed by flooding resulting from beaver activities. Standing dead wood will provide nesting and feeding habitat.
© Laurie Campbell

Table 3.16
Summary of potential interactions between beavers and birds. At some sites appropriate management may be needed to counteract negative effects and promote positive effects. Note that the significance of any individual effect may be far higher or lower than that of other effects.

Activity	Mechanism	Positive effects	Negative effects	Notes
Felling	Change in riparian woodland: Opening of woodland canopy and increased patchiness	– A more open woodland canopy improves foraging habitat for small insectivorous birds, e.g. tree pipit – Overall positive effects on diversity at landscape scale since beaver activity markedly increases habitat heterogeneity and patchiness through the creation of canopy gaps, etc.		
Felling	Change in riparian woodland: Change in relative abundance of different tree species			The structure of woodland is likely to be more important than the species mix for birds
Felling	Change in riparian woodland: Change in age classes of trees	– Beaver-coppiced riparian woodland is likely to benefit many small insectivorous species, e.g. warblers	– Fewer large trees may adversely affect some groups of birds, e.g. woodpeckers	
Felling	Change in riparian woodland: Amount/diversity of fallen dead wood on woodland floor	– Uncertain, but may be beneficial impacts on invertebrate and other prey species		
Felling and constructions	Changes in amount/ diversity of woody material in watercourses	– Uncertain, but may be beneficial impacts on prey species, e.g. fish for mergansers, goosanders, etc.		
Feeding	Feeding on specific terrestrial herbaceous and aquatic plant species			
Dams/pond creation	Change from lotic to lentic habitat	– Overall positive effects on diversity at landscape scale since beaver activity markedly increases habitat heterogeneity and patchiness, with lentic and associated wetland habitat interspersed with lotic habitat – The creation of pond habitat will boost prey abundance for many bird species	– The creation of habitat which may benefit invasive non-native species such as mandarin duck	

Activity	Mechanism	Positive effects	Negative effects	Notes
Dams/pond creation	Change in hydrological processes on riparian and downstream habitat	– The creation of new riparian wetland will boost prey abundance for many bird species		
Dams/pond creation	Changes in water quality downstream	– Uncertain, but may be beneficial impacts on prey species, e.g. fish		
Dams/pond creation	Change in standing dead wood resulting from inundation of trees	– May provide increased nesting and feeding opportunities for woodpeckers, nuthatches and raptors		
Dams/pond creation	Longer term successional changes after dam abandonment, e.g. beaver meadows	– Evidence from North America of an increase in diversity and number of grassland bird species on beaver meadows		
Dams/pond creation	Impacts on movement of species		– Beaver dams may sometimes have adverse impacts on migratory fish species, with consequent localised impacts on piscivorous birds	See Table 3.14 for effects of beavers on fish
Other constructions	Creation of lodges, burrows, canals, etc.	– Lodges provide additional secure nesting and resting places for a variety of bird species	– Invasive non-native Canada geese may utilise these structures	
Other		– Beavers (especially juveniles) may be a prey species for predators, such as white-tailed eagle		
Indirect habitat creation/ restoration initiatives as result of beaver presence	Beaver used to promote opportunities for riparian and freshwater habitat creation/ restoration	– Presence of beavers may act as an incentive for greater investment, management and monitoring. This could those related to the restoration and management of riparian woodland and wetlands, which would benefit a range of bird species		

3.4.10 Mammals

Overview

Beaver activity may influence the local distribution and abundance of other mammal species in a number of ways:

- By creating new areas of open water and associated wetland rich in aquatic plants, fish, amphibians and invertebrates, beavers can increase the availability of food for other mammal species. Many species that occur in Scotland, such as bats, water vole *Arvicola amphibius* (Figure 3.60) and Eurasian otter *Lutra lutra* (Figure 3.61), are likely to benefit from the creation of these new wetlands[1, 2]
- Through effects on some invasive non-native mammals, notably American mink *Neovison vison*, which are also likely to benefit. However, there is evidence from Patagonia and Russia[3] of American mink avoiding beavers, so the assumed habitat benefits to mink may potentially be cancelled out, at least to some extent, by such behaviour
- Through the construction of lodges and the creation of burrow systems in riverbanks, beavers can create additional secure dens and resting places for other mammal species. Again, there are perceived benefits and disadvantages, as both native species, such as otter, and non-native American mink may utilise these structures[4], although how mink respond to the presence of beavers is not clear
- By creating newly coppiced riparian woodland, the resultant opening of the woodland canopy is likely to be beneficial to some species, such as bats. However, the regrowth is also likely to attract herbivores, such as deer, which, if browsing rates are excessive, may ultimately inhibit the regeneration capacity of the affected woodland[5] (see section 3.4.1)
- By creating channels through dense emergent vegetation (reed beds, etc.), beavers can potentially increase the permeability of these habitats to other mammal species. This could have both positive and negative effects. For example, there is evidence from England that water voles and American mink, which rarely coexist, can do so in dense reed beds[6] as the mink tend to occupy the main water channels while the water voles occur in the more densely vegetated areas

A recent review identified 35 published studies investigating the impact of beavers on terrestrial mammal diversity and abundance[7]. Twenty-five of these studies suggested that terrestrial mammal species interact with beavers, either as predators or by making use of beaver ponds and other beaver-created habitat, but did not make a comparison with where beavers were absent. The remaining 10 studies investigated the differences between areas affected by beavers and areas where there was no impact from beavers. Beaver activity was found to have a positive effect on the abundance of a mammal species, or overall mammal diversity, in half of these studies, and no difference in the other half. No study found a negative impact of beavers on mammal diversity or abundance.

Four of the studies focused on bats, with two finding a positive impact of beaver activity. One Finnish study showed that ponds created by beavers supported a higher abundance of bats than other ponds[8]. Bats are

Figure 3.60
Water vole.
© Laurie Campbell

thought to benefit from beaver activity because of an increase in prey abundance and availability, and improved foraging habitat due to the creation of more gaps in the forest canopy[2]. In a Polish study, four species of bat that also occur in Scotland – the widespread and abundant common pipistrelle *Pipistrellus pipistrellus* and soprano pipistrelle *P. pygmaeus* and the much rarer noctule *Nyctalus noctula* and Nathusius' pipistrelle *P. nathusii* – were all positively affected by beaver activity[2]. No impact of beavers on Daubenton's bats *Myotis daubentonii* was found, which is unexpected given that this species is particularly associated with water and frequently catches its insect prey directly off the water surface. In this case, the lack of any effect of beavers may have been due to a layer of duckweed impeding hunting on some of the beaver ponds in the study. However, the effect of beavers on Daubenton's bats may be either positive or neutral depending on the characteristics of the open water habitat created, and indeed an increased abundance of this species was found following beaver impoundment in another study[9]. Beaver impoundments that result in waterbodies characterised by a smooth, uncluttered surface might be expected to benefit Daubenton's bats, as these provide an ideal foraging environment. When ponds created by beavers develop further to form beaver meadows, any benefit for bats seems to be lost[10].

Bats may also make use of beaver habitat in other ways, for instance by roosting under the exfoliating bark from trees killed by beaver flooding[11].

Other small mammals do not seem to be heavily influenced by beaver activity[12, 13], although a diverse range of small mammals are known to use beaver lodges[14].

A number of mammal species may utilise abandoned beaver lodges or dams as resting sites including pine marten *Martes martes*, badger *Meles meles* and red fox *Vulpes vulpes*[15, 16].

Numerous mammals have been reported to prey on beavers, some of which are widespread in Scotland[15, 17–20]. These include red fox, which has been recorded predating on young beavers, and non-native American mink. Beaver fur has been found in pine marten scats which may be a result of predation or scavenging.

Beaver herbivory may benefit local ungulate populations, although this can have wider implications for woodland ecology, as discussed in section 3.4.1. Heavy browsing by red deer *Cervus* spp. on regrowth from beaver-felled trees has been reported[5]. Trees felled but not utilised by beaver may provide food for browsing ungulates[21]. However, a Canadian study reported that beaver presence had no influence on large mammal diversity or abundance in protected areas or agricultural landscapes, although it was important for maintaining water levels in agricultural wetlands, and therefore ecological heterogeneity[22].

In two studies on the interaction between North American beaver and semi-aquatic mammals, one reported a positive impact on North American river otter *Lontra canadensis*[23], and the second a negative impact on American mink in Patagonia, where both mink and beavers are introduced[24]. This result has also been reported with the Eurasian beaver and non-native American mink in Russia[3].

Otters are likely to benefit from beaver activity. Beavers increase the amount of aquatic habitat, and hence increase suitable otter habitat. The ponds formed are

Figure 3.61
Otter.
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often rich in otter prey species such as fish, amphibians and invertebrates. Abandoned beaver lodges and bank dens may also provide important shelter for otters[25–28]. Beaver-created habitat is an important predictor of North American river otter distribution[23].

While the majority of the literature focuses on the North American river otter, a number of reports also describe the benefit beavers have on Eurasian otter[1, 9, 29]. As the positive mechanisms are associated with pond creation and the creation of shelter for resting sites, similar effects are expected for both species.

Scottish experience

The available evidence comes from the SBT and a separate SNH-commissioned survey in 2011 and 2012 of the 44 SACs for which the otter is a qualifying feature. Otters are one of the qualifying features of both the Taynish–Knapdale SAC and the River Tay SAC. They are also a UK BAP (UK Biodiversity Action Plan) priority species and a European Protected Species. In Knapdale there was no evidence of an effect of beavers on otter presence[30]. The conditions of both the River Tay SAC and the Taynish–Knapdale SAC were independently assessed in 2012 and 2011 respectively. Both were classed as being in favourable condition, with 92% otter occupancy recorded for the River Tay SAC and 80% for Taynish-Knapdale SAC[31].

The water vole, another UK BAP priority species, was also included in the SBT monitoring programme, but no evidence of the species was recorded during the trial. This is not surprising given the unfavourable heavily shaded habitat at many of the locations where the surveys were undertaken, and the autumn and early winter survey period that was employed. A single sighting of a water vole was recorded by the SBT staff on Loch Linne in August 2012, suggesting that this species is present in the area, but at a low density.

Beavers may influence local mink activity, as mink are known to use beaver lodges as den sites and beaver ponds for foraging elsewhere in Europe and in North America[21, 32, 33]. Mink abundance in Knapdale (based on records of scats and footprints on mink-monitoring rafts) appeared to be low, although there is ample evidence from other studies that mink are abundant in coastal habitats in Argyll[34]. The highest densities of mink (and otters) occur in productive coastal habitats[35, 36], and therefore the potential for interaction with beavers may be limited. Control methods for this non-native invasive species are well established and are already in place at Knapdale and the wider area.

Potential future implications for Knapdale and Tayside

Negative impacts from beavers on other native mammals are considered unlikely at Knapdale and Tayside, given the important ecological role that beavers play in influencing the hydrology of their habitat and the experiences from elsewhere in their European range.

Beaver activity in Knapdale can be expected to lead to:

- The creation of further areas of wetland that will provide additional foraging resource for otters and other species reliant on wetland and riparian habitats. The extent to which this extra resource will actually benefit otters is difficult to judge, as the habitat in the release area and nearby coast is already excellent for otters. The coast is likely to remain the focus for much of the otter foraging activity in the area. Should beavers expand north of the Crinan Canal into the River Add catchment, more tangible benefits to otters can be expected, as the SBT monitoring indicated that otter activity in this area was consistently less than in Knapdale with its more varied habitats[30]. Evidence from elsewhere in Europe strongly suggests that local bat populations will benefit from the activities of beavers in the area. At least five species occur in the Knapdale/mid-Argyll area
- The creation of additional otter holts and lie-ups (and dens for other species) in the form of disused and abandoned lodges and bankside burrows. For all species, except American mink, this is regarded as a neutral or positive effect. It is unclear whether these extra places of shelter would actually influence the population density of territorial species at Knapdale. In the case of otters, for example, food supply is more likely to limit population density than the availability of holt sites or lie-ups

Fish form a significant component of otter diet, and fish surveys undertaken at Knapdale during the trial period found no significant change in the species composition or the number of fish found at sites where beavers have become active[37]. Should further beaver releases take place in Knapdale, ongoing monitoring of the fish population would be recommended. Further monitoring of the mink population would also be recommended, as it is unclear how this species will respond to an increasing beaver population, given the evidence from other parts of the world that suggests mink appear to avoid beaver-modified habitat. Mink monitoring would need to take place in areas where mink are both controlled and not controlled.

In Tayside, further expansion of the beaver population is anticipated as the species colonises the remaining parts of the catchment where suitable habitat exists. Many habitats and species are expected to benefit, as noted above for the Knapdale area, with positive or neutral effects on native mammals. Mink are already controlled throughout much of the Tay catchment, but it is unclear how an expanding beaver population might affect this species. If it transpires that mink, in fact, do not avoid beaver-altered sections of watercourses (as suggested by other studies) and actively utilise them, they could conceivably become easier to detect and control. This is because the rafts which form the basis of the Tayside control operation are best placed in still, slack water, such as that created by beaver activity.

Potential future implications for a wider reintroduction in Scotland

Beaver ponds are often frequented by otters because of the high abundance and diversity of prey that may be found in them. In some parts of Scotland, for example the Dinnet Lochs on Deeside, there is evidence of a decline in breeding otters which has been associated with the wider decline in eel stocks[38]. In a review of the impact of beavers on fish populations, it was noted that positive impacts were cited more frequently than negative impacts[39] (see section 3.4.7). Some species may benefit more than others from beaver activity; for example, cyprinids, trout, pike, perch and eels may benefit, but migratory salmonids may experience adverse impacts. In Scotland, more work is needed to better understand how fish populations respond to beaver activity[40], so it remains unclear to what extent otters are likely to benefit from beaver presence. However, it is reasonable to conclude, on the basis of the monitoring undertaken at Knapdale and elsewhere, that beavers will have no negative impact on otters and are considered likely to have a net positive effect through the creation of new resting sites and additional amphibian (and possibly fish) prey in beaver ponds.

Beaver pond creation and herbivory has the potential to have a large positive influence on water voles in the absence of American mink. The water vole has experienced a dramatic population decline across Britain, particularly in the latter part of the twentieth century[41]. Reintroducing beavers would create and improve habitat for water voles, which have a strong preference for slow-moving water with abundant aquatic, emergent and herbaceous bankside vegetation; all features that are characteristic of beaver ponds. A key management technique used to improve water vole habitat is thinning woody riparian vegetation, an effect beavers can also create[42]. Evidence for a positive relationship may come from the muskrat *Ondatra zibethicus*, which is ecologically similar and seems to derive benefit from beaver-influenced habitat[29, 43]. However, although habitat for water voles may improve, they are unlikely to thrive if mink are present in the area. Predation by mink has resulted in the extinction of water vole colonies along most river main-stems and major tributaries in Scotland where the species previously occurred. The best populations are now mostly found in upland headwaters and are characterised by slow-flowing small burns meandering through areas underlain by deep peat. Potential beaver woodland habitat is usually absent at these sites.

Coordinated landscape-scale mink control projects, such as the Scottish Mink Initiative, have resulted in an apparent recovery of water voles in some areas which, if colonised by beavers, could allow water voles to realise the anticipated benefits of beaver activity.

Overall, the current distributions of mink and water vole across Scotland suggest that there is likely to be a greater degree of overlap between an expanding beaver population and mink than with the more restricted water vole population. Beaver activity is likely to lead to an increase in the availability of prey for mink, notably invertebrates, fish and amphibians[29, 32]. However, the apparent avoidance of beaver-modified habitat by mink reported from Patagonia and Russia may potentially occur elsewhere and, if observed in Scotland, could have important implications for the future strategic management of mink in Scotland. Consequently, the interaction between the two species needs to be carefully monitored if further beaver expansion occurs.

The water shrew *Neomys fodiens* may also benefit from wider beaver activity. This species is under-recorded in Scotland and is commonly associated with fast-flowing, clean water courses. However, it also occurs in still and slow-flowing waters[44, 45], and there is an anecdotal report of water shrews using a beaver lodge at an enclosed site near Beauly.

Key issues for consideration can be summarised as follows:

– Beavers are not considered to be detrimental to any native mammal species that occurs in Scotland. Beaver activity is likely to benefit a range of mammal species though the creation of new wetlands and riparian habitats and the food resources they support
– Beavers have the potential to provide substantial benefits to water voles, but only if mink are also systematically removed from the areas affected by beavers
– Beaver activity can be expected to result in local increases in amphibian populations, which will benefit otters. Frogs and toads are important seasonal prey items for otters, notably at breeding ponds in the early spring
– It is unclear how beaver activity will affect some fish populations and how this may affect otters. The decline in eel stocks has had noticeable negative effects on otters in some areas. If beaver activity leads to a net increase in the availability of other fish prey, this has the potential to reverse such trends

The interaction between the expanding beaver population and American mink would need to be closely monitored.

Species of European importance

Otter (listed in Annexes II and IV of the Habitats Directive) - there is a high likelihood that beaver will interact with this species based on levels of potential overlap. Any interaction with beaver is likely to have a large impact, for the reasons set out above.

Bat species (listed in Annex IV of the Habitats Directive) - there is a high likelihood that beaver will interact with some bat species, such as common pipistrelle and Daubenton's, based on levels of potential overlap. Any interaction with beaver is likely to have a medium to large impact, for the reasons set out above.

The wildcat *Felis silvestris* is another Annex IV species that occurs in Scotland. There are no reports of the species interacting with beavers, and any possible impacts are likely to be minimal and not negative.

Table 3.17
Summary of potential interactions between beavers and other mammals. At some sites appropriate management may be needed to counteract negative effects and promote positive effects. Note that the significance of any individual effect may be far higher or lower than that of other effects.

Activity	Mechanism	Positive effects	Negative effects	Notes
Felling	Change in riparian woodland: Opening of woodland canopy and increased patchiness	– A more open woodland canopy improves foraging habitat for bats – Increased light levels at water's edge may improve water vole habitat – Overall positive effects on diversity at landscape scale since beaver activity markedly increases habitat heterogeneity and patchiness through the creation of canopy gaps, etc.		Water vole populations are expected to respond to improved habitat conditions only where American mink are controlled
Felling	Change in riparian woodland: Change in relative abundance of different tree species			
Felling	Change in riparian woodland: Change in age classes of trees	– Coppiced riparian woodland is likely to benefit many species – Regrowth is likely to attract herbivores such as deer	– Regrowth may be restricted where deer numbers are high	
Felling	Change in riparian woodland: Amount/diversity of fallen dead wood on woodland floor	– Uncertain, but may be beneficial impacts on prey species		
Felling and constructions	Changes in amount/ diversity of woody material in watercourses	– Uncertain, but may be beneficial impacts on prey species, e.g. fish for otter		
Feeding	Feeding on specific terrestrial herbaceous and aquatic plant species			
Dams/pond creation	Change from lotic to lentic habitat	– Overall positive effects on diversity at landscape scale since beaver activity markedly increases habitat heterogeneity and patchiness, with lentic and associated wetland habitat interspersed with lotic habitat – The creation of pond habitat will boost prey abundance for many bat species and otter	– Non-native American mink may benefit from new pond creation	The water shrew may be influenced; however, it occupies both lentic and lotic habitats and the effects are unknown

Activity	Mechanism	Positive effects	Negative effects	Notes
Dams/pond creation	Change in hydrological processes on riparian and downstream habitat	– The creation of new riparian wetland will boost prey abundance for many bat species and otter	– Non-native American mink may benefit from new wetland creation	
Dams/pond creation	Changes in water quality downstream	– Uncertain, but may be beneficial impacts on prey species, e.g. fish for otter		
Dams/pond creation	Change in standing dead wood resulting from inundation of trees	– May provide roosting opportunities for bats		
Dams/pond creation	Longer term successional changes after dam abandonment e.g. beaver meadows			
Dams/pond creation	Impacts on movement of species		– Beaver dams may sometimes have adverse impacts on migratory fish species, with consequent localised impacts on otter	See Table 3.14 for effects of beavers on fish
Other constructions	Creation of lodges, burrows, canals etc.	– Burrows and lodges will provide additional secure dens and resting places for a variety of mammal species	– Non-native mink may utilise these structures – Foraging trails increase accessibility to dense habitats used as cover, such as reed beds, potentially increasing predation	
Other		– Beavers (especially juveniles) may be a prey species for a variety of predators		
Indirect habitat creation/ restoration initiatives as result of beaver presence	Beaver used to promote opportunities for riparian and freshwater habitat creation/ restoration	– Presence of beavers may act as an incentive for greater investment, management and monitoring. This could include those related to the restoration and management of riparian woodland, which would benefit a range of mammal species, e.g. otter, water vole, bats, red squirrel		

3.5 Summary

- Beavers are widely considered to be 'ecosystem engineers', a term reserved for those species that have a large impact on habitats and species through the alterations they make to the physical environment. Beavers can fundamentally change ecosystems and create new habitats
- Beaver activity is largely restricted to freshwater and associated riparian habitats, in particular where broadleaf woodland is present. Substantial areas of these habitats occur across much of Scotland, and these would be able to support a viable population of beavers. Other habitats in Scotland would generally be unaffected by the presence of beavers
- Experience from Scotland and overseas has demonstrated that, overall, beavers have a very positive influence on biodiversity, including on the abundance and diversity of species. Their ability to modify the environment through felling trees and impounding watercourses means that beavers not only create new habitats but also increase habitat heterogeneity at the catchment scale. Their impacts are dynamic and change across space and time
- The mechanisms by which beavers change environments and affect biodiversity include:
  - The creation of ponds and wetland habitat upstream of dams, which store water and can help to combat effects associated with periods of low flow
  - The creation of dams, which alter sediment transport processes and can lead to changes in composition of both the upstream and downstream bed sediments
  - The import of woody debris into both running and standing water environments
  - The creation of important habitat features such as standing dead wood following inundation
  - The creation of coppiced stands and unique vegetation structures due to the combination of flooding and herbivory
  - The creation of longer term, successional stages such as beaver meadows
- Beaver activities therefore result in habitat change, which will result in some species benefiting and others being disadvantaged. The habitat changes brought about by beavers in Scotland will benefit a range of species, such as plants that prefer more open woodland habitat, a range of aquatic invertebrates, eels, amphibians, waterfowl, woodpeckers, bats, water voles (in places where mink are removed) and otters
- There may be localised losses of certain species, for example aquatic macrophytes used as food by beavers, species that prefer running waters and more shaded woodland, and those intolerant of increases in water depth in standing waters. However, some of these species may colonise new habitat created by beavers or they may benefit in other ways (e.g. dams may improve water quality in downstream running waters), resulting in neutral effects or overall benefits at the catchment/wider scale
- In Scotland, some species and habitats of high conservation importance have the potential to be adversely affected by beavers. This is especially the case where they are isolated and in close proximity to riparian areas, and where ecological continuity could be affected. There may be localised losses of riparian stands of aspen and Atlantic hazel, and their associated species. The regeneration of other woodland tree species felled by beavers may also be hindered where deer are abundant
- Some fish species may benefit more than others from beaver-mediated habitat modification and creation. It is possible that migratory salmonids (e.g. the spring stock component of Atlantic salmon) may experience adverse impacts under certain circumstances
- In the event of any wider beaver reintroductions there would be a need to monitor, and further investigate, beaver interactions with species and habitats of conservation concern and to employ appropriate management when necessary. Habitat mapping and population modelling tools have been developed that will assist in monitoring and management planning
- There is now a greater understanding of the genetic backgrounds of beavers across Europe and in Scotland, including risks to genetic health that may arise from inbreeding, which will assist in the development of any future reintroduction and reinforcement planning

Chapter 4
Beavers and their interactions with the human environment

This chapter summarises what is known about how beavers interact, or might interact, with land uses (such as forestry, agriculture, fisheries and associated land use infrastructure), public and animal health, and overarching socio-economic factors.

The sections in this chapter are set out in the same way as those for the habitats and species sections of Chapter 3. Once again, each topic is described under four sub-headings: overview; Scottish experience; potential future implications for Knapdale and Tayside; and potential future implications of a wider beaver reintroduction to Scotland (although there is a slight variation to this structure in the public and animal health section 4.6). The socio-economics section 4.1 finishes with the same standard table used in the Chapter 3 sections, setting out potential positive and negative effects that beaver activities and mechanisms might have on Scottish socio-economic factors.

Overall, there is far less published information on these topics from Europe and North America than there is on ecological topics. However, for certain topics some very useful studies have been carried out in Scotland in recent years, and these are summarised here.

4.1 Socio-economics

Overview

Social and economic ('socio-economic') impacts related to environmental change have recently been formalised using the Ecosystem Services Framework (ESF). This is an analytical framework that has been promoted in the Millennium Ecosystem Assessment[1] and has guided the development of the UK National Ecosystem Assessment work[2, 3]. The ESF provides a way to describe socio-economic impacts based on the relationship between biophysical structures and processes (and the resulting ecosystem functions) and the ecosystem 'services' they generate defined in terms of benefits to humans: provisioning, regulation and maintenance, and cultural. Figure 4.1 shows a simplified outline of the ESF.

'Provisioning ecosystem services' include products that are partly dependent on nature, such as food and water. 'Regulation and maintenance ecosystem services' include mediation of waste and toxins and mediation of flows (mass, liquid and air), as well as habitat preservation, pest control, decomposition and climate regulation. 'Cultural ecosystem services' relate to recreational, educational and spiritual interactions with the environment, plus the value humans attach to the simple existence of nature. One thing that all of these services have in common is that they contribute to human wellbeing and have socio-economic impacts. These impacts can sometimes be expressed in monetary terms, but it is often more appropriate to express them in non-monetary terms.

At the end of this section, Table 4.4 summarises the main ways in which beaver activities might have implications for the 'human environment' (this standard table is also used to summarise implications for species and habitats in the 'natural environment' in Chapter 3). The activities and mechanisms of beavers are briefly described in the first two columns. The next two columns note any relevant positive and negative socio-economic effects. These columns are effectively describing the 'ecosystem services' (positive effects) and 'ecosystem disservices' (negative effects) associated with beaver activity. The final column provides clarification as to why the particular ecosystem (dis)service will have repercussions for people.

There are a number of studies from North America that demonstrate beavers' ecosystem functions and the resulting 'regulation and maintenance ecosystem services' which have socio-economic implications. For example, the trapping of sediments[4] and diffuse pollutants[5] might mitigate costs associated with addressing water quality. During dry summers beaver dams and canals have been shown to hold more than 60% more water (including ground table water) than comparable environments without beaver activity[6], and the delivery of standing water during times of drought[7] might help alleviate the negative socio-economic impacts of droughts. The potential for carbon sequestration through wetland creation[8] has been judged to contribute to climate change mitigation efforts.

Another study from the USA explicitly used the ESF to illustrate the socio-economic impacts of beavers[9]. They investigated beavers' functions in the Escalante River basin in Utah, with a focus on the resulting 'regulation and maintenance of ecosystem services' (Figure 4.2). The study went on to describe the socio-economic benefits, in both monetary and non-monetary terms, associated with each of these ecosystem services.

The study is based on the North American species of beaver[9], although the predominantly positive evidence accords with evidence from beaver reintroductions across Europe. There are some notable examples of beavers' role in tourism, education and economic development, including the 'Pays des Castors' project in Belgium and Klosterheden Forest in Denmark, which illustrate how the presence of beavers can contribute to local economies. In Latvia, beavers reportedly purify 34 billion cubic metres of water a year; if this was done artificially, it would cost in the region of £40 million[10]. Dam-building by the Latvian population of 100,000 beavers was predicted to create 100–200 km^2 of wetlands, worth £0.6 billion to £1.3 billion in fixed capital[11]. A study in Belgium suggests that a series of beaver dams in the upper catchment of the Ardennes has played a significant role in the reduction of discharge peaks, and hence has mitigated flood events in villages lower down in the catchment[12] (see also section 3.4.3).

Figure 4.1
Simplified outline of the Ecosystem Services Framework.

Scottish experience

Public consultations and surveys

A number of public consultation and survey exercises have been conducted in Scotland since 1998 (Table 4.1, Figure 4.3), exploring attitudes to beaver reintroduction in general and to a trial at Knapdale in particular.

Table 4.1 demonstrates public support for beaver reintroduction in general and for the SBT in particular (Figure 4.4). The 2014 SWT/RZSS consultation, when compared with their 2007 consultation, suggests that this support has increased over time[16]. However, concerns have been raised, especially by some land use sectors and by people living close to Knapdale itself (e.g. in the 2007 SWT/RZSS consultation).

There has also been a beaver stakeholder event, held by SNH in November 2014 and described in Chapter 6. This provided an opportunity to gather views on potential future scenarios for beavers in Scotland.

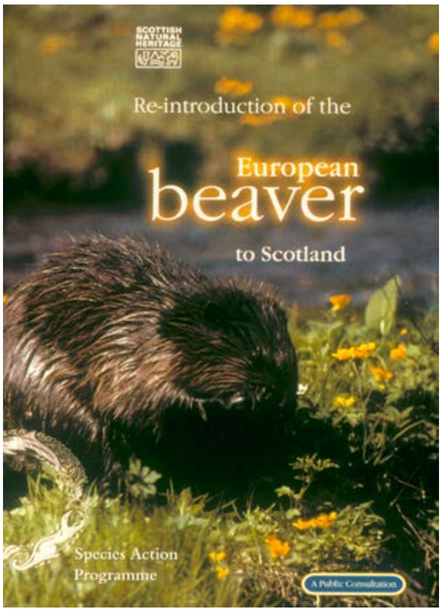

Figure 4.3
SNH commissioned a national consultation on beaver reintroduction in 1998[13].

Figure 4.2
Beavers' potential impacts based on a study from Utah, USA[9]. The arrow direction indicates an increase (up) or reduction (down) in the impact of beavers. For example, it is suggested that beavers mitigate the severity of downstream flooding.

	Beavers' potential impacts on streams and related ecosystems	
	Upstream impacts	**Downstream impacts**
Water quantity	▲ Precipitation storage ▲ Water depth	▼ Velocity ▼ Flooding severity ▲ Consistency of flow ▲ Groundwater recharge ▲ Late season flow
Water quality	▲ Methane production ▲ Carbon production ▲ Aerobic respiration ▼ Oxygen concentration ▲ Other nutrients ▲ Sediment retention	▼ Sediment retention ▼ Temperature
Ecosystems	▲ Wetland area ▲ Riperian area ▲ Open canopy area	▲ Riparian area ▲ Open canopy area
Habitat	▲ Big game habitat ▲ Fish habitat ▲ Insect habitat ▲ Bird habitat ▲ Small mammal habitat ▲ Amphibian habitat	▲ Big game habitat ▲ Fish habitat ▲ Insect habitat ▲ Bird habitat

Table 4.1
Public consultation and survey exercises held between 1998 and 2014.

Year	Key information and outcomes
1998[13]	– National consultation organised by SNH – Respondents asked if they support beaver reintroduction to Scotland – 63% support from 'passive public' – 86% support from 'pro-active public' – Mixed responses from other 'key consultees'
2000[14]	– Local consultation in mid-Argyll – Majority of the public and local organisations were in favour of a trial at Knapdale – NFU Scotland expressed concerns
2002[14]	– Independently co-ordinated Argyll and Bute Citizens' Panel – 46% of Argyll and Bute residents supported a trial at Knapdale – 21% opposed a trial – 33% neither supported nor opposed a trial
2003[15]	– Organised by the Scottish Economic Policy Network – 72% expressed support for beaver reintroduction – Average willingness to pay of £24 per household per year to fund a pilot reintroduction project
2007[16]	– Consultation led by SWT/RZSS – 73% of respondents from mid-Argyll were in favour of a trial at Knapdale – 44% of respondents from the Knapdale area were in favour of a trial
2014[16]	– Consultation led by SWT/RZSS – 84% of respondents from mid-Argyll were in favour of beavers living in the area – 80% of respondents from mid-Argyll believed that beavers' presence could help with tourism and the economy

Socio-economic studies

There are differences not only between the natural environments at Knapdale and Tayside, but also between the human environments in each area. In addition, the trial (Knapdale) has quite different socio-economic implications from an unplanned release (Tayside): in the former it was easier to *plan for* beaver impacts (both positive and negative) before animals were released, but in the latter there was more of a need to *react to* beaver impacts.

For these reasons, separate socio-economic studies were carried out for the SBT[17] and the Tayside release[18]. The methodology for each evaluation was consistent with the recommendations set out for central government decisions involving environmental appraisal and with other governmental advice on judging evidence for impact assessments. Further information can be found in HM Treasury's Green Book[19] and Magenta Book[20].

Each report involved two broad stages of analysis:

- Identification of relevant changes against a baseline of no beavers
- Conversion of these changes into values that allow a comparison of socio-economic benefits and costs

The main challenge for each study was to ensure a fair comparison of impacts, and this included the recognition that a single, typically monetary, metric does not provide an unambiguous basis for such a comparison.

Socio-economic study – Knapdale

The SBT study[17] found evidence of several cultural ecosystem services, which meant that there were discernible monetary benefits in the following categories:

- Site visitors and public talks
- Educational value
- Volunteering
- Non-use value

Estimates of monetary benefits for the full five-year trial period are summarised in Table 4.2.

Guided walks at Knapdale were used as a proxy for 'wildlife experiences', and these were calculated to have a value of between £355,000 and £520,000 (Figure 4.5). An educational value of approximately £56,000 was calculated by considering the resource investment costs of the equivalent time spent on educational activities by both primary and secondary schools (Figure 4.6). SBT staff recorded 3,882 volunteer hours between July 2012 and December 2013. During this period, 42 individuals volunteered to assist staff with beaver tracking/monitoring and helped with public events. The value of volunteering was therefore estimated to be at least £84,000, assuming a similar level of activity throughout the duration of the trial.

In addition to what we might call the 'use values' associated with the SBT (e.g. as captured in recreational and educational values, Figures 4.7 and 4.8), the trial

Table 4.2
Summary of estimated monetary benefits at Knapdale for the full trial period (to May 2014)[17].

Category	Value	Comments
Recreational visitors	£355,000 to £520,000	Based on inferred number of 6,582 visitors since the trial began and regional expenditure data
Educational value	£56,000	Educational investment value since the trial began
Volunteer time	£84,000	Replacement calculation based on volunteer hours between July 2012 and December 2013. Extrapolated to cover the full trial period
Non-use value	£564,000 to £6,038,000	The low estimate of non-use value is based on half the households in Argyll and Bute with a WTP (willingness to pay) of £5.60 per year. The high estimate is based on all households in Argyll and Bute with a WTP of £30 per year
Total	Low £1,059,000 High £6,698,000	

also includes an element of value termed 'non-use value' (NUV). NUV is a significant value category relevant to the social impact of reintroducing a charismatic species, associated with the mere existence of a species irrespective of any type of direct or indirect use. Evidence to support how NUV can be calculated is contested: aggregating NUVs over large populations of people, including many who may hold no demonstrable preferences for the species, can lead to a large aggregate value, which can overwhelm other benefit categories. In addition, the juxtaposition of these wider benefits with more localised costs raises questions of fairness and equity. Indeed, some have been very critical of the underlying 'stated preference' methodology used in these types of assessments[21].

The SBT socio-economic study[17] suggested a wide range of possible monetary values for NUVs based on different estimates of 'willingness to pay' (WTP) for the existence of beavers at Knapdale and on different estimates of the number of households which are deemed to have a WTP.

Table 4.2 includes only benefits for which a monetary estimate is feasible. There is a range of positive impacts that can be expressed in non-monetary terms. For instance, the educational value estimate of £56,000 does not reveal the longer term benefit of ecological knowledge and the possible impacts of pro-social and environmental behaviours, and as such is highly conservative. In addition, Table 4.2 does not include the value of entertainment, educational and scientific ecosystem services associated with the widespread media

Figure 4.4
There was support for the SBT from a number of local businesses.
© Martin Gaywood/SNH

Figure 4.5
One of many organised walks held for visitors at Knapdale.
© Lorne Gill/SNH/2020VISION

Table 4.3
Summary of estimated monetary costs at Knapdale for the full trial period (to May 2014)[17].

Category	Value	Comments
Woodland and timber	£1,000 to £6,000	Based on 1.59 hectares of flooded land now unavailable for forest operations (although this was an area of native woodland where no timber production was anticipated for the foreseeable future)
Road and other civil engineering costs	£35,000 to £38,000	Costs to repair damage caused by flooding and mitigate the future risk of flooding (includes £22,000-£25,000 for replacement forest track which has not been installed to date)
Trial administration costs	£2,080,000	This excludes some staff costs and certain elements of the scientific monitoring. It includes projected costs to 2015
Total	Low £2,116,000 High £2,124,000	

coverage of the SBT, such as the BBC's *Springwatch* and *Autumnwatch* television programmes.

Discernible monetary costs associated with the SBT are shown in Table 4.3. As with the benefits, these are shown for the full trial period.

Monetary costs due to damage caused by beavers (these can be thought of as 'ecosystem disservices') were limited in the SBT. In terms of unavailable woodland and flooding-related repairs, these are estimated to be no more than £44,000. The administration costs of the SBT itself are outside the ESF (they are not connected to the mechanisms by which beavers affect ecosystems), but are included in Table 4.3 for reference. The licence partners (SWT and RZSS) budgeted costs of almost £1.6 million for the seven-year period to 2015, and the independent monitoring partners also contributed to the SBT. The main costs related to the following elements:

- Beaver capture, quarantine and transport (£375,000)
- SWT and RZSS staff, equipment and premises (£640,000)
- Scientific monitoring – SWT/RZSS (£180,000)
- Scientific monitoring – SNH (£275,000)
- Scientific monitoring – other monitoring partners (£176,000)
- Management overheads (£245,000)
- Interpretation and communication (£85,000)
- Education ranger (£56,000)

Therefore, the overall administration costs of the trial total just over £2 million, as set out in Table 4.3. It should be noted that this estimate does not include the cost of SNH or FCS staff time. It also excludes the cost of the four scientific monitoring projects that were not led by SNH. As such, £2 million is a minimum estimate of the costs incurred between 2008 and 2015. However, it might be that the actual costs are lower than those budgeted. For example, SNH's actual contribution to the scientific monitoring is likely to be less than £250,000, and not £275,000 as estimated above.

Socio-economic study – Tayside

The socio-economic study of Tayside[18] found very little evidence of monetary benefits associated with beavers, apart from NUVs. A low and high estimate of NUV, using similar assumptions to those used for Knapdale, might imply an annual WTP for the Tayside beavers of between £182,000 and £2 million. However, this estimate needs to be interpreted with caution, for the same reasons mentioned above in relation to the NUV of the SBT beavers.

The Tayside study[18] included a business survey, which recorded that, out of 27 responses, 30% believed that beavers were having a positive impact on their business, compared with only 7% who believed that they were having a negative impact (the majority, 63%, stated that the beavers were having no impact on their business). Over 80% of respondents were in favour of beavers' future presence in the Tay catchment. The authors of the Tayside study suggest that the relatively neutral response to current beaver presence might be explained because: 'in their current largely unsanctioned status the Tay beavers are not actually marketed in any systematic or strategic way with land owners and businesses capitalising in a somewhat opportunistic way'[18].

There is evidence of other benefits at Tayside. For example, a charitable initiative, the Scottish Wild Beaver Group, mobilised local interest in beaver conservation and recreation. The group provided some information for visitors and reported to have given six to eight talks per year for the last 12 years. In 2013 it recorded 155 visitors from various groups and clubs to the beaver site at Bamff. The group has also spoken to 700 schoolchildren.

In summary, there is more evidence of current benefits at Knapdale than at Tayside. To an extent, the opposite is true in relation to costs: the beaver population at Knapdale is much smaller and the trial area itself is more remote from heavily populated centres, and so negative socio-economic impacts are more limited. The beaver population

Figure 4.6
The educational value of the SBT was calculated to be approximately £56,000[17].
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Figure 4.7
Interpretive material inside the visitor centre at Knapdale.
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at Tayside is much larger and more widespread, and beavers are more frequently recorded near agricultural land.

Concerns about costs are exemplified by the results of a survey reported in the Tayside study[18] which involved targeting those engaged in land management in the Tay catchment. A total of 111 responses were received, with the primary land uses on the properties surveyed being crops (50%) and livestock (43%), and the remainder being horticulture (3%), fishing (2%), sport (2%) and forestry/conservation (1%). The properties surveyed covered a total area of 158,543 ha. For all respondents, 40% had seen beavers and/or evidence of beaver activity on their land and 46% had seen no sign of beaver activity (14% were unsure).

Respondents were asked to report any benefits and/or costs caused by beavers. There were few reported benefits: 73% (based on 60 respondents, i.e. excluding the 51 (46%) of respondents who reported no beaver presence) believed that there were no benefits, and the remainder thought that beavers provided some flood prevention and improved the water quality (and to a lesser extent increased wetland area and brought aesthetic benefits). In contrast, many respondents reported costs. The main costs can be categorised and the number of responses listed by descending order: damage to trees; damage to banks and drains; damage to crops; and flooded fields/trees/crops. Just 32% of respondents believed that there were no costs. Most respondents provided only a qualitative description of damage, but 13 respondents (out of the 41 who reported damage) were able to provide a monetary estimate of costs incurred, and these totalled £34,490 per annum.

Note that this represented just a sample of costs from land managers within the population of Tayside, so an estimate of costs for the whole population of land managers was attempted[18]. This involved a series of steps based on what was known about the split of identified costs (£34,490) between land managers in the upper and lower catchments, and extrapolating to the full Tay catchment land area (572,867 ha). The costs for the whole catchment were estimated to be £179,900 per annum. This estimate needs to be interpreted with caution, as there are several key assumptions, notably that the samples are representative of the wider populations about which inferences are made.

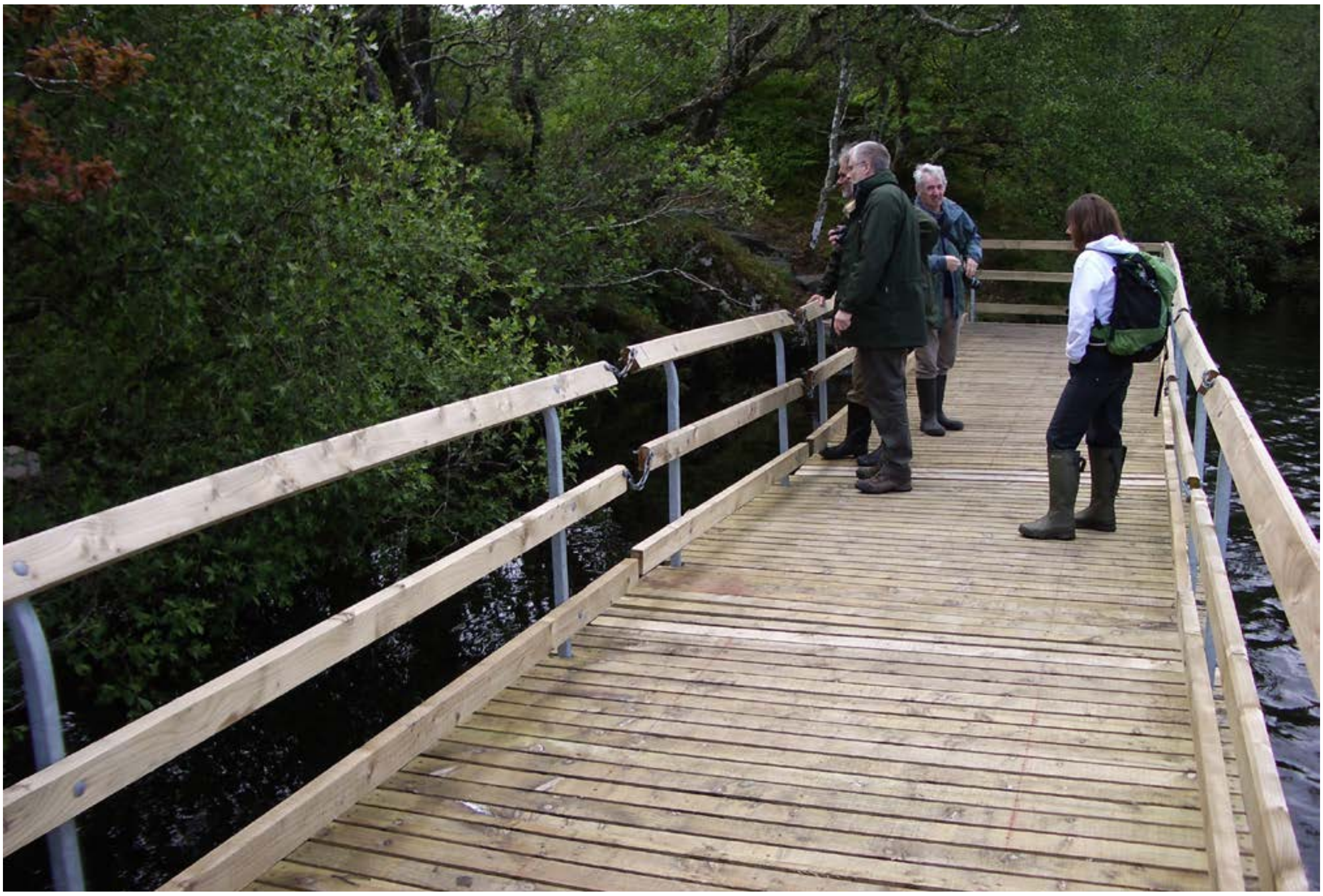

Figure 4.8
Forestry Commission Scotland installed a floating pontoon at Knapdale to allow visitors to view the Dubh Loch beaver dam.
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Potential future implications for Knapdale and Tayside

Sections 4.2 to 4.5 describe how there are unlikely to be significant implications for fisheries, commercial tree species, agriculture or infrastructure at Knapdale. The SBT socio-economic study[17] noted that, in the post-trial period at Knapdale, a significant reduction in the overall project management costs can be expected, meaning that benefits are likely to exceed costs in the medium term. There will be some costs in terms of the maintenance and staffing of road and visitor facilities (Figure 4.10), and associated with land lost to beaver activity, although there has been limited impact on conifer timber crops to date. However, there will also be some additional short-term costs associated with any reinforcement of the beaver population. The SBT study suggested that the relative novelty of the animals will be maintained, thereby sustaining the levels of visitation, educational and volunteering benefits. It also seems likely that local businesses will feel more confident to invest in longer term facilities and marketing, thereby increasing the 'honeypot' effect of the site[17].

In terms of benefits, and even in the event of a wider reintroduction of beavers across Scotland, it is suggested that Knapdale can maintain the allure and marketing appeal of being the 'original' release site, in a similar way that Loch Garten does for ospreys. Knapdale has the benefit of a head start, which means that is likely to maintain its share of visits[17].

The potential impacts on the River Tay fishery have been reported as uncertain, although possibly high[22], particularly if beaver management measures are not in place (see section 4.2). The potential for beavers to negatively affect forestry in Tayside is greater than at Knapdale, as broadleaved tree species are managed commercially in parts of Tayside and there are larger areas of potential beaver habitat (section 4.3). Sections 4.4 and 4.5 discuss implications for agriculture and infrastructure, respectively.

The Tayside socio-economic study employed a simple modelling exercise to predict the future expansion of the beaver population in the Tay catchment. It used the data from the 2012 Tay beaver survey[23] to estimate that beavers occupied just under a quarter of the length of the 1,000 km of main and secondary rivers in the Tay catchment. The future colonisation of all of the major and secondary rivers was estimated to involve costs of up to £365,000 per year[18]. An alternative method was also used based on the current, estimated beaver population

Figure 4.9
The scientific monitoring of the SBT was one of the major costs.
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density in the Tay catchment. This resulted in lower estimated annual costs of up to £232,000 for the full catchment, should colonisation occur at the predicted maximum population density rates[18]. If beavers also populated minor rivers, the costs (using either method) would be significantly higher, although it was thought that this scenario is unlikely as much of the habitat was judged unsuitable for beavers[18].

In spite of these potential costs, the Tayside report[18] concluded that: 'In summary, there is the potential for high impacts and costs in certain parts of the catchment, primarily in the lower catchment, with impacts to flood defence infrastructure. The relatively small market benefits currently being realised have the potential to increase, and the non-use value may be considerable. Taking these estimates in aggregate and pending judgement on non-use value, the benefits of beaver tolerance are likely to outweigh the costs incurred, which can themselves be lowered by appropriate management and mitigation measures.'[18]

The report also acknowledges that the modelling efforts at Tayside are preliminary[18]. SNH has recently revised its potential beaver woodland map for Scotland and has worked with the University of Newcastle to develop a population model to provide a more accurate means of predicting the potential colonisation of catchment by beavers (see section 3.2).

Another potential future cost at both Knapdale and Tayside relates to beavers' impact on public and animal health. This is covered in section 4.6, and a range of potential diseases and parasites are considered, including *Echinococcus multilocularis* and rabies. The potential future additional risk to Knapdale and Tayside arising from the presence of beavers has been judged to be low. However, it is noted that key requirements for any future beaver imports are pathogen screening and health assessments.

Potential future implications of wider reintroductions in Scotland

The benefits of wider reintroductions will depend on the extent of beaver colonisation, and Chapter 6 considers some future scenarios, including some of the issues surrounding future costs and benefits. One thing to note is that the *marginal* benefits from 'cultural ecosystem services' (e.g. benefits relating to recreation, education and NUV) are likely to decrease as the beaver population increases. For example, beaver release sites outside Knapdale are unlikely to attract the same number of

Figure 4.10
Visitor facilities at Knapdale.
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tourists, as they will not have the marketing appeal of being the 'original' release site, and might not have the same infrastructure in place to attract visitors. In contrast, the marginal impacts in terms of 'provisioning' and 'regulation and maintenance' ecosystem services, both positive and negative, should be maintained in the event of a wider reintroduction.

Sections 4.2 to 4.6 consider the implications of an increased beaver population for fisheries, forestry, agriculture, infrastructure and public/animal health. There is some evidence of benefits (e.g. for land use objectives that relate to recreation and biodiversity) and, where costs are likely, a general conclusion is that negative impacts may be avoided or mitigated through suitable management. In the survey of land managers, the Tayside study[18] asked respondents about their preferences between different management and mitigation strategies. The most popular were compensation, dam removal and local control measures. Other options that received less support were translocation, fencing, tree planting and flow controls. The legal and practical issues surrounding the management of beavers are set out in Chapter 5, including cost estimates of individual management techniques.

Table 4.4
Summary of potential interactions between beavers and the human environment. At some sites appropriate management may be needed to counteract negative effects and promote positive effects. Note that the significance of any individual effect may be far higher or lower than that of other effects.

*Note that for all these activities, there will be a range of positive and negative effects on habitats and species (described in sections 3.4.1 to 3.4.10), with consequent implications, especially for 'cultural ecosystem services'. Atlantic salmon is one particular species with a high socio-economic value, and for which the potential interaction with beavers is likely to be complex, and may be positive or negative depending on the specific situation (see section 3.4.7 for details). However, beavers are likely to have an overall positive effect on biodiversity, and therefore on a range of ecosystem services. Outcomes could be further improved through appropriate planning of any further reintroductions and targeted management.

Activity	Mechanism	Positive effects	Negative effects	Notes
Felling	Change in riparian woodland: Opening of woodland canopy and increased patchiness	– Overall positive effects on habitat diversity at landscape scale since beaver activity markedly increases habitat heterogeneity and patchiness through the creation of canopy gaps, etc. Therefore, overall positive effects on biodiversity and, consequently, on a range of ecosystem services – Increase in amount of light reaching watercourses, and therefore stabilisation of banks and reduction in erosion due to binding effect of bank and riparian species		*See above
Felling	Change in riparian woodland: Change in relative abundance of different tree species		– Possible reduction in deep-rooted species that bind bank material, and therefore possible increase in erosion – Felling of trees of commercial or ornamental value. Minor, localised reduction in timber availability in longer term	*See above Timber availability likely to be a minor impact, as Scottish forestry relies mainly on conifer species, which are unattractive to beavers
Felling	Change in riparian woodland: Change in age classes of trees		– Implications for deer management planning	*See above
Felling	Change in riparian woodland: Amount/diversity of fallen dead wood on woodland floor			*See above
Felling and constructions	Changes in amount/ diversity of woody material in watercourses	– Increased number of wood jams, resulting in attenuation of flow and lowering of downstream flood risk and improvements in water quality as fine sediments settle in areas of slower flow	– Increased number of wood jams, so a possibility of localised floodplain inundation and impacts on land use	*See above
Feeding	Feeding on specific terrestrial herbaceous and aquatic plant species	– Clearance of vegetation that is acting as a barrier to water flow may restore flushing rates in standing waters and prevent backing-up and consequent flooding	– Feeding on crops in the riparian zone	*See above

Activity	Mechanism	Positive effects	Negative effects	Notes
Dams/pond creation	Change from lotic to lentic habitat	– Overall positive effects on habitat diversity at landscape scale since beaver activity markedly increases habitat heterogeneity and patchiness, with lentic and associated wetland habitat interspersed with lotic habitat. Therefore, overall positive effects on biodiversity and, consequently, on a range of ecosystem services – Increased flood storage, and therefore a decrease in downstream flooding – Improvements in base flow during drought periods due to increased water storage – Creation of pond–wetland systems may improve the quality of water flowing into lochs, thereby improving the water quality of standing waters	– Increased flooding of riparian zone and beyond, so potential impacts on land use	*See above
Dams/pond creation	Change in hydrological processes on riparian and downstream habitat	– Hydrological cycle and water flow maintenance: - improvements in base flow, and protection of lochs, during drought periods due to increased water storage. Increase in water tables would lead to larger stock of water for drinking and non-drinking purposes (e.g. domestic use, irrigation, livestock consumption, industrial use) - increased flood storage, and therefore a decrease in downstream flooding - hydrological alternations may restore natural connectivity in wetland–loch systems - water level rise in standing waters would be expected to increase the area of standing water habitat - water level rise increases the volumes of standing waters, and greater volume may improve the capacity of a loch for dilution of nutrients and phytoplankton - Carbon sequestration through wetland creation	– Increased flooding of riparian zone and beyond, so potential impacts on land use such as cultivated crops, meat and dairy products and timber (indirect impacts due to localised flooding), plus infrastructure (direct impacts due to localised flooding of roads and tracks, blocking of culverts, weirs, fish passes, etc.) – Flooding of terrestrial land upstream/adjacent to lochs may result in deterioration of water quality through decay of vegetation and leaching of nutrients from soils – Flooding of peaty soils may result in an increase in the concentration of humic substances in the water of lochs, thereby causing a decrease in light penetration – With increasing loch volume, water retention time increases, flushing rate decreases and nutrients and phytoplankton are retained for longer within the loch	*See above Problems resulting from leaching of nutrients from soils are more likely in catchment areas that are fertilised Volume and flushing rate are variables that have considerable influence on the effects of nutrient loadings in lochs. Effects of alteration of these factors by beavers are unknown and would be site specific. In effect, a reduction in flushing rate may offset an increase in volume

Activity	Mechanism	Positive effects	Negative effects	Notes
Dams/pond creation	Changes in water quality downstream	– Bio-chemical remediation, e.g. beaver dams reduce the rate of erosion and sediment movement, and therefore the speed at which sediment leaves streams and rivers – Creation of ponds on inflow waters may lead to improvement in the quality of water in the receiving waterbody through attenuation of flow, sedimentation of solids and assimilation of nutrients within the ponds	– Reduction in turbulence upstream of dam, and so a decrease in the rate of water oxygenation – Creation of ponds on inflow waters may lead to deterioration of water quality of loch inflows through changes in pH, a decrease in dissolved oxygen levels, a build-up of pollutants and disturbance within the ponds	*See above Reduction in erosion may mitigate downstream water treatment costs Build-up of pollutants within created ponds would be a consequence of upstream land use rather than of beaver activity, so overall the effects of beavers may be neutral/positive May mitigate downstream water treatment costs. Also potential benefits of improved water quality for recreation activities and fisheries, etc.
Dams/pond creation	Change in standing dead wood resulting from inundation of trees		– Standing dead wood could harbour diseases that affect health of commercial tree species	*See above
Dams/pond creation	Longer term successional changes after dam abandonment, e.g. beaver meadows	– Overall positive effects on habitat diversity at landscape scale since beaver activity markedly increases habitat heterogeneity and patchiness. Therefore, overall positive effects on biodiversity and, consequently, on a range of ecosystem services – Improvements in natural flood management, reconnection of streams and rivers with floodplains, and therefore lateral extension of river corridors		*See above
Dams/pond creation	Impacts on movement of species		– Potential impacts on the movement of fish, with associated socio-economic consequences for food, tourism and recreation	*See above
Other constructions	Creation of lodges, burrows, canals, etc.		– Burrowing activity affects flood defences, agricultural land, sites of historical importance, etc.	*See above

Activity	Mechanism	Positive effects	Negative effects	Notes
Other		– Various 'cultural ecosystem services' related to recreational, educational, aesthetic and symbolic aspects		*See above These types of impacts are not connected to any single beaver activity *per se*, and may relate to the mere presence of beavers (e.g. as an 'iconic' animal). Also relates to socio-economic 'existence' values, and the bequest value for future generations
Indirect habitat creation/ restoration initiatives as result of beaver presence	Beaver used to promote opportunities for riparian and freshwater habitat creation/ restoration	– Restoration of riparian habitat, aquatic and wetland, for example by extending 'buffer zones' along the edges of watercourses, is likely to result in improvements to water quality of standing waters, restore natural connectivity in wetland–loch systems and benefit habitat and species (including those which may be otherwise adversely impacted, e.g. aspen), with consequent 'cultural ecosystem services' benefits		*See above This may include positive impacts on tourism (e.g. for wildlife watching associated with riparian and freshwater habitats). Also relates to socio-economic 'existence' values, and the bequest value for future generations

4.2 Fisheries

Overview

The potential for interactions between beavers and fish have been reviewed extensively[1, 2]. Whilst these reviews focused on the potential impact of beavers on 'fish' rather than 'fisheries', it is clear that any impacts on fish of commercial or sporting value may also have direct impacts on associated fisheries. Published data on the direct impact of beavers on freshwater fisheries outside Scotland are surprisingly few.

Scottish experience

The report of the Beaver-Salmonid Working Group[3] (BSWG) critically reviewed the potential impact of reintroduced beavers on Atlantic salmon and, to a lesser extent, trout within Scotland. These species were covered in greater detail because salmonids comprise the highest-profile freshwater fisheries in Scotland, but they are not the only fisheries sector that may be affected by the reintroduction of beavers.

Scottish freshwater fisheries can be broadly characterised as being either game (salmonid) or coarse (non-salmonid). In Scotland, Atlantic salmon is widely regarded as the most iconic freshwater fish species, and fishing for this species, and sea trout, takes place in almost every river where they are known to occur. The current management framework for Scottish freshwater fisheries, with most powers being devolved to a network of 42 District Salmon Fishery Boards (DSFBs), clearly signifies the importance of migratory salmonids to the angling sector. In addition to DSFBs, the *Scotland Act 1998* makes special provision for the management of salmon and freshwater fisheries in the Borders rivers, the Esk and the Tweed. Unlike the DSFB role, the *Scotland Act 1998 (River Tweed) Order 2006* empowers the River Tweed Commission to manage all species of freshwater fish within its district.

In Scotland, fishing rights are private and it is not the fish but the right to fish that is owned. Salmon fishing rights (including those used by netsmen) are heritable titles, which may be held with, or separate from, any land. The right to fish for salmon also carries with it the right to fish for trout but this right must not be exercised in a way that will interfere with the rights of the riparian owner. Access to fisheries is largely controlled by the proprietors, who include, for example, The Crown Estate, private individuals, companies, local authorities and angling clubs/associations. This complex system of fishing rights and ownership means that reintroducing beavers may affect a wide range of stakeholders.

The last national assessment of the value of freshwater fisheries in Scotland estimated that salmon angling was worth over £73.5 million per year to the local economy[4] (Figure 4.11). Angling for brown trout, which is also widespread throughout Scotland, was assessed as being worth £14.7 million to the Scottish economy. Other angling sectors, such as those for rainbow trout and coarse fisheries (e.g. pike, roach, perch, carp) were, at the time of the assessment, estimated to contribute £19.4 million and £4.9 million to local economies. The rise in popularity of coarse angling in Scotland suggests that the 2004 figure may be an underestimate. Taken as a whole, angling in Scotland provides almost £113 million to the Scottish economy and supports around 2,800 jobs, many of which are in rural areas. The BSWG[3] was clear in

Figure 4.11 Fisheries are an important part of the Scottish rural economy.
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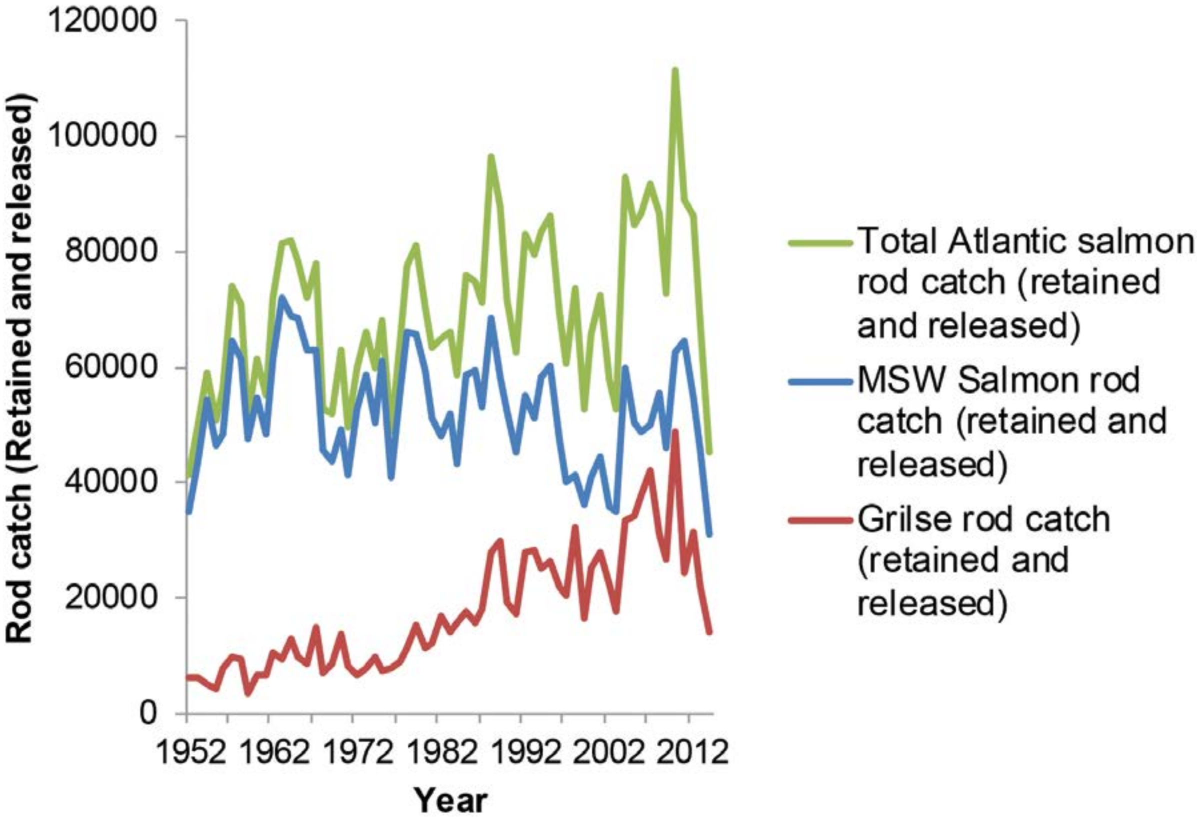
Figure 4.12
The number of fish retained and released by anglers during the period 1952–2014, broken down into Multi-Sea-Winter (MSW) and grilse stock components (data provided by MSS, Crown copyright).



its view that the economic and social benefits to be gained from the presence of beavers must be balanced against the threat of any damage they might cause.

The BSWG was set up in 2009, as a sub-group of the National Species Reintroduction Forum, to critically examine the impact that reintroduced Eurasian beaver may have on the Atlantic salmon resource (see Chapter 2). Atlantic salmon stocks have declined across much of their geographical range[5]. In Scotland, where the annual rod catch is used as a broad indicator of trends in the size of the spawning population, adult abundance is also influenced by the activity of distant water and coastal net fisheries[6]. Rod catch data, available from 1952 to the present day, show that considerable variation in annual abundance exists within each of the 109 Fishery Districts and also among individual stock components. Generally, the available data suggest that the overall number of Atlantic salmon returning to Scottish rivers increased over recent years, with the highest recorded rod catch occurring in 2010. Since 2010, however, the recorded rod catch has dropped in each subsequent year and the 2014 catch is the lowest in the data series. However, some limited independent data from traps and fish counters collated by Marine Scotland Science (MSS) did not show the same major decline in Atlantic salmon abundance between 2013 and 2014. This suggests that poor angling conditions, rather than actual fish abundance, may have also contributed to the low reported catches. These data are shown in Figure 4.12.

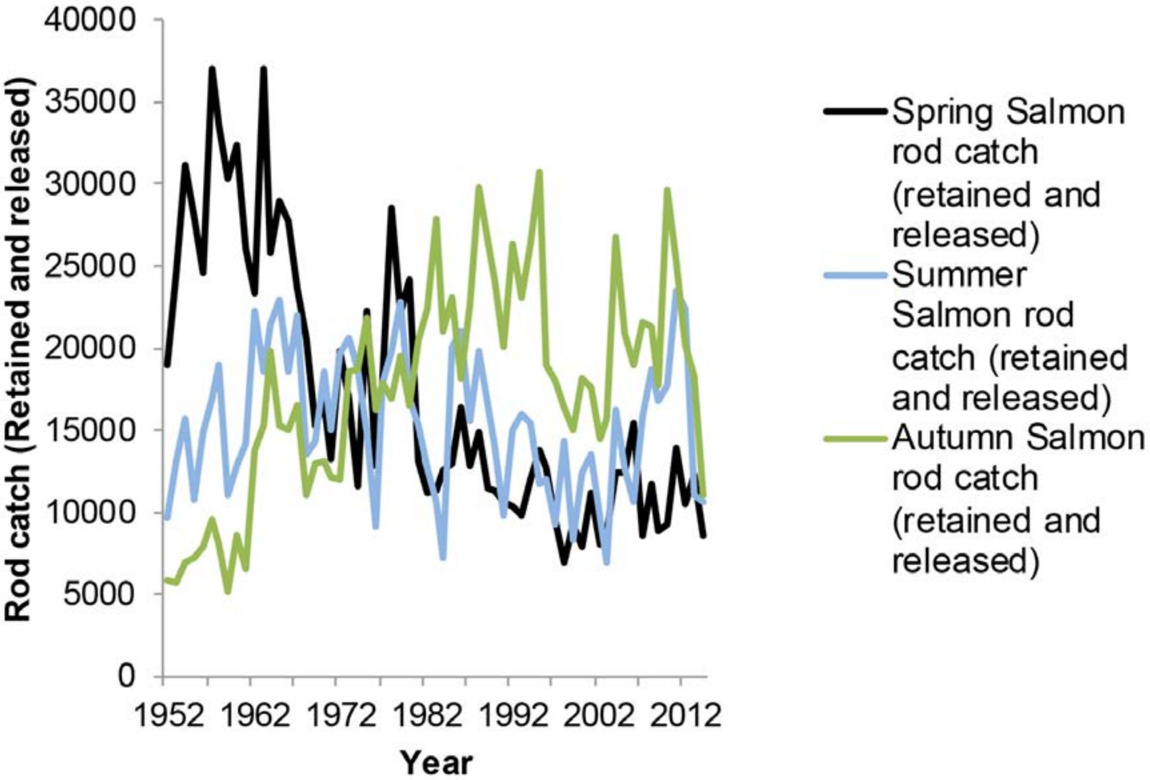
However, the spring Atlantic salmon stock component (fish which have spent at least two winters at sea and enter the river during the period January to May) has been in decline over the time series and, although numbers have generally stabilised over recent decades, they remain at historically low levels (Figure 4.13).

MSS[6] suggests that, on occasion, the number of returning spring salmon is insufficient to ensure that enough adults reach the spawning tributaries of this stock component to maximise the production of juvenile emigrants. The spawning areas of spring salmon tend to be located in the upper reaches of river catchments[7], and it is important that access to such areas is assured.

Scotland hosts the majority of the UK's Atlantic salmon rivers and 17 rivers have been classified as SACs for this species. The presence of a range of life-history types, including the presence of a spring Atlantic salmon stock component, was one of the factors used to identify the 11 rivers where Atlantic salmon is a primary reason for selection. Spring salmon are also present in the six remaining SAC rivers where Atlantic salmon are identified as a qualifying feature, but not a primary reason for site selection.

It is now illegal to kill any Atlantic salmon (which are principally 'spring salmon') caught from January to 1 April under *The Conservation of Salmon (Annual Close Times and Catch and Release) (Scotland) Regulations 2014*. In three rivers (Annan, Eachaig and Esk), the annual close time extends beyond this date, and in the Tweed

Figure 4.13
The number of spring, summer and autumn Atlantic salmon retained and released by anglers during the period 1952–2014 (data provided by MSS, Crown copyright).



system it is illegal to kill any salmon caught before 30 June. In a further attempt to control the exploitation of Atlantic salmon populations, the Scottish Government is currently consulting on a proposal to ban the killing of wild Atlantic salmon except under licence. This, along with the establishment of a new management structure for freshwater fisheries, was a key recommendation of the recent government-sponsored Wild Fisheries Review.

Significant sea trout fisheries (the anadromous form of *Salmo trutta*) also exist in Scotland. Whilst rod catches have declined in many areas of Scotland since 1952, recent data[6] suggest that, overall, numbers have stabilised. Like Atlantic salmon, most of the sea trout captured in Scotland by anglers are released.

When assessing the scale and direction of any possible interactions between beavers and fisheries (for any species), it is important that the ecological requirements and behaviour of beavers, and the fish species concerned, are understood. The ecology of Atlantic salmon is well understood and the ecology of Eurasian beaver can be broadly inferred from published literature, including that arising from the Scottish Beaver Trial (SBT). This approach allowed the BSWG to assess the potential magnitude of spatial overlap between the possible range of beavers and the distribution of salmon[3, 8]. These analyses, based on an earlier version of the potential beaver woodland described in section 3.2, suggested that a large overlap would generally be expected but will vary spatially, both within and between catchments.

This does not infer that the level of overlap equates to the total area over which interactions between beavers and Atlantic salmon may occur. Neither does it predict the scale or direction of any impact. The BSWG report[3] suggests that whilst tributaries can be important spawning and rearing areas for Atlantic salmon throughout catchments, the upper tributaries which are commonly used to produce the spring Atlantic salmon stock component are currently under the most threat, and hence are the most vulnerable to any obstructions from beaver dams (Figure 4.14).

Opportunities to monitor the impact of the beaver reintroduction at Knapdale have been limited. Recreational angling within the SBT area is controlled by the Lochgilphead & District Angling Club (LADAC). LADAC maintains boats for its members and carries out light stocking activities to supplement brown trout populations within each of the 15 hill lochs that it manages. There was no indication during the trial period that beavers, which utilised the lochs extensively[9], negatively affected the operation of Loch Barnluasgan and Loch Coillie-Bharr as a recreational fishery.

The BSWG report[3] concluded that a fundamental prerequisite for any decision to formally reintroduce beavers would be the development of a general beaver management strategy, which includes provisions for

Figure 4.14
Beaver dam on Tayside.
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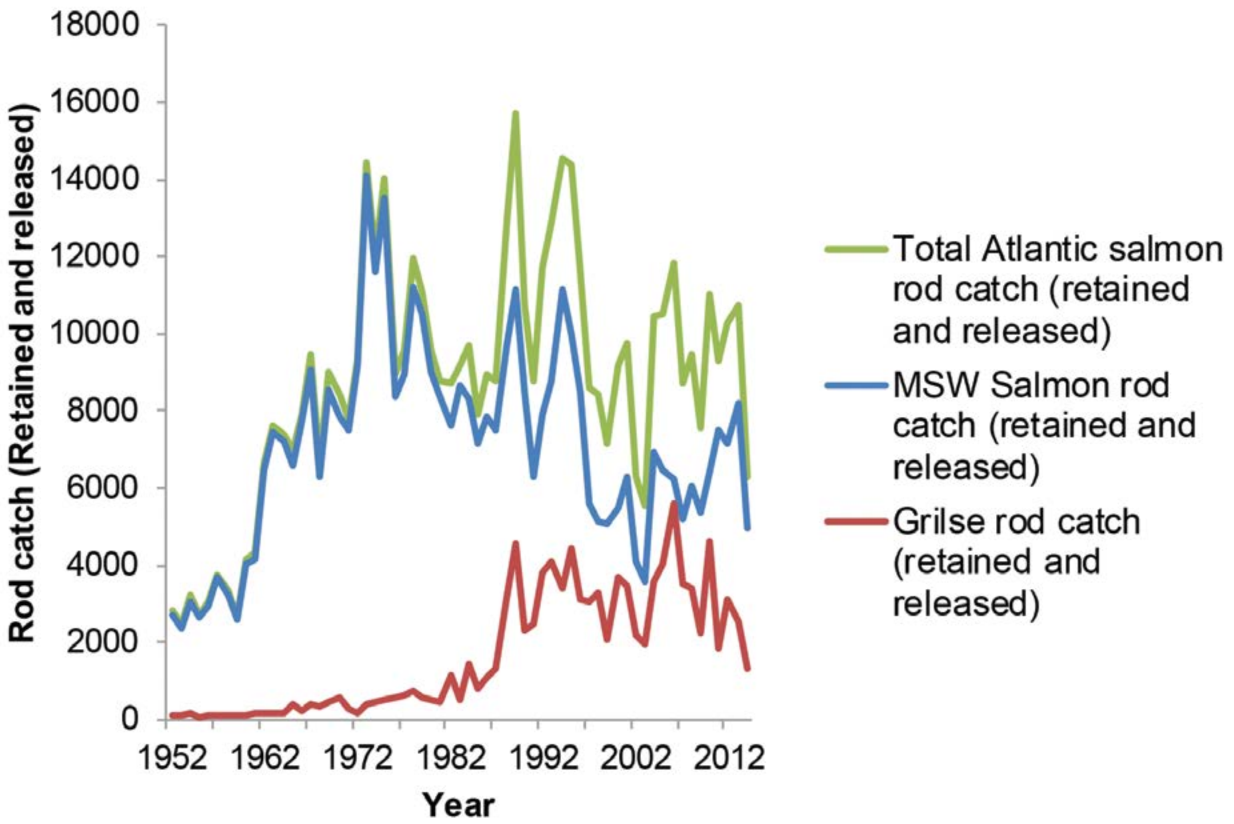
salmonids, as well as consideration of where responsibility for meeting any associated management costs should rest. The group recommended that this management strategy should be developed in full consultation with all key stakeholders. From a fisheries perspective, this would also include representation from trout and grayling anglers as well as input from the coarse angling sector. The BSWG report also recommended that any strategy should consider the following:

– The construction of beaver dams, beavers at pinch-points 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 recent GIS-based analysis of the overlap of areas predicted to be less likely to be dammed with existing anthropogenic watercourse structures showed that 78% of all culverts, weirs, and fish passes in Scotland were at locations where damming was less likely[10]. However, of key importance is the location of impassable dams, and the reduction in accessible habitat that they would cause. Further analysis could be done in the future to highlight which structures risk impeding Atlantic salmon access to key habitats.
– The development of a beaver management strategy, which 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. Chapter 5 provides a detailed overview of the legal and regulatory framework relating to the management of beavers in Scotland, including options for control. The BSWG recommendations go on to state that beaver presence alone should not be a trigger for action and that a strategy should allow a range of management interventions to be undertaken from short-term action to longer-term intervention. The requirement or otherwise for such intervention may be determined partly 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
– The imperative of ensuring free passage of migratory fish suggests that any management strategy should recognise the dynamic nature of beaver dams and the resources required in assessing such structures on multiple occasions. In addition, any removals of dams from watercourses must adhere to current regulatory guidance and be completed without causing pollution or affecting stream biota
– The resource implications associated with monitoring and management. The BSWG considered it vital that such resources are committed, over the medium to long term, to relevant management authorities

Figure 4.15
The number of Atlantic salmon retained and released by anglers in the River Tay during the period 1952–2014 broken down into Multi-Sea-Winter (MSW) and grilse stock components (data provided by MSS, Crown copyright).



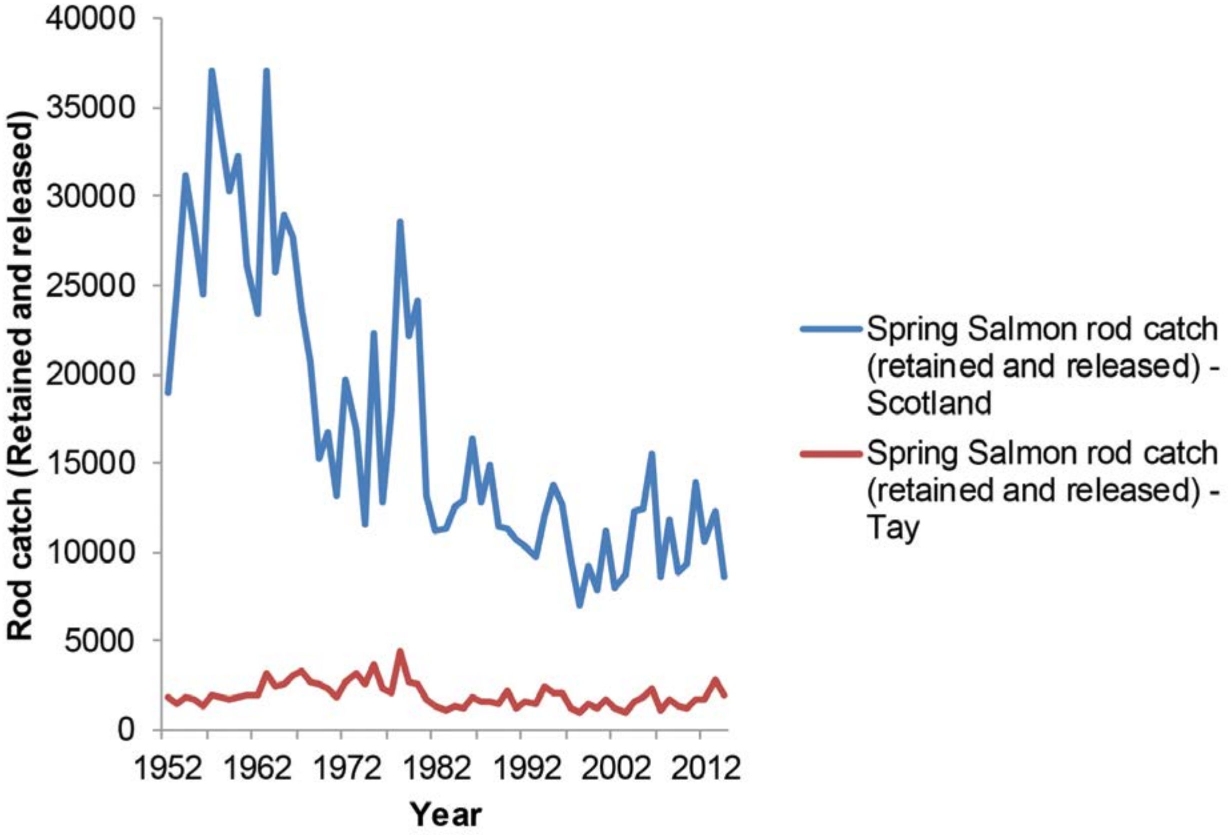
– The significant gaps in our knowledge of beaver–salmonid interactions, both within Scotland and abroad. There is also a lack of data available to inform our knowledge of the interaction between beaver and other species of conservation interest, including the European eel, lamprey species and freshwater pearl mussel (see section 3.4.6). Further research in Scotland is considered necessary to help inform when management intervention may, or may not, be required
– The potential, and possibly extensive, overlap between known Atlantic salmon distribution and potential beaver habitat in major rivers, with potential overlap in minor rivers varying considerably between catchments. Both the mapping study carried out by MSS[8] and the more recent GIS-based analyses of dam-building potential in SACs[10] (Table 4.5) suggest significant variability in the extent of areas likely to be affected. In 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 with certainty whether the overall net impact of beaver presence will be positive, negative or negligible on salmonid fish or other species of conservation importance. However, beaver dam-building activity, and the associated potential hindrance to fish passage, is of particular conservation concern to the spring salmon component of the Atlantic salmon stock, which utilise upland nutrient-poor streams
– The wider socio-economic and ecosystem service benefits which could result from the presence of beavers. There are also potential benefits of beaver presence to salmonids, and these may be realised, particularly where management options are available

Potential future implications for Knapdale and Tayside

The potential for using Knapdale as a study site for assessing the impact of beavers on stream fisheries is extremely limited because these areas are themselves not used as a fisheries resource. These streams do, however, provide spawning habitat for those fish which are present in connected standing waters. The existing monitoring programme has already provided some evidence that trout are able to utilise spawning habitat in the presence of beavers, although these data are limited[11]. If allowed to continue, and if work is focused on areas where beaver activity is greatest, this research may help elucidate the impact of beaver activity on trout recruitment in loch-based fisheries within the Knapdale area.

All angling in the Knapdale area is restricted to standing waters. These waters are regularly, but lightly, stocked by LADAC with brown trout. Rainbow trout

Figure 4.16
The number of spring salmon retained and released by anglers in Scotland compared with that of the River Tay during the period 1952–2014 (data provided by MSS, Crown copyright).



have also been stocked into at least one loch within the area[11]. Baseline data for fish in standing waters within the Knapdale area are lacking, making an assessment of fisheries impact difficult.

The River Tay supports significant recreational fisheries for Atlantic salmon, trout (including sea trout) and grayling. It is one of the most iconic of the Scottish Atlantic salmon rivers and the number of rod-caught Atlantic salmon makes it one of the most important catchments for this species in the UK. Data available for 2014 showed that the Tay rod catch (6,279 fish) was the second highest in Scotland in that year (Figure 4.15).

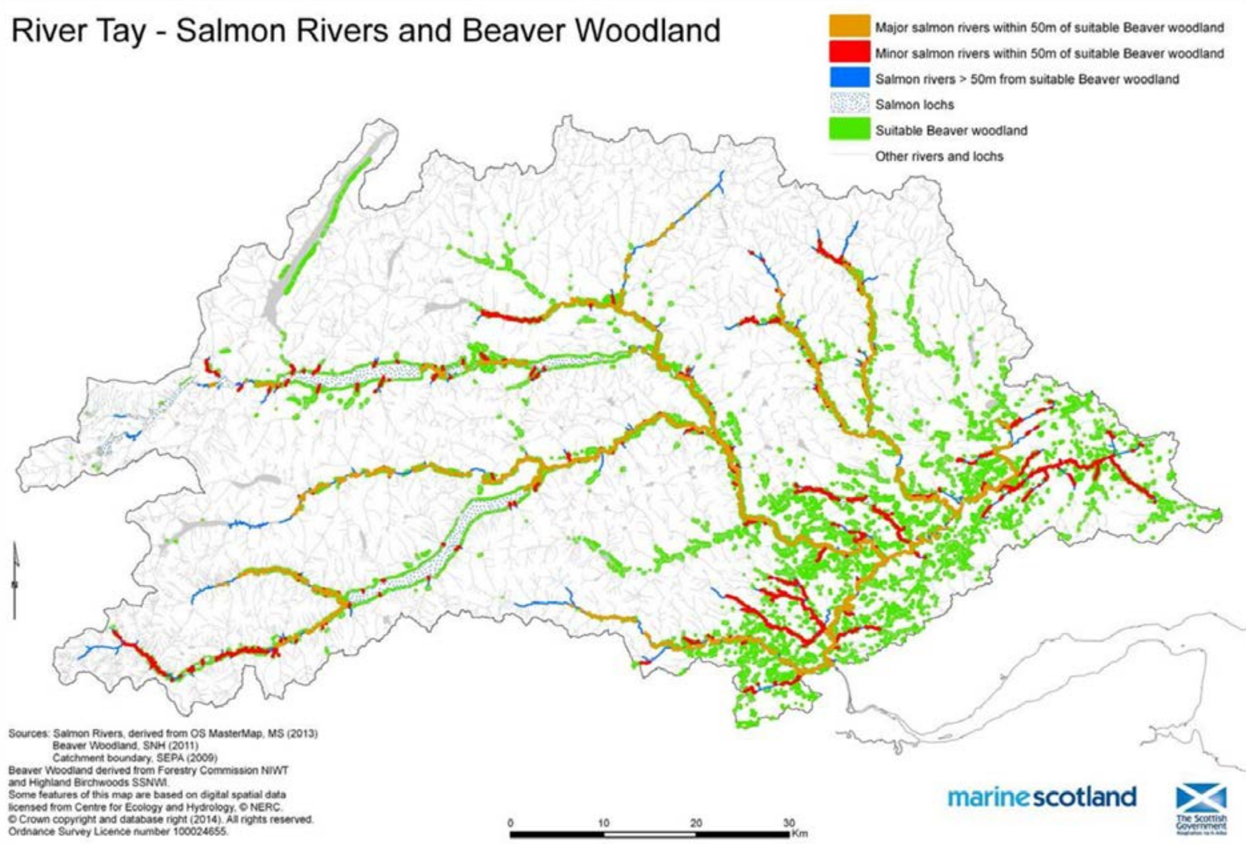
The spring salmon rod catch was the highest in that year (1,931 fish) and 91% of these fish were returned to the water after capture. This clearly indicates the relative importance of the River Tay for this stock component in a national context. Figure 4.16 shows that, despite declines elsewhere, the spring stock component has performed remarkably consistently over the period for which records are available.

Although little is known about the actual impact of beaver activity on fish in Scotland, the potential for fishery impacts within the River Tay is considered high[3], particularly if beaver management measures are not in place.

As well as supporting a fishery of national importance, Atlantic salmon are also a qualifying feature within the River Tay SAC. Three other fish species (brook lamprey, river lamprey and sea lamprey) and otter are also present as a qualifying feature within the site. Although not a qualifying feature, the river also hosts a nationally significant population of freshwater pearl mussel, a species that depends on the presence of salmonids to complete its life cycle. Freshwater fish are important elements of the ecology of both freshwater pearl mussel and otter, though only the freshwater pearl mussel is wholly dependent on the presence of salmonids. A reduction in the number or distribution of fish may negatively affect either feature, although it is possible that negative impacts may be offset by potential improvements in water quality for freshwater pearl mussel or the creation of habitats that may benefit otter (see sections 3.4.6 and 3.4.10).

The River Tay SAC is currently in favourable condition for its Atlantic salmon, lamprey and otter conservation features, and deterioration from this status, for any feature, should be prevented. This suggests that a careful assessment of the potential and current impact of beaver not only on Atlantic salmon, but also on brook lamprey, river lamprey, sea lamprey and otter should be carried out to ensure that deterioration in conservation status is avoided. For Atlantic salmon, the Scottish Government must also consider its international obligations, such as those to the North Atlantic Salmon Conservation

Figure 4.17
Map produced by the BSWG showing areas of the River Tay catchment where Atlantic salmon waters are present within 50 m of 'suitable beaver woodland' (this is equivalent to 'potential beaver woodland' described in section 3.2 of this report, but based on an earlier version of the dataset)[8].



Organization (NASCO), to maintain and manage this species.

A GIS analysis of the River Tay catchment by the BSWG[3, 8] showed that generally a large overlap would be expected between potential beaver woodland and Atlantic salmon distribution, but this will vary spatially within the catchment (Figure 4.17). Interrogation of these data suggests that the potential beaver–salmon overlap within the River Tay catchment is, at 72%, extensive, although this is a maximum figure which may not be reached. The potential for overlap is highest in rivers wider than 10 m (75%) and slightly lower in rivers less than 10 m wide (59%). It is important to note, however, that 'potential' overlap does not in itself represent the total area over which interactions between beavers and Atlantic salmon may occur, and nor does it provide information relating to the scale or direction of any impact. In some areas, beaver activities and dam-building may have positive effects on factors such as water quality downstream. Conversely, obstructions at the downstream end of important tributaries, such as those used by the spring stock component of Atlantic salmon populations, may affect access to important spawning areas. A more recent database was produced by SNH to identify river sections which are less likely to be dammed based on two main criteria: river widths greater than 6 m and the absence of potential core beaver woodland (section 3.2 and Table 4.5). This showed that, for the River Tay, which has a total river length of 1,029 km, a low likelihood of dam-building was estimated, along about 93% of the river.

A one-off survey in 2003 reported an estimate of 35,000 Atlantic salmon 'angling days' spent within the Tay system each year. Approximately 42% of these (15,000) were by anglers who resided outside Scotland. This suggests that Atlantic salmon angling contributes substantially to the local economy within Tayside. The Tay District Fisheries Management Plan for 2009–2015[12] states that angling effort has reduced markedly, particularly during the early spring. In this respect, beavers could potentially offset losses in visitor revenue. Socio-economic assessments of the SBT and Tayside[13,14] have described the public interest in and economic value of beaver presence, and this is summarised in section 4.1. The Tayside report noted that whilst some landowners had incurred management costs, they were willing to tolerate them pending appropriate control and potential compensation. Like the situation in Knapdale, businesses and conservation organisations suggested that beaver presence could be exploited and would benefit local businesses through increased tourism draw.

Angling within the River Tay catchment is not, however, restricted solely to Atlantic salmon, and well-developed riverine fisheries exist for a range of other species, such as trout and grayling. These are well described within the

Tay District Fisheries Management Plan[12]. Trout are, as in most Scottish fresh waters, the most widely distributed fish within the Tay catchment, including upland areas that are inaccessible to Atlantic salmon. Both brown trout (the freshwater resident form of *S. trutta*) and sea trout (the anadromous form) typically spawn in small watercourses that range from 1 to 3 m in width, and these fish may migrate over short and (particularly in the case of sea trout) long distances to reach these areas. Both forms of trout are exploited by anglers, although information relating to the actual contribution of this species to the local economy is lacking. As a function of their widespread distribution within small watercourses, it is possible that the potential overlap between beaver activity and trout may be more significant than has been estimated for Atlantic salmon. It is therefore not possible at this time to predict what impact reintroduced beaver might have on trout fisheries within the River Tay catchment.

Grayling are not native to Scotland, but have been present in the River Tay since the nineteenth century and have spread throughout the main stem of the Tay, the Isla, the lower Tummel and the Earn[12]. Grayling angling, mostly on a catch-and-release basis, is well established in these watercourses. As this species appears to be limited to relatively large watercourses, the interaction between beavers and grayling may be less than that predicted for Atlantic salmon and trout. Little information is available relating to the population status and local ecology of grayling within the River Tay system, and few data are publicly available on the numbers of grayling caught and its value to the local economy. This makes an assessment of the impact of beavers on the grayling fishery difficult.

Both the European eel and pike are present within running waters in the Tay system. European eel is widely distributed throughout the catchment, although pike is limited to slower-moving reaches of the larger river systems and standing waters. Although angling for pike is popular where they occur within the system, this activity appears to be unregulated and unmonitored. Both European eel and pike are species which benefit from the presence of impoundments and the creation of wetland habitats. For instance, a study of fish community structure in the Canadian Shield Lakes suggested that North American beavers had an overall positive impact on pike abundance and productivity[15]. It might be expected that a similar response could occur in relation to the Eurasian beaver. Perch and roach are probably not native to the Tay catchment and are also present in slower-moving reaches of the larger river systems, as well as some standing waters. Similar to the situation for pike, this fishery is unregulated and unmonitored. The ecology of these species suggests that they may also benefit from the presence of beaver-created impoundments and the creation of wetland habitats.

Potential future implications of wider reintroductions in Scotland

It is widely accepted that the Eurasian beaver is a natural component of Scotland's wildlife heritage and that it was lost as a result of man's activities. Atlantic salmon and other native freshwater species, such as trout, European eel and lamprey, evolved with beavers over millennia and clearly these species co-occurred in Scotland.

Table 4.5
The proportions of river lengths of Atlantic salmon SACs that are estimated to be less likely to be dammed by beavers. These estimates are based on river width (greater than 6 m) and the absence of potential core beaver woodland.

SAC	River length (km)	River length predicted to have less likelihood of being dammed (%)	River length predicted to have an unknown likelihood of being dammed (%)
Little Gruinard River	57	100.0	0.0
River Thurso	114	100.0	0.0
Langavat	107	99.6	0.4
North Harris	311	99.6	0.4
Berriedale and Langwell Waters	46	99.3	0.7
River Oykel	242	98.1	1.9
River Naver	141	97.2	2.8
River Borgie	17	95.9	4.1
River Teith	188	94.8	5.2
River Bladnoch	154	93.7	6.3
River Tweed	1,089	93.4	6.6
River Tay	1,029	93.4	6.6
River Moriston	43	93.0	7.0
Endrick Water	47	92.5	7.5
River South Esk	188	87.9	12.1
River Dee	686	85.0	15.0
River Spey	1,042	84.5	15.5

Past and recent reviews[1, 2], as well as the report of the BSWG[3], acknowledge that beavers can have overall positive effects on the production of some species of fish. This is largely because of the ability of beavers to modify river habitats and, as a consequence, influence hydrological characteristics and water chemistry within the watercourse. This must, however, be balanced against possible negative impacts of dam-building on the movement of fish within river systems and their effect on critical in-stream habitats.

From a fisheries perspective, it is likely that the two species which will be most influenced by the presence of beavers are Atlantic salmon and trout. Whilst Atlantic salmon and trout co-exist across much of their range, they differ in respect of their in-stream habitat requirements[16, 17]. As well as differing in their usage of in-stream habitats, trout do not make as much use of larger tributaries for spawning as Atlantic salmon. This means that beaver activity on small streams may have a disproportionate importance for trout production. The contribution of trout from these streams to the overall fishery resource within the Scottish river catchments, including the supply of fish to already declining sea trout fisheries, is a key consideration.

The status of Atlantic salmon, and the spring stock component in particular, has already been described in this section. The decline in pre-fishery abundance within the overall southern Europe Atlantic salmon stock since 1970 (which also includes the UK) points towards a significant reduction in marine survival[18]. The causes of this are unclear, although climate change may be a significant factor[19]. The resilience of migratory salmonid populations to new pressures is an issue that must be considered in respect of how beaver–salmonid interactions are managed.

Mapping work carried out for the BSWG[3, 8] indicates, for the six catchments studied (Awe, Ayr, Conon, North Esk, Tay and Tweed), that the percentage overlap between potential beaver woodland habitat and the wetted area of Atlantic salmon habitat ranged from 47% to 73%. This overlap was greater in rivers wider than 10 m (54–87%) than for rivers less than 10 m wide (15–59%). As previously mentioned, a more recent SNH assessment predicted river sections which are thought to be less likely to be dammed by beavers (section 3.2). This suggests that, within the SACs classified for Atlantic salmon, the lengths of the rivers predicted to be less likely to be dammed range from 84.5% for the River Spey up to 100% for the Little Gruinard River and River Thurso (Table 4.5).

This type of approach, extended throughout Scotland, can help identify areas where effective management may be required and available resources usefully deployed. Prioritising areas where the Atlantic salmon spring stock component are known to spawn, for example, may be a useful starting point if that element of the fishery resource is to be protected. Such an approach would also help ensure that international obligations under the Habitats Directive, and to NASCO, are delivered.

The impact of beaver activity on other native species for which recreational fisheries exist in Scotland, such as pike, roach and perch, may be less controversial. These are species which utilise a wide range of habitats and can establish in both rivers and standing waters. Whilst these species do undertake spawning migrations, or spawning movements, they are possibly less likely to be found in situations where they are affected by beaver dams.

The development of a management strategy is key to the successful coexistence of beavers and fisheries. The BSWG[3] is clear that such a strategy should be a fundamental prerequisite of any decision to license the reintroduction of beavers in Scotland. This strategy should provide guidance on the type(s) of interventions which can be made, the evidence base required and resourcing. The strategy should be developed in full consultation with stakeholders from the fisheries management sector.

Effective management is also dependent on a good understanding of the actual, rather than perceived, impacts of beaver on aquatic ecosystems, and fish in particular. A list of research requirements has been developed by the BSWG[3] to guide efforts in this area.

4.3 Forestry

Overview

The main mechanisms by which beavers affect woodland are tree-felling (for food and construction) and flooding. They use most Scottish broadleaved species but generally avoid conifers, although they may occasionally ring-bark them or feed on saplings in the late winter/early spring. They may also fell them for construction purposes if few broadleaved trees are available[1]. Since most Scottish forestry relies on conifers, beavers are unlikely to have much impact through felling. None of the major coniferous species grown in Scotland is tolerant of prolonged flooding, so beaver impoundments would lead to the death of trees within the flooded area. Flooding will also affect forestry infrastructure (e.g. forest tracks, culverts) and access for forest management, deer management and recreation, where it overlaps with inundated areas. Increased areas of dead wood, for example in flooded areas, could also increase the abundance of damaging pests such as the European spruce bark beetle *Ips typographus*, thereby affecting tree health. Some of the issues covered in sections 4.4 and 4.5 also apply to forestry. Management options are presented in Chapter 5.

Relatively little information is available on the impact of beavers on forestry. Damage to forestry by felling is reported only where broadleaved tree species are managed commercially, but minor damage from flooding is more widespread. This is largely anecdotal, although a Polish survey reported that 3,200 ha out of a total of 27,472,000 ha (i.e. 0.01%) of agricultural and forestry land in Poland was flooded by beavers[2]. In addition, 65 km of embankment and 229 culverts were affected, but it is not known whether these were in forested areas. Given that, at the time, Poland had a population of 18,000–23,000 beavers, this suggests a relatively minor impact on forestry. However, there is less rainfall in Poland and there is likely to be less use of culverts there than in Scotland, so any comparisons should be treated with caution. It has also been reported that 0.1% of the productive forest in a 34.7-km^2 study area in south-eastern Norway was flooded as a result of beaver dams[1]. Finnish foresters have expressed more concerns about beaver damage than Norwegians, probably because of smaller mean property size, making the cost of even small areas of damage relatively high for the individual foresters affected[1].

The Scottish Forestry Strategy is the Scottish Government's framework for taking forestry forward through the first half of this century and beyond[3]. It identifies timber production as a core theme, but also sets out six others: climate change, business development, community development, access and health, environmental quality and biodiversity. Therefore, although beaver presence will result in some costs to forestry, it will also bring about a range of benefits (described in Chapter 3 and section 4.1) that will contribute to the outcomes set out in the strategy, such as improving the health and wellbeing of people, and ensuring a high-quality, robust and adaptable environment. This approach is further developed in the strategy for Scotland's National Forest Estate[4], which highlights the multi-purpose role of the estate and the growing emphasis on integrated land management, including its substantial contribution to the Scottish Biodiversity Strategy.

Scottish experience

The SBT took place on FCS land at Knapdale. A very limited impact of beavers on productive forestry was found at Knapdale[5] (Figure 4.18), although habitat monitoring focused more on the native woodland around the loch shores rather than the areas of coniferous plantation.

The socio-economic monitoring work reported potential forestry losses due to flooding at Dubh Loch that amounted to £108 per year, or a one-off loss of £6,279[6], although this was in an area of native woodland with minimum intervention, where no timber production

Figure 4.18
The majority of Knapdale is commercial conifer plantation, although the beavers favour broadleaf woodland along the edges of freshwater lochs.
© Lorne Gill/SNH/2020VISION

Figure 4.19
Beaver dam in the drainage channel of a Tayside conifer plantation.
© Helen Dickinson/TBSG

was likely to happen in the foreseeable future. The loss of forestry infrastructure was reported to have a replacement cost of £22,000–£25,000, specifically for a new 400 m stretch of forest track, which has not been installed to date.

Knapdale is not representative of forestry land in Scotland as a whole. The species composition within the Knapdale Woods section of the SAC where the SBT was focused is 14%:86% coniferous to broadleaved, compared with 75%:25% coniferous to broadleaved in the wider Knapdale forest, and 93% coniferous across the whole of Scotland.

The impact of the Tayside beavers was assessed by asking land managers to report damage. Two cases were reported for impacts on commercial tree species[7]. At one site, about 70 trees of commercial value, including 15 mature trees, were damaged in a mixed broadleaf plantation. At the second, a potential issue from a dam flooding a small area of conifer plantation was reported (Figure 4.19).

Potential future implications for Knapdale and Tayside

Beavers are currently present mainly within the Taynish and Knapdale Woods SAC component of Knapdale, which is managed primarily for conservation, so any impacts on commercial tree species in these areas might be considered acceptable unless they have a negative ecological impact. In the short to medium term, beavers would be expected to colonise other parts of Knapdale and move more widely outside the SAC. The terrain would limit areas vulnerable to inundation due to beaver activity. However, depending on the site of future dams, including the blocking of any culverts, it is possible that forest tracks might be flooded, affecting forestry activities. The level of deer management may also need to be reviewed to take into account the ability of trees felled by beavers to re-sprout and the longer term implications for woodland structure and quality (see section 3.4.1).

The potential for beavers to affect forestry in Tayside is greater, as broadleaved tree species are managed commercially in parts of this area and, because of the flatter terrain, a greater proportion of the land is accessible to beavers. Based on experience elsewhere in Europe, it seems unlikely that impacts will be severe at the catchment scale, although they may be more significant at the very local scale.

Potential future implications of wider reintroductions in Scotland

It seems unlikely that the impact of beaver on timber production will be high at the national scale, taking into account experiences elsewhere in Europe and the fact that a high proportion of Scottish forestry relies on conifer species that are less attractive to beavers.

The most vulnerable areas of timber crops will be flat, or very gently sloping, ground adjacent to watercourses, which might be inundated by impoundments. The total area of coniferous forest in Scotland is about 447,000 ha, so assuming a scenario where 0.1% of this area was flooded (i.e. the proportion reported from Norway, see above), this would result in the loss of 447 ha, with an approximate value of £3-7 million. However, this is highly speculative, and more detailed assessments of the areas where flooding may be more likely, or unlikely, could be made in the future using the types of GIS-based datasets described in section 3.2. Further research on the localised flooding of forestry areas would also help clarify potential impacts of beavers.

The UK Forestry Standard Guidelines on Forests and Water provide statements of requirements for sustainable forest management[8]. The guidelines specifically highlight the environmental roles of the riparian zone and the need to identify effective buffer areas to protect them and aquatic habitats. Forest managers are required to identify and set aside such areas to help buffer any potentially adverse effects of adjacent forest management. The recommended minimum buffer widths range from 10 m wide along watercourses less than 2 m wide, 20 m along lochs, wetlands and watercourses more than 2 m wide, and 50 m wide along abstraction points for public or private water supply. Therefore, riparian zones should already be set aside by forest managers where most beaver activity is likely to be concentrated. However, in some cases the location of riparian zones will change as a result of beaver activity, which will mean changes to the location of buffer areas. Beavers will add a new dimension to how the guidelines are applied.

The diversification of the national forest resource is currently under way and it is likely that larger areas of more productive broadleaved tree species will be planted, including more substantial floodplain forests, where beavers are likely to have a particular impact. The possibility of an expanding beaver population could discourage the use of productive broadleaved species in some places. Alternatively, the presence of beavers could be used as a reason to promote the funding and support of planting schemes in riparian areas. The development of strategic planning, and appropriate best practice management, will be required to deal with negative beaver impacts and issues, including mitigation against flooding and the management of forest operations near breeding lodges (see Chapter 5). There are also opportunities for forestry in terms of the biodiversity and socio-economic benefits that beavers can bring, and these should also be included within any management planning.

4.4 Agriculture

Overview

Since beaver distribution is always associated with running or standing water, the potential for beaver activity to have an impact on agricultural interests is limited to where they occur in the vicinity of streams, rivers, drainage ditches, wetlands, lochs or ponds (Figure 4.20). Once beavers occupy an area, they actively modify their surroundings to suit their needs, so they are able to use a wide range of wet environments, whether artificial or more natural.

Published information about beaver impacts on agriculture is limited. Impacts can arise from a range of beaver activities, including burrowing and canal construction to gain safe access to a lodge/burrow or to feeding areas; dam-building on smaller watercourses, ditches and pond outflows; blocking of culverts; direct foraging of crops; and gnawing and felling of trees of commercial value for food or construction materials. The extent and significance of the impacts will depend on the local topography, soil structure and hydrology, and the vulnerability of the affected interests. In general, there appears to be less concern about beaver activity in areas of low commercial value. The greatest concern arises where beaver activities affect areas of more intensive agricultural activity.

Beavers come into direct contact with agricultural land usually within about 20 m of watercourses, although very occasionally they have been found to range up to 150 m to gain access to a favoured food source[1–3]. Indirect impacts on agriculture can be more extensive, such as those arising from the flooding or waterlogging of fields behind beaver dams. Some of the issues covered in sections 4.3 and 4.5 also apply to agriculture. Management options are described in Chapter 5.

The Scottish Rural Development Programme (SRDP) 2014–2020, Pillar 2, Agriculture Environment and Climate Scheme (AECS), has the aim of encouraging sustainable economic growth in Scotland's rural areas. Its priorities include supporting agricultural business and protecting and improving the natural environment. Further details are given in Chapter 5, but there are several management options that would enable farms to receive payments for managing areas of farmland likely to be most affected by beaver activity. In addition, the Greening element of the Pillar 1, Basic Payment Scheme, has the requirement that farms must manage 5% of their arable area to promote biodiversity. This may potentially include the management of riparian buffer zones.

Figure 4.20
Areas of agricultural land closest to running and standing waters will tend to be most affected by the presence of beavers.
© John MacPherson/SNH

Burrowing

Beavers will burrow into the banks of watercourses, as do a number of other species. All burrows, whether constructed by beavers or other species, can make banks more vulnerable to erosion during high water flows, especially in areas with more friable soils. The construction of canals by beavers may do the same. Damage to a river bank can result in the subsequent erosion of adjoining productive land and localised flooding of crops. There are some records of beaver burrows collapsing on farm land[4]. Each individual burrow will be of a limited extent, but there can be many burrows along a stretch of river, and their collapse may potentially pose a hazard for walkers, livestock and machinery operations, although few occurrences of actual harm have been recorded. These effects would have cost implications, in particular where they impede farming operations that have strict time constraints, such as during harvesting[2, 4].

Burrowing may be a particular problem where it occurs in flood-banks protecting intensive agriculture on low-lying flood plains. The more extensive the floodplain, the more vulnerable it is to the consequences of any flooding caused by the failure of a flood-bank. Flooding can inhibit or prevent cultivation and damage or destroy crops and grazing for livestock. Flood-bank failures arise in the absence of beavers, including as a result of burrowing activity by other species, although beaver activity can render them more vulnerable because the entrances to beaver burrows are usually below the water level. This means that during high flows there can be a build-up of water pressure within a burrow, which is then applied to the internal structure of a flood-bank. This can cause a collapse of the soil above the burrow, leading to the possible flooding of protected farm land behind it.

Although burrowing can be completely prevented by the installation of 'hard' reinforcements such as stone-filled gabions, large rocks, sheet/mesh metal or concrete piling, these options may be neither commercially viable nor ecologically desirable along extensive lengths of watercourse (see Chapter 5).

Dam-building

Dam-building by beavers on running waters, or at the outflow of a pond, loch or reservoir, will raise water levels, but will be of little concern in many situations. However, it may cause direct waterlogging of adjacent farm land, and sometimes the erosion of banks (Figure 4.21). Beaver canals may also radiate from beaver ponds to extend their feeding range into the surrounding farmland. If a dam is at a pinch point and some water level rise is acceptable, the

Figure 4.21
The diversion of water around a beaver dam has caused bank erosion at this Tayside site.
© Helen Dickinson/TBSG

agricultural impacts may be managed and limited through the installation of a water flow device or the cutting of a notch into the dam (Chapter 5). Beavers may also block drainage culverts using woody material and other vegetation, and can cause localised flooding of crops and farm access infrastructure.

The most significant impacts on agriculture arising from dam-building activity are likely to occur on intensive arable land on fertile flood plains, where cultivation is reliant upon an extensive network of drainage ditches and field drains. In these situations the shallow gradients present a very low tolerance threshold for any rise in the water table before the drainage system fails. Such failure can cause the direct damage of crops through flooding or waterlogging, and the inhibition of cultivation across a large area well beyond dam-building sites. As a consequence, checking for and managing beaver dams may become a regular activity for land managers, with attendant costs in terms of time and machinery. Where inundated soil has been fertilised, this may also result in a significant increase in nutrient loading of waterbodies. The use of techniques such as notch weirs or flow devices is not usually effective in these situations, and the removal of dams is usually followed by rapid reconstruction if the beavers remain (Chapter 5). Effective mitigation is difficult and farmers, and farmers' organisations, have expressed the view that the presence of beavers is not appropriate on these types of farmland.

Feeding on crops

Beavers are highly adaptable and may quickly exploit new food resources. Agricultural crops may be eaten in close proximity to watercourses. Feeding on a wide variety of agricultural crops has been recorded, including sugar beet, maize, cereals, oilseed rape, peas, potatoes, asparagus and carrots[2–5]. In most cases the scale of crop loss is not commercially significant and usually confined to an arc of about 10 m in radius extending from the water access point. There are a number of fencing techniques to help minimise this, including the use of temporary electric fencing (Chapter 5).

Tree- and shrub-felling

Felling of woody material for food or construction materials can be an agricultural issue for a variety of reasons. Felled trees can obstruct farm roads and access tracks, damage fences and block drainage ditches. There can also be a direct loss or damage to orchard trees, soft fruit bushes, landscape trees, farm woods and shelter belts[2], and the potential for damage to hedges. Protection measures include fences, tree guards and protection paint (Chapter 5).

Scottish experience

The TBSG was informed about 56 beaver sites across Tayside, 28 of which (50%) reported negative impacts[1]. The majority of negative impacts were recorded in the more intensively farmed lowland areas at sites directly adjacent to watercourses. The types of impacts recorded included burrowing into banks and increased erosion and bank collapse; crop foraging (wheat, barley and carrots); and dam-building and associated erosion and flooding (Figure 4.21). Of those experiencing negative impacts, 70% reported a financial cost.

One particular lowland farm on Tayside had 13.8 km of actively managed burns and drainage ditches on 445 ha of arable land[1]. Between September 2013 and November 2014, 32 dams were built, or in the process of being built, by beavers. Dam-building occurred in seven sections of burns and drainage ditches. The dams were regularly removed by the landowner, mainly by hand, to avoid potentially serious impacts on field drainage. Dams in two of the seven sections were rebuilt within one day of removal, and at another two sections they were rebuilt a week after removal. Before beavers started to occupy the area, farm staff carried out walked inspections of burns and ditches twice a year to monitor for blockages. Following the arrival of beavers, the frequency of inspection was reported as increasing to once a week, requiring one day of work on each occasion. Approximately four hours per week was spent removing dams.

Issues and potential issues arising from beaver burrows in flood defence banks protecting intensive arable land were recorded on five sites on Tayside[1]. At two sites, beaver burrowing activity had resulted in several breaches costing £5,000 to repair in 2013, and flood debris deposited on the land behind. A further breach was reported in early 2014. No breaches were recorded on the other three sites, but concerns were raised about increased risk due to burrowing activity in the area. In all cases, the flood-banks were within 10 m of the river and the burrow entrances were below the water level, resulting in a greater risk of erosion and collapse during spate flows.

Potential future implications for Knapdale and Tayside

In Tayside there is already considerable beaver presence in agricultural areas. Between early 2012 and late 2014 during the course of the TBSG studies, the beaver range continued to expand within the catchments of the Rivers Tay and Earn, and colonisation is expected to continue into the future, ultimately occupying most of the suitable habitat if the decision is made to allow the animals to remain (section 3.2). Colonisation of adjacent catchments is also anticipated if there is no intervention. This will inevitably bring them into further and increasing contact with riparian farmland. The incidence of agricultural conflicts would increase with particular concern for the management implications for the intensively drained and flood-bank-protected arable farms such as those on the floodplains of the Rivers Tay and Earn.

At present, there is a very limited opportunity for beavers to come into contact with agricultural activity in Knapdale. There are some small areas of grazing within Knapdale Forest but the main land use is forestry. If beavers were to remain at Knapdale, and the population reinforced, then it is anticipated that the animals would start to colonise along freshwater networks in the medium to longer term, some of which borders agricultural land, primarily grazing (section 3.2). Inevitably there is likely to be some increase in management issues related to agricultural activity and impacts of local significance to individual farmers, although probably not to the extent that might be expected on Tayside.

Potential future implications of wider reintroductions in Scotland

If the decision is made to allow beavers to remain in Scotland and for wider reintroduction to occur, the types of beaver interactions with agricultural interests highlighted above will increase. Their significance would vary greatly across the country depending on the vulnerability of the land and the intensity and value of the crops. As beaver impacts would be a novel experience for most land managers, it is anticipated that there will be an increasing demand for management advice and mitigation.

There would also need to be a review of the types and extent of impacts on agricultural land, and how rural funding through schemes such as the SRDP might be designed and applied to cater for increasing beaver presence in riparian areas (see also Chapter 5).

Chapters 5 and 6 examine the types of management implications that may be relevant in an agricultural and wider context, some of which are based on the experiences from Tayside. They include:

- Legal/licensing considerations
- Assessments of management techniques
- The role of riparian buffer zones
- Advisory/management support and the role of local stakeholder groups and project officers
- Cost issues

4.5 Infrastructure and general land use

Overview

Infrastructure and general land use will tend to be at risk only where they are in proximity to beaver activity, and therefore near running and standing waters. Impacts can arise from the direct and indirect implications of dam-building, burrowing and tree-felling. Since beavers readily use natural, semi-natural and artificial waterbodies, the likelihood of beavers coming into contact with human infrastructure is high. The scale and significance of the resulting impacts will vary according to local circumstances, but in most situations management will be required, with associated costs.

There is limited information in the literature about beaver impacts on such issues, so many of the following experiences have been collated from discussions with European and North American colleagues, from a recent review of beaver management[1] and from Scottish experience to date. Related issues are described in sections 4.3 and 4.4, and management options are set out in Chapter 5.

Roads and tracks

Dam-building on a stream, ditch or pond outflow can cause direct flooding of an adjacent road or access track. If this is located in a low-lying area, the scale and depth of flooding can cause significant obstruction until the dam is removed or managed. Beaver burrows may also undermine roads, tracks and other structures, causing subsidence.

Culverts, weirs, sluices, fish passes

Although beavers normally construct dams using natural foundations, they can also use man-made structures. Even with no beavers present, such structures tend to be vulnerable to blockage by water-borne debris, and therefore need regular checking and maintenance. Beaver activity, however, can exacerbate problems. There are many records from across Europe and North America of beavers building dams across the mouths of culverts, on sluices and weirs and on fish counters and fish passes. Any suitable structure located in water can be used in this way.

Subsidence caused by beaver burrows can also lead to in-stream structures, such as weirs and fish passes, being bypassed. Water may flow into a burrow upstream and then re-enter the watercourse downstream, eroding the bank in the process.

Flood-banks and other river structures

Burrowing into flood-banks weakens their structure and renders them more susceptible to collapse and overtopping, or direct erosion in times of spate. The protected land behind, which might include housing, business/industry and farmland, is then vulnerable to flooding.

Dams and burrowing can also cause a diversion of water flow and lead to erosion of riverbanks and the undermining of any associated water-side infrastructure, which could potentially include bridge supports, utility pipes, roads and tracks.

Figure 4.22
Mature poplars felled by beavers next to the A90 trunk road.
© Helen Dickinson/TBSG

Canals

Beavers readily use artificial as well as more natural watercourses, so are frequently found in canal systems. There are cases of burrows damaging retaining banks of canals not reinforced by revetments, leading to leakage or localised failure. Similar impacts can occur in canals constructed to distribute water supplies for drinking, hydro-schemes and other purposes.

Water treatment plants

If sewage settlement beds are in close proximity to a watercourse, they may be accessible to beavers and may overflow as result of any woody debris and dam-building[2]. They contain reliable water supplies and are commonly surrounded by lush vegetation that may attract beavers.

Recreational facilities

Beavers will readily occupy environments that are regularly used for recreational activities such as swimming, leisure boating, jet skiing and canoeing. They can habituate to reasonable levels of disturbance, and tend to be more active at quieter times of the day when there is less human activity. Streams and ponds in places such as golf courses or parks can also provide suitable habitat. In most cases there are few conflicts, although dam-building, burrowing and tree-felling may sometimes cause problems.

Ornamental gardens, trees and ponds

Ornamental gardens and ponds that connect to watercourses may be occupied by beavers. In most cases they may not be present for very long, but they can radically alter the aesthetic appearance by felling ornamental trees, burrowing or feeding on garden plants. Ornamental gardens and arboreta are relatively common features in Scottish, and the wider British, landscapes, with some being of international importance.

Large specimen trees in the vicinity of watercourses can be readily protected, although this may be harder for multi-stemmed shrubs or other palatable vegetation. It is likely that they will feed on a range of plant species that do not occur in their natural habitats.

Sites of historic value

There is the potential for beaver activity, for example through burrowing causing subsidence, or dam-building causing localised floods, to affect historic sites, although there appears to be little recorded evidence of this happening.

General

Felled trees have the potential to cause incidental damage when they fall on fences, power lines, buildings or transport routes. Although the frequency of these events is rare, if they occur they may be significant in terms of disruption, cost and risk to human wellbeing.

Scottish experience

Roads and tracks

The flooding of a forest track occurred during the SBT at Knapdale, following the impounding of water behind a beaver dam across a minor watercourse (see section 4.3).

On Tayside, beavers felled some poplar trees alongside a 200 m stretch of the A90 trunk road near Forfar, presenting a risk of some falling onto the carriageway (Figure 4.22). Transport Scotland arranged for trees gnawed by beavers to be cut down and the remainder to be protected with mesh fencing[3].

At the Loch of the Lowes, an SWT nature reserve near Dunkeld in Tayside, there was beaver activity along a narrow strip of riparian woodland situated 10 m from the edge of approximately 1.6 km of a well-used road. Over the last few years at least two trees have fallen onto the road, presenting risks in terms of safety and obstruction. This led to a greater intensity of checking by ranger staff to identify any beaver-damaged trees, which were then felled. Fencing to prevent beavers gaining access to the trees was judged not to be a practical option in this location[3].

At another Tayside site, 150 m of an access track to a small area of residential housing, next to a burn, was flooded during a period of high rainfall. The flow patterns of the burn had been affected by the raising of the water table on adjacent land caused by beaver dam-building[3].

Culverts, weirs, sluices, fish passes

A recent GIS-based analysis was done to examine the overlap of areas predicted to be less likely to be dammed by beavers, with existing anthropogenic watercourse structures. It was found that 78% of all culverts, weirs and fish passes in Scotland were at locations where dam-building was predicted to be less likely[4] (see section 3.2).

On Tayside there were two instances where dam-building activity had the potential to impede fish movement along fish passes. At one of these sites, the dam was built against a fish counter. The manager cleared the dam but then had to remove new debris from the counter every morning over a number of weeks after the beavers started to replace it. The debris prevented the counter from working and the manager eventually decided to remove it to discourage further dam-building[3].

Flood-banks and other river structures

Bank erosion was reported at four Tayside sites resulting from the redirection of water flows around a beaver dam. At one of these, access for farm machinery had been impeded. At another, there was a report of dam-building causing erosion next to a bridge, although there are no details of the type of bridge, size or scale of impact. Issues and potential issues were also recorded on five sites where there were beaver burrows in flood defence banks (Figure 4.23, and described further in section 4.4)[3].

Ornamental gardens, trees and ponds

There have been nine records of beaver impacts on ornamental and amenity value trees in Tayside (Figure 4.24). There was also a record of a fish pond being flooded[3].

Sites of historic value

At Knapdale, Historic Scotland monitored potential beaver impacts on a crannog on Loch Coille-Bharr, in particular to assess whether foraging on aquatic plants might affect the scheduled monument[5]. No impact was observed and the likelihood of impact was thought to be low. The Crinan Canal, immediately to the north of Knapdale, is also a scheduled monument, although no impact was observed during the trial period.

Potential future implications for Knapdale and Tayside

The Knapdale beaver population would be expected to expand, with some likely further impacts on forestry infrastructure. This might include some flooding of tracks and other infrastructure resulting from beaver dam-building activity (including attempts to block culverts) and some occasional felling of trees onto tracks and footpaths. Animals will eventually start to move outside the forest itself, with increasing incidences of the types of impacts described above in the wider area. Continued monitoring would be required along the Crinan Canal, in particular to look for any burrowing into the canal embankments and for any beaver activity in the feeder lochs above the canal.

Tayside is a more populated area with a greater intensity of land use, and so the opportunities for beaver activity to impinge upon a range of land uses, and the associated infrastructure, is much greater. The TBSG have already recorded a variety of issues experienced by land managers and members of the public, many of which are summarised above. The expectation is that this pattern of impact will continue as the beaver population continues to expand throughout the catchment and beyond.

Potential future implications of wider reintroductions in Scotland

Ultimately it is expected that beavers will occupy the most suitable habitat within their range. In the long term it is therefore anticipated that there will be regular and fairly frequent management issues to deal with. Based on the European experience, cases involving serious infrastructure issues are likely to be rare, but they do occasionally happen.

There are a number of methods that can be used to protect infrastructure interests (summarised in Chapter 5) and in some cases it may be prudent to protect especially sensitive interests before problems arise. This is more achievable for small-scale structures, such as culverts under roads. The pre-emptive protection of larger scale structures that may be vulnerable to beaver activity, such as canals and flood-banks, would be more challenging. The scale and costs involved for revetment or reinforcement to prevent burrowing would be high. There would therefore be a need to identify and prioritise those structures that may be most vulnerable. Scotland could draw on European approaches to targeting sites for management, and GIS-based tools to identify areas where beaver activity is predicted to be more likely (see section 3.2)[4].

There are other issues that might affect small numbers of individuals, for example damage to ornamental trees and gardens. For these, and the more complex infrastructure issues described above, the development of an appropriate management strategy will be required. This will need to include guidance on management techniques (for both pre-emptive and reactive actions) and information on sources of advice and support. This is described further in Chapter 6. The effectiveness of beaver management in Scotland will increase over time as experience is gained and methods refined.

Figure 4.23
Burrowing by beavers led to this breached flood-bank on Tayside.
© Helen Dickinson/TBSG

Figure 4.24
Tree damage caused by beavers in a Tayside garden.
© Helen Dickinson/TBSG

4.6 Public and animal health

The conservation translocation of a species involves a whole 'biological package', reflecting the assortment of bacteria, viruses, fungi, parasites and other micro-organisms which any single animal or plant, such as a beaver, may naturally harbour. Some of these additional organisms have the potential to become pathogenic (i.e. capable of causing disease), while others may be present (although not necessarily prevalent) and exert no discernible effect upon its host or the wider receiving environment[1].

Eurasian beavers host a number of external and internal parasites. A list of common European rodent diseases and parasites associated with beavers is provided in a recent review[2]. Some of these are already present in the UK (e.g. *Cryptosporidium parvum*) and some are not (e.g. *Echinococcus multilocularis*)[3]. Many of these rodent diseases and parasites have the potential to cause zoonotic diseases and may be notifiable and/or reportable in the UK.

Beavers may be involved in the transfer and hosting of diseases and parasites in three main ways:

- Beavers acting as a mechanism for the introduction of new or eradicated diseases and parasites, and acting as potential transmission routes for the infection of humans, domesticated livestock and existing wildlife
- Diseases and parasite transfer from existing wildlife populations to translocated and wild beavers
- Beavers acting as a reservoir host for infectious diseases and parasites already present in Scotland, with potential transmission routes for infection of humans, domesticated livestock and existing wildlife

Before the SBT, little information was published on beaver health surveillance, disease or mortality despite the relatively large number of beaver translocation projects across Europe and elsewhere. A beaver health surveillance programme for the SBT was established that addressed International Union of Conservation of Nature (IUCN) and governmental guidelines, as well as public health concerns[4]. This included pre-release health screening and regular post-release monitoring, including the post-mortem examination of all cadavers (Figures 4.25 and 4.26)[5]. It was used as a template for a health screening programme carried out on a sample of live and dead beavers from Tayside[6]. During the SBT there was also public health monitoring by independent local authority specialists (Figure 4.27). The results are set out below.

Beavers acting as a mechanism for the introduction of new or eradicated diseases and parasites, and acting as potential transmission routes for the infection of humans, domesticated livestock and existing wildlife

i. Alveolar hydatid tapeworm *Echinococcus multilocularis*

Overview

- *E. multilocularis* is one of the most pathogenic parasitic zoonoses in the northern hemisphere and is the causative agent of alveolar echinococcosis disease in humans[3, 7]
- Adult tapeworms live in the small intestine of the definitive (final) host, usually red foxes. Eggs are shed into the environment with host faeces[8]. Small mammals, which are the main intermediate host, are then infected through ingesting parasite eggs[9]. The indirect wildlife-based life cycle is then completed by carnivorous predation of an infected intermediate (non-egg-shedding) host
- Infection of unusual intermediate hosts, such as beavers, occurs through an increase in infected foxes leading to heavy environmental contamination with eggs. The first cases of beaver infection were reported in Switzerland and Austria[10], and more recently in Serbia[11]
- Finland, Ireland, Malta and the UK are considered free of *E. multilocularis*[12]. The translocation of beavers from central Europe is generally accepted to present a risk of importing the disease[6, 7]

Figure 4.25
A beaver receiving health checks under anaesthetic.

Figure 4.26
A blood sample being taken from the ventral tail vein of a beaver.

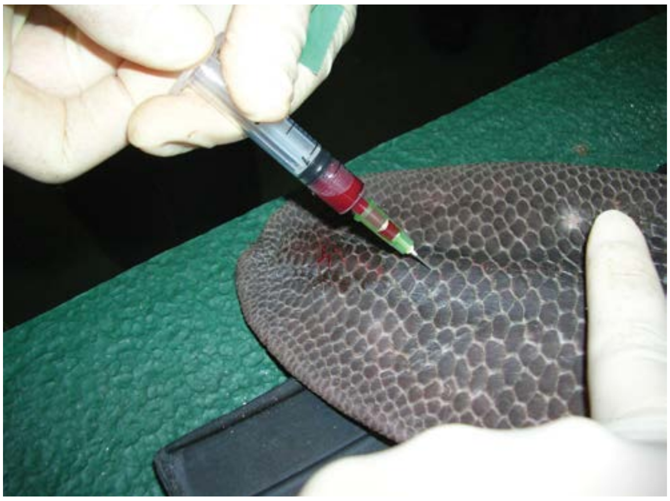


Figure 4.27
A water sampler at Knapdale. Public health monitoring for the SBT involved taking water samples from four to five sites every three months, and testing for *Giardia* and *Cryptosporidium*[29].
© Argyll and Bute Council

Scottish experience

- Beavers imported for the SBT were not considered to present a risk, as the donor country, Norway, was considered free of *E. multilocularis*. At the time of trapping, there was no diagnostic test available for live animals[5]
- The animals on Tayside were from unknown sources. However, none of the beavers tested from the Tayside catchment was positive for *E. multilocularis*. Recently developed techniques, including in-field laparoscopy and abdominal ultrasound, were used to diagnose abdominal lesions[6, 8, 13], together with corroborative immunoblotting[8]

Potential future implications for Knapdale and Tayside, and wider reintroductions in Scotland

- Previous assessments have concluded that the risk of this tapeworm becoming established as a result of infected beavers imported from *E. multilocularis*-free areas is negligible, and is low but very uncertain for those from endemic areas[14]
- It follows, therefore, that the risk appears negligible for the beavers at Knapdale, as well as for other wildlife and humans. The risk associated with any future releases of beavers at Knapdale would need to be re-assessed, taking into account the origin of the animals
- The situation at Tayside is more complicated in that the origin and health status of the entire beaver population is unknown, although no evidence of *E. multilocularis* has been found in the sample tested[6]
- Health assessment and pathogen screening before release is regarded as a key requirement in any translocation[15]. There is now an effective diagnostic test for live animals, together with serological screening. Such testing would provide further reassurance that the parasite does not become present in the wild in Scotland as a result of any beaver reintroduction

ii. Rabies

Overview

- Rabies is an acute infection of the central nervous system caused by a lyssavirus of the Rhabdoviridae family. It affects all mammals, including humans[3], and the main reservoir is wild and domestic canids (e.g. dogs, wolves and foxes)[16]
- The last case of classical (sylvatic) rabies in an animal outside of quarantine in the UK (a dog in Newmarket) was in 1970[3], although the related European Bat Lyssavirus 2, which causes the same clinical symptoms as classical rabies, has been recorded in a small number of wild British Daubenton's bats since 2002. The import of beavers to the UK is subject to strict animal health and disease-control legislation. The quarantine period is deemed sufficient to prevent the entry of rabies

Scottish experience

- A total of 27 European beavers were imported from Norway for use in the SBT. They were quarantined for a period of six months during which time six individuals died with no common cause identified
- In view of these mortalities, and the fact that Norway is considered free of classical (sylvatic) rabies, the RZSS received permission to import a further four Norwegian beavers without the full quarantine requirements. This was subject to strict criteria, including the need for four weeks' quarantine in Norway under veterinary supervision[2]

Potential future implications for Knapdale and Tayside, and wider reintroductions in Scotland

- There is no reason to believe that any further import of beavers for Knapdale, or elsewhere in Scotland, would increase the risk of rabies, provided appropriate statutory animal health procedures are followed

iii. Tularaemia *Francisella tularensis*

Overview

- *F. tularensis* is an intracellular bacterium found in a wide range of invertebrates, birds and mammals, with transmission to humans causing tularaemia[17]. It has a broad geographical distribution across Europe but does not occur in the UK[18]
- It is thought to be spread in the environment by rodents, particularly water voles but also squirrels (Sciuridae), muskrats *Ondatra zibethicus*, beavers and rabbits (Leporidae). However, there is no evidence to suggest that any of these species constitute a natural reservoir of this bacterium[17, 19]

Scottish experience

- None of the 29 beavers tested at Knapdale were antibody positive for *F. tularensis*, nor were any of those tested at Tayside[5, 6]

Potential future implications for Knapdale and Tayside, and wider reintroductions in Scotland

- Health screening during quarantine provides an opportunity to test for infection with *F. tularensis* and, if necessary, to act accordingly to ensure that the UK remains free of the pathogen
- If captive animals already present in the UK were used to bolster the population at Knapdale, then they would require screening for *F. tularensis* (and other pathogens/parasites) as they may not have been subject to any additional health testing during the original rabies quarantine

iv. Beaver fluke *Stichorchis subtriquetrus*

Overview

- The trematode *S. subtriquetrus* is the most frequently found parasite in beavers[20]. It has an indirect life cycle requiring an intermediate host, such as aquatic snails[21]. It had not been reported in the wild in the UK before being found in beavers in Scotland

Scottish experience

- Pre-release screening identified beaver fluke in eight beavers at Knapdale. It was detected in 10 beavers after release. It is not considered pathogenic under normal circumstances[5]
- Fifteen beavers at Tayside were found to be positive for beaver fluke[6]
- The first documented example of the completion of the beaver fluke life cycle was from a beaver, presumed to be wild-born, from Tayside[21]
- Beaver fluke was also found following the screening of wild-born kits at Knapdale, indicating that its parasitic life cycle is also being completed there, presumably via aquatic snails[5]

Potential future implications for Knapdale and Tayside, and wider reintroductions in Scotland

- Its presence is not considered a threat to other wildlife or humans[20] as it is a strictly specialised parasite of beavers, and intermediate host species have been demonstrated to be fully functional when infected[22, 23]

v. Beaver beetle *Platypysllus castoris*

Overview

- The beaver beetle *P. castoris* is a small, wingless, ectoparasitic beetle associated with beavers[24]. It is not considered detrimental to its host, and it is thought to have a commensal relationship[25]
- A single record from a North American river otter *Lontra canadensis* was thought to be a result of accidental transference[26], with a similar observation found on a Caucasian otter *Lutra lutra meridionalis* in Russia[24]

Scottish experience

- Pre-release examination of beavers at Knapdale did not detect any adult beetles[5]. Post-release examination of a young kit at Knapdale revealed a number of beetles as well as the identification of larvae[25]
- No evidence was found on any of the beavers examined from Tayside[6]

Potential future implications for Knapdale and Tayside, and wider reintroductions in Scotland

- Although there is a low level of uncertainty as to whether this ectoparasite is entirely exclusive to beavers, there seems little doubt that there is any detriment to the host species
- Continued screening of beavers at Knapdale would be of interest to see if it spreads between individuals and families
- Continued screening for the presence of the parasite on imported animals, or those from other UK sources, would allow greater understanding of its colonisation and distribution in Scotland
- Further examination of the published literature and other information sources would help to assess the potential for species other than beavers to become a permanent host

vi. Beaver nematode *Travassosius trus*

Overview

- The beaver nematode *T. trus* has a life cycle specific to beavers. Parasite eggs are expelled in faeces, and larvae are ingested while feeding[2]

Scottish experience

- Pre-release screening at Knapdale identified the beaver nematode in eight animals[5]
- It was not detected in any screened animals from Tayside[6]

Potential future implications for Knapdale and Tayside, and wider reintroductions in Scotland

- Continued health surveillance at Knapdale and Tayside would help to ascertain whether any infestation of this nematode is deemed pathogenic to beavers, as would the screening of any imported beavers or those brought in from elsewhere in the UK
- The beaver nematode is entirely species-specific and it is not viewed as a threat to any existing wildlife or human populations

Parasite and disease transfer from existing wildlife populations to translocated and wild beavers

i. Examples of transfer of parasites and diseases from existing wildlife populations to beavers

Overview

- Yersiniosis and leptospirosis were identified in seven out of 22 dead beavers examined during a Dutch translocation programme. Infection was considered to have occurred after release, and factors relating to the translocation process, including stress, were thought to contribute to the susceptibility of the animals[27]

Scottish experience

- *Cryptosporidum* oocysts were identified in surface water burns at Knapdale, attributed to a combination of animals (livestock, deer and other wild animals) or run-off from soil[28, 29]. It was not detected in any beavers prior to release at Knapdale, but was found in a dead, wild-born beaver kit, suggesting that infection was acquired from existing sources in the wider environment[5]
- *Giardia* cysts were identified in surface water burns at Knapdale[28, 29]. It was not detected during pre- and post-release screening of beavers at Knapdale, meaning that no transfer from wild populations occurred during the trial[5]. These were similar results to a study in Norway, in which no *Giardia* cysts were detected in any of the 241 beaver samples, despite the presence of cysts in Norwegian surface waters[30]

Potential future implications for Knapdale and Tayside, and wider reintroductions in Scotland

- Monitoring would help identify parasites and pathogens of most importance[31]. Continued health surveillance of beavers at Knapdale and Tayside may be useful to ascertain whether there is any increase in the prevalence and/or susceptibility of beavers to *Cryptosporidium*, *Giardia* and *Leptospira* from existing wildlife populations
- Infection does not appear to be pathogenic to beavers under normal circumstances. Further commentary on each of these pathogens is provided below in relation to the potential role of beavers as reservoir hosts

Beavers acting as a reservoir host for infectious diseases and parasites already present in Scotland, with potential transmission routes for the infection of humans, domesticated livestock and existing wildlife

i. *Leptospira* spp.

Overview

- *Leptospira* bacteria have been found in virtually all mammalian species and the associated pathogenic disease, leptospirosis, is the most widespread zoonosis worldwide[32]
- Humans most commonly acquire infection through occupational, recreational or domestic contact with the urine of carrier animals[32]
- There is little information regarding beavers, although it has been documented in North American beavers from a number of Swiss zoos[33]

Scottish experience

- Pre-release testing at Knapdale found five animals positive for *Leptospira* antibodies. Post-release testing found two animals seropositive for *Leptospira*[5]
- None of the 17 beavers tested positive at Tayside[6]

Potential future implications for Knapdale and Tayside, and wider reintroductions in Scotland

- Given the widespread nature of *Leptospira* infection (160 mammalian species have been identified as a natural carrier[34]) and the lack of evidence of beaver as a reservoir host, it would seem likely that the additional risk to existing wildlife populations at Knapdale and Tayside (and across Scotland) would be minimal
- Continued health surveillance of both beaver populations would help to verify this assessment in the longer term
- Any significant increase in beaver numbers across Scotland in the longer term could conceivably lead to a greater overlap of human recreational activity in areas inhabited by beavers. However, the risk of acquiring leptospirosis appears to be highest among farmers, veterinarians and sewer workers, who all work around animals, rather than among those engaged in recreational activity[34]

ii. *Cryptosporidium* spp.

Overview

- *Cryptosporidium* species are intestinal, protozoan parasites of mammals that cause cryptosporidiosis, the symptoms of which may include life-threatening diarrhoea in immunosuppressed humans and young livestock. Disease in humans is predominantly caused by *C. parvum* and *C. hominis*. Rodents are considered important reservoirs of the parasite[35]. It is considered endemic in most cattle holdings and is common in sheep and deer[3]
- Faecal screening of 182 beavers in Norway found no oocysts in any sample despite the frequent occurrence of oocysts in surface water sources[30]

Scottish experience

- No *Cryptosporidium* was detected from beavers screened during quarantine and prior to release at Knapdale[5]
- *Cryptosporidium* was detected in a dead wild-born beaver kit at Knapdale, suggesting that the parasite was acquired from existing sources in the wider environment
- One beaver from Tayside was found to be positive for *Cryptosporidium* following faecal examination. The individual was in good body condition with no signs of ill health[6]

Potential future implications for Knapdale and Tayside, and wider reintroductions in Scotland

- Public health monitoring at Knapdale showed that *Cryptosporidium* is present in the existing wild mammal population[28]
- The additional risk to human health from the presence of beavers in Knapdale has been assessed as very low[29]
- At a wider scale, the Centre of Expertise on Animal Disease Outbreaks (EPIC) consider the likelihood of beavers acting as an important source of contamination of *Cryptosporidium* to water supplies as 'very low to low (high uncertainty)' in the context of other sources of contamination, such as humans, livestock, other wildlife and domestic animals[36]
- However, as a precaution, and to provide further reassurance, it has also been recommended that there is enhanced surveillance of human cases for a set period; further reintroduction proposals should be discussed with local authority environmental health teams and Scottish Water to allow levels of risk to be evaluated; and best practice in relation to public and private water supplies should continue to be promoted[36]

iii. *Giardia duodenalis*

Overview

- *Giardia duodenalis* (also known as *G. lamblia* or *G. intestinalis*) is an intestinal, protozoan parasite of mammals. It causes giardiasis, the most common cause of parasitic, diarrhoeal disease in humans worldwide. It was the most frequently raised public health issue relating to beavers prior to the SBT, perhaps because giardiasis is sometimes referred to as 'beaver fever' in North America[37]
- Studies of *Giardia* prevalence showed rates of 8% in Eurasian beavers in Poland[38], and 7–16% in North American beavers in the USA[39]. In comparison, other semi-aquatic rodents, such as muskrats, are thought to constitute a more important reservoir with a much higher prevalence of 37–96%[40]
- Faecal screening of 241 beavers in Norway found no *Giardia* cysts, despite the frequent presence of the parasite in Norwegian surface water sources[30]. A 2002 study noted that there had been no waterborne outbreaks of giardiasis reported in Norway despite having a beaver population of over 50,000 animals at the time, and the rate of giardiasis in the human population was similar to that of Scotland that had no beavers (with most cases originating from travel abroad)[37]
- A single study in Colorado found that beavers shed *Giardia* cysts in their faeces throughout the year, with temporal variation in prevalence. They became infected as kits and remained so into adulthood, presumably related to their coprophagic (eating of faeces) behaviour. This led to the suggestion that beavers act as an 'amplification host'[41]

Scottish experience

- *Giardia* was not detected during the screening of the Knapdale beavers, before or after release. This suggested that no transfer had occurred from wildlife populations to beavers during the trial, and therefore it was also unlikely that any of the beavers acted as a reservoir for other wildlife populations[5]
- There were similar observations at Tayside, with no detection of *Giardia* in beavers[6]

Potential future implications for Knapdale and Tayside, and wider reintroductions in Scotland

- The additional risk to human health from the presence of beavers in Knapdale was assessed as very low[29]
- While the presence of *Giardia* cysts in the watercourses at Knapdale means there is potential for individual beavers to become infected, it should be noted that there has been no evidence to date of such transmission occurring in Norway[30]
- Continued health screening to confirm the presence of this parasite in the beaver populations at Knapdale and Tayside would also help elucidate any amplification role given the lack of evidence for this in the published literature
- At a wider scale, EPIC considers the likelihood of beavers acting as an important source of contamination of *Cryptosporidium* to water supplies as 'very low to low (high uncertainty)' in the context of other sources of contamination, such as humans, livestock, other wildlife and domestic animals[36]
- However, as a precaution, and to provide further reassurance, it has also been recommended that there is enhanced surveillance of human cases for a set period; further reintroduction proposals should be discussed with local authority environmental health teams and Scottish Water to allow levels of risk to be evaluated; and best practice in relation to public and private water supplies should continue to be promoted[36]

4.7 Summary

- Beavers provide a range of ecosystem services. These include 'provisioning ecosystem services' such as increased ground water storage, 'regulation and maintenance ecosystem services' such as flow stabilisation and flood prevention, and 'cultural ecosystem services' that relate to people's recreational, educational and spiritual interactions with the environment. They all contribute to human wellbeing and have socio-economic impacts
- Public consultation and surveys carried out over the last 17 years have demonstrated overall public support for beaver reintroduction, although concerns have been more evident amongst some land use sectors
- Socio-economic assessments have been undertaken at Knapdale and Tayside, and a range of costs and benefits has been identified. In the event of a wider reintroduction it is anticipated that there may be more opportunities to invest in wildlife tourism for Knapdale and that it should be able to maintain the marketing appeal of being the 'original' release site
- There is the potential for high impacts and costs in certain parts of Tayside, primarily in the lower catchment, in particular on impacts to flood defence infrastructure and drainage networks. However, it has been suggested that the benefits of beaver presence on Tayside are likely to outweigh the costs incurred overall, and that costs may be lowered through appropriate management. Nevertheless, individuals who may be most affected by the negative impacts of beavers may not necessarily be the same as those who benefit from the positive impacts
- Recent reviews have focused more on the potential impact of beavers on 'fish' rather than 'fisheries', but it is clear that any impacts on fish of commercial or sporting value may also have direct impacts on associated fisheries. Beavers are thought to have overall positive effects on the production of some fish species. The impact of beaver activity on some native species, such as pike, roach and perch, for which recreational fisheries exist in Scotland, are likely to be relatively uncontroversial
- The two species of fishery interest most likely to be influenced by the presence of beavers are Atlantic salmon (especially the spring stock component) and trout. Although there are potential benefits of beaver presence to salmonids, there may also be possible negative impacts of dam-building on the movement of fish within river systems and on critical in-stream habitats
- Beaver activities that may affect land use, such as agriculture and forestry, include burrowing and canal construction, dam-building on smaller watercourses, blocking of culverts, direct foraging of crops and felling of trees of commercial value. The extent and significance of the resultant impacts will depend on the local habitat, topography, soil structure and hydrology, and the vulnerability of the affected interests. The most vulnerable areas will be flat, or very gently sloping, ground adjacent to watercourses, which might be inundated by impoundments. Concerns will tend to be greatest in areas where beaver activities affect intensive agriculture
- Since most Scottish forestry relies on conifers, beavers are unlikely to have much impact through felling. None of these major coniferous species is tolerant of prolonged flooding, so beaver impoundments would lead to the death of trees within flooded areas in riparian zones. Current guidelines on how forestry is managed in riparian zones will need to take account of the effects of beaver activity. Beavers may also contribute positively to other forestry objectives relating to the improvement of the health and wellbeing of people and aspirations for a high-quality, robust and adaptable environment
- The dam-building, burrowing and tree-felling activities of beavers can affect a range of infrastructure, including roads and tracks, culverts, weirs, sluices, fish passes, flood-banks and other river structures, canals and water treatment plants. There is also the potential for beavers to affect ornamental gardens, ponds and sites of historic value
- The development of a management strategy will therefore be key to the successful coexistence of beavers and fisheries, agriculture, forestry and other land uses (see Chapter 5). This will need to include necessary surveillance, monitoring and research requirements. For example, there is a need to understand the actual, rather than perceived, impacts of beavers on aquatic ecosystems, and fish in particular
- The translocation of a species involves a whole 'biological package', reflecting the assortment of bacteria, viruses, fungi, parasites and other micro-organisms which any single animal, such as a beaver, may naturally harbour. Beavers could be involved in the transfer and hosting of diseases and parasites in three main ways:
  - Beavers may act as a mechanism for the introduction of new or eradicated diseases and parasites (such as the tapeworm *Echinococcus multilocularis*, rabies and tularaemia) and act as potential transmission routes for the infection of humans, domesticated livestock and existing wildlife
  - Beavers may be involved in parasite and disease transfer (such as leptospirosis and giardiasis) from existing wildlife populations to translocated and wild beavers
  - Beavers may also act as a reservoir host for infectious diseases and parasites already present in Scotland (such as cryptosporidiosis and giardiasis), with potential transmission routes for infection of humans, domesticated livestock and existing wildlife
- In all cases, health assessment and pathogen screening are regarded as key requirements in the translocation process before release. Consultation with local authority environmental health teams and Scottish Water is also recommended during the planning stages, and post-release monitoring may also be required in some cases
- Animals used for the SBT were quarantined and screened before, and monitored after, release, and there was a programme of public health monitoring at Knapdale. A sample of Tayside beavers were also tested for a range of parasites and diseases, and no evidence was found of pathogens that may cause an increased health risk to humans, livestock and other wildlife

Chapter 5
Legal issues and the management of beavers and their impacts

Introduction

Chapters 3 and 4 have set out how beavers can have a wide range of interactions with both the natural and the human environment. Beavers are often described as a keystone species because of their ability to influence and shape their environment. This ability to alter the environment, either natural or man-made, is one of the reasons that may bring beavers into conflict with people. Although conflict with human land use is likely to be the main driver for management intervention, there may also be a need to manage beavers and their impacts for other reasons, for example to protect the natural heritage or prevent the spread of animal diseases. Across the beaver range, whether in Europe, Asia or North America, a wide variety of techniques has been developed either to manage the impact of beavers or to directly manage the animals themselves.

This chapter sets out the current and likely future legal position of beavers in Scotland and considers a range of management techniques. It provides a basis from which to begin assessing the types of management which may be required if the decision is made to allow beavers to remain. Some of the techniques are more relevant to a specific scenario, or scenarios, set out in Chapter 6.

This chapter also seeks to describe a range of techniques which may, subject to legal and animal welfare considerations, be employed to manage either beaver impacts or beavers themselves. It is likely that the efficacy, costs and legal considerations surrounding the use of any technique will change over time.

It is important to emphasise that this chapter is a product of the time and environment in which it was written; that is, prior to a ministerial decision on the future of beavers following a trial reintroduction and with some experience of free-living beavers which have escaped from captivity or been released illegally into the wild. As such, caution should be taken when seeking to understand which techniques may be feasible, practicable or legal at any future point in time.

Much of the work to identify possible techniques and the financial, animal welfare and legal implications of their deployment is new and the collective thinking will evolve as decisions are made and challenges present themselves. At the time of writing, it is considered that certain techniques to manage either beavers or their impacts are likely to be more or less acceptable depending on the ministerial decision on the future of beavers and the constraints placed on government by EU law, which may also change over time.

- **Key consideration:** *The appropriate management of beavers and their impacts will inevitably change over time*

Legal considerations

The legal considerations associated with any type of conservation translocation are also explored in the Best Practice Guidelines for Conservation Translocations in Scotland[1].

European legislation, as transposed into domestic legislation

Beavers are listed on various annexes to *Council Directive 92/43/EEC on the conservation of natural habitats and of wild fauna and flora*, referred to here as the 'Habitats Directive'. This is given legal effect in Scotland by the *Conservation (Natural Habitats, &c.) Regulations 1994* (as amended), referred to here as the 'Habitats Regulations'.

The Habitats Directive gives beavers and their breeding sites and resting places strict legal protection, although this is not presently the case in Scotland, as the natural range of beavers did not include Scotland when the current Schedule 2 to the Habitats Regulations was written. It is anticipated that if the decision is made to allow beavers to remain in Scotland, having accepted the desirability of beaver reintroduction as described in Article 22 of the Habitats Directive, then beavers will receive the protection set out in the Directive. It is possible that this position could change in the future if either the Directive or the associate annexes are reviewed.

- **Key consideration:** *For the purposes of this chapter, it is assumed that beavers, if reintroduced to Scotland, will be given full legal protection under the Habitats Regulations (i.e. as a 'European Protected Species'), as required by the Habitats Directive*

The protection of beavers in Scotland will not preclude the legal management of beavers or their impacts. It is likely that many beaver impacts will be able to be managed without recourse to licensing.

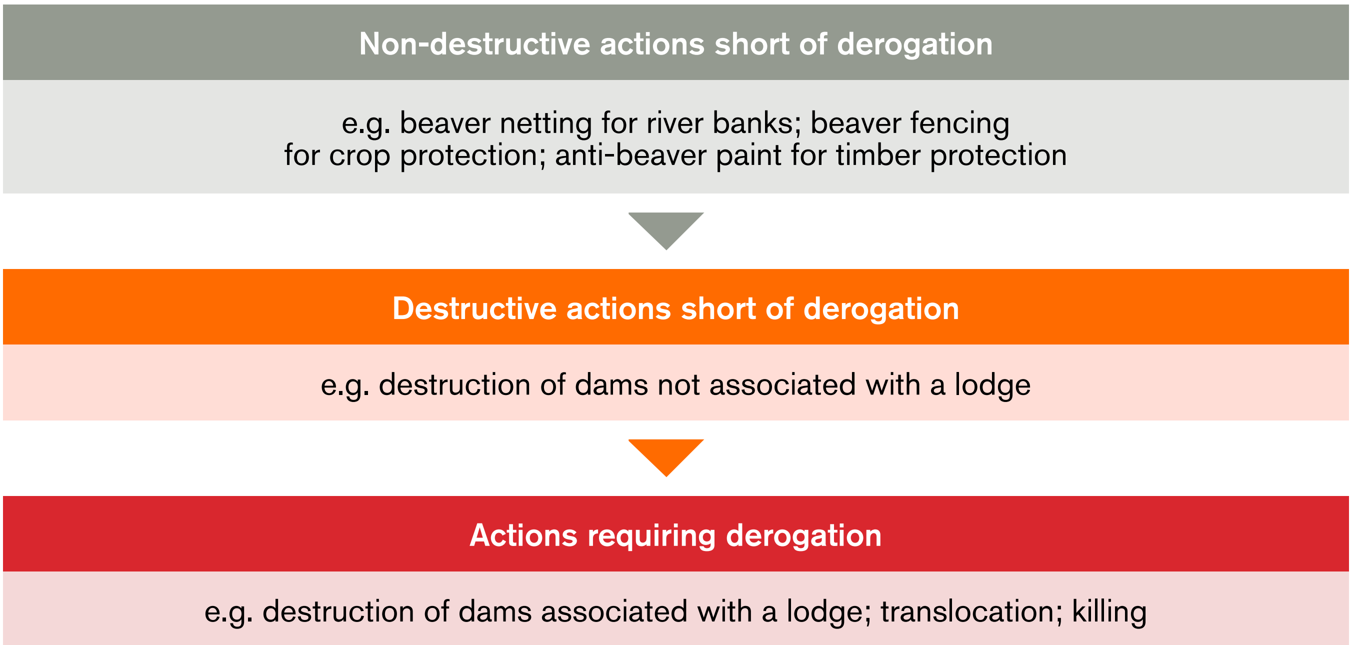
Article 16 of the Habitats Directive sets out under what circumstances derogations may be applied (by way of a licence to permit an otherwise illegal act). In summary, provided there is no satisfactory alternative and the derogation is not detrimental to the maintenance of favourable conservation status of the species in its natural range, they can be applied in the following situations (the following list is not exhaustive or complete, but these elements are considered of greatest relevance to the management of beavers and their impacts):

- To protect wild flora and fauna and conserve natural habitats
- To prevent serious damage, particularly to crops, livestock, forests, fisheries, water and other property
- In the interests of public health or safety or for other imperative reasons of overriding public interest including social or economic interests or beneficial consequences of primary importance for the environment

Member States must report on the use of these derogations every two years and the Commission will form a view on their use, including examining the alternatives that had been tried prior to resorting to derogation.

SNH commissioned research on behalf of the National

Figure 5.1
Beaver management actions and derogation (licence) requirements under the Habitats Regulations[2]. Some of these actions may also fall within other regulatory regimes. Note that these are the views of the authors, and not necessarily those of SNH (the relevant licensing authority).



Species Reintroduction Forum to look at various species reintroduction projects across Europe. This work examined beaver management and the use of derogations in several countries[2]. A summary of the authors' interpretation of the hierarchy of intervention is presented in Figure 5.1.

A further consequence of beavers being listed on the annexes to the Habitats Directive is that there is a requirement, under Article 11, for Member States to undertake surveillance of the conservation status of protected species and places. This is in addition to requirements under Article 17 to report on measures taken under the Habitats Directive, and also to monitor incidental capture and killing (such as accidental road kills) under Article 12.

Beavers are also listed on Annex II of the Habitats Directive. This means that, at some point in the future, consideration may need to be given to establishing Special Areas of Conservation (SACs) for beavers under the Habitats Regulations. It may not be necessary for this consideration to take place soon after a reintroduction event, and nor is it automatic that such a consideration will result in the designation of an SAC.

Other major provisions of the Habitats Regulations make it an offence, except in certain circumstances, to possess, control or transport beavers. It is likely that these provisions will have an impact on certain management techniques.

Some watercourses and other places used by beavers may be within or close by SACs or Special Protection Areas (SPAs), both of which are afforded protection under the Habitats Regulations. This means that any work associated with the management of beavers and their impacts within or affecting an SAC or SPA will need to be assessed for its effect on the site's protected features by the relevant competent authority in accordance with the Habitats Regulations.

Under the *Environmental Assessment (Scotland) Act 2005*, any public body preparing certain plans (including strategies, policies or programmes) is required to undertake a Strategic Environmental Assessment (SEA) of that plan if it is likely to have significant environmental effects. In this respect, the Scottish Government, as the competent authority, will need to consider the requirements of the 2005 Act in coming to a decision on the future of beavers in Scotland. If the decision is made to implement one of the scenarios in Chapter 6 in the form of a plan or policy, then there will need to be consideration of the likely significant effects on the environment arising from that plan or policy. The SEA process requires the identification and assessment of the effects of reasonable alternatives and it may be appropriate for the scenarios presented in Chapter 6 to form the basis of this if it is decided an assessment is required.

– **Key consideration:** *In coming to a decision on the future of beavers in Scotland, the potential requirement for a Strategic Environmental Assessment will need to be considered.*

Domestic legislation

The management of beavers and their impacts, although primarily governed by European legislation transposed into law in Scotland, will also be affected by a range of purely domestic legislation.

The most important piece of legislation in this context is the *Wildlife and Countryside Act 1981* (as amended) (the 'WCA'). In Scotland, this was amended by the *Wildlife and Natural Environment (Scotland) Act 2011*.

Under the WCA, former native species which have been or are to be reintroduced are regarded legally as non-native species. The major implication is that non-native species cannot, by definition, have a native range within Scotland. This means that any future release of beavers will need to be licensed by SNH.

– **Key consideration:** *Any release of beavers in Scotland presently requires a licence from SNH, and is likely to continue to do so in the future.*

As described above, any work associated with the management of beavers and their impacts on SACs and SPAs needs to be assessed for its effect on the protected features of the relevant site. The same applies to Sites of Special Scientific Interest (SSSIs) protected under the *Nature Conservation (Scotland) Act 2004*. In some circumstances, SNH will need to issue consent for operations to be carried out on a SSSI.

In terms of the management of beaver impacts, another important piece of legislation is the *Water Environment (Controlled Activities) (Scotland) Regulations 2011* ('CAR'), which regulate activities associated with the water environment. While this potentially covers all works in waterways, SEPA has developed a pragmatic position statement on the management of beaver structures, which is available from its website.

The *Salmon and Freshwater Fisheries (Consolidation) (Scotland) Act 2003* ('2003 Act') contains a number of provisions in relation to the maintenance of free passage for migratory fish. Section 23 in particular makes it an offence to impede the movement of salmon (meaning both Atlantic salmon and sea trout) to spawning areas or to affect their quality or quantity. This may affect certain management techniques, and consultation with District Salmon Fishery Boards (DSFBs) would be needed. However, it should also be noted that there is an expectation that the current system of fishery management, and associated legislation, will be revised in response to the 2014 Wild Fisheries Review.

– **Key consideration:** *Management of beavers and their impacts will involve the interaction of a number of pieces of legislation. Further advice for land managers and owners will be required.*

Table 5.1
Beaver management techniques employed in Europe and North America.

<table>
<tr><th></th><th></th><th>Management technique</th><th>Summary</th></tr>
<tr><td rowspan="9">Management of beaver impacts</td><td rowspan="5">Dam-building</td><td>Dam-notching</td><td>Removal of a small section of beaver dam, usually by hand, to increase water flow over that section</td></tr>
<tr><td>Flow devices</td><td>Placing a pipe through a dam to manage the water level behind it on a permanent basis</td></tr>
<tr><td>Dam removal</td><td>Removal of a dam, either by hand or using mechanical devices</td></tr>
<tr><td>Discouraging dam-building</td><td>Use of dissuasive techniques to prevent dam-building either where known 'pinch points' occur or where a dam has been removed and is likely to be reconstructed</td></tr>
<tr><td>Grilles</td><td>Use of metal grilles to prevent access to certain types of likely damming points, such as culverts</td></tr>
<tr><td rowspan="2">Burrowing activity</td><td>Prevention of burrowing</td><td>Use of sheet metal piling, rock armour or mesh to prevent burrowing, or further burrowing, into vulnerable flood defences or adjacent land</td></tr>
<tr><td>Realignment of flood banks</td><td>Expanding the riparian zone used by beavers by moving existing flood defences a minimum of 20 m from the edge of a watercourse</td></tr>
<tr><td rowspan="2">Foraging activity</td><td>Exclusion fencing</td><td>Fencing, either permanent or temporary, to prevent beavers accessing areas of water, crops or trees where damage is deemed intolerable</td></tr>
<tr><td>Individual tree protection</td><td>Protection of individual or small numbers of amenity or other valuable trees by use of individual fences, mesh wrapping or deterrent paints</td></tr>
<tr><td colspan="2" rowspan="4">Management of beavers</td><td>Wildlife rehabilitation and euthanasia</td><td>Rehabilitation of injured beavers prior to their release into the wild, and humane euthanasia where necessary</td></tr>
<tr><td>Trapping</td><td>Live trapping beaver(s) for transport and release (i.e. translocation), for a further procedure to occur (e.g. sterilisation) or for their humane dispatch, or lethal trapping</td></tr>
<tr><td>Culling</td><td>Culling of beavers by land managers or public bodies, or as part of a regulated sporting harvest to reduce/ manage the population or to remove 'problem' animals</td></tr>
<tr><td>Fertility control</td><td>Affecting the fecundity of beavers by catching and surgically sterilising beavers or by darting with contraceptive drugs</td></tr>
</table>

Appendix 2 provides a more detailed summary of relevant legislation that SNH believes is most relevant to beavers and beaver management issues, and provides an indication of the possible implications.

Management techniques

Techniques for the effective management of beavers and beaver impacts are well developed across Europe and North America. Many of these will have a potential application in Scotland if beavers are reintroduced.

Table 5.1 lists some specific beaver management techniques, with more detail in the following text. Further information can be found in the full SNH Commissioned Report which reviews beaver management[3]. In considering each of these techniques, there are underlying assumptions that the relevant legislation will be followed, and SNH's position statement on wildlife welfare taken into account. Consideration needs to be given not just to the potential impacts of the management techniques on beavers and their habitats, but also the needs of other protected species and protected habitats. In addition, where such management may be employed more than once in a given area and/or over a certain time interval, the impacts may be cumulative and would need to be accounted for in any licensing decisions.

Dam-building and associated management techniques

As has been discussed in sections 3.4.3 and 4.1, beavers building dams on rivers may bring a range of benefits. It is also important to accept that beaver dam-building will sometimes conflict with human interests and impose a cost in terms of resources (including time and money), especially in intensively managed landscapes. There is a particular issue over the possible effects of beaver dams on the movement of migratory salmonids under certain conditions (section 4.2).

Dam-building and the incidence of dams varies depending on habitat characteristics. On lochs or rivers more than 6 m wide, dam-building is uncommon. Beavers utilising narrower water bodies (less than about 6 m wide and 0.8 m deep) often build dams and can create extensive systems of multiple dams and impoundments. Where watercourses are steeper in gradient with higher banks in narrow valleys, the capacity for beaver activity to alter or create habitats on a significant scale is much more limited.

The length of time that dams persist in the environment varies and can be relatively short lived, particularly if food resources become depleted and/or they are not worth maintaining compared with the costs and benefits of exploiting resources elsewhere[4].

There is a paucity of documented management techniques employed throughout Europe which specifically address the issue of beaver dams. A summary of possible techniques is given below. Some of these may help to address potential impediments to fish movement.

i. Dam-notching

- **Summary:** Removal of a small section of beaver dam, usually by hand, to increase water flow over that section.
- **Purpose/uses:** Most often associated with aiding fish passage. May be used to lower water levels in beaver ponds behind a dam.
- **Limitations:** In active territories, beavers will often repair notched dams within 48 hours. Labour intensive, especially at a catchment scale.
- **Animal welfare:** Reducing water levels to less than 0.8 m on the upstream side of the dam could cause significant welfare issues, including lodge abandonment (a particular concern in breeding territories).
- **Timing:** Management efforts should be co-ordinated with fish migration or coupled with a flow device to manage water levels in the long term. Potential impacts on heavily pregnant females and dependent juveniles during approximately April to September would need to be considered.
- **Legal considerations:** Dam-notching using hand tools, rope or grapnels can occur without prior authorisation from the Scottish Environment Protection Agency (SEPA). Work causing damage or destruction of a lodge or burrow (a 'breeding site' or 'resting place') or resulting in deliberate or reckless disturbance of animals whilst they are occupying such a structure or place, for example, is likely to be in contravention of the Habitats Regulations.
- **Costs:** The majority of dams could be notched with widely available hand tools in around an hour (not counting travelling to the site, etc.). At current agricultural wages, this is likely to be something in the order of £10 per dam.
- **Regulatory burden:** Unlikely to require a licence from SNH or SEPA provided certain methods are followed and the minimum level of water is maintained behind the dam.

ii. Flow devices

- **Summary:** Placing a pipe through a dam to manage the water level behind it on a permanent basis (Figure 5.2).
- **Purpose/uses:** Used to manage water level behind or above a dam where a certain water level is tolerable, but any further increase would not be. Essentially, it acts as an overflow device for the dam.
- **Limitations:** Can be time consuming to install. Unlikely to be effective if poorly installed or the pipe is sized wrongly. Generally ineffective if less than 0.8 m of water remains behind the dam. Requires some ongoing maintenance.
- **Animal welfare:** Reducing water levels to less than 0.8 m on the upstream side of the dam could cause significant welfare issues, including lodge abandonment (a particular concern in breeding territories).
- **Timing:** Theoretically possible to install at any time, although more straightforward at times of low water level. Potential impacts on heavily pregnant females and dependent juveniles during approximately April to September would need to be considered.
- **Legal considerations:** Work causing damage or destruction of a lodge or burrow (a 'breeding site' or 'resting place') or resulting in deliberate or reckless disturbance of animals whilst they are occupying such a structure or place, for example, is likely to be in

contravention of the Habitats Regulations. Installation of any structure into a waterway will at least require consultation with SEPA, although they could be considered temporary and generally permitted provided General Binding Rules are followed. Likely to require assessment of impact on migratory fish passage (in relation to the 2003 Act).
- **Costs:** Typically in the region of £300–400 per device, with costs reducing as practitioners gain experience.
- **Regulatory burden:** Likely to require consultation with SEPA and DSFBs. Unlikely to require a licence from SNH provided certain methods are followed and the minimum level of water is maintained behind the dam.

iii. Dam removal

- **Summary:** Removal of a dam, either by hand or using mechanical devices.
- **Purpose/uses:** Used where no increase in water level, or potential blockage to fish passage, is considered acceptable in a watercourse or part of a watercourse.
- **Limitations:** Removal of dams often stimulates beavers to rebuild the structure using fresh woody material. Likely to require repetition. Manual removal may be more time consuming than using heavy machinery, but less likely to result in sudden release of water and/or silt.
- **Animal welfare:** Complete removal of a dam, which may often reduce water levels to less than 0.8 m on the upstream side of the dam, could cause significant welfare issues, including lodge abandonment (a particular concern in breeding territories) and access to food caches.
- **Timing:** Subject to the animal welfare considerations above, theoretically possible at any time provided there is safe access to the river or bank. Potential impacts on heavily pregnant females and dependent juveniles during approximately April to September would need to be considered, as would accessibility of food caches between October and March, although this would be more of an issue in harsh winters.
- **Legal considerations:** Work causing damage or destruction of a lodge or burrow (a 'breeding site' or 'resting place'), or resulting in deliberate or reckless disturbance, is likely to be in contravention of the Habitats Regulations. Likely to require assessment of impact on migratory fish passage (in relation to the 2003 Act). General animal welfare legislation.
- **Costs:** Vary significantly depending on manual or mechanical removal. Several hours' labour at general farm worker rates (currently £7.14 per hour minimum) or time for excavator and operator (typically £300–400 per day), although many farms will have this equipment available. Time associated with assessing if it is a breeding site or resting place, and what possible impacts could result from action.
- **Regulatory burden:** Dependent on timing and nature of beaver territory that any dam removal may affect (e.g. natal lodges, harsh winters). May require a licence from SNH. In-river works with mechanical excavators will require prior approval from SEPA. Consultation with DSFBs.

Figure 5.2
A flow device – the pipe has been placed in the beaver dam to manage the water level behind it.
© Helen Dickinson/ TBSG

iv. Discouraging dam-building

- **Summary:** Use of dissuasive techniques to prevent dam-building either where known 'pinch points' occur or where a dam has been removed and is likely to be reconstructed.
- **Purpose/uses:** Prevention of dam-building or rebuilding where dam-building is deemed intolerable.
- **Limitations:** A range of techniques have been trialled and found ineffective. Might include electric fencing strung above the dam site. Flashing lights etc. may work until animals become habituated to them.
- **Animal welfare:** Unlikely to have animal welfare implications, although could be construed as disturbance.
- **Timing:** Theoretically possible at any time.
- **Legal considerations:** Work causing deliberate or reckless disturbance, including harassment of animals, is likely to be in contravention of the Habitats Regulations.
- **Costs:** Vary significantly dependent on technique used. A small electric fencing unit and battery are likely to cost about £250.
- **Regulatory burden:** Provided that the technique is deemed not to cause disturbance to protected species, then there is unlikely to be any regulatory burden.

v. Grilles

- **Summary:** Use of metal grilles to prevent access to certain types of likely dam-building points, such as culverts.
- **Purpose/uses:** Prevents access for beavers to dam natural pinch points in watercourses.
- **Limitations:** Easily blocked by debris from beaver activities upstream or general detritus. Requires regular clearance and monitoring.
- **Animal welfare:** Unlikely to cause animal welfare issues.
- **Timing:** Not time dependent. Permanent structures.
- **Legal considerations:** Likely to require assessment of impact on migratory fish passage (in relation to the 2003 Act). CAR will apply.
- **Costs:** Many different designs for these structures, which vary in specific extent and the strength of their required materials, according to the requirements at individual sites.
- **Regulatory burden:** Will require authorisation from SEPA and consultation with DSFBs.

Burrowing activity and associated management techniques

Beavers are strong and able diggers, and can readily excavate burrows and canals, which may collapse and/or increase bankside erosion to varying extents, depending on associated water flow and substrate type. Beaver burrows tend to be large and can end in sizeable chambers. Although the route of these structures is occasionally visible, the position of many others is difficult to determine. Beavers will readily excavate burrow systems which begin under water with entrances which can be obscured by tree roots or vegetation. Although the actual instances of beaver burrows causing the collapse of engineered flood walls are few, European water agencies have developed a range of remedial measures. Other concerns relate to the possibility of livestock, horses, humans or farm machinery breaking through the surface into a beaver burrow with resultant damage or injury.

i. Prevention of burrowing

- **Summary:** Use of sheet metal piling, rock armour or mesh to prevent burrowing, or further burrowing, into vulnerable flood defences or adjacent land.
- **Purpose/uses:** Prevents beaver burrowing activity from starting or continuing in new or remodelled flood banks or into adjacent land.
- **Limitations:** Not straightforward or cheap. Can have considerable hydrological or hydrogeomorphological impacts. Likely to displace activity rather than completely prevent it.
- **Animal welfare:** Potential to disturb or damage a resting place or breeding site of a range of species.
- **Timing:** Not time dependent. Permanent structures.
- **Legal considerations:** CAR will apply. Work causing damage or destruction of a lodge or burrow (a 'breeding site' or 'resting place'), or resulting in deliberate or reckless disturbance, is likely to be in contravention of the Habitats Regulations. This is particularly relevant where there are existing burrows.
- **Costs:** Recent work in the Czech Republic cost approximately £158,000 to net wire 1,600 m of flood bank. Metal sheet piling of 800 m of flood bank cost approximately £225,000. Work in Austria has been estimated at £215–360 per metre.
- **Regulatory burden:** Will require authorisation from SEPA. Where there has been no burrowing, then unlikely to require a licence from SNH provided certain general conditions are followed. Where there has been burrowing, a licence from SNH may be required.

ii. Realignment of flood banks

- **Summary:** Expanding the riparian zone used by beavers by moving existing flood defences a minimum distance (in the region of 20 m) from the edge of a watercourse.
- **Purpose/uses:** Reduces the likelihood of beaver activity in flood defences or productive land. Allows for a greater floodable area within a catchment and may provide wider opportunities for riparian habitat creation and restoration and flood management.
- **Limitations:** Loss of productive land. Not all areas have sufficient room for expansion. Likely to be significant resistance from some stakeholders. Expensive.
- **Animal welfare:** Potential to disturb or damage a resting place or breeding site of a range of species.
- **Timing:** Work to remove existing lodges etc. would need to be carefully timed. There is a potentially limited window of opportunity where beaver territories are already established.
- **Legal considerations:** CAR will apply. Work causing damage or destruction of a lodge or burrow (a 'breeding site' or 'resting place'), or resulting in deliberate or reckless disturbance, is likely to be in contravention of the Habitats Regulations. Likely to require assessment of impact on migratory fish passage (in relation to the 2003 Act).
- **Costs:** Poorly defined, but likely to be significant –

arable ground currently selling for about £18,000 per hectare, plus costs of new flood defences.
- **Regulatory burden:** Will require authorisation from SEPA. May require licence from SNH if there might be disturbance, or damage or destruction of a resting place or breeding site. Consultation with DSFBs. Could require compulsory purchase of land (note that compulsory purchase legislation is currently being reviewed in Scotland).

Foraging activity and associated management techniques

Beavers are herbivores and will readily consume a wide range of bark, shoots and leaves of woody (primarily broadleaved species), herbaceous and aquatic vegetation. Whilst beaver foraging activity is most noticeable on trees and woody vegetation, beavers will also forage in crops both as a source of food and for construction material where there is limited woody material available. Beavers display regular routines and feeding patterns, resulting in well-worn trails and canals being easily visible.

i. Exclusion fencing

- **Summary:** Fencing, either permanent or temporary, to prevent beavers accessing areas of water, crops or trees where damage is deemed intolerable.
- **Purpose/uses:** Prevents beaver access to areas where their impacts cannot be tolerated or prevents beavers accessing vulnerable or valuable crops or trees.
- **Limitations:** Not suitable for extensive areas. All fencing requires maintenance. Fencing to prevent the movement of beavers along a waterway may provide a dam-building point or act as an impediment to the movement of fish and other species. Inappropriate fencing could exclude other grazing/browsing species with consequent impacts on habitats. Probability of displacing impacts.
- **Animal welfare:** Dependent on scale. There could be issues about preventing access to food and construction materials.
- **Timing:** Fencing needs to be established before unacceptable levels of damage become apparent.
- **Legal considerations:** Work causing damage or destruction of a lodge or burrow (a 'breeding site' or 'resting place') is likely to be in contravention of the Habitats Regulations.
- **Costs:** Heavy-duty, permanent exclusion fencing costs in the order of £40 per metre. Temporary electric fencing costs around £1 per metre.
- **Regulatory burden:** May require a licence from SNH if damage or destruction of a resting place or breeding site is likely to occur.

ii. Individual tree protection

- **Summary:** Protection of individual or small numbers of amenity or other valuable trees by use of individual fences, mesh wrapping or deterrent paints (Figure 5.3).
- **Purpose/uses:** Prevents beavers foraging on individual trees.
- **Limitations:** Relatively high visual impact. Only suitable for small numbers of trees.
- **Animal welfare:** Dependent on scale. There could

Figure 5.3
Individual fences or mesh wrapping can be used to protect specific trees.
© Helen Dickinson/ TBSG

be issues about preventing access to food and construction materials.
- **Timing:** Needs to be established before unacceptable levels of damage become apparent.
- **Legal considerations:** Unlikely to be significant.
- **Costs:** Vary depending on method chosen. Fencing averages £3 per tree. Paint varies from £1 to £5 per tree depending on product used.
- **Regulatory burden:** Provided that the technique is deemed not to cause disturbance to protected species, then there is unlikely to be any regulatory burden.

Management of beavers

The management techniques described in the preceding sub-sections all focus on the management or mitigation of beaver impacts. This section considers management of the animals themselves.

The perceived need for, and methods of, regulating beaver populations vary greatly across Europe, from hunting quotas in Norway (frequently unlimited because the demand for hunting is below the rate of natural increase in many river systems) to removal by employed or trained volunteer beaver managers in Germany. In countries where beaver populations are still recovering they are usually fully protected and mitigation and non-lethal management methods prevail.

In cases where beaver conflicts cannot be suitably managed, because costs are too high or the potential impacts too great, the removal of their presence through trapping and translocation, or culling, may be the only practical solution.

i. Wildlife rehabilitation and euthanasia

- **Summary:** Rehabilitation of injured beavers prior to their release into the wild, and humane euthanasia where necessary.
- **Purpose/uses:** To provide care of injured or orphaned animals prior to their release into the wild, or euthanasia if rehabilitation is not possible.
- **Limitations:** Currently, few facilities would be capable of providing such care. Potential difficulties may arise where individuals or organisations involved are either against euthanasia or subsequent release into the wild.
- **Animal welfare:** Any facility would be subject to the general provisions of the *Animal Health & Welfare (Scotland) Act 2006.*
- **Timing:** Time in captivity should be kept to a minimum, although the timing of release would need to be considered on a case-by-case basis to take into account animal welfare implications, for example the age and status of the animal (e.g. whether part of a family group or a dispersing sub-adult), seasonality and food availability.
- **Legal considerations:** General exemptions from

Figure 5.4
Beaver trap used at Knapdale.
© Lorne Gill/ SNH/2020VISION

licensing exist for this purpose in the Habitats Regulations. The release of beavers into the wild will require a licence from SNH under the WCA. Injured beavers that die would need to be reported to SNH.
- **Costs:** It is assumed that wildlife rehabilitation charities will shoulder the burden of cost, providing that eventual solutions for the fate of the animals are palatable to their donors.
- **Regulatory burden:** Licences will be required from SNH for release of rehabilitated animals into the wild. Organisations such as road operating companies, local authorities and animal welfare and rehabilitation bodies will need to report to SNH on any incidental killing (such as accidental road kills) or euthanasia of beavers.

ii. Trapping
- **Summary:** Live trapping (Figure 5.4) of beaver(s) for transport and release (i.e. translocation) for a further procedure to occur (e.g. sterilisation) or for their humane dispatch, or lethal trapping.
- **Purpose/uses:** To reduce the beaver population, remove 'problem' animals, translocate animals (including for conservation purposes) or keep them captive for other procedures to occur.
- **Limitations:** Time consuming. Requires some knowledge of beaver behaviour. Requires suitable equipment set at an appropriate site. Limited options for approved traps (only live-capture cage-type traps). Lethal traps are used in some other countries, but currently there are no approved lethal traps which could be operated in Scotland.
- **Animal welfare:** Trapping should cease when heavily pregnant females and/or dependent juveniles are potentially present. Any trapping effort to remove beavers from an area should seek to ensure that whole families are captured and dependent juveniles are not left behind. Trapping should not occur when very low temperatures or large fluctuations in water levels are anticipated. Risk of incidental capture of non-target species. Subsequent transport needs to use appropriate crates and vehicles. Care needs to be taken not to mix unrelated individuals indiscriminately either during transport or at release.
- **Timing:** Trapping should cease when there is the potential for heavily pregnant females and/or dependent juveniles to be present (approximately April to July for non-lethal trapping). If translocation is planned, appropriate preparations need to be made in advance and translocation protocols followed (including those set out in the Scottish Code for Conservation Translocations[1] if a conservation translocation is involved).
- **Legal considerations:** Deliberate capture, disturbance, killing (i.e. euthansia after live trapping) and the possession, control and transport of a beaver is likely to be in contravention of the Habitats Regulations and require an SNH licence. The method of taking or killing may need to be licensed, too. Legal requirements around the checking of traps. The *Animal Health and Welfare (Scotland) Act 2006* applies once animals are captive. Risk of incidental capture of protected non-target species. The release of beavers into the wild will require a licence from SNH under the WCA.
- **Costs:** In 2002 in the USA, professional beaver trappers charged about £100 to trap a single animal or £495 for a family of up to five animals. Beaver traps cost £450 each. Time is required to place, monitor and remove traps. Transport crates typically cost £300 each.
- **Regulatory burden:** Disturbance, possession, control, transportation and killing all require a licence from SNH. Subsequent release would require a licence. Incidental capture/killing of Annex IVa species should be reported to SNH.

iii. Culling
- **Summary:** Culling of beavers by land managers or public bodies or as part of a regulated sporting harvest to reduce/manage the population or remove 'problem' animals.
- **Purpose/uses:** To reduce the beaver population and remove 'problem' animals.
- **Limitations:** Time consuming. Difficult to identify the correct 'problem' animal to target. Difficult to establish the level of off-take in a system with land manager involvement. Limited practical experience of beavers within the professional or recreational wildlife management sector in Scotland.
- **Animal welfare:** Likely that guidance on appropriate calibres, ranges, etc. would need to be developed. Potential loss of wounded animals in watercourses, especially in the dark. Risk of orphaning dependent juveniles or disturbing group dynamics.
- **Timing:** Likely prohibition during period of juvenile dependence (approximately April to September).
- **Legal considerations:** Deliberate killing, transport, control and the possession of a carcass is likely to be in contravention of the Habitats Regulations and would require a licence from SNH. The number of animals killed would need to be monitored and reported on. May not be straightforward to justify action during the early stages of population establishment.
- **Costs:** Estimate of £100 per animal for public-funded personnel. Land managers are likely to do this at their own cost or to derive some benefit by selling the opportunity to cull.
- **Regulatory burden:** Killing, and subsequent possession of the carcass, would require a licence from SNH.

iv. Fertility control
- **Summary:** Affecting the fecundity of beavers by catching and surgically sterilising beavers or by darting with contraceptive drugs.
- **Purpose/uses:** Allows for the retention of stable but non-breeding beaver populations. Unlike lethal control, this does not leave a territory vacant for colonisation by other beavers.
- **Limitations:** Time consuming. Little knowledge of efficacy of immune contraception. Not possible to sex animals from a distance. Very difficult to ensure that all animals in target groups are sterilised.
- **Animal welfare:** Where trapping and surgical sterilisation is performed, all of the animal welfare considerations associated with trapping apply to this technique. Risk of injury to animals if darting. Risks associated with anaesthesia and the return to

the wild of animals that have undergone a surgical procedure.

- **Timing:** Unknown effect of contraceptive agents means this technique would need to be avoided during the possible period of pregnancy. Trapping should cease when there is the potential for heavily pregnant females and/or dependent juveniles to be present (approximately April to July).
- **Legal considerations:** See trapping section above. Trapping would require a licence, as would subsequent release.
- **Costs:** See trapping section above. In addition, surgical sterilisation is likely to be in the region of £200–400 per animal. Immuno-contraceptive drugs are likely to be in the region of £10 per animal, with time costs for training and darting.
- **Regulatory burden:** Disturbance, possession, control and transportation all require a species licence from SNH. Subsequent release would also require a licence.

Approaches to management

A large number of the above techniques have been developed in response to both legal constraints and a wider social interest in non-lethal wildlife management solutions. A survey of European beaver managers found that non-lethal mitigation constituted the majority of management practices[5]. Whilst this may reflect the protected status of this species in many countries, it also offers a more practical solution as the culling of problem individuals in a highly territorial species such as beaver may create an empty territory which may soon be filled by further dispersing animals[5].

Beaver removal

Continual dam and/or beaver removal programmes are expensive and time consuming[6], particularly in areas of suitable, accessible beaver habitat[7]. However, lethal management may still present a practical option where beavers occur at higher population densities.

Once reintroduced into a river system beavers will, over time, spread to occupy any accessible habitats throughout the entire catchment in the absence of any significant physical barriers. If this is undesirable the only management solution to limit beavers to particular areas is through a constant, consistent process of removal via trapping or culling. In the longer term, and where densities rise and/or populations expand, this requirement may become more common. As the conservation status of beavers improves it may become more possible to license beaver removal.

Although potentially less acceptable to some sections of society, hunting has been demonstrated in some European countries to be a flexible and cheaper management option in maintaining healthy populations. Such an approach would afford land managers the power to manage impacts whilst potentially reaping benefits from hunting income for having beavers on their land. In developed western European landscapes the specific targeting of 'problem' individuals may be a more effective conflict resolution than a randomised approach to reducing numbers in a wider population. There are already good examples of species which receive protection in Scotland (although not as European Protected Species), like deer, which are managed on this basis.

Buffer zones

The creation and restoration of riparian 'buffer zones', and the identification of existing ones, could be an effective way of planning beaver management on a more long-term basis. Such riparian buffer strips, or zones of woody vegetation, could be managed to encourage and/or allow for beaver presence.

A buffer zone along watercourses separates the activity of beavers and land-use interests to reduce human–wildlife conflict and diminish the need for beaver management. This is because the great majority of beaver activity occurs in close proximity to the watercourse. Around 95% of beaver foraging activity has been shown to be within 5 m of the watercourse in some areas[8]. The level of foraging activity also declines with distance, and almost all activity is likely to occur within 50 m of watercourses (section 3.2). The majority of damage caused by burrowing is expected to occur less than 10 m from watercourses[9]. However, although smaller ponds and wetland created by beavers may fall within these distances, larger areas of wetland may extend further, depending on the local topography. A 20 m riparian buffer zone has been proposed as an effective measure to help reduce beaver conflict[9, 10], while, for wider conservation purposes, buffer zones of 50 m have been proposed[11].

The aim would be to make such buffer zones as attractive to beavers as possible, for example through the planting and management of native riparian tree and shrub species, encouraging natural regeneration to produce suitable beaver habitat and allowing localised flooding after dam-building. This process of increasing and restoring suitable beaver habitat in the immediate vicinity of a water body will reduce the need for the animals to forage further afield, and help limit the associated, potentially problematic, behaviours such as burrowing and canal-building.

The creation of attractive riparian habitat would provide an alternative approach to dam and beaver removal in areas where beaver presence could be tolerated more. A well-planned adoption and use of buffer zones at the landscape scale should reduce the number of human–beaver conflicts. However, this approach will not always be practicable where flood banks exist, in artificial and/or heavily modified and managed water bodies, or where land is considered too valuable for buffer zones to be created.

Significantly, such buffer zones have been shown to have a variety of wider beneficial effects. These include bank stabilisation, increasing woody debris influx into watercourses, reducing flooding, regulating water temperatures, and reducing the influx of pollutants, excess nutrients and chemicals into watercourses[12–16]. The larger the size of a buffer zone, the greater its effects[14, 17]. In addition, buffer zones composed of trees and woody vegetation have been shown to have a greater ability to filter pesticides than shrub or grassland buffers[14]. They may also play an important role in supporting terrestrial biodiversity in more heavily modified landscapes, providing habitat and movement 'corridors' for a wide variety of species[11, 15, 18, 19].

Because there are a wide variety of potential benefits that result from the creation of riparian buffer zones, a number of programmes already exist to promote them. If the decision is made to allow beavers to remain in Scotland, there is therefore an opportunity to build on, and coordinate, any future buffer zone planning for the purposes of beaver management with the types of work already going on, some of which are described here:

- *Forestry Grant Scheme (Forestry Commission)* – this scheme promotes woodland creation and could be utilised on land adjacent to watercourses. A range of grants is available under the SRDP
- *'Pearls in Peril' (LIFE+ NATURE project)* – this project involves a range of activities, including the promotion of tree planting to help improve freshwater pearl mussel habitat. It is focused on 21 different river catchments
- *Water Environment Fund (SEPA)* – this supports projects which aim to restore Scotland's watercourses, and these projects may include promoting native bank-side vegetation
- *Scottish Rural Development Program (SRDP)* – in order to be eligible to claim basic payments in Pillar 1 (which is the replacement for what was previously called the Single Farm Payment), farms must adhere to the new Greening elements of the Common Agricultural Policy. This states that farms are required to farm 5% of their arable area as an Ecological Focus Area to promote biodiversity. This could be focused on riparian buffer zones. In addition, all farms must adhere to Good Agricultural Environmental Conditions. This now has the requirement for a 2 m uncultivated strip adjacent to all watercourses or ditches. There are also a number of opportunities under the recently launched Agri-Environment Climate Scheme. These include funding management and capital items, which could enhance habitat and reduce conflict with beavers. As with other funding streams, any enhancement and mitigation on agricultural land in relation to beavers would cover the SRDP funding period, any longer-term funding required would need alternative sources

Beavers are a high-profile and charismatic species and could be used to promote riparian buffer zone establishment, not only as a useful tool to reduce conflict, but also as a catalyst for wider habitat restoration and creation. In some situations this could be further targeted at potential beaver habitats of high conservation value, such as aspen and Atlantic hazel woodland. There is the opportunity to develop larger co-operative ventures with multiple land owners covering larger areas which would be more likely to receive project funding, especially in protected places.

A strategic approach to beaver management

Scottish and European species management experience has shown the value of producing and adopting a pragmatic and responsive management strategy at an early stage in any reintroduction or removal process. This could include accompanying management information and guidance for land managers. This is discussed further in Chapter 6.

Beaver management in other European countries

It is estimated that there are now over one million Eurasian beavers occurring in at least 25 European countries[20]. Beavers are managed in the majority of countries in which they occur. Approaches vary according to landscape and land use and also the regulatory regimes that are in force, with EU Member States employing different management strategies from those countries which are not in the EU. The following examples include one non-EU country (Norway) and four EU Member States. One of the EU Member States, Finland, is exempt from the Habitats Directive Annex IV protection measures (as are Latvia, Estonia, Lithuania, Poland and Sweden). Further details are provided in the SNH Commissioned Report on beaver management[3].

Norway

In Norway, annual harvest quotas are set by regional game boards, and then divided among landowners. The right to hunt belongs to the landowners. They are expected to control the beaver population on their land at their own expense by either hunting or trapping, or letting others do so, for example for sport. Beaver management is therefore achieved at little cost to the public purse, and some income is generated by the landowners. It must initially be done during the normal open season and within the limits of their quota. Beavers can be controlled outside of the open season if significant damage is demonstrated and an application is made to the authorities. Permission is almost always given, although it is not uncommon for landowners to act without applying for permission, as they are rarely indicted for breaking the law this way. Beaver lodges and dams are protected in Norway and landowners must apply for permission to remove them. This is usually given, and the work is done by the landowners themselves. Thus, the cost of beaver damage control in Norway is covered almost completely by the landowner. Currently, new beaver management by-laws are being considered by the central authorities, and one major revision may include the replacement of the quota system with a landowner-regulated harvest, through which landowners can determine the size of the harvest themselves.

Germany

In Bavaria, a beaver management programme was established in 1996 (some 30 years after beaver reintroduction) as a direct result of increasing tensions between land managers and conservationists. Although not every conflict can be resolved, there is a willingness amongst landowners to accept beavers, providing advice, assistance and financial support are available. Beaver management is jointly operated between NGO-operated beaver managers, state agencies and volunteer beaver consultants (who receive expenses). Beaver managers (currently two individuals for the whole of Bavaria) monitor national beaver population data. Around 1,000 beavers are culled annually under the direction of the nature agency, which issues permits. Removal of beavers is done only if they are causing (or might cause) severe damage and no reasonable and affordable preventative measures are available. Removal is, however, not a permanent solution, as the vacant territories are usually recolonised by migrating juveniles. A key consideration in the beaver management programme is long-term landscape planning for beavers and their habitat, through the creation of buffer zones around fresh waterbodies to reduce future conflict. Concerns have been raised that the Bavarian model may not be compliant with EU law[2].

Denmark

The Danish beaver reintroduction started in 1999. Beaver reintroduction and management is coordinated by a steering group of public body staff, with no one person working full time on beaver issues. Mitigation costs have, to date, been in the region of about £720–2,150 per year, although staff costs have risen significantly over the last five years to about £50,100 per year. Over 100 volunteers participate in annual beaver count estimates, with expenses for this monitoring work estimated at approximately £28,600 per year.

Czech Republic

The Ministry of the Environment and Nature Conservation Agency of the Czech Republic is responsible for beaver management. In 2013, a management plan for beavers was adopted by the state authorities. This 10 to 15-year management plan aims to sustainably manage beavers across various catchments and provide the administrative and legislative structures to deal with beaver conflicts, a public awareness programme that targets land managers, and a research and monitoring programme to assess population development and distribution. Currently, one person is employed specifically for beaver management. Beaver populations are monitored every two years within seven Natura 2000 sites at public expense. A public-funded beaver compensation system has been in place since 2000. A total of approximately £2,030,000 has been paid out since 2000, with the majority of this compensation paid to state-owned forests. Some limited lethal control has been exercised. This plan creates differential protection zones: Zone A, largely Natura sites, where impacts are considered low risk and a viable, long-term population can be maintained; Zone B, where there is greater management of beavers and their impacts; and Zone C, where beaver presence is deemed undesirable and is prevented. At present, the system is considered to be under-resourced (both financially for compensation payments and in terms of staff time) and there is a lack of support and advice available.

Finland

The Finnish Wildlife Agency is responsible for beaver management in Finland. Both Eurasian and North American beavers are present. Beaver management does not constitute much beyond beaver hunting. There are future plans to reintroduce Eurasian beavers to various locations. Currently, there is no management plan for beavers in Finland. Beavers can be hunted for recreation and to remove 'problem' individuals. Hunting of North American beavers is quite straightforward under a general hunting licence and with landowner permission. For Eurasian beavers a special permit is required, and this is given only for 'problem' animals. In 2013 about 4,200 (± 1,500) beavers were hunted, with 214 of these being Eurasian. There is no government compensation for beaver damage, although some landowners have insurance to cover losses. Management plans are being developed in a bid to prevent range conflation between Eurasian and North American beavers, and this is likely to be the first step in the development of a national beaver management plan.

Summary

- The appropriate management of beavers and their impacts will inevitably change over time
- It is assumed that beavers, if reintroduced to Scotland, will be given full legal protection under the Habitats Regulations (i.e. as a 'European Protected Species'), as required by the Habitats Directive
- In coming to a decision on the future of beavers in Scotland, the potential requirement for a Strategic Environmental Assessment will need to be considered
- Any release of beavers in Scotland presently requires a licence from SNH, and is likely to continue to do so in the future
- Management of beavers and their impacts will involve the interaction of a number of different pieces of legislation. Further advice for land managers and owners will be required
- Beavers now occur in over 25 European countries. Techniques for the effective management of beavers and beaver impacts are well developed across Europe and North America, providing a range of beaver management options and experiences to draw upon
- A large number of techniques have been developed in response to both legal constraints and a wider social interest in non-lethal wildlife management solutions. This offers a more practical solution to the culling of problem individuals in a highly territorial species such as beavers. Many management techniques are unlikely to require a licence, but some may. It should be possible to develop a regulatory regime in Scotland which is balanced, proportionate and legally compliant
- Once reintroduced into a river system beavers will, over time, spread to most accessible habitats throughout catchments. If this is undesirable the only management solution to limit beavers to particular areas, especially in the longer term, is through a constant, consistent process of removal via trapping or culling
- The creation and restoration of riparian 'buffer zones', and the identification of existing ones, could be an additional and effective way of planning beaver management on a more long-term basis and providing wider environmental benefits

Chapter 6
Future scenarios for beavers in Scotland

Introduction

Two beaver populations currently exist in Scotland. The first was established during the SBT and currently consists of four families. A second population exists primarily within the Rivers Tay and Earn catchments, and consisted of about 38 to 39 families when last surveyed in 2012.

Four potential scenarios for the future of beavers in Scotland are presented here. These range from the full removal of beavers to the widespread reintroduction of beavers across Scotland. The scenarios are broad and a number of sub-options are possible. Few of the scenarios are discrete, so scenarios may be combined and there is the potential to change between different scenarios over time.

More detailed options, such as the number and design of any potential future releases, are not discussed. Once the broad scenario(s) has (have) been decided then a detailed management strategy, including more refined objectives, can be developed.

A summary of the key issues is set out for each scenario, including potential implications for beaver populations, the effects on the wider environment and particular management actions that may be required, and the main benefits and risks. The chapter finishes by highlighting the need to develop an appropriate beaver management strategy based on the scenario selected.

The scenarios were developed with the help of feedback received both during and after the Beaver Stakeholder Event held at the SNH Battleby conference centre on 21 November 2014.

The stakeholder event and feedback

The Beaver Stakeholder Event brought together a large range of organisations to discuss future scenarios for beavers in Scotland. Sixty-four individuals from 44 organisations attended the event, representing a wide variety of land use, conservation, government, non-government, academic and special interest organisations and groups. Some other individuals contributed after the event.

A number of draft visions and scenarios for the future of beavers in Scotland were presented. The discussions led to the refinement of the drafts, which then formed the basis for the scenarios presented here.

The purpose of the event was to provide stakeholders with an opportunity to comment on and develop the scenarios, discuss practical implications and pragmatic responses and identify any issues that may have been missed. It was useful to develop the scenarios in an open and inclusive manner with such a wide range of parties.

There was a range of feedback. In particular, it was felt to be useful to consider the widest possible range of future scenarios. One option involved restricting the range of beavers but the plausibility and costs associated with this were questioned. A subsequent analysis of the network connectivity of beaver habitat (section 3.2) has confirmed that this would be difficult to manage, and therefore would be an expensive and labour-intensive scenario.

The most common type of feedback was that scenarios that had significant biological drawbacks – in particular those which might result in beaver populations inbreeding – should not be presented as an option, and this was taken into account during the revision process. The other frequently made point was that all scenarios will need an associated and detailed management strategy.

Some stakeholders were also concerned that allowing the Tayside beaver population to persist gave support to a population that may have formed through escapes from captivity or illegal releases. However, it was accepted that two key specific concerns (the species of beaver present and disease issues) had now been resolved through the work of the TBSG.

The main future scenarios

A scenario which involved allowing the two current beaver populations to remain, but without population reinforcement, was originally considered. However, feedback from the Beaver Stakeholder Event, and a subsequent population analysis and assessment of beaver genetics issues, led to the view that the current number of beavers released into Scotland may not constitute a sufficiently large or suitable founder population. The current population is at a high risk of inbreeding, so any scenario which proposes future beaver presence in Scotland would also require population reinforcement. This would need to be addressed within any long-term management strategy (including genetic monitoring requirements) to ensure that the Scottish founder population is large enough to avoid inbreeding depression and is sourced from a diverse range of populations and individuals, and that the long-term population has the genetic robustness to adapt to future pressures such as disease or climate change (section 3.3).

Any population reinforcement, or any other type of further release, would need to be done under licence from SNH and address the Scottish Code for Conservation Translocations.

For all scenarios a strict management regime for captive collections would also be required. Scenario 1 could not be achieved if animals continue to escape into the wild, and it would also be difficult to meet the objectives of any management strategy produced for scenarios 2–4. For example, any beaver originating from an unauthorised release would present increased risks associated with unknown provenance, including those relating to public health.

Robust management will be required, at least some of the time, under all the scenarios. Standard beaver management techniques are outlined in Chapter 5.

Scenario 1 – Full removal

Description

Beavers would be fully removed from the wild in Scotland.

Timescale

It should be possible to remove the vast majority of beavers from the wild in Scotland within five years. However, this will be dependent on the scale of resources available. There would need to be a certain level of surveillance and reactive management to deal with any remaining individuals, further escapes from captive collections and illegal releases.

Implications for beavers

This would involve the killing and/or capture of all beavers from Knapdale (likely to be over 10 animals) and the Tay and Earn river catchments (where there may be very approximately 200 animals). Some may be rehoused in private collections, but given the numbers involved it is likely that most would have to be humanely destroyed.

There may also be longer term inconsistency and implications if England decided to reintroduce beavers more widely in the future and animals start to colonise the Scottish Borders and Dumfries and Galloway. These animals would then need to be removed, probably on a continuous basis. At present, beaver reintroduction has been proposed in Wales and beavers are being tolerated and monitored at the River Otter in south-west England for a trial period.

Effects on the environment

Removal would avoid the need to put in place management to protect certain vulnerable species and habitats from detrimental impacts.

However, there would be an overall loss of potential future biodiversity benefits and wider positive ecosystem services. The overall detrimental impact on long-term ecological goals to halt biodiversity loss, including contributions to meeting Aichi 2020 targets on biodiversity, would be hindered.

Management implications

It can be assumed that the Tayside beaver population has grown since the last Tay beaver survey in 2012, which estimated 38 or 39 beaver colonies (approximately 106–187 animals). The TBSG final report noted that there were 11 reports of beaver activity between 2013 and 2014 in areas not identified in the 2012 survey[1]. Population growth rates have been measured at anywhere between 5% and 34% per year in other studies[2–7]. The recent modelling study estimated 46 colonies (198 beavers) present in 2016[8].

One study has estimated the time required to clear a beaver colony as being three days using two people and a combination of trapping and shooting techniques[9], although this is based on methods that would be illegal under Scots law (Chapter 5). If these figures are applied to Tayside, then approximately 280 person-days would be required to clear the estimated number of colonies if the locations are known. However, it would take longer to remove the animals because of the types of techniques that would be legal and appropriate for Scotland.

Once the main recorded colonies have been removed, it becomes more difficult to estimate the medium to longer term resources required for this scenario. There would be diminishing returns as the beaver density is reduced, since finding individuals from a low-density, dispersed population would be a difficult task. Significant time would be needed to deal with any new reports of activity or sightings and to check the Tay, Earn and surrounding catchments to confirm eradication.

The 2012 Tay survey involved identifying previously reported areas of beaver activity and suitable beaver habitat to target the fieldwork[10]. Similar techniques could be used for any beaver removal operation, for example by applying the types of mapping and predictive modelling outputs described in section 3.2, combined with more recent field records and survey work[1].

Resources would also be required to remove several beaver families from Knapdale. Although a detailed assessment would be needed to calculate the likely costs of removal, a rough estimate, taking the above into account, could be around 1,000 person-days to complete the main initial task, with further time required for follow-up surveillance. For example, any beaver originating from an unauthorised release presents increased risks associated with unknown provenance, including those relating to public health.

This can be compared to the complex and ambitious Hebridean Mink Project which started in 2001 and costs about £350,000 per year. Mink are more difficult to locate than beavers, and the original numbers of mink were far higher, but statistical models have predicted that the project will have successfully extirpated American mink from Lewis and Harris between 2014 and 2021[11].

It is anticipated that many land managers would be willing to collaborate with any removal of beavers. Working with land managers through a voluntary approach is always the preferred option, although legal powers now exist to compel people to take action when necessary.

A trial reintroduction of beavers to Wales has been proposed and the English wild beaver population on the River Otter will be tolerated until 2020. There are reports of beavers living in the wild in other parts of England, although to date these have been in the south. In the long term it is possible that other populations may become established in England or Wales, arising from authorised or unauthorised releases, and ultimately beavers may start to colonise Scotland. Under scenario 1, beavers would be culled if they colonised Scotland, with the possibility of ongoing and long-term management and associated costs.

Removal will be contentious and will be opposed by a range of individuals and organisations. There is the possibility of interference with any trapping or culling operations.

Discussion

This scenario has similarities to the approach used for some non-native species, such as American mink.

There would be short-term costs of eradication and longer term costs of surveillance within Scotland and preventing colonisation from any potential populations south of the border. Resources already invested in the SBT and other Scottish initiatives may be perceived as wasted by some parties. These can be compared with the costs and benefits associated with allowing beavers to remain.

Key benefits

- Certain environmental and land use interests would no longer be at risk from beaver activity
- After removal, the recent historical status quo would be maintained and there would be no need to plan for and resource beaver management
- The Tayside population, the origin of which has been perceived as having undermined lawful best practice, would be removed

Key risks

- The active removal of a former native species would be viewed as a controversial decision and could undermine Scotland's international reputation for biodiversity conservation. There could be an impact on Scotland's image as a destination for wildlife experiences and tourism
- There would be the cultural loss of a species with high popular appeal
- There would probably be a strong public response to any beaver eradication programme (there was a campaign to prevent the removal of beavers on Tayside prior to the ministerial decision in 2012 to tolerate their presence for a trial period, and a petition with over 13,000 signatures was produced against the removal of beavers from the River Otter in southern England)
- There are a number of risks associated with the effectiveness of eradication techniques and the length of time eradication could take
- The removal of beavers would be seen as a lost opportunity to benefit biodiversity and key ecosystem services and to contribute to Aichi 2020 targets on biodiversity
- There may be legal challenges over the interpretation of the Habitats Directive and the use of lethal control, and any decision on the desirability of reintroducing beavers

Scenario 2 – Restricted range

Description

Beavers would be allowed to expand from their current range, but specific catchments would be managed to keep them free from beavers.

Timescale

Although it is difficult to predict, population models suggest that beavers may not expand far from their current catchments over the next two or three decades (section 3.2), assuming there is no human assistance. However, as the density of the populations increase over time, there is an increased likelihood of dispersal into neighbouring catchments.

Implications for beavers

There would be no further releases of beavers other than for population reinforcement, for genetic reasons and/or to increase the numbers of animals. Beaver range expansion would probably be slow from the current populations (see section 3.2) with population models suggesting no or limited natural expansion outside the Tay and Earn catchments over the next 30 years. Range expansion at the national scale would therefore take far longer in comparison with scenarios 3 and 4.

Although the Knapdale population is currently stable, there are inherent risks to it if reinforcement is delayed. It was not designed as a founder population for a reintroduction, and there is a risk that it will become extinct in the short term (section 3.2). There may also be a risk of inbreeding on Tayside in the future, and so further monitoring of genetic health would be needed to decide if reinforcement is required.

If numerous catchments were 'designated' as beaver free, beavers could be restricted to a series of isolated ranges, and there is a risk that the overall population would require regular reinforcement to combat genetic drift.

Effects on the environment

Some of the potential benefits of reintroduction would be retained, although over a relatively small area, particularly in the short to medium term. There would be some future biodiversity benefits, and wider positive ecosystem services, including a limited contribution to meeting Aichi 2020 targets on biodiversity. The status quo would be maintained within beaver-free catchments.

Beavers would have positive and negative impacts on a wide range of environmental and socio-economic interests where they occur. Within the areas where beavers are currently present, or may be colonised, appropriate monitoring and management would be needed. For example, the monitoring of potentially vulnerable species and habitats would be required and robust beaver management required in specific areas. Further research may also be needed (e.g. examining potential impacts on biological or socio-economic factors) and appropriate levels of targeted deer management may be required to avoid potential negative, and promote positive, ecological effects (see section 3.4.1).

Within the catchments concerned there would be an opportunity to develop a programme of riparian habitat restoration and creation targeted in beaver areas, and areas which may be colonised ('buffer zones', see Chapter 5), which would help to promote the positive effects of beavers, benefit land managers and users, reduce conflict and benefit vulnerable species.

Management implications

The management strategy developed for this scenario would include detailed guidance on the practical and legal issues surrounding beaver management. Standard beaver management techniques, outlined in Chapter 5, would be employed in the colonised area. The costs of management would increase as the beaver population increased in size and range. There is predicted to be a relatively high level of connectivity between catchments for beavers (see section 3.2). Therefore, over the long term and once populations within catchments are established, beavers are unlikely to be significantly restricted from colonising other catchments by the natural features of the landscape. However, beaver colonisation from the two current beaver areas is expected to be slow in the short to medium term.

Keeping an entire catchment beaver free would be labour intensive. The difficulties would be highly dependent on the nature of the catchment, the potential barriers to dispersal to adjacent catchments and surrounding beaver populations. For example, large catchments, with large borders, adjacent to high-density beaver populations, may require high levels of monitoring and management to keep them beaver free into the long term.

An option that might be applied within this scenario would be 'designating' specific beaver-free areas within an individual catchment, based on factors such as sensitive land use. This approach would require intensive management over the long term. Non-lethal options, such as the creation of 'buffer zones' in other areas (see Chapter 5), may have a role, but it would also require the culling or trapping of potentially high numbers of dispersing beavers on an annual basis. A Norwegian study highlighted that '…the spread of beavers within a river system cannot, in practice, be contained without a heavy, and constant, directed hunting or trapping effort'[12]. Any future management strategy would need to examine the feasibility, practicality and resourcing of such an approach.

Certain types of management, such as culling or trapping, would be more likely to be required in the longer term and would be more contentious. Keeping areas free of beavers may go against the wishes of some land managers, as well other individuals and organisations.

There is a risk that some may view this as too slow an approach and unauthorised releases may become more prevalent. Appropriate management and legal action would then be needed.

Discussion

This scenario has similarities to the approach used to manage the spread of some non-native species, such as sika deer *Cervus nippon*.

Although there are uncertainties, it seems likely that, overall, the ongoing costs of keeping a catchment beaver-free could be significant.

Key benefits

- The ecological and ecosystem service benefits of beavers would be maintained in specific areas. A programme of riparian habitat restoration and creation ('buffer zones') targeted in beaver areas, and areas which may be colonised, could help to promote the positive effects of beavers, reduce conflict, benefit land managers and users and protect vulnerable species
- Beaver-free catchments could be identified to reduce the risk of potential negative impacts on sensitive land use or vulnerable habitats and species such as Atlantic hazelwood and aspen
- Beaver areas could be promoted to benefit socio-economic interests, such as wildlife tourism

Key risks

- There is no experience of this type of restricted reintroduction for any other native species in Scotland. Clear justification, taking into account biological and socio-economic factors, would be required to garner support
- Costly, intensive management would be required, and it would be very difficult to guarantee catchments could be kept beaver free into the long term
- The translocation of beavers from 'designated' beaver-free catchments, rather than culling, may be a more acceptable approach for many people. However, the identification of suitable receptor sites will become more challenging as beaver density increases
- There would need to be a clear legal basis for any licensing decisions over the use of certain management techniques, taking into account the conservation status of the species. Even in the long term there would only be a relatively small population and restricted range, which may have implications on the conservation status of beavers and on licensing decisions relating to management
- If numerous catchments are designated as beaver-free, beavers may be restricted to a series of restricted and isolated ranges. Hence, the population(s) may require regular reinforcement to combat genetic drift
- Appropriate levels of deer management would be needed in beaver areas to avoid potential negative effects and enable positive ecological effects
- Monitoring and research into the impacts on vulnerable species and habitats, and wider environmental and socio-economic interests, would be required to inform management requirements
- Predicted recolonisation rates of beavers are expected to be slow in the short to medium term, resulting in a delay to the realisation of potential benefits across a larger part of Scotland

Scenario 3 – Widespread recolonisation

Description

The beaver population would be allowed to expand to its natural limits. Eventually this could include further releases outside the two current population areas. However, initially the focus of resources would remain with Tayside and Knapdale and in developing an appropriate management strategy. This would be a more cautious approach than in scenario 4.

Timescale

Although it is difficult to predict, population models suggest that beavers may not expand far from their current catchments over the next two or three decades (section 3.2) without human assistance. As the density of the populations grow over time, there would be an increased pressure upon young animals to disperse into neighbouring catchments to find unoccupied suitable territories. Conversely, if further releases took place in new catchments with large areas of available suitable beaver habitat, then populations may not expand substantially beyond those catchments for two or three decades. At a national level, the range of beavers and size of the population will depend on the number and timeframe of further releases.

This scenario envisages a cautious approach to further releases over the short term (e.g. the next three to five years or so), allowing time to develop a detailed management strategy and for resources to be focused on ensuring that viable, appropriately managed populations are established at Tayside and Knapdale.

Implications for beavers

The Knapdale beaver population borders the River Add and a series of small coastal catchments. These are the areas that would be expected to be colonised first after population reinforcement. In the longer term the population is likely to expand into Loch Awe and across much of Argyll.

The 2012 River Tay beaver survey located animals in the Tay, Earn and Forth river catchments. These catchments border the Dee, South Esk, Lunan, Monikie, Dighty, Dundee Coastal, Annaty, Farg, Loch Leven, Devon, Allan, Bannock, Carron, Lomond, Awe, Etive, Blackwater, Lochy and Spey catchments, which would be expected to be colonised first (section 3.2 highlights the predicted high connectivity between catchments). Therefore, the Tay population has the potential to colonise much of Scotland in the longer term. In particular, the Spey catchment to the north and the Loch Lomond catchment to the south-west, have large areas of suitable beaver habitat.

It is expected that beavers will need to be present within an area for 25 years before population growth plateaus and beavers may be considered to be at high density. A key conclusion of the recent population modelling work was that beaver range expansion will be slow[8]. For example, beavers are unlikely to significantly expand from their current catchments within the next two or three decades.

Therefore, there is an argument for further releases in due course. The size of the founder populations and the suitability of release sites will be the key determinants of the success of beaver reintroduction, as for any species reintroduction[13]. The Best Practice Guidelines for Conservation Translocations in Scotland sets out key considerations[14]. This scenario provides time to develop a more strategic approach to planning a national reintroduction that addresses these issues, and therefore a better chance of establishing a viable, long-term beaver population.

For example, enabling the two current populations to link up may provide improved population stability. Further releases within the Awe catchment may be the simplest approach to linking the populations, as it borders the Tay catchment, and lies just 8 km from the Knapdale population.

Other prioritised areas could be identified for further releases based on the abundance of potential core beaver habitat within a catchment. The Ness, Spey, Tay and Lomond catchments were previously identified as major areas of potential beaver habitat within Scotland[15]. More recent analyses have supported this assessment (section 3.2), although other areas would also be suitable.

Effects on the environment

The current benefits of the Knapdale and Tayside beavers to biodiversity and wider positive ecosystem services would be retained. In addition, the wider reintroduction of beavers would represent a clear commitment to creating longer term biodiversity benefits.

The speed of colonisation in this scenario would depend on the timing and extent of further releases. A slow speed of colonisation would mean widespread positive ecological effects might not be felt for some years and beaver presence would play a limited role in contributing to Scotland's Aichi 2020 targets. However, a slower colonisation may also provide more time to plan and prepare for appropriate management. Further beaver releases could be targeted to help restore degraded ecosystems.

Beavers would have an impact on a wide range of environmental and socio-economic factors where they occur. Within the areas where beavers are currently present, and are likely to be colonised, appropriate monitoring and management would need to be in place. For example, the monitoring of potentially vulnerable species and habitats would be required, and robust beaver management in specific areas. Further research may be also be needed (e.g. examining potential impacts on biological or socio-economic factors), and appropriate levels of targeted deer management may be required to avoid potential negative, and promote positive, ecological effects. A programme of riparian habitat restoration and creation targeted in beaver areas, future release sites, and areas which may be colonised ('buffer zones'), would help to promote the positive effects of beavers, reduce conflict, benefit land managers and users, and benefit vulnerable species.

Management implications

In this scenario further releases of beavers would be considered, although releases at sites outside Knapdale and Tayside would not be encouraged for a number of years. Short-term effort could concentrate on improving the viability of the Knapdale and/or Tayside populations.

The management strategy developed under this scenario would include preparing detailed guidance on the practical and legal issues surrounding beaver management. This would be developed over the next few years with key stakeholders, and would include a strategic approach to identifying where further releases might be most appropriate.

The types of standard beaver management techniques outlined in Chapter 5 would be employed in areas with beavers. In the longer term the costs of management would increase as the beaver population increases in size and range. There are no significant predators of beavers in Scotland, and populations may become large and/or high density in places. Management would be required to reduce potential negative impacts (much like deer management currently). Certain types of management that are more likely to be required in the longer term, such as culling or trapping, will be more contentious.

All further releases would need to address the Scottish Code for Conservation Translocations. The merit of further releases would be assessed against a range of criteria including local public support, ecological impacts, impacts on the status of the wider beaver population and an assessment of how quickly they may colonise an area without a release.

There is a possible risk that some may view this as too slow an approach, and unauthorised releases may become more prevalent.

The option of 'designating' specific beaver-free areas within an individual catchment, described in scenario 2, could be considered for scenario 3 as well.

Discussion

This is similar to the approach taken in Denmark. There, 18 beavers were released at a single site at Kosterheden in 1999 and impacts were monitored. The population had increased to approximately 165 individuals by 2011. Animals were then released at a second release site, at Arresø, in 2009. In the long term the Danish population is expected to be reinforced through the natural migration of beavers from Germany.

The environmental and socio-economic benefits and risks of beavers (section 4.1), including those associated with their management, (Chapter 5), are summarised below.

Key benefits

- This scenario would be expected to provide a stable population of beavers over the long term, and the conservation status of the species will progressively improve
- Decisions on further releases could be highly selective. This would allow specific locations to be chosen, for example to limit human conflict and protect vulnerable species and habitats
- New release sites would not be approved for a few years, and this would allow more time to improve and streamline management techniques before a widespread beaver population becomes established. Management techniques could be based on European experience and tailored to the Scottish situation
- This would also allow time for research to be completed on issues where there is still uncertainty over impacts, such as on Atlantic salmon
- There would be widespread ecological and ecosystem service benefits in current and future beaver areas. A programme of riparian habitat restoration and creation ('buffer zones') targeted in beaver areas, and areas which may be colonised, would help to promote the positive effects of beavers, reduce conflict, benefit land managers and users, and protect vulnerable species
- A widespread beaver reintroduction would enhance Scotland's international reputation for biodiversity conservation, and as a wildlife destination for visitors. This may translate into a specific tourism boost near release sites and wider socio-economic benefits

Key risks

- For the current and future populations, as the range and population densities of beavers increase, there will be an increase in human–beaver conflict and associated management needs. Appropriate measures would need to be established to reduce conflict in consultation with relevant stakeholders, such as careful selection of release sites, the establishment of riparian buffer zones where acceptable, etc. In the medium to long term, there may be a need for culling under certain circumstances, which may prove contentious
- There would need to be a pragmatic and flexible approach to licensing in relation to releases and the use of certain management techniques, taking into account the conservation status of the species
- Appropriate levels of deer management would be needed in beaver areas to avoid potential negative effects
- Monitoring and research into the impacts on vulnerable species and habitats, and wider environmental and socio-economic interests, would be required
- Predicted recolonisation rates of beavers are expected to be relatively slow in the short term, resulting in a delay to potential benefits in the wider countryside and possible frustration amongst some stakeholders
- Tourism benefits for specific areas with beavers may decrease as they become more ubiquitous

Scenario 4 – Accelerated widespread recolonisation

Description

The beaver population would be allowed to expand to its natural limits. Proposals for new releases could be considered immediately. This would be a less cautious approach than scenario 3, and more reactive to new release proposals.

Timescale

Many of the timescale issues set out for scenario 3 also apply to scenario 4. However, it is anticipated that releases at sites other than Knapdale and Tayside would happen sooner under this scenario, probably within the next few years. This would be subject to organisations coming forward with appropriate project proposals and resources.

Implications for beavers

Many of the implications for beavers set out for scenario 3 also apply to scenario 4. However, under this scenario releases at new sites may happen over the next few years, and therefore beavers will become re-established over wider areas within a quicker timeframe. However, there are risks that resources may be diverted from ensuring that the current populations at Knapdale and Tayside are viable. There may also be a lost opportunity in planning for the next phase of beaver releases at a national level, and ensuring the best chance of establishing a viable, long-term beaver population with wider benefits.

Effects on the environment

Many of the effects on the environment set out for scenario 3 also apply to scenario 4. Since there is the possibility of more beaver release sites over the next few years under this scenario, then that would mean any benefits to biodiversity and ecosystem services could be distributed more widely more quickly. The potential disadvantage is that there would not be the opportunity to plan the next phase of further releases in a way that may target and maximise these benefits most effectively and efficiently.

Management implications

Many of the management implications set out for scenario 3 also apply to scenario 4. However, new beaver release sites may be approved before a management strategy has been finalised. There may be a risk that land use organisations, and some specialist conservation groups, feel beaver reintroduction is being rushed before some of their concerns are being adequately addressed. Other stakeholders may welcome such an approach, and there may be less risk of unauthorised releases taking place.

The option of 'designating' specific beaver-free areas within an individual catchment, described in scenario 2, could be considered for scenario 4 as well.

Discussion

This approach has some parallels with other beaver reintroductions. In Switzerland there were uncoordinated releases of beavers at 33 sites over a 22-year period, and this lack of strategic approach to reintroduction was judged to be a major reason why there were initial problems with the viability of the population[16].

The environmental and socio-economic benefits and risks of beavers (section 4.1), including those associated with their management, (Chapter 5), are summarised below.

Key benefits

- This scenario would be expected to provide a stable population of beavers over the long term, and the conservation status of the species will progressively improve. It is possible this may happen a few years earlier than scenario 3 if wider releases are authorised sooner, although scenario 3 would ensure they could be planned more carefully, and thereby increase the chances of better outcomes
- There would be widespread ecological and ecosystem service benefits in current and future beaver areas. A programme of riparian habitat restoration and creation ('buffer zones') targeted in beaver areas, and areas which may be colonised, would help to promote the positive effects of beavers, reduce conflict, benefit land managers and users, and protect vulnerable species
- A widespread beaver reintroduction would enhance Scotland's international reputation for biodiversity conservation and as a wildlife destination for visitors. This may translate into a specific tourism boost near release sites and wider socio-economic benefits
- This scenario may minimise the risk of unauthorised releases taking place

Key risks

- New releases may take place before any management strategy has been finalised. This could mean a lost opportunity in planning beaver reintroduction at the national scale that could bring most environmental and socio-economic benefits and minimise conflicts
- There may be a risk that land use organisations, and some specialist conservation groups, feel beaver reintroduction is being rushed before some of their concerns are being adequately addressed through the development of a management strategy
- The effectiveness of management techniques may require time to be tried, tested and refined, and for managers to become suitably trained and experienced
- For the current and future populations, as the range and population densities of beavers increase, there will be an increase in human–beaver conflict and associated management needs. Appropriate measures would need to be established to reduce conflict in consultation with relevant stakeholders, such as careful selection of release sites, the establishment of riparian buffer zones where acceptable, etc. However, in the medium to long term, there may be a need for culling under certain circumstances, which may prove contentious

- There would need to be a pragmatic and flexible approach to licensing in relation to releases and the use of certain management techniques, taking into account the conservation status of the species
- Appropriate levels of deer management would be needed in beaver areas to avoid potential negative effects and enable positive ecological effects
- Monitoring and research into the impacts on vulnerable species and habitats, and wider environmental and socio-economic interests, would be required
- Tourism benefits for specific areas with beavers may decrease as they become more ubiquitous

Financial costs and benefits

The potential financial consequences of different future beaver scenarios are, understandably, uppermost in the minds of many in the land use and conservation sectors.

Section 4.1 sets out some of the socio-economic costs and benefits that may arise from beaver reintroduction. Some of these elements may be easier to assess at the local spatial scale and in the short term, but more difficult as the spatial and temporal scales increase. Other elements are more difficult to assess at any scale, for example where impacts are intertwined with the complex effects of other environmental and human causes, such as flood amelioration. There is often limited information to draw on in relation to beavers or other species.

Putting monetary figures to these costs and benefits is extremely difficult when there is so much uncertainty and potential variation, including within most of the broad scenarios set out above. These uncertainties and variables include, very broadly:

- The number of future beaver releases
- The population sizes and colonisation patterns resulting from future releases
- The location of future releases
- The timescale of future releases
- The timescale over which future costs and benefits are measured following release
- The associated positive or negative impacts beavers may have on the human and natural environment, which are dependent on the above factors
- The management requirements associated with such positive or negative impacts

Therefore, it would be inappropriate and potentially misleading to try to set out monetary costs and benefits. However, it is possible to highlight some broad categories of costs and benefits, and these are set out below:

- Removal costs – Details are set out in scenario 1 above, including comparisons with similar exercises. Up to 1,000 person-days may be required to complete the initial task, with further time required for follow-up surveillance
- Reinforcement costs – These are the monetary costs associated with any necessary population reinforcement. In the short term, reinforcing the Knapdale population may involve the release of at least another five pairs of animals (scenarios 2–4), followed by further phased releases
- Reintroduction costs – These are the monetary costs associated with a specific conservation translocation, including the immediate post-release phase (scenarios 2–4). The approach set out in the Scottish Code for Conservation Translocations would need to be addressed[14]. The costs associated with the SBT, over a seven-year period, were high (in the region of £2 million, see section 4.1), but such an intensively monitored and managed project is unlikely to be necessary at other sites. There will also be costs at the wider level, in terms of research and monitoring the population and impacts
- Management and associated monitoring/surveillance costs – The monetary costs associated with mitigating impact on human and natural interests. This will be the element of biggest concern to the land use sector, although there are also implications for the conservation/environmental sectors. The potential impacts are set out in Chapters 3 and 4 and the costs of specific management techniques are described in Chapter 5. Extrapolating these costs to the catchment and wider scale is difficult due to the uncertainties and variables listed above. In addition to management costs, there may also be surveillance/monitoring costs associated with initial checking for impacts, and assessing the effectiveness of management
- Advisory staff – One option is to support dedicated 'project officers', who would liaise with local stakeholders and volunteers and provide relevant advice and support (scenarios 2–4, and possibly scenario 1). This would be similar to the TBSG or Bavarian approach. An alternative, or additional option, is to set up advisory teams using existing staff based at relevant organisations
- Socio-economic benefits – Section 4.1 describes the range of monetary (and non-monetary) benefits that may be derived from beaver reintroduction (scenarios 2–4). These include the benefits that are derived from cultural ecosystem services such as recreational visitors, educational value and non-use value. There are also the 'provisioning' and 'regulation and maintenance' ecosystem services, such as the potential benefits of beaver dams to hydrology and water quality

There is also experience from European countries, and some examples are set out in Chapter 5. These provide a rough indication of some of the costs involved at national levels. Most of the information available highlights costs associated with the management of negative impacts, with less information available on monetary benefits.

Reinforcement and reintroduction costs are likely to be relatively short term, and will probably be funded from parts of the conservation sector. The management costs will be more significant, especially into the longer term as population sizes grow and expand. The decision on how to balance costs associated with management between private and public sources will be difficult. However, any such decision could also examine, for example, the potential opportunities for supporting positive beaver habitat management programmes which may prioritise riparian woodland creation and restoration, and other types of beaver habitat which may ameliorate downstream flooding and provide other ecosystem services, thereby benefiting a range of other environmental and land use priorities.

The fundamental challenge will be to ensure that those who may be most affected by the negative impacts of beavers can also benefit from local and wider socio-economic benefits. There are 'economic instruments' which can help address this (e.g. payments for ecosystem services) and these would need to be fully considered once a reintroduction decision has been made.

All the scenarios have a cost attached, and there are no free options. Scenario 1 is likely to be the cheapest overall, although there are still likely to be some longer term costs even after animals have been removed from the two main sites, especially if animals are reintroduced to England and disperse into Scotland. It is more difficult to tease apart the costs between scenarios 2, 3 and 4, but ultimately costs will increase as the population grows and expands, especially where there is a need to keep catchments or areas free of beavers. Similarly, the benefits will also increase.

Overview of the four scenarios

Some of the key messages from the scenarios assessment can be summarised:

- Scenarios 2–4 would involve beaver reintroduction. Scenario 1 would involve full removal
- The scenarios are not discrete. There is the option to use different scenarios at different times (e.g. scenario 2 in the short term to allow further trials to be undertaken, and then widespread recolonisation in the longer term)
- This is particularly the case with scenarios 3 and 4. The differences between these scenarios is relatively small time-wise, but depends on whether the decision is made to focus on Knapdale and Tayside for a few years, and in developing a national, strategic approach to beaver reintroduction and management
- There are a range of risks and benefits associated with each scenario; no scenario is risk or cost free
- All four scenarios will have long-term implications. This includes scenario 1, for which the main action may be short term but for which there would be long-term implications of not having beavers present (and there may still be a need for surveillance and removal in the longer term, especially if animals disperse into Scotland from an English reintroduced population)
- Each scenario will have different levels of support and opposition from different stakeholder organisations.

The decision on which scenario(s) may be most appropriate will need to take into account the Habitats Directive Article 22 requirement to consider the ‘desirability’ of reintroduction, based on the evidence collated to date and summarised in this report. Scotland has taken a precautionary approach by holding ‘trial’ reintroductions, and collating information from a wide range of sources, to help provide an assessment of desirability. Denmark has been the only other EU country that has taken a similar trial approach.

Whichever scenario, or combination of scenarios, is decided upon, there will be a need to manage beaver impacts and/or the animals themselves. The precise nature of this management will inevitably be influenced by the decision taken.

Development of a management strategy

Scottish and European species management experience has shown the value of producing and adopting a pragmatic and responsive management strategy early on. This would help alleviate land owner, land manager and public concerns that potential impacts may be unmanageable and to clearly establish parameters for intervention.

The potential benefits of such a management strategy have also been key and recurring themes from groups such as the BSWG and the TBSG, along with discussions with key stakeholders. The BSWG went as far as to describe it as a ‘…fundamental pre-requisite for any decision to formally reintroduce beavers’[17].

A management strategy could be produced in collaboration with stakeholders in the period immediately following any government decision on beavers, and be based around appropriate and realistic timescales (e.g. five years for immediate actions, but taking into account longer term goals).

Any management strategy would set out the wider and longer term aims and objectives of the beaver scenario concerned, but in particular it would need to:

- Set out a clear approach as to how decisions will be made when assessing any new reintroduction proposals in the future (the National Species Reintroduction Forum would be likely to have a role)
- Take into account the social and economic situation prevalent in a Scottish context. It should provide a range of management options and tools, so that tailored, site-specific actions can be applied. Such management should be acceptable to both land managers and the wider society[18]
- Draw on the experiences of the most effective management systems already in place in Europe and North America, including adaptive management methods[19]. However, no single one of these approaches could be simply translated to the Scottish beaver context
- Adopt a pragmatic approach, which is flexible and open to revision as appropriate. This is likely to be a more successful approach in the long term than any rigid, heavily licensed and structured system of control
- Adopt an approach that will allow quick decisions to be made, avoiding complicated and/or lengthy licensing processes
- Provide clear guidance to land managers on what management options are available to them, when they can be used and what actions are and are not permitted (this could be made available in the form of an associated manual, etc.)
- Plan for how certain management techniques, such as culling, may be required more often in the longer term once populations expand. Some options for non-lethal management of ‘problem’ animals and families, including translocation, will become more limited over time
- Assess the feasibility and practicality of ‘designating’ specific beaver-free areas within individual catchments, based on factors such as sensitive land use or the presence of vulnerable species and habitats
- Plan periodic management reviews, the coordination of translocations of ‘problem’ animals, and reporting to the National Species Reintroduction Forum and/or other appropriate groups
- Develop a research and monitoring programme. This would include assessments of population size and distribution, and addressing key knowledge gaps such as the interaction between beavers and salmonids[17], deer and vulnerable habitats, and the efficacy and development of certain management techniques
- Resolve the question of who pays for management (including any necessary surveillance), especially for significant impacts and/or those requiring repeated mitigation. This will need to take account of how the situation, and associated costs and benefits, may change in the future as any beaver population expands
- Identify sources of advice and support for land

managers. These may be dedicated project officers, volunteers or advisory teams made up of existing staff. They may provide practical assistance with the deployment of effective management techniques, and record issues and solutions. This type of advisory service could be overseen by a broader management group (perhaps linked to the National Species Reintroduction Forum) that would be able to take a wider and more strategic approach to issues

- Address the issue of captive collections to reduce the risk of animals escaping into the wild
- Plan education programmes covering beaver management issues and the associated costs and benefits of beaver presence
- Identify opportunities for beaver reintroduction and management to be set within the wider aims of long-term land use planning, the ecosystem approach and habitat restoration in a multi-functional landscape. The wide range of 'cultural' and wider socio-economic benefits should also be taken into account. Beavers could be used to promote and support the resourcing of riparian habitat creation and restoration, and flood alleviation programmes ('buffer zones'), thereby contributing to long-term beaver management solutions and conflict resolution

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Appendix 1

Assessment of the Scottish Beaver Trial

Introduction

The Scottish Beaver Trial (SBT) was set up to facilitate a scientifically monitored trial reintroduction of the Eurasian, or European, beaver to Knapdale, mid-Argyll. The post-release monitoring phase lasted five years from May 2009 to May 2014. Five project aims were set out as part of the licence application submitted by the SBT partners, the Royal Zoological Society of Scotland (RZSS) and the Scottish Wildlife Trust (SWT), along with a number of criteria against which success or failure could be assessed.

SNH were charged by Scottish ministers with coordinating the independent monitoring of the trial, and ensuring that the trial adhered to the licence conditions. A monitoring programme was established at the start of the trial, and a number of 'Independent Monitoring Partners' were brought in to lead, or jointly lead, on specific projects.

This document is an assessment by SNH of how the aims, and the success and failure criteria, of the SBT were met, based on the May 2014 monitoring completion date.

In summary, all five of the project aims were achieved. Three of the five success criteria were met, one was partially met. There were limited opportunities for the other success criterion to be met. None of the four failure criteria were met.

Project aims

1. Study the ecology and biology of the European beaver in the Scottish environment
Achieved

The design, analysis and reporting of the research on the ecology of the beaver population at Knapdale was managed independently by the University of Oxford (WildCru) in partnership with SNH. SBT staff organised the collation of data. The independent monitoring of the animal health (veterinary) aspects was led by the Royal (Dick) School of Veterinary Studies, University of Edinburgh, in liaison with RZSS veterinary specialists. Outputs from the projects are available on the SNH website. The beaver ecology and animal health monitoring projects demonstrated that the beaver population exhibited the full range of expected behaviours[1, 2].

2. Assess the effects of beaver activities on the natural and socio-economic environment
Achieved

Monitoring projects were set up by the Independent Monitoring Partners in discussion with SNH, to cover the effects of beavers on otters, fish, dragonflies and damselflies, woodland habitat, loch habitat including aquatic plants, river habitat, hydrology, fluvial geomorphology and socio-economics. Further details of all of these and other projects, including the interim and final reports, are published on the SNH website.

3. Generate information during the proposed trial release that will inform a potential further release of beavers at other sites with different habitat characteristics
Achieved

SWT and RZSS: A final report[3] was produced by SWT and RZSS following completion of the trial and is available on the SBT website. This records the planning and management of the trial, from inception through to completion. It provides a commentary on the process, details of the experiences gained, and recommendations for future beaver translocations.

– *SNH and Independent Monitoring Partners:* All of the independent monitoring outputs are available on the SNH website. The final SNH 'Beavers in Scotland' report to the Scottish Government is also available, and this includes references to the outputs of the Tayside Beaver Study Group, the Beaver–Salmonid Working Group, the National Species Reintroduction Forum, other SNH-commissioned projects and other Scottish and international sources of information

4. Determine the extent and impact of any increased tourism generated through the presence of beavers
Achieved

An independent study of socio-economics was led by Scotland's Rural College, in collaboration with SNH. The final report is available on the SNH website.

– *Local business activity:* Local tourist and retail operators were generally favourable in their assessment of the local and regional added value of the trial[4]
– *Visitor trends:* Over 8,000 individuals participated in events, talks, walks and education sessions held by the SBT. Of these, 2,194 took part in guided walks, which were restricted to a maximum number of participants. This does not include the large number of unguided visitors, estimated to be over 4,000. The number of guided walks has been used as a proxy for 'wildlife experiences', and these have been calculated as having a value of between £355,000 and £520,000[4]

5. Explore the environmental education opportunities that may arise from the trial itself and the scope for a wider programme should the trial be successful
Achieved

– *SBT education plan and pack:* SBT developed an education plan with seven objectives, including a model of education practice to be used in future environmental education projects[3]. An education pack was sent to every school in Scotland. In addition, two curriculum-linked outreach lessons were developed and delivered at over 70 primary schools across Scotland, a continuing professional development workshop was delivered to over 110 teachers, and SBT education staff visited over 200 schools, nurseries and colleges. A learning zone was created on the SBT website and two learning events were facilitated via the Scottish Schools National Intranet, Glow

– *Educational value:* A highly conservative value of £56,000 has been estimated as the educational value of the trial. This figure describes the financial outlay for an activity that can contribute to the acquisition of ecological knowledge[4]. Further details are provided in the socio-economic monitoring report[4]

Criteria for success

1. Survival of introduced animals is similar to successful reintroduction programmes elsewhere in Europe at similar period of population establishment

Success criterion met

– *Individual survival rate:* There have been many beaver reintroductions across Europe. Three projects provide detailed information on survival and population demography. Survival of individuals translocated to the Netherlands (Biesbosch), Germany (Penne Valley) and Poland (Vistula Basin) one year after release varied between 64% and 86%. The SBT recorded a survival rate of 68%, which takes account of missing animals as well as known deaths[1, 5, 6]
– *Mortality rates:* If the known mortalities in the first year of release are included, then 19% of all individuals released at Knapdale died. This is similar to the 14% mortality reported for the Vistula Basin and the 20% reported for the Penne Valley and lower than the Biesbosch project, which reported 33%[1, 5, 6]. Mortality of established adults at Knapdale was low[1]

2. A stable or increasing core population is achieved within the limits of the study site

Success criterion partially met

– *Reproductive success:* The reintroduced population of beavers at Biesbosch, Netherlands, experienced a low reproductive rate initially, with the proportion of pairs breeding at 31%. This was considerably lower than that reported from the Vistula Basin in Poland (60%) and from Knapdale (50–75% – for the years when there were four adult pairs present). However, the mean litter size at Biesbosch was recorded as 2.4 kits, which is similar to that of an established population in the Elbe region of Germany with 1.98 kits, whereas 1.4 kits have been recorded at Knapdale. In comparison, the beaver population in the Telemark region of Norway, from where the SBT animals were sourced, produces 1.4–2.0 kits. The slightly lower reproductive rate experienced at Knapdale could be attributed to a combination of inexperienced animals, older aged mother(s) and the fact that some adult pairs were not released until 2010[1, 5–7]
– *Population growth:* The initial annual population increase has been reported as 20% in the Vistula Basin and 34% in the Penne Valley, although comparative data are very limited. At Knapdale the data are more complicated (–9% to 22%). Reintroduced populations tend to grow between 0% and 15% annually[6]. Knapdale has seen negligible population growth over the five years of the trial, and a number of factors may have contributed to this situation
  – The short duration of the trial means that there was limited growth of both the sub-adult and the adult population due to the time lag from the birth of a kit to the point at which it reaches sexual maturity and thus joins the adult population
  – The trial included only a small number of animals – the trial was not designed to establish a founder population nor to be self-sustaining in the long term
  – The dispersal of sub-adults, which resulted in a loss of animals from the trial (and therefore the loss of new breeding pairs)
  – The low survival rates of wild-born kits in the last two years of the trial period
– All of these factors meant that the population did not reach its predicted size. The beaver population currently present at Knapdale appears to be stable but not increasing[1]

A recent population modelling exercise predicted that, if the decision is made to allow beavers to remain, the Knapdale population will expand, assuming that average population parameters are appropriate for Knapdale and that the poor values for kit mortality observed in the SBT are the result of chance events rather than an unknown feature of the Knapdale environment or the beavers released there[8]. The population is predicted to fare much better if there is reinforcement.

3. The beaver population demonstrates a positive contribution to ecosystem function

Success criterion met

The influence of the SBT beavers on ecosystem function and services can be broadly summarised and include:
– *Hydrology and aquatic systems:* Despite the limited influence of beavers at Knapdale on fluvial geomorphology and river habitat, dam creation had some effect on the hydrology of the lochs and their outflow streams. These included a temporary increase in loch water storage, elevation and stabilisation of the water level, an increase in dry weather flows in some streams and a possible delay in the time of peak flow. An increase in the diversity of stream habitat and diversifying flow patterns were observed on a small scale[9]
– *Biodiversity:* There were overall positive effects on habitat diversity at the landscape scale, since beaver activity increased habitat heterogeneity and patchiness. The increase in loch surface area as a result of a dam at the Dubh Loch in Knapdale saw the creation of new loch edge and emergent habitat, an increase in the number and diversity of plant species and rapid invertebrate colonisation, with an increase in water beetle density[10]. Amphibians, bats, and dead wood specialists are likely to benefit from the habitat created. Felling of trees by beavers at Knapdale, predominantly focused near the water's edge, led to a change in woodland structure by opening up areas of the canopy to help create open space habitat. A reduction in the vertical density of trees and a change in the ground flora composition were also observed[11]
– *Cultural:* Cultural ecosystem services include the recreational and educational aspects recorded as part of the socio-economic monitoring (see above). Some

of these relate to visitors' experiences at Knapdale itself, other aspects may relate to the wider Scottish (and UK) population and the 'existence' value of beavers at Knapdale[4]

4. Beaver reintroduction is integrated with habitat management/restoration
Limited opportunity to meet success criterion

– *Habitat restoration:* Since about 2000/01, much of the conifer plantation within Taynish and Knapdale Woods Special Area of Conservation (SAC) has been removed as part of a programme of targeted restoration where there is 'Plantation on Ancient Woodland Sites'. In some places, this has led to a pulse of natural regeneration, in particular dense, even-aged, semi-mature downy birch. Beaver activity (felling and flooding), particularly around the Dubh Loch and Loch Coille-Bharr areas, have contributed to the opening up of patches of the dense birch woodland

5. The impact on the economy of the area as a result of the presence of beavers is positive
Success criterion met

– *Local business activity:* Positive impacts on turnover for local businesses appear to be modest, with a mean additional annual turnover estimated to be under £3,000 in 20144. In addition, other socio-economic benefits have been identified, such as the number of guided walks for visitors, which can be used as a proxy for measuring 'wildlife experiences', calculated as having a value of between £355,000 and £520,000[4]

Criteria for failure

1. Mortality levels preclude establishment of a population
Failure criterion not met

– *Mortality:* Mortality of established adults at Knapdale was low, with no adult deaths recorded after the first year of the trial1. Pre- and post-release health screening indicated that the beavers appeared to be in good health and within the expected weight range for Norwegian beavers[2]. Sixteen beavers were released at Knapdale between 2009 and 2010. Over the course of the trial, two died shortly after release, five went missing, one was removed from the trial owing to poor body condition and later died in captivity and eight remained alive as at May 2014. This equated to a mortality rate of approximately 0.19. Fourteen wild-born kits were observed, of which 10 went missing, two were predated as kits and two were assumed to be alive at the end of the trial. This equates to a mortality rate of 0.14. By May 2014, 10 beavers remained at Knapdale, although this excluded any kits born in 2014 that would not have emerged from their natal lodge until later in the year. Assuming that the litter size was consistent with previous years, with between one and three individuals, then the total number of animals present at Knapdale at the end of the trial in May 2014 will have been broadly the same as the number released. Mortality levels did not preclude the establishment of a population[1]

Further commentary on the potential future development of the Knapdale population, and the application of modelling techniques, is provided elsewhere[1], including section 3.2 of the SNH 'Beavers in Scotland' report.

2. Significant and unsustainable damage is incurred by the ecosystem within the study site
Failure criterion not met

An ecosystem includes all the living organisms in an area (in this case the area within the trial boundary) and the physical environment. In order to address this criterion, the following summarises whether beavers have had 'significant or unsustainable damage' on a sample of ecosystem measures, in particular species and habitats of conservation importance (Table 1) and physical processes monitored during the trial.

In terms of abiotic factors, limited influence on fluvial geomorphology and river habitat was observed at Knapdale during the five year trial, as beavers appeared to have exploited little of the river and riparian resources available[9]. The impact on standing waters was more obvious, but 'significant and unsustainable damage' was not recorded.

3. The area suffers significant economic loss as a result of beaver activities
Failure criteria not met

– *Local business activity:* No reported negative impact on either recruitment or turnover in terms of local business activity was found as a result of the trial. Positive impacts on turnover appear to be modest, with the mean additional annual turnover estimated to be under £3,000 in 2014, although other socio-economic benefits were also identified[4] (see also failure criterion 4, below)

4. Costs of project/damage/management significantly exceed expectations
Failure criterion not met

– *Beaver damage – Forestry Commission Scotland (FCS) incurred costs:* An area of about 1.6 ha was flooded by beavers. The flooded and surrounding area is classified by FCS as 'minimum intervention / native woodland' and is located within Taynish and Knapdale SAC. There is therefore no likelihood of any conifer or other softwood production in this area. If this area were available for softwood production, then the likely revenue foregone would amount to £603 across the trial period. Alternatively, if this theoretical loss was estimated using volume per hectare and average stump values, it would have amounted to £6,279[4]

The flooding inundated a 400 m section of forest track, which, had it been replaced elsewhere, would have cost between £22,000 and £25,000. SBT incurred costs of £22,000 associated with this flooding, which included the realignment of the paths and road improvements. Similarly, road improvement

Table 1

Table 1. Assessment of whether beavers have caused significant or unsustainable levels of damage on features of conservation importance at Knapdale, as of May 2014.

There may be a need to continue monitoring some of these features if beavers remain at Knapdale, and to put in place appropriate management if negative impacts become more significant in the future (e.g. Atlantic hazel within the woodland habitat qualifying/notified features, and the associated lichen assemblage). SPA = Special Protection Area; SSSI = Site of Special Scientific Interest.

Name of site	Qualifying/notified feature name	Conclusion
Taynish and Knapdale Woods SAC This site is underpinned by both Knapdale Woods SSSI and Taynish Woods SSSI	SAC – Otter	No evidence of an effect of beavers on otter presence in the trial area[1] (SNH 'Beavers in Scotland' report, section 3.4.10)
	SAC – Old sessile oak woods with *Ilex* and *Blechnum* in the British Isles SSSI – Upland oak woodland	Beaver impact not considered as having a damaging effect (SNH 'Beavers in Scotland' report, section 3.4.1)
	SAC – Clear-water lochs with aquatic vegetation and poor to moderate nutrient levels SSSI – Loch trophic range	Beavers not considered to have a detrimental impact on specific aquatic vegetation features[10] (SNH 'Beavers in Scotland' report, section 3.4.2)
	SAC and SSSI – Marsh fritillary butterfly	No impacts recorded on this species[12]
Knapdale Woods SSSI	Bryophyte assemblage	Negative impacts from beavers on this feature have been insignificant[12]. Beavers are not considered to have had an unacceptable adverse impact on the quality of the SAC qualifying woodland, for which bryophytes are typical species[13] (SNH 'Beavers in Scotland' report, section 3.4.4)
	Lichen assemblage	Beavers are not considered to have had an unacceptable adverse impact on the quality of the SSSI interest, and the SAC qualifying woodland, for which lichens are typical species[13] (SNH 'Beavers in Scotland' report, section 3.4.4)
	Dragonfly assemblage	The trial period was too short to discern any effects to the populations of hairy dragonfly and beautiful demoiselle. Four new species of dragonfly were recorded at the Dubh Loch in 2013[14] (SNH 'Beavers in Scotland' report, section 3.4.6)
	Breeding bird assemblage	Impacts from beavers, positive or negative have been insignificant (SNH 'Beavers in Scotland' report, section 3.4.9)
Knapdale Lochs SPA and Knapdale Lochs SSSI	Black-throated diver	No impacts recorded on this species[12] (SNH 'Beavers in Scotland' report, section 3.4.9)

works to raise the level of the road adjacent to a beaver loch (Lochan Buic) amounted to £13,000, although no damming or rise in loch level was observed and this work was carried out speculatively[4]

– *Beaver damage – Private landowner costs:* Compensation was paid to a local landowner who sustained limited damage to his willow copse as a result of beaver activity. This amounted to less than £300 (SBT, pers. comm.)
– *SBT budget:* The SBT was estimated to cost around £850,000 at the beginning of the trial; by the end the budget was estimated to be in the region of £2 million. Staffing and equipment represented 41% of this figure, and 15% comprised management costs[3]. This included the cost of the independent monitoring programme incurred by SNH (budgeted at £275,000, completed under budget), plus £176,000 from Independent Monitoring Partners

In summary, damage costs and site management costs did not exceed expectations. Some elements of the project costs came in higher than expected, although these were to a large extent offset by major sources of private funds organised by the SBT partners. Overall, the increase in some elements of the project costs were not significant enough to prevent the trial from being completed and in addressing all the main aims, and beaver damage costs did not exceed expectations.

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Appendix 2

Summary of relevant legislation

The table below gives a synopsis of the legislation that SNH believes is most relevant to beavers and beaver management issues, and provides an indication of some possible implications. It should not be considered exhaustive or absolute.

Legislation (as amended where applicable)	Summary description	Relevance to beavers
Nature conservation law		
Habitats Directive	Requires Member States to study the desirability of reintroducing Annex IVa species; to establish a system of strict protection for these species; to keep their conservation status under surveillance and to allow for derogations; and to designate Special Areas of Conservation (SACs) for species listed on Annex II, avoiding disturbance to the species for which a site has been selected and deterioration of dependent habitats, and assess the impacts of projects or plans proposed for these sites on such species	Beavers are listed on Annex IVa for the UK. Some EU populations are not listed on Annex IVa Beavers are listed on Annex II for the UK Note: Beavers are listed on Annex V for those Member States whose populations are not listed on Annex IVa. Annex V listing is therefore not relevant to the UK
Habitats Regulations 1994	Regulations 37A–46A describe the protection given to Annex IVa species and European Protected Species (EPS; those Annex IVa animals whose natural range includes any area of Great Britain), and the licensing regime. Regulations 7–37 and 47–85E describe the Natura site designation process and assessment implications	Limited Scottish protection given to beaver at the moment, although listed on Annex IVa. If formally reintroduced, beavers would become an EPS and require strict protection (this can be done for Scotland only within the UK). A licensing regime would become more applicable Site(s) may require designation as SACs for beavers. Plans or proposals affecting beaver SACs would require assessment in the light of the site's conservation objectives before being approved Plans or proposals affecting any Natura site (SAC or Special Protection Area for birds), including any beaver reintroduction, would also require a 'Habitats Regulations Appraisal' before proceeding. Some of these might require an 'Appropriate Assessment' before a decision is made about whether or not to proceed
Wildlife & Countryside Act 1981	Under Section 14 it is illegal to release, allow to escape from captivity or cause to be at a place outside the control of any person any animal species outside its native range (as defined in the Act) without a licence under Section 16. 'Former native' species are considered to be 'non-native species' for the purposes of the Act	Any release of beaver into the wild in Scotland would require a non-native species licence from SNH, given its 'former native' status
Nature Conservation (Scotland) Act 2004	SNH must notify Sites of Special Scientific Interest (SSSIs) for natural features (including certain animals) according to published selection guidelines and describe 'operations requiring consent' (ORCs). The ORC provides details of acts or omissions which might damage the natural feature of interest, and therefore require SNH consent before being carried out	Currently, SSSIs cannot be notified for beavers. However, if released onto an existing SSSI notified for other feature(s), beaver management might require consent
Salmon & Freshwater Fisheries (Consolidation) (Scotland) Act 2003	Sets out the law governing Scotland's District Salmon Fishery Boards and other important regulatory areas, including an offence in relation to passage of salmon. Persons acting to prevent salmon passage or disturb any spawning bed may be guilty of an offence	The implications of possible riverine habitat change/engineering resulting from beaver activity (e.g. dam construction), or beaver management, which might impede fish movement within river systems and affect in-stream habitat require clarification and guidelines to be produced. Consultation with relevant DSFBs, fishery owners and SEPA will be a requirement

Trade and movement of animals		
Balai Directive 1992	Animals may be collected from Scotland and released elsewhere, or collected elsewhere and released in Scotland. The national regulations and permit procedures in other countries involved must be adhered to. Balai Directive 1992 lays down animal health requirements governing trade in and imports into the EU of certain animals	Beavers imported from other EU Member States and non-EU countries will require the appropriate authorisation
Animal welfare law		
Animal Health & Welfare (Scotland) Act 2006	This law protects the welfare of all vertebrate animals kept on a temporary or permanent basis in Scotland Animals transported by air (either outside or within Scotland) must comply with the International Air Transport Association's 'Live Animals Regulations' (LAR)	Beaver welfare should be considered when animals are captured, transported or held in captivity, and during and after release into the wild Persons responsible for holding beavers in captivity must not cause them unnecessary suffering or fail to take reasonable steps to ensure their welfare Where capture or release of beavers is undertaken in another country, the relevant animal welfare legislation of that country must be adhered to If transported by air in Scotland or to/from Scotland, beavers must be held in containers as specified under LAR
European Zoos Directive 1999 Zoo Licensing Act 1981	Establishments holding wild animals kept for exhibition (other than circus or pet shop), where the public have access for seven or more days a year, must be inspected and licensed in most cases. Under zoo law, persons wishing to operate a zoo must be licensed by the local authority	Establishments holding beavers for exhibiting purposes and open to the public for at least seven days a year must be inspected and licensed by the relevant local authority
Pests and diseases		
Balai Directive Rabies (Importation of Dogs, Cats & Other Mammals) Order 1974	The Balai Directive provides a framework for animal health requirements governing trade between EU Member States and imports into the EU. There are health certification requirements, and premises holding animals need to be registered and approved by the Animal and Plant Health Agency (APHA). Beavers are listed on Schedule 1 Part II of the Rabies Order 1974	All imported beavers held in captivity in Scotland should be accompanied by an appropriate health certificate Premises holding imported beavers need to be registered with the APHA Beavers entering the UK are subject to six months quarantine at an approved establishment (although exceptions have been applied in Scotland) If beavers are to be exported to an EU country, the exporter requires an export health certificate
Responsible access		
Land Reform (Scotland) Act 2003	The 2003 Act gives everyone statutory access rights to most land and inland water for recreational or educational purposes	The reintroduction of beavers into Scotland is not primarily a recreational or educational activity, so access rights do not apply. Therefore, projects involving the capture or release of beavers should seek landowner/occupier permission

Water and flood risk management		
Water Framework Directive 2000 Water Environment & Water Services (Scotland) Act 2003 Water Environment (Controlled Activities) (Scotland) Regulations 2011 ('CAR')	Establishes a regulatory structure aimed at protecting, improving and sustainably using water. The 2003 Act and 2011 Regulations transpose the Directive into Scots law and gives Scottish Ministers regulatory controls over water activities – the Controlled Activity Regulations (CAR). Persons intending to carry out any activity which might affect Scotland's water environment require authorisation from SEPA	The management of beavers on a site might result in CAR applications to SEPA (e.g. river impoundment works to protect river banks). SEPA has developed a pragmatic position statement on the management of beaver structures (available from the SEPA website)
Floods Directive 2007 Flood Risk Management (Scotland) Act 2009	The 2009 Act transposes the Floods Directive into Scots law, introducing requirements to reduce the adverse consequences of flooding for a range of reasons, including human health and the environment. It aims to establish a framework of responsibility for assessing and managing flooding and places a strong emphasis on working with nature to manage flood risk	Habitat change brought about by beaver activity might contribute to restoring natural processes within catchments. Beaver presence might increase or reduce flood risk at a local level. Strategic and local flood risk management planning will need to take account of potential beaver activity in managing flood risk sustainably
Reservoirs (Scotland) Act 2011	Sets down the regulatory regime for the safe construction and operation of 'controlled reservoirs' in Scotland. Requires compulsory registration of controlled reservoirs, regulates their construction and denotes inspection requirements. SEPA must assess the risk of uncontrolled releases of water from controlled reservoirs (in terms of adverse consequences and probability). The Act also gives SEPA the power to act in an emergency to protect people or property from water escaping from a controlled reservoir	There is the potential for beaver burrowing, for example, to damage 'controlled reservoirs' with consequent risk to public and infrastructure safety. More frequent inspection of some controlled reservoirs may be required. Plans for new reservoirs might need to take into account possible beaver activity in the area
Environmental liability and impact assessments		
Environmental Liability Directive 2004 Environmental Liability (Scotland) Regulations 2009	Under the Directive and the transposed Scots law, operators causing, or causing a risk of, environmental damage (which includes offences affecting Annex II species and Annex IV species and their breeding sites or resting places) are held financially liable for remedying the damage. Protection applies whether the species is inside or outside a Natura site	Operators who kill (large numbers of) beaver (when their population is low) or damage their breeding sites or resting places may be held financially liable for remedying the situation
Strategic Environmental Assessment Directive 2001	This law requires that any public body preparing certain plans must carry out a strategic environmental assessment of them if they are likely to have significant environmental effects	Scottish Ministers will need to consider whether or not the reintroduction of beaver in Scotland requires a strategic environmental assessment and, if so, arrange for one to be completed

Glossary

Definitions relate to the context in which the terms are used in this document.

- *Adaptation*: individuals or populations that are suited to a particular set of environmental conditions
- *Adaptive management*: a cyclical approach to conservation management in which the outcomes of management actions are used to improve and refine future management activity
- *Allochthonous*: something that originated outside of the system it is currently in e.g. dead wood in watercourses
- *Ammocoetes*: lamprey larvae
- *Anadromous fish*: those that migrate from the sea as adults to fresh water to spawn
- *Beaver canal*: a channel dug by beavers, often to better access feeding sites
- *Beaver meadows*: grasslands that may develop after a beaver pond has been drained or is silted up
- *Biodiversity*: biological diversity
- *Bryophytes*: small plants that include the mosses and liverworts
- *Commensalisms*: relationships among organisms where one benefits without affecting the other
- *Conservation translocation*: the intentional movement and release of a living organism where the primary objective is a conservation benefit
- *Cultural ecosystem services*: all the non-material, and normally non-consumptive, outputs of ecosystems that affect physical and mental states of people. These include recreational, educational and spiritual interactions with the environment
- *Demography*: measuring populations including the number of individuals, representation in different age classes, and birth and death rates
- *Derogation*: an exemption from a law
- *Designated site*: a site designated for a specific purpose, such as an SAC designated for wildlife conservation
- *Diadromous fish*: those that migrate between freshwater and the sea to complete their life cycle
- *Donor site/location/population*: the place where translocated organisms are taken from
- *Ecosystem engineer*: a species which fundamentally changes the ecosystem in which it lives
- *Ecosystem services*: the direct and indirect contributions of ecosystems to human well-being
- *Epiphytic*: a plant which grows on another plant
- *Extirpated*: local extinction
- *Fluvial geomorphology*: the study of the physical process and forms that occur in streams and rivers
- *Food cache*: a store of food created by beavers within a watercourse or water body
- *Former native*: species or type that were previously native in a location but became extinct there and no longer have the potential to recolonise that location naturally. (The term 'former native' is used in Scotland in relation to 'native range')
- *Genetic heterozygosity/allelic richness*: measures of genetic diversity at the population scale
- *Genetic incompatibility*: barriers to breeding and/or the production of healthy viable offspring
- *Habitat heterogeneity*: diversity of habitats
- *Hydrology*: the study of the occurrence, distribution and movement of water
- *Impoundment*: the impoundment of water behind a beaver dam creating a beaver pond
- *Invasive species*: species which, if not kept under control of any person, would be likely to spread and have a significant effect on biodiversity, or other environmental or socio-economic interests
- *Kit*: young beaver (generally used for animals less than one year old)
- *Lentic*: standing or very slow moving water
- *Lotic*: moving water
- *Macrophytes*: aquatic plants that live in or near water
- *Monitoring*: observation and measurement of the performance of a population or the state of a habitat
- *Mycorrhizal fungi*: fungi that live in symbiosis with the roots of a plant
- *Native range*: the locality to which the animal, plant or fungus of that type is indigenous. It does not refer to any locality to which that type of animal, plant or fungus has been imported (whether intentionally or otherwise) by any person. (Note that once a type of animal or plant becomes extinct in a locality, and it is unable to re-colonise naturally, that locality is now outwith its 'native range'. The term 'native range' is used in Scottish legislation)
- *Natural range*: the natural past or present distribution of a species or other taxonomic entity but for the direct intervention of man (natural range includes all locations where a species is or was indigenous).
- *Notifiable disease*: a disease which if detected by law must be reported to the relevant government agency
- *Ontogenetic*: based on life stage
- *Oviposition*: the process of laying eggs
- *Phylogeographic structure*: variation within a species which corresponds to genetically distinct geographical races
- *Piscivorous*: fish-eating
- *Population*: a group of individuals that occur in the same place
- *Preferred species*: species eaten by beavers in greater proportion than their abundance in the landscape
- *Provisioning ecosystem services*: those material and energetic outputs from ecosystems that contribute to human well-being, such as food and water
- *Recipient site/location/population*: the place where translocated organisms are released
- *Regulation and maintenance ecosystem services*: all the ways in which ecosystems and living organisms can mediate or moderate the ambient environment so that human well-being is enhanced. This includes the mediation of waste and toxins, mediation of water flows, habitat preservation, pollination and climate regulation
- *Reinforcement*: translocation of an organism into an existing population of the same species
- *Reintroduction*: translocation of an organism inside its natural range from where it has disappeared
- *Release site/location/population*: the place in which translocated organisms are released
- *Release*: the placement of living organisms into the wild
- *Reservoir host*: a host that maintains a population of a parasite, acting as a source of infection

- *Rhizomatous*: having a rhizome; a root-like subterranean stem
- *Riparian*: the zone associated with the terrestrial edges of watercourses or water bodies
- *Salmonids*: fish from the salmon family, such as Atlantic salmon and brown trout
- *Saproxylic*: associated with dead and decaying wood
- *Scenario*: see Chapter 6
- *Socio-economic*: factors related to people and livelihoods
- *Source population*: the place where translocated organisms are taken from (the donor site)
- *Sun-shoots*: regrowth resulting after a tree is cut or coppiced
- *Translocation*: the deliberate movement of organisms from one place to another
- *Vascular plants*: plants which have a vascular system of plant tissue i.e. xylem and phloem for conducting liquids. They include the seed plants and ferns and their allies
- *Zoonotic disease*: diseases which can be transmitted between animals and humans

List of acronyms

–	AECS	Agriculture Environment and Climate Scheme
–	BSWG	Beaver-Salmonid Working Group
–	CAR	Water Environment (Controlled Activities) (Scotland) Regulations 2011
–	DSFBs	District Salmon Fishery Boards
–	EPIC	Epidemiology, Population health and Infectious disease Control (Centre of Expertise on Animal Disease Outbreaks)
–	EPS	European Protected Species
–	ESF	Ecosystem Services Framework
–	ESU	Evolutionarily Significant Unit
–	EU	European Union
–	FCS	Forestry Commission Scotland
–	GIS	Geographic Information Systems
–	IUCN	International Union for the Conservation of Nature
–	LADAC	Lochgilphead and District Angling Club
–	MSS	Marine Scotland Science
–	NASCO	North Atlantic Salmon Conservation Organization
–	NFI	National Forest Inventory
–	NUV	Non-Use Value
–	NWSS	Native Woodland Survey of Scotland
–	RZSS	Royal Zoological Society of Scotland
–	SAC	Special Area of Conservation
–	SBT	Scottish Beaver Trial
–	SNH	Scottish Natural Heritage
–	SPA	Special Protection Area
–	SRDP	Scottish Rural Development Programme
–	SSSI	Site of Special Scientific Interest
–	SWT	Scottish Wildlife Trust
–	TBSG	Tayside Beaver Study Group
–	UK	United Kingdom
–	UK BAP	UK Biodiversity Action Plan
–	WCA	Wildlife and Countryside Act 1981 (as amended)
–	WTP	Willingness To Pay

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