Effectiveness of Beaver Management

Rapid Evidence Assessment on the Management of Impacts of Beavers on Humans and the Natural Environment

Full Report

March 2025

Natural England Evidence Review NEER153

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Report details

Author(s)

Cornelia Bentsen, William Muckley, Emma Lockley, Jack Lee, Kathy Peck, Isabel Alonso

Project Manager

Cornelia Bentsen

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Foreword

Beavers are ecosystem engineers that modify the environment, affecting both humans and other wildlife (1). They are native to Britain, but humans hunted them to extinction around 400 years ago (2). Their return to Britain is celebrated by some stakeholders, but others are concerned about how potential negative beaver impacts will be managed.

Natural England is an evidence-led organisation. It aims for all its conservation actions to be based on the latest scientific evidence. More than this, it seeks to be a leader in environmental science. It strives to identify evidence gaps and undertake research to improve scientific understanding.

This evidence review is part of that work. In response to uncertainty around what is known about beaver management, it sought to review the empirical evidence and map the evidence landscape. This has helped to improve our understanding of what science knows about beaver management, how robust this science is, and areas where we need further research.

As humans learn how to live alongside beavers, this evidence review forms the start of human-beaver coexistence supported by science. It promotes understanding around what management techniques can work. Natural England hopes this will make management more successful and satisfactory to humans, beavers, and other wildlife.

Executive summary

Context and objectives

Beavers are ecosystem engineers that modify the environment, affecting both humans and other wildlife. Beavers are native to Britain, but humans hunted them to extinction around 400 years ago. In the last three decades, Eurasian beavers have returned to Britain. Some stakeholders are celebrating their return due to beavers' ecological benefits. Others are concerned about how potential negative beaver impacts will be managed, and whether management techniques are effective.

In response to these concerns, this evidence review assessed the empirical evidence around beaver management. The report intends to clarify what science knows about beaver management, how robust this science is, and areas where we need further research.

Research questions

- How effective are interventions for managing negative beaver impacts?
- What ecological mitigation and compensations measures exist for beavers and how effective are they in the context of development?

Methods

We conducted a rapid evidence assessment of academic literature through a systematic search of two academic databases (Scopus and CAB Direct) using pre-defined search strings. This was supplemented by a search of the reference lists of relevant publications and grey literature sources.

We identified 6,737 records from academic databases and removed 1,085 duplications. After screening the remaining 5,652 citations, 32 were eligible for inclusion in this report. An additional 41 publications were identified from the supplementary searches, giving a total of 73 pieces of evidence. All evidence identified underwent critical appraisal to provide a strength of evidence rating.

Caveats

This report details the results of the evidence review. As such, the review presents an objective summary of the scientific evidence. It does not provide guidance on which management options to take or advise about the legal context of management actions in specific countries.

Readers in England should note that beavers are a European Protected Species. As such, there are legal regulations on which management actions people can take for beavers.

The results and conclusions discussed below should therefore be considered within the legislative context in England. Furthermore, some management actions require additional environmental permits from the relevant risk management authority. More information can be found at Protection and management of beavers in England - GOV.UK (www.gov.uk).

Readers should also be aware that this evidence review only considers published scientific literature and published or unpublished grey literature. There is extensive knowledge around the efficacy of different beaver management techniques held in practitioner experience. However, the systematic process of producing evidence reviews is not designed to capture these types of evidence; it is only designed to capture documented evidence.

Results

Most of the identified studies were based in the USA or Europe. Over half of studies investigated North American beavers *(Castor canadensis),* almost a third examined Eurasian beavers (*Castor fiber),* and the remaining few examined species with similar impacts, such as mountain beavers (*Aplodontia rufa),* Coypu (*Myocastor coypus),* and muskrats (*Ondatra zibethicus*).

There was more empirical evidence for some interventions than others.

- There were ≥11 studies on flow devices, culvert protection, repellents, tree protection, and monitoring.
- There were between 5 and 10 studies on education and stakeholder engagement, dam removal, trapping and translocation, and lethal control.
- There were between one and four studies on scarer devices, electric fencing, buffers of preferred tree species, embankment protection, lodge removal and burrow infilling, and measures to mitigate for the impacts on development on beavers. These are areas for future research.

In general, the strength of evidence was weak; over half of the studies had a weak strength of evidence rating. However, the strength rating varied from one intervention to another.

- Studies on repellents, tree protection, and monitoring had the highest strength of evidence ratings.
- Whereas studies on flow devices and culvert protection were particularly weak.

Management methods had varying levels of effectiveness.

- Monitoring (except when using tail-mounted transmitters or thermal imaging), education and stakeholder engagement, tree protection mechanisms, odour and texture repellents, tree guards, flow devices and culvert protection were generally effective[1].

- Other repellents, electric fencing, dam removal, trapping, translocation, and lethal control had mixed effectiveness.
- The effectiveness of tree protection using buffers of preferred tree species was unclear.
- Monitoring via tail-mounted transmitters and thermal imaging, and scarer devices were ineffective.
- Conclusions couldn't be made around embankment protection, the use of riparian buffers, lodge removal and burrow infilling, and measures to mitigate for the impacts of development on beaver due to insufficient published evidence.

Conclusions

The evidence presented in this review improves our understanding of beaver management. The findings can be used alongside prior reviews on beavers and their impacts, as well as insights from practitioners, to inform future management decisions concerning beavers. Natural England hopes this will help to support successful co-existence between humans and beavers

[1] Defined as an intervention that minimises cost, time, and other resource requirements; supports the development of healthy and sustainable beaver populations; maximises the benefits of beavers to other species (including humans); minimises the costs of beavers to other species (including humans); responds to risks and/or conflicts early and reasonably from the perspective of all stakeholders (human and non-human); and therefore facilitates the successful coexistence of humans and beavers.

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Background and context

The Eurasian beaver *Castor fiber* is native to Britain, but it was hunted to extinction by humans around 400 years ago (2). Since the early 2000s, the Eurasian beaver has returned to Britain through a combination of enclosed releases, escapes from enclosures, illegal wild releases, and sanctioned wild releases (3). In England, there are now more than 40 enclosed beaver populations, and a free-living population of more than 500 individuals, spread over more than 120 territories (pers. comm, 2024). In Scotland, the free-living population of beavers is estimated at 954 individuals, spread over 251 territories (4). In Wales, there are three known enclosed beaver populations, and a small unsanctioned free-living population, the exact size of which is unknown (3).

In Britain, there is mounting interest in beaver reintroduction due to the ecological benefits associated with them. As ecosystem engineers, beavers modify their habitats to suit their needs. In so doing, they initiate trophic cascades and ecosystem processes which restore degraded riparian ecosystems and provide ecosystem services to humans (5). Beaver dams attenuate water flow, holding back water during flood events and slowly releasing water during drought (6). Beaver dams also encourage sediment to drop out of the river (1). This removes silt and pollutants, improving water quality, and locks up carbon in deposited sediment, promoting carbon sequestration (1, 7). Moreover, beavers increase biodiversity. Their engineering processes diversify riparian habitats, opening new ecological niches for species colonisation and sending a positive multiplier effect through riparian food webs (8). Beaver wetlands also act as a natural barricade to forest-fires and serve as a vital oasis for biodiversity during drought events (9).

Nonetheless, reintroduced beavers occupied a legal grey space for almost three decades (10). Following several centuries of absence, beavers were no longer considered ordinarily resident Britain. This meant that they were not legally protected and guidance around their management was unclear. In May 2019 the Scottish Government listed beavers under Schedule 2 of the Conservation of Habitats and Species Regulations 2017 and Schedule 9 of the Wildlife and Countryside Act 1981 (WCA), giving beavers European Protected Species (EPS) status and officially recognising them as native to Scotland (11). Following a public consultation, England followed suit in October 2022 (The Beavers Order 2022). In Wales, beavers were listed under Schedule 9 of the WCA in 2015; however, a decision is yet to be made about listing them under Schedule 2 of the Conservation of Habitats and Species Regulations 2017, and therefore, whether they will be given EPS status (12).

As popular interest in beavers grows, and national governments grapple with the legislative challenges of bringing beavers back to Britain, it is vital to have robust scientific evidence available to inform human-beaver coexistence. A significant amount is known about the Eurasian Beaver, particularly in terms of its (historical) demography, its biology, its ecological interactions, and the social dimensions of reintroduction (1, 3, 13-16). There is a growing body of knowledge around beaver management techniques. However, most of this knowledge is held in practitioner experience, rather than open access, empirical, and peer-reviewed literature. This has led to perceived and actual knowledge gaps around the effectiveness and best use of beaver management techniques. A knowledge gap also exists around the effectiveness of ecological mitigation and compensation measures for beavers in the context of development.

Aims and objectives

Natural England is an evidence-led organisation. It aims for all its conservation actions to be based on the latest scientific evidence. More than this, it seeks to be a leader in environmental science. It strives to identify evidence gaps and undertake research to improve scientific understanding. This evidence review is part of that work.

In response to the uncertainty around what is known about beaver management, Natural England sought to review the scientific evidence and map the evidence landscape. This evidence review assesses the scientific evidence on beaver management, appraises the strength of the evidence, and shows areas where further research is needed. Additionally, by reviewing the empirical evidence, this project promotes context-dependant conclusions around what management techniques can work. The aim of this work is to promote evidence-led management, increased trust from stakeholders that beavers can be managed effectively, and to help humans and beavers coexist more successfully.

Research questions

The project addresses the following research questions:

1. How effective are interventions for managing negative beaver impacts?
2. What ecological mitigation and compensations measures exist for beavers and how effective are they in the context of development?

Methods

The evidence review was designed to capture the documented scientific evidence on beaver management[2]. The methods used to systematically search for scientific papers is detailed in this section.

[2] Note that the systematic process of producing evidence reviews is not designed to capture undocumented evidence, such as expert knowledge/experience; it is only designed to capture documented evidence.

Data sources

Natural England identified relevant data from the following sources:

- Electronic databases
- Reference lists of relevant publications (including primary publications and systematic reviews)
- Conference proceedings
- Other grey literature

Electronic databases

The following academic databases were interrogated using the search terms provided in Appendix A:

- Scopus, 1823 to present
- CAB Direct, 1973 to present

Reference lists

Reference lists of relevant primary publications, systematic reviews, and meta-analyses were interrogated to identify further relevant primary publications.

Conference proceedings

The following conferences were searched for relevant abstract published in the last 20 years (2003–):

- British Ecological Society Annual Meeting
- Ecological Society of America Annual Meeting
- International Beaver Symposium

Other grey literature sources

Other grey literature sources, particularly from outside the United Kingdom, were identified through a snowballing approach. The Natural England Beaver Team and the 8th and 9th International Beaver Symposium delegate lists were used as the start of the snowball process. Based on the recommendations of these experts, the project team identified grey literature sources, as well as other contacts who were able to further direct the project team to grey literature sources. The following sources were identified and searched for relevant material:

- Department for Environment, Food, and Rural Affairs
- Natural England Access to Evidence
- Environment Agency

- Nature Scot Information Hub
- Natural Resources Wales
- The Wildlife Trusts
- Agentura ochrany přírody a krajiny České republiky (Eurasian Beaver (zachranneprogramy.cz))
- Czech Republic Faculty of Environmental Sciences
- The Ministry of the Environment of the Czech Republic Publication database
- Danube Parks (DANUBEPARKS - Network of Protected Areas)
- The Beaver Institute (North America) (www.beaverinstitute.org)
- Beavers Northwest (Beavers Northwest (beaversnw.org))
- Beavers: Wetlands and Wildlife (Manage Flooding - Beavers: Wetlands & Wildlife (beaversww.org))
- Worth a Dam (Solving Problems – Worth A Dam (martinezbeavers.org))
- Montana Beaver Working Group (Montana Beaver Working Group (nwf.org))
- Project Beaver (Flow device BMPs — Project Beaver)
- Cows and Fish, Canada (https://cowsandfish.org/publications/)
- The Miistakis Institute, Canada (https://www.rockies.ca/)
- Working With Beavers (Working with Beavers - Home)
- FITHydro
- Michigan Department of Natural Resources
- Office National de la Chasse et de la Faune Sauvage
- Lithuanian Research Centre for Agriculture and Forestry WAMBAF | LAMMC
- Gerhard Schwab Publications (gerhardschwab.de)
- Swiss Federal Office for the Environment
- National Data and Information Centre for Swiss Fauna - Info Fauna | National Data and Information Centre for Swiss Fauna
- Kenniscentrum Bever (www.kenniscentrumbever.nl)
- Marijan Grubešić: Dabar u Hrvatskoj | (crveniperistil.hr)

Eligibility criteria

The eligibility criteria for the rapid evidence assessment are provided in Table 1. The reviewer(s) had the discretion to use expert opinion to include highly relevant studies that did not meet the full inclusion criteria.

Table 1: Summary of eligibility criteria. Note: some cells have been left blank.

Criteria	Inclusion	Exclusion
Population	Eurasian beaver (*Castor fiber),* North American beaver (*Castor canadensis*), mountain beaver (*Aplodontia rufa*); Muskrat (*Ondatra zibethicus*); and Coypu (*Myocastor coypus*). *Readers should note that North American beaver have very similar behavior and impacts to the Eurasian beaver and therefore management that works for the North American beaver works for the Eurasian beaver. Mountain beaver, muskrat, and coypu also have similar behavior and impacts.	

Intervention	Any intervention associated with the management of beaver-related conflicts, including but not limited to:
	• Flow devices/ pond levellers
	• Culvert protection
	• Fencing
	  ○ In-stream fencing
	  ○ Tree guards
	  ○ Area/exclusion fencing
	  ○ Electrical fencing
	• Tree paint
	• Scarer devices
	• Dam alteration or removal
	• Grilles
	• Bank wall protection
	• Burrow or lodge infilling, alteration, or removal
	• Riparian buffers
		This study does not include interventions intended to manage beaver impacts not associated with conflict with humans, including but not limited to:
		• Genetic management
		• Disease management
		
		This study does not include interventions intended to manage muskrat or coypu impacts where there is not a direct application for beaver management. This includes but is not limited to:
		• Muskrat and coypu feeding preferences.
		• The effects of chemical repellents on muskrat and coypu.
		• The dispersal patterns of muskrat and coypu post-translocation.

<table>
<tr><th>Criteria</th><th>Inclusion</th><th>Exclusion</th></tr>
<tr><td></td><td>The protection of water assets
Monitoring of beaver impacts
Education and other social tools that encourage human tolerance
Countryside stewardship options that encourage land managers’ tolerance
Water level management
Translocation
Culling
Any intervention associated with ecological mitigation and compensation for beavers, including but not limited to:
Alternative territory creation
Alternative habitat creation
Tree planting
Scrub creation
Territory/ habitat protection
Riparian buffer strips
Artificial burrow creation</td><td>This study does not include interventions designed to monitor or model beaver populations or predict future demographic trends and dynamics.</td></tr>
<tr><td>Comparator</td><td>No restriction</td><td></td></tr>
<tr><td>Outcomes</td><td>Impact of interventions on the following:
Organisms and the landscape, including but not limited to:</td><td></td></tr>
</table>

Criteria	Inclusion	Exclusion
	○ Frequency and extent of localised flooding ○ Rate of riverbank erosion ○ Rate of tree felling (by tree species where possible) ○ Population of fish, molluscs, and crustaceans in the area local to beaver activity ○ Migration patterns of fish in the area local to beaver activity ○ Number of benefits delivered to other species/ the landscape by beavers ○ Costs associated with beaver activity to human infrastructure • Agriculture and fisheries including but not limited to: ○ Rate of crop loss due to flooding ○ Costs associated with beaver activity (productivity costs, equipment damage, etc) • Humans ○ Perceptions of beaver activity ○ Number and size of benefits and costs to human populations • Beaver welfare • Conservation practices ○ Level of ongoing intervention required ○ Cost, time, and other resource inputs required to manage beaver impacts	
Study design	Any method of primary research	Systematic reviews or meta-analyses**

Criteria	Inclusion	Exclusion
Geography	UK focussed, but data from Europe and South America, and North America is included	
Language	Academic studies published in English; no restriction for grey literature	

* Readers should note that North American beaver have very similar behavior and impacts to the Eurasian beaver and therefore management that works for the North American beaver works for the Eurasian beaver. Mountain beaver, muskrat, and coypu also have similar behavior and impacts.
**Systematic reviews and meta-analyses were interrogated for relevant primary articles.

Screening

Citations identified by the database search were deduplicated in EndNote and exported to Microsoft Excel®. The citations were then screened in two stages: 1) title and abstract and 2) full publication. In the first stage, the titles and abstracts of citations were screened against the inclusion/exclusion criteria in Table 1. Papers deemed relevant at the title and abstract stage were obtained via the DEFRA library. In the second stage, the full publications of potentially relevant studies were reviewed, and a final decision on their eligibility was made. Studies excluded at this stage were given a reason for exclusion.

Screening at both stages was conducted by a single specialist, and a second specialist checked 10% of the citations. Disputes were referred to a senior reviewer (strategic adviser or project manager) and resolved by consensus.

Data extraction

Eligible studies were extracted into an Excel®-based data extraction table (DET; Appendix B). A pilot DET was designed by the project team and reviewed by the sounding board (see acknowledgements) to ensure that column headings were fit for purpose. Three extractions were completed in the pilot DET. Filters were provided to ensure that data is accessible for different subgroups.

Each of the eligible studies were extracted by one reviewer (not necessarily the same reviewer for each study), and a senior reviewer checked 20% of the extractions for accuracy.

Critical appraisal of the strength of evidence

To provide a standardised overview of the strength of evidence produced through the rapid evidence assessment protocol, critical appraisal of the quality of the eligible academic research studies was performed using a modified version of the tool developed by Mupepele and others (Full description in Appendix C) (17).

Papers were initially ranked by study design in relation to the weight of their evidence, placing them within four categories ranging from “very strong evidence” to “weak evidence” (Table 2). Following this initial ranking process, a critical appraisal checklist was used to assess the potential for bias within a paper, and studies downgraded as necessary.

This approach provided each academic research paper with a “strength of evidence” rating between 1 and 4, with 1 indicating “very strong” evidence and 4 indicating “weak evidence”.

Table 2: Hierarchy of evidence, modified from Mupepele and others (2016).

Strength of Evidence	Associated Studies
1. Very strong evidence	**A. Review:** Systematic review
2. Strong evidence	**A. Studies with a reference/control:** • Case-control • Before-after control-impact **B. Or** • Multiple lines of moderate evidence
3. Moderate evidence	**A. Observational Studies** • (Inferential) studies with statistical testing • (Descriptive) studies with statistical testing **B. Or** • Conventional Review **C. Or** • Multiple lines of weak evidence
4. Weak evidence	**Studies without underlying data** • Individual expert opinion • Mechanism based reasoning

Results

Summary of screening process

The search of academic databases yielded 6,737 references: 4,440 from Scopus and 2,297 from CAB Direct. After removal of 1,085 duplicates, 5,652 citations were screened. The titles and abstracts of the citations were interrogated first, and 5,497 studies were excluded at this stage. The remaining 155 studies were sought for retrieval, but seven could not be obtained. Of the 148 full publications that were available for screening, 116 studies were excluded. The reasons for exclusion were as follows:

- Non-relevant population: 15
- Non-relevant intervention: 63
- Non-relevant outcome: 15
- Non-relevant study design: 18
- Language: 3
- Duplicate publication: 2

In total, 32 articles were included from the academic database search. An additional 41 publications were identified from the supplementary searches, giving a total of 73 eligible publications.

Of the 73 publications that met the inclusion criteria, six were guidance documents that did not provide any empirical data. These studies are provided in the DET but were excluded from the analysis in this report. This left 67 studies that were eligible for analysis.

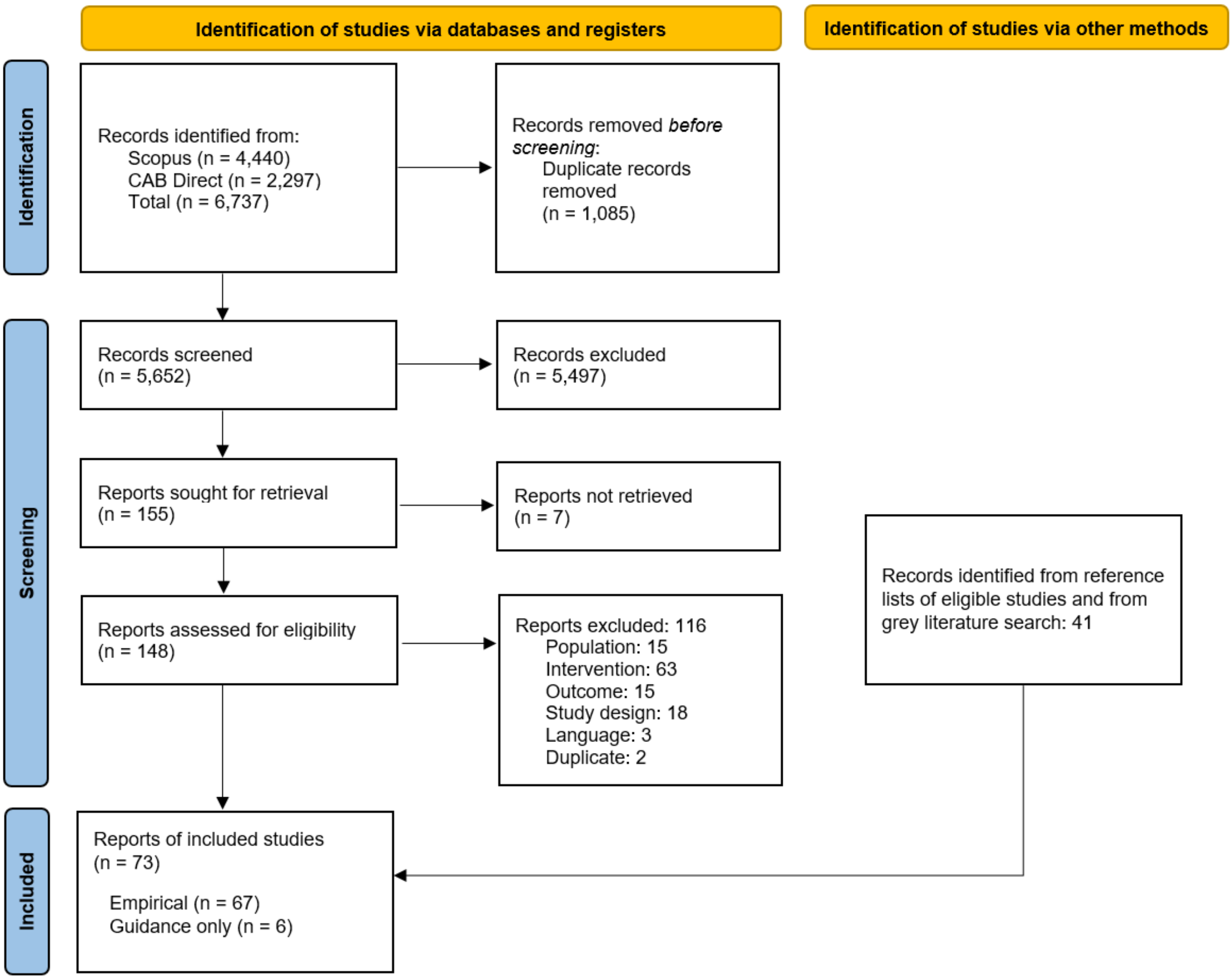

Figure 1: Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) flow diagram.

Summary of study characteristics

Most of the identified studies examined beavers. North American beavers were examined most often (n=42), followed by Eurasian beavers (n=17). The review also identified studies that examined mountain beaver (n=1), Eurasian beavers and North American beavers (n=1), Eurasian beavers and coypu (n=1), and beavers without specifying the species (n=1). Four studies only examined non-beaver species: coypu (n=3) and muskrat (n=1).

Most studies were based in the USA (n=34). Other countries studied include Argentina (n=3), Brazil (n=1), Canada (n=7), Czech Republic (n=1), France (n=1), Lithuania (n=1), Netherlands (n=2), Norway (n=1), Poland (n=3), Romania (n=1), Switzerland (n=1), United Kingdom (England, n=4; Scotland, n=2; England, Scotland, and Wales, n=1). The review also identified multinational studies (n=2) and studies that did not report the study country (n=2). The distribution of studies is visualised in Figure 2.

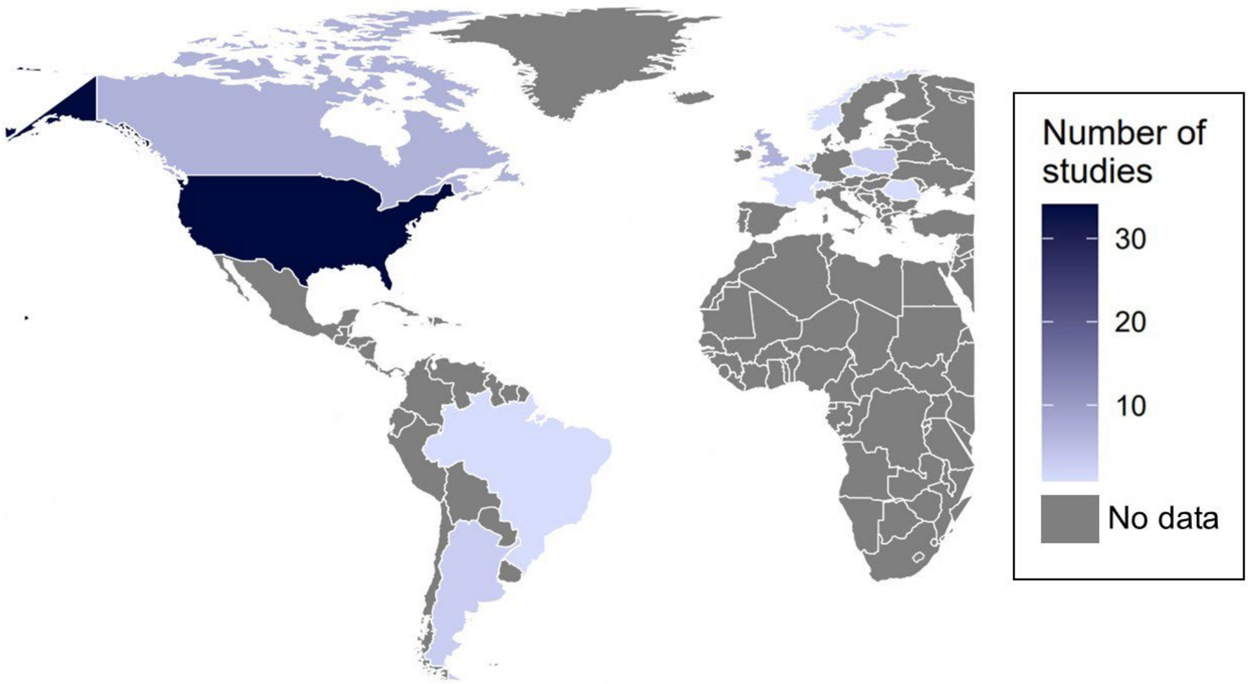

Figure 2: Map showing the distribution of included studies; multinational studies and studies that didn't report a study country are not included in the map.

The studies identified by the review reported the efficacy or costs of the following management and mitigation interventions (some studies examined more than one intervention):

- Monitoring (n=11)
- Education and stakeholder engagement (n=6)
- Tree protection: fencing and barriers to movement (n=12)
- Tree protection: choice of tree species (n=4)
- Repellents (n=13)

- Scarer devices (n=4)
- Electric shock devices (n=4)
- Embankment protection (n=2)
- Flow devices (n=22)
- Culvert protection (n=12)
- Dam removal (n=7)
- Lodge removal and infilling burrows (n=2)
- Trapping and translocation (n=10)
- Lethal control (n=6)
- Ecological compensation (n=1)
- Other (n=5)[3]

The distribution of empirical evidence for different interventions is visualised in Figure 3.

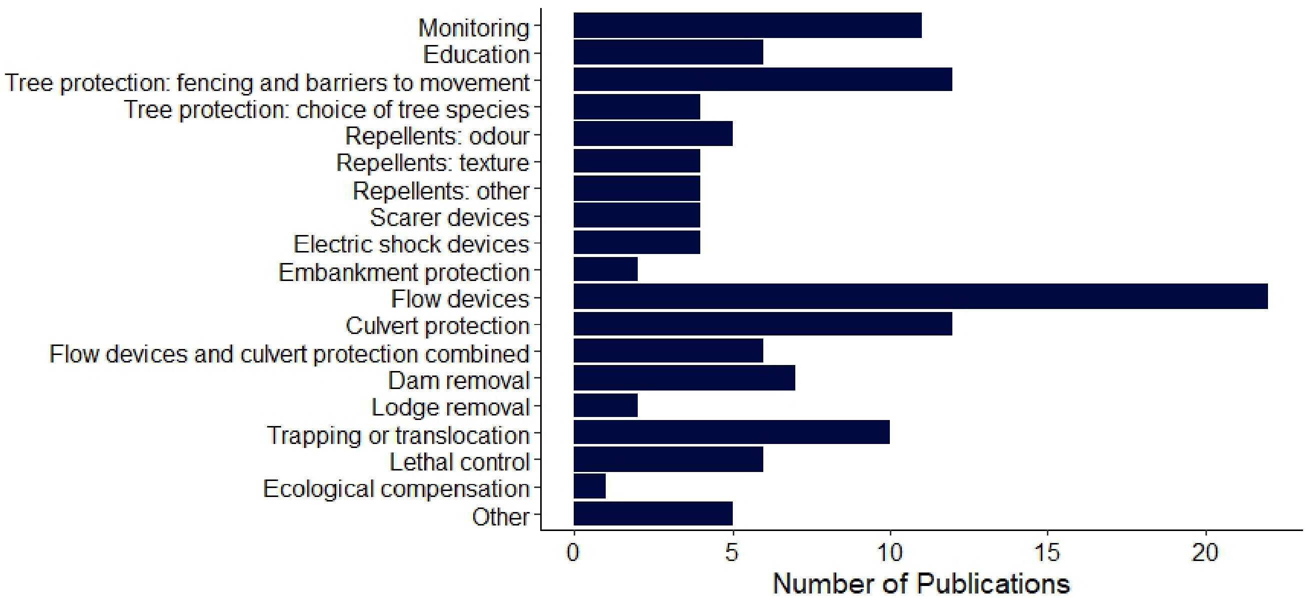

Figure 3: A bar chart showing the amount of evidence found for different interventions.

The majority of studies included in the review were observational (n=25) in design. The review also identified experimental studies (n=21), case studies (n=9), cost-benefit analyses (n=3), mixed-method studies (n=2; part observational and part experimental), reviews (n=1), guidance and expert opinion (n=5), and a modelling study (n=1).

[3] Effect of natural water level fluctuations and river flow changes on beaver behaviour and population dynamics

Summary of the strength of evidence

Results of the strength of evidence assessment are reported in Figure 4, which shows scores from 1 (strongest evidence) to 4 (weakest evidence). Most of the studies had a weak strength of evidence rating, with 37 of the 74 studies receiving a score of 4. A total of 22 studies had a moderate rating, 11 each for 3A and 3B. Only eight studies received a strong rating, with one study scoring of 2A and seven studies scoring 2B.

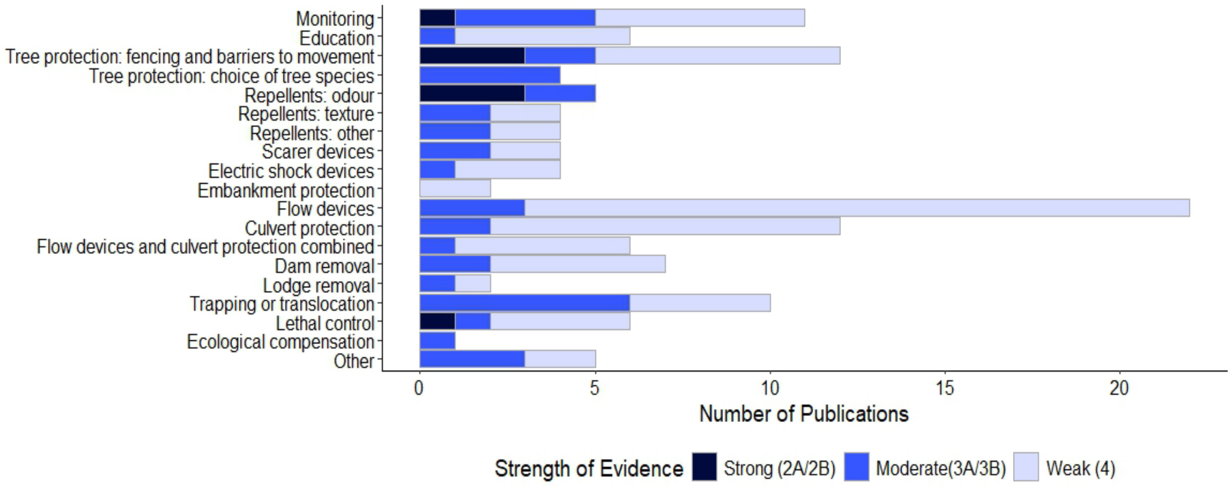

Figure 4: Bar chart showing the distribution of evidence according to strength of evidence rating; 1 represents the strongest evidence and 4 represents the weakest evidence.

Strength of evidence scores are summarised for different management and mitigation options in Figure 5. Studies investigating repellents, tree protection, and monitoring had the strongest evidence. Studies reporting on the remaining interventions generally had a moderate–weak strength of evidence ratings.

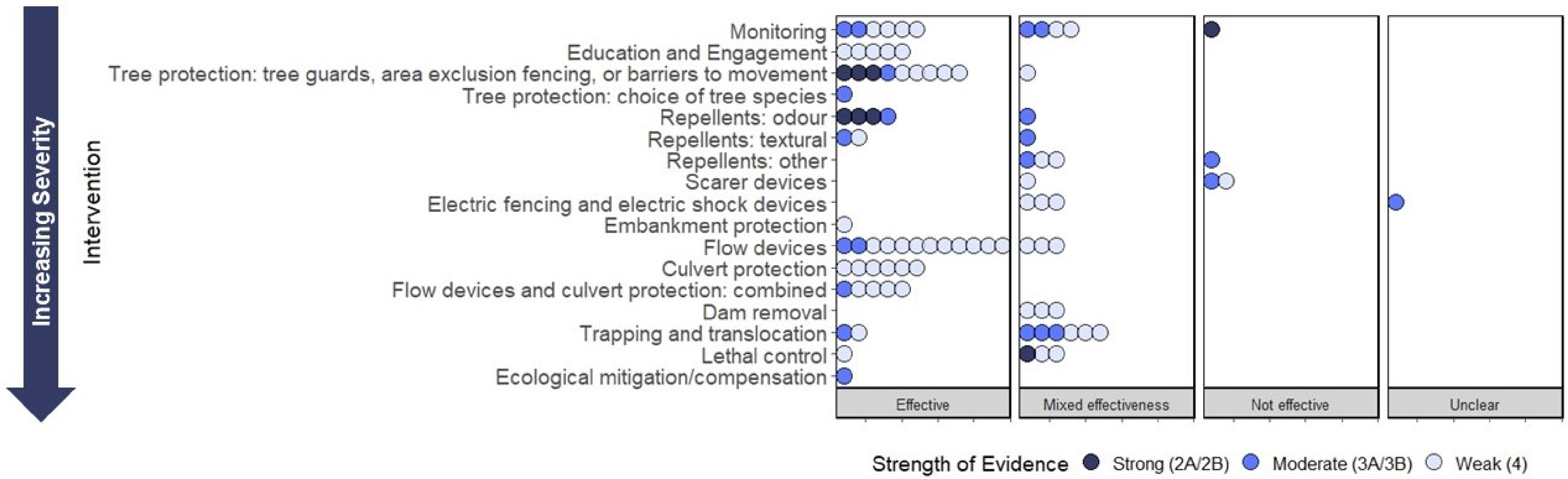

Figure 5: Dot plot showing the amount of evidence, strength of evidence, and direction of the evidence for each intervention; studies with results which could not be categorised by efficacy are not included.

Summary of data

The following sections summarise the effectiveness and cost of interventions for managing beavers. It includes both quantitative and qualitative measures.

Not all publications provided full cost details, so this report presents costs in as much detail as the original studies allow. All costs have been converted to 2023 GBP to enable meaningful comparison between studies. Costs in other currencies were converted using gov.uk currency exchange rates for the relevant year. Once the costs were in GBP, they were then inflated to 2023 GBP using inflation rates provided on gov.uk.

Monitoring

Section summary

- Eleven studies were found on monitoring.
- Evidence on transmitters was moderate strength, but evidence on other monitoring techniques was weak.
- Field surveys (foot and canoe), GIS-based monitoring, and remote sensing (e.g., aerial surveys) allowed successful identification of beaver distribution, beaver territory location, and potential management issues.
- However, field surveys are time intensive and remote-sensing imagery had difficulty determining whether lodges were occupied or abandoned.
- Camera trapping can be used to track beaver activity, but it had limited success in published studies.
- Thermal imaging was only successful at identifying active beaver lodges under a niche set of conditions.
- Tail-mounted transmitters had poor retention rates and caused negative impacts on beavers' health.

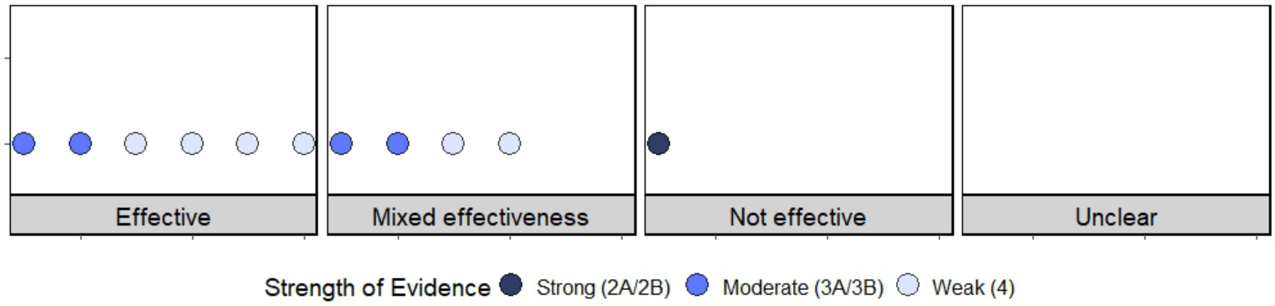

Figure 6: Dot plot showing the amount of evidence, strength of evidence, and direction of the evidence found on monitoring; studies with results which could not be categorised by efficacy are not included.

Experimental evidence

The evidence review identified two experimental studies that reported on monitoring of beavers (18, 19).

Windels and Belant (2016) conducted an experimental study between 2006 and 2014 that examined the performance of tail-mounted transmitters attached to North American beavers in Minnesota, USA (number of sites was unclear) (18). Researchers attached 63 modified ear tag transmitters with a mortality sensor to the tails of 58 adult beavers (five beavers lost their transmitter and had a second attached). The transmitters had a maximum battery life of two years. Retention of tail-mounted transmitters by beavers was low: only 7% of beavers retained transmitters for more than a year. Transmitter retention was not influenced by body mass, tail size, sex, or season attached (all $p>0.05$). 24 beavers without a transmitter were re-captured, allowing the researchers to diagnose the cause of transmitter loss. 63% of transmitters were torn out through the side of the tail, 25% of transmitters became unscrewed, and 13% of transmitters were pulled out through the widening of the attachment hole. Wounds caused by loss of the transmitter healed within a few months. On average, beavers with transmitters lost body mass and tail thickness in the winter but similar proportions were regained in the summer, suggesting weight changes were due to environmental conditions not transmitters [Strength of evidence 2B].

Smith and others (2016) conducted an experimental study between 2006 and 2014 that examined whether transmitters affect the survival or condition of North American beavers at two lake sites in Minnesota, USA (19). Beavers were trapped. If beavers weren't already tagged, researchers attached a self-piercing Monel no.3 tag to each ear. From autumn 2006 to spring 2007, beavers aged 2.5 years or older received tail-mounted modified cattle-ear-tag transmitters. Following poor retention of these transmitters, from autumn 2007 to autumn 2008, beavers aged 2.5 years or older received an internal transmitter. The total number of beavers captured and equipped with transmitters was unclear. In summer, there was no difference in condition of beavers based on transmitter attachment or type. In winter, beavers equipped with transmitters showed greater weight loss (t_{22}=-2.033; p=0.054) and reduced tail area (t_{31}=-3.037; p=0.005) than beavers with ear tags only. The overall probability of beavers surviving 12 months with implants or tail-mounted transmitters was 86% (95% CI 0.71, 0.94). The researchers' models indicated there was no difference in survival of beavers according to transmitter type (tail-mounted, implanted, or ear-tag only) [Strength of evidence 3A].

Mixed-method evidence

The evidence review identified one mixed-method study that that reported on monitoring of beavers (20).

Hood and Yarmey (2015) conducted a mixed-method study between May 2014 and August 2015 that examined the efficacy of flow devices at sites dammed by North American beavers in Alberta, Canada (number of sites unclear) (20). As part of the study, the researchers used three orthophotos (0.25 m resolution) from the years 2007, 2009, and 2010 to identify and digitise beaver lodges in the study area. Researchers then conducted a density analysis using Spatial Analyst Tools in ArcGIS, allowing them to identify hotspots of beaver activity and predict where human-beaver conflicts were occurring. Orthophotographs and GIS-based monitoring enabled the effective identification of beaver territories and potential management issues. However, researchers could not identify whether the lodges were occupied or abandoned [Strength of evidence 4].

Observational evidence

The evidence review identified five observational studies that reported on monitoring beavers (21-25).

Mortensen and Rosell (2020) conducted an observational study that used monitoring data from 1997 to 2018 to investigate the impact of long-term repeated capture and handling on Eurasian beavers from one beaver population in Vestfold and Telemark County, Norway (21). The study modelled the effect of explanatory variables (e.g., number of captures, years of monitoring, etc) on body condition, reproduction, and survival of beavers. The number of capturing events, number of years of monitoring, and presence of a monitoring device did not have a significant effect on beavers' tail fat, body size, or survival. Beavers that were captured more often were less likely to reproduce and had smaller litter sizes in the early years of monitoring, but after the third year of monitoring this effect disappeared. Capturing had a significant effect on adult beavers' body mass (effect estimate -0.148; SE 0.044; 95% CI -0.235, -0.062) but not on kit body mass. The number of years of monitoring and presence of a telemetry device did not have a significant effect on body mass of beavers [Strength of evidence 3A].

Zhang and others (2023) conducted an observational study to determine whether multi-source remote sensing data and an advanced fuzzy Analytical Hierarchy Process model could be used to identify North American beaver ponds at two sites in Ontario, Canada (study date[s] were unclear) (23). The model used three sources of data: 1) a digital elevation model, 2) Sentinel 2 multispectral imagery, and 3) RadarSat 2 Polarimetric Synthetic Aperture Radar data. Known locations of beaver dams and manually digitised beaver ponds were used to validate the results from the two 5 km x 5 km plots. The model correctly identified 83% of known beaver dams and 72.5% of known beaver ponds [Strength of evidence 3B].

Campbell-Palmer and others (2021) conducted two observational studies between 2012 and 2019 that developed and tested a standardised field-sign survey method for monitoring Eurasian beavers at two sites: the Tayside catchment and River Wye, UK (22). The studies reported that walking- and canoe-based beaver sign surveys, along with geospatial analysis and expert analysis of the data, allowed the identification of beaver distribution, beaver territory location, and potential management issues during winter [Strength of evidence 4].

Ribic and others (2017) conducted an observational study between 1983 and 2003 that examined the effect of a monitoring and trapping management programme on North American beaver colony density at two sites in Chequamegon-Nicolet National Forest, Wisconsin, USA (24). The researchers reported that monitoring via aerial surveys allowed the identification of beaver colonies and lodges during spring the following year [Strength of evidence 3B].

Januszewicz and others (2018) conducted an observational study between November 2014 and February 2015 that examined the effectiveness of thermal imaging technology for confirming habitat colonisation by Eurasian beaver at 40 sites in Suwalki, north-eastern Poland (25). The study found that thermal imaging could be effective at identifying active beaver lodges, but it had a number of limitations. The researchers reported that thermographic measurement shouldn't be used under the following conditions: absence of snow cover, sunny days, falling snow, temperature above -2°C, and wind speed higher than 4 m/s [Strength of evidence 4].

Cost-benefit analysis

No evidence identified.

Case studies

The review identified one publication that reported case studies on monitoring of beavers (26).

Bos and others (2022) reported on a case study conducted between August and November 2021 where researchers used camera traps to monitor activity of a Eurasian beaver around a railway in Taarlo, Netherlands (26). Between August and November 2021, cameras were placed around the railway tracks and adjacent waterway. Monitoring of the site captured the presence of the beaver on three nights in October 2021. In November, the beaver wasn't captured on camera and there were no signs of fresh tracks on visual inspection (8^{th} and 17^{th} November) [Strength of evidence 4].

Guidance

The review identified two guidance documents that reported on monitoring of beavers (27, 28).

The Beaver Protocol for Utrecht (2023) provides guidance on managing conflicts caused by activity of Eurasian beavers in Utrecht, Netherlands (27). As part of the protocol, authors provide the cost of management options used in the Netherlands. Deploying beaver watchers for 30 hours a year cost £435. Ground radar surveys were conducted to search for bank cavities at a cost of £1,360 to £3,871 per survey. Sonar inspection for bank cavities had a comparable cost of £1,928 to £4,205 per survey [Strength of evidence 4].

NatureScot (2022) reviewed the environmental effects of reintroduction of Eurasian beavers in Scotland (28). As part of the study, NatureScot (2022) provided qualitative comments on the effectiveness of management interventions, including monitoring. The study reported that some cameras were effective at monitoring dam building behaviours or monitoring the familial status of beavers. The study also reported that water level monitors were effective at alerting landowners to changes in water levels in the vicinity of dams. Water level monitors had an annual cost of £162/unit [Strength of evidence 4].

Other study designs

No evidence identified.

Education and stakeholder engagement

Section summary

- Six studies were found on education and stakeholder engagement.
- The strength of evidence was weak.
- Education and stakeholder engagement improves stakeholder knowledge, promotes successful management techniques, and facilitates better communication and more collaborative decision-making.
- Both methods promote peaceful human-beaver coexistence.
- However, both methods are resource intensive and require ongoing commitment.

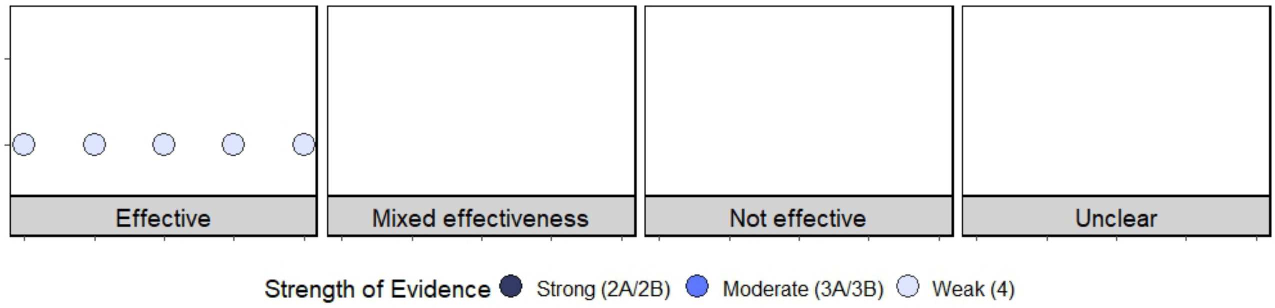

Figure 7: Dot plot showing the amount of evidence, strength of evidence, and direction of the evidence found on education and stakeholder engagement; studies with results which could not be categorised by efficacy are not included.

Experimental evidence

No evidence identified.

Mixed-method evidence

No evidence identified.

Observational evidence

The evidence review identified five observational studies that reported on education and stakeholder engagement as a management technique (29-33).

Morzillo and Needham (2015) conducted an observational study in 2011 that examined landowners' perceptions of methods used to control North American beavers in Oregon, USA (29). Researchers sent out 5,200 questionnaires and received responses from 1,204 landowners. The questionnaires asked respondents to rate the acceptability of different beaver management strategies in response to six different hypothetical beaver impact scenarios. Educating landowners to coexist with beavers was considered an acceptable form of management, regardless of impact scenario (e.g., beavers seen in area, beavers foraging trees, beavers flooding buildings, etc). Landowners who had experienced prior beaver impacts found education significantly less acceptable compared with landowners that hadn't experienced prior beaver impacts ($t=4.59–6.17$; $p<0.001$) [Strength of evidence 3B].

Auster and others (2022) conducted an observational study between January and February 2022 which examined the role of beaver management groups in Eurasian beaver reintroduction at two sites in Devon, England (30). The study conducted interviews with individuals involved with beaver management in the River Tamar catchment and also consolidated findings from a previous study in the River Otter catchment. The study found that successful beaver management groups can facilitate renewed coexistence between humans and beavers. Beaver management groups can facilitate knowledge-sharing, enabling participants to learn how to live alongside beavers, correcting misinformation, and raising public awareness of beavers as a native animal; create a respectful environment for conflict resolution; give stakeholders a voice; build and strengthen relationships between stakeholders; help stakeholders find ways to address key knowledge questions; and empower stakeholders to capitalise on the opportunities presented by beaver reintroduction. To be successful beaver management groups need clearly defined project objectives; committed and transparent leadership; to be adaptive; resources; meaningful stakeholder outreach; inclusive dialogue; diverse stakeholder participation; a pathway for conflict resolution; clear communication; long-term thinking; and to be catchment specific. A significant challenge to the replication of beaver management groups nationally was resource-intensiveness [Strength of evidence 4].

Auster and others (2023) conducted an observational study between January and March 2022 which investigated the role of beaver management groups in Eurasian beaver reintroduction at one site in Devon, England (31). The researchers interviewed 10 members of the River Tamar beaver management group to gather their experiences with the group. Qualitative data suggests that beaver management groups help facilitate renewed coexistence between beavers and humans where groups have adequate resources to be flexible and adapt to catchment specific needs. Beaver management groups can help re-familiarise the population with reintroduced species, but they need to be able to evolve with changing policy and public perception. Groups may be too resource-intensive to be sustainable in the long-term, but they are unlikely to be needed in the long-term because as beavers become normalised, there will be less need for management assistance [Strength of evidence 4].

Auster and others (2021) performed an observational study between January 2018 and December 2019 examining the role of stakeholder engagement in Eurasian beaver reintroduction at one site in Devon, England (32). The researchers interviewed 13 stakeholders of the River Otter Beaver Trial to identify key themes around stakeholder engagement and identify how engagement could be used to improve beaver reintroduction conflict scenarios. The study found that proactive/prompt engagement, appropriate communication, shared decision-making, accountable management authorities, and the provision of certainty to stakeholders increased trust in management authorities, decreased the risk of conflict escalation, and made individuals more likely to respond positively to species reintroduction. This suggests that certain stakeholder engagement can facilitate successful human-beaver coexistence [Strength of evidence 4].

Charnley and others (2020) conducted an observational study between June 2016 and November 2018 to investigate ranchers' perceptions of North American beaver restoration at six sites in California, Oregon, Idaho, and Nevada, USA (33). Researchers interviewed 105 ranchers, most of whom were involved in beaver restoration projects. The study found that most ranchers believed that the benefits of beavers outweighed the costs. Ranchers who believed beavers to be net-beneficial were more likely to support and participate in beaver-related stream restoration. Education and technical and financial assistance for landowners increased their tolerance of beaver-related impacts. Successful beaver restoration required flexible and adaptive stakeholders (policymakers, wildlife managers, landowners) [Strength of evidence 4].

Cost-benefit analysis

No evidence identified.

Case studies

The review identified one publication that reported case studies on education as a management technique (34).

Pollock and others (2018) reported a series of 11 case studies conducted between 1996 and 2015 that examined techniques for managing impacts of North American beavers at 11 sites in six states in the USA (34). As part of one beaver management case study conducted in 2007 in California, education was provided through several channels, including:

- Outreach in the form of talks at town halls and community lectures.
- Education of children through fieldtrips and beaver-related projects.
- Interaction with the media (e.g., radio and TV news).
- Presence at an annual beaver festival.
- Citizen steward projects (e.g., tree planting events).
- Input from the public via letters to city leaders.

The study reported that education was effective but requires an ongoing commitment [Strength of evidence 4].

Guidance

No evidence identified.

Other study designs

No evidence identified

Tree protection: tree guards, area exclusion fencing (non-electric), or barriers to movement

Section summary

- Twelve studies were found on tree guards, exclusion fencing (non-electric), and barriers to movement.
- The strength of evidence was moderate.
- Tree guards and exclusion fencing reduced damage to trees caused by beavers.
- Paths and/or human presence on the paths may deter beavers from crossing and foraging on trees and saplings uphill of the paths, although evidence for this was based on one weak-strength study.

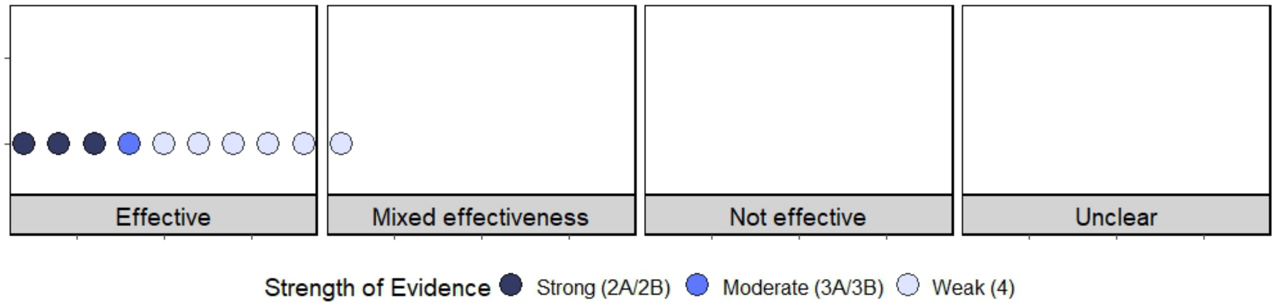

Figure 8: Dot plot showing the amount of evidence, strength of evidence, and direction of the evidence found on tree protection: tree guards, area exclusion fencing, or barriers to movement; studies with results which could not be categorised by efficacy are not included.

Experimental evidence

The evidence review identified five experimental studies that examined tree guards and/or exclusion fencing (35-39). The designs of tree guards and exclusion fencing are reported in Table 3. Three studies examined beavers (35-37) and two studies examined coypu (38, 39).

Runde and others (2008) conducted an experimental study between July 2004 and June 2005 that examined the efficacy of tree guards at preventing damage to Douglas fir seedlings by mountain beavers in Washington State, USA (36). The study was conducted with 13 mountain beavers held in individual pens. The researchers tested 19 different tree guards, which fitted into four categories: tree shelters (open-ended cylindrical, pyramidal, or square tubes), rigid mesh tubes, protection netting, and fabric shelters. Each type of tree guard was installed on three seedlings in each of the 13 pens. Nine seedlings in each pen were left unprotected as a control. After 18 weeks, 97% of unprotected seedlings had been damaged compared with 15% of protected seedlings. The amount of damage sustained by trees significantly differed between the four types of tree guard (x^2_3=168.34; p<0.0001). Tree shelters protected 98% of seedlings. Fabric shelters protected 95% of seedlings. Rigid mesh tubing protected 85% of seedlings. Protection netting protected 65% of seedlings. The purchase price for a single tree guard ranged from £0.07 to £1.74, depending on the design. The average cost was £0.08 for protection netting, £0.42 for rigid mesh tubes, £1.28 for fabric shelters, and £1.57 for tree shelters [Strength of evidence 2B].

Nolte and others (2003) conducted an experimental study that examined the efficacy of five interventions, including exclusion fencing, for the management of North American beavers at four ponds in Arizona, USA (study dates not reported) (35). Exclusion fencing was constructed around the perimeter of six test plots: four terrestrial, containing cottonwood stems and two aquatic, containing aquatic vegetation. Damage to vegetation was recorded weekly for four months and compared to the damage of vegetation in six untreated, control plots. In terrestrial plots, exclusion fencing prevented damage to cottonwood stems, with a mean damage score of 0[4]. Plant cover in the fenced aquatic plot increased over time. However, there was no statistical difference between fenced and unfenced plots for either the terrestrial or the aquatic sites ($p>0.35$) [Strength of evidence 3A].

Kamczyc and others (2016) conducted an experimental study between April 2014 and June 2014 that examined the efficacy of a chain-link fence for preventing damage by Eurasian beavers at one site in Lubuskie Province, Poland (37). The researchers constructed chain-link fences around two forest stands where beavers were causing damage. Fencing was built around the forest stands on three sides, so that the stands had a U-shape of fencing around them. Two forest stands also with beaver activity were left unfenced as a control. In two months, beavers damaged no trees in the fenced stands and 75 trees in the unfenced stands [Strength of evidence 4].

Sheffels and others (2014) conducted an experimental study in 2009 that examined the efficacy of tree guards for management of coypu at one site in Oregon, USA (38). Researchers planted three types of live stakes (black cottonwood [n=55], red osier dogwood [n=69], and willow [n=116]), half of which were protected with Vexar® tubing (n=120) and half were unprotected (n=120). Researchers checked the survival of stakes on days 9, 44, 94, and 100 after planting. The study reported that protected stakes were six times (RR 6.0; 95% CI 4.0, 9.0; $p<0.001$) more likely to survive than the unprotected stakes. All 120 of the protected stakes survived, compared with only 17% of the 120 unprotected stakes [Strength of evidence rating 2B].

Breton and others (2014) conducted an experimental study between 2009 and 2011 that investigated the survival of different lengths of willow and poplar planted with and without exclusion fencing at one river occupied by coypu in north-west France (near Brittany) (39). The researchers planted 40 cm and 80 cm cuttings of six species of willow (*Salix sp.)* and one species of poplar. The cuttings were planted with or without a 0.6 m high plastic mesh

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[4] Damage intensity was scored from 0 to 7 for each stem by visual estimation: 0 = no damage; 1 = tooth marks; 2 = <10% bark removed; 3 = 10–25% bark removed; 4 = 25–75% bark removed or stem gnawed less than 25% through; 5 = 25–75% bark removed or stem gnawed between 25 and 50% through; 6 = >75% bark removed or stem gnawed between 50 and 75% through; 7 = stem gnawed through.

fencing. The authors reported that the cumulative survival rate of tree cuttings was significantly higher for protected cuttings compared with unprotected cuttings (94% vs 84.5%; $p<0.001$). With regards to coypu damage, the researchers found no evidence of browsing on cuttings planted inside the fencing [Strength of evidence rating 2A].

Table 3: Summary of the design of tree protection used in experimental studies.

Study	Type	Dimensions	Materials
Runde and others (2008)	Tree shelters (nine designs)	71.1–91.4 cm x 8.9–12.7 cm (height x diameter)	Seedling protectors with solid walls
	Rigid mesh tubes (four designs)	61.0–91.4 cm x 8.9–12.7 cm (height x diameter)	Open-ended cylinders with firm but bendable walls made of extruded plastic mesh with diamond-shaped openings
	Protection netting (four designs)	30.0–91.4 cm x 5.7–21.0 cm (height x diameter)	Lightweight tubular elastic sleeves designed to protect small conifer seedlings
	Fabric shelters (two designs)	86.4–91.4 cm x 11.4–15.2 cm (height x diameter)	Flexible cylindrical sleeves sewn from limp high-density polyethylene textile to form protection tubes with heavy seams facing outward
Nolte and others (2003)	Exclusion fencing	0.95 m x 4 m x 4 m (high x width x length)	A 0.095 core 9 gauge chain-link with a 5 cm mesh
Kamczyc and others (2016)	Exclusion fencing	0.5 m underground; 1 m x 40 m x 40 m (high x width x length)	Chain link fencing made from steel wire with a 6 cm mesh
Sheffels and others (2014)	Tree guards (Vexar tubing)	1 m x 0.1 m (height x diameter)	Plastic mesh anchored to the ground with a bamboo stake
Breton and others (2014)	Exclusion fencing	0.6 m high	Plastic wire fence

Mixed-method evidence

No evidence identified.

Observational evidence

The evidence review identified five observational studies that examined tree guards, exclusion fencing, and/or barriers to migration (29, 40-43). The designs of tree guards and exclusion fencing are reported in Table 4.

Westbrook and England (2022) conducted an observational study between September 2017 and May 2018 that examined the efficacy of four tree guards used to prevent damage caused by North American Beavers at four sites in Saskatchewan, Canada (41). The researchers surveyed the four sites, noting the type of tree guard in use and the level of damage on trees. The study examined the effectiveness of four types of wire tree guard: Type I, Type II, Type III, and Type IV on 151 trees. 11% of trees with guards were damaged by beavers: 7% had minor cuts and 4% had severe cuts. No trees were fully severed. Type I and type II guards protected more trees than type III and type IV guards, although the trees which were cut with type I and type II guards had more severe cuts than the trees cut with type III and type IV guards. 35% of tree guards were installed in accordance with guidelines. Only 3% of trees protected with guards that met guidelines were cut by beavers, suggesting that tree guards that were correctly installed were more effective [Strength of evidence 4].

NatureScot (2021) conducted an observational study that examined the cost of installing exclusion fencing as part of three Eurasian beaver management projects in Scotland (project dates and exact locations were not reported) (42). The fences were made from equine or high specification weld, but no further details on their design were reported. The study reported that the average cost of exclusion fencing was £27–30/m, including labour. NatureScot also provided costs of installing tree guards. The study estimated that the cost of 25 m weld mesh to protect 10 trees is £101 and that one person could erect five to six tree guards in an hour. The combined cost of materials and labour was not reported [Strength of evidence 4].

Morzillo and Needham (2015) conducted an observational study in 2011 that examined landowners' perceptions of methods used to control North American beavers in Oregon, USA (29). Researchers sent out 5,200 questionnaires in January 2011 and received responses from 1,204 landowners. The questionnaires asked respondents to rate the acceptability of different beaver management strategies in response to six different hypothetical beaver impact scenarios. Landowners considered wrapping trees and installing fences or screens an acceptable strategy for management across all impact scenarios. Landowners who had experienced prior beaver impacts found wrapping trees and installing fences and screens less acceptable compared with landowners that hadn't experienced prior beaver impacts (tree wrapping: $t=1.40–2.78$; $p=0.162–0.006$; fences and screens: $t=1.93–2.79$; $p=0.055–0.006$), suggesting landowners who had experienced beaver impacts wanted more severe management interventions [Strength of evidence 3B].

Willging and Sramek (1989) conducted an observational study that examined residents' attitudes towards methods used to control North American beavers in Texas, USA (survey date not reported) (43). Researchers sent 15-question surveys to residents of one metropolitan area in Texas who had been assisted with beaver problems between 1984 and 1988. The survey obtained information on damage estimates, type of damage, beaver control methods, and perception of beaver control. A total of 87 surveys were sent and 63% were returned; 37 respondents reported that they had used tree wrapping and 10 had used exclusion fencing. Respondents reported that tree wrapping was partially or entirely successfully, and exclusion fencing had mixed success (Figure 9) [Strength of evidence 4].

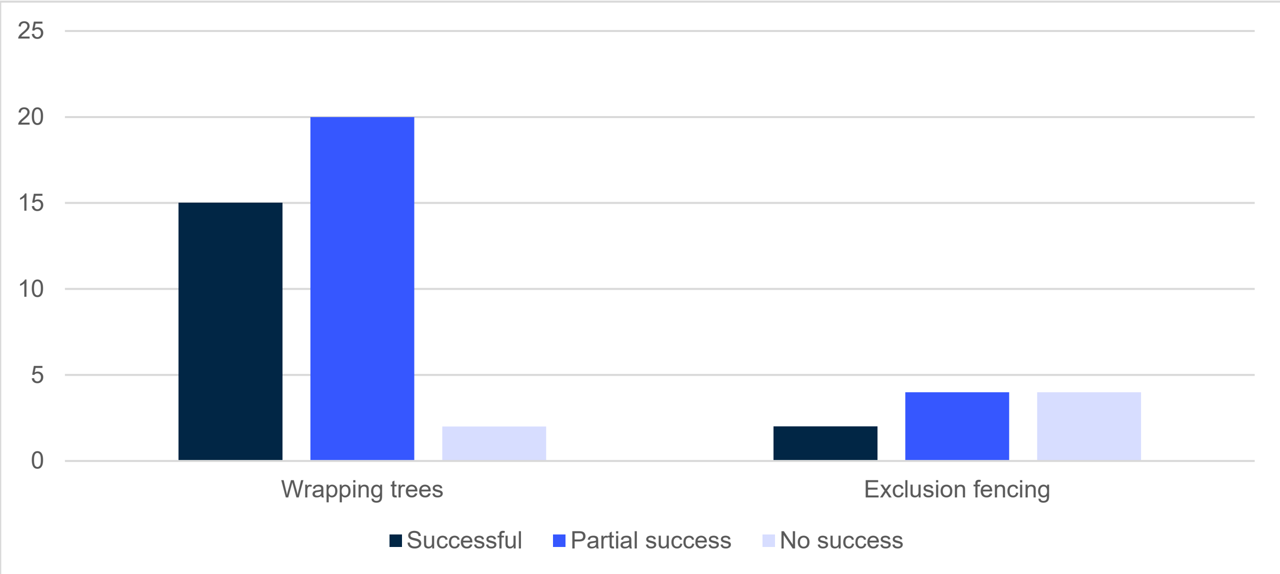

Figure 9: Number of fencing methods that were successful, partially successful, not successful.

Loeb and others (2014) conducted an observational study that examined the effect of human and deer pathways on foraging behaviour of North American beavers at five sites in Tennessee, USA (study date not reported) (40). The study examined damage to trees and saplings at plots uphill and downhill of paths. Damage was measured at five paths: three pathways, used by more than 100 humans/day, and two deer pathways (not used by any humans except park rangers around once/month). Trees and saplings uphill experienced less damage than trees downhill of surveyed paths ($p<0.043$; $p<0.001$), suggesting proximity from the riverside and land gradient limit beaver foraging movement. Trees and saplings on the three paths used heavily by humans experienced less damage than paths rarely used by humans ($p<0.03$; $p<0.015$). This suggests that human presence or odour deters beaver activity [Strength of evidence 4].

Table 4: Summary of the design of tree protection used in observational studies.

Study	Type	Dimensions	Materials
Westbrook and England (2022)	Type I tree guards	Mean guard height 120 cm, mean diameter difference[5] 38 cm	Square wire mesh fencing (50 mm x 50 mm), gauge 16/1.29 mm diameter
	Type II tree guards	Mean guard height 148 cm, mean diameter difference 39 cm	Rectangular wire mesh fencing (100 mm x 150 mm), gauge 14/1.63 mm diameter
	Type III tree guards	Mean guard height 90 cm, mean diameter difference 12 cm	Chain-link fence with diamond mesh (50 mm x 50 mm), gauge 6/4.12 mm diameter
	Type IV tree guards	Mean guard height 67 cm, mean diameter difference 1.0 cm	Wire poultry netting with hexagonal mesh (25 mm), gauge 20/0.81 mm diameter
NatureScot (2021)	Tree guards and exclusion fencing	NR	Equine or high specification weld exclusion fencing

[5] Diameter difference measures the difference between the diameter of trees and tree guards.

Study	Type	Dimensions	Materials
Morzillo and Needham (2015)	Tree guards and exclusion fencing	NR	NR
Willging and Sramek (1989)	Tree guards and exclusion fencing	NR	NR
Loeb and others (2014)	Human pathways	1.5 m – 7.5 m wide	Wood chip, wood, or macadam
	Deer pathways	10 cm wide	Bare earth

Cost-benefit analysis

No evidence identified.

Case studies

The evidence review identified one publication that reported case studies on tree protection (34).

Pollock and others (2018) reported a series of 11 case studies conducted between 1996 and 2015 that examined techniques for mitigating impacts of North American beavers at 11 sites in six states in the USA (34). As part of one case study conducted in California, tree guards were used in 2007 to manage beaver damage to urban trees, although it was unclear what design was used. The case study reported that tree guards prevented beaver-related tree damage and were relatively inexpensive. The study reported that the total cost of installing tree guards and tree paint was £221, but the number of trees involved was unclear [Strength of evidence 4].

Guidance

The evidence review identified one study that provided guidance on tree protection (28).

NatureScot (2022) reviewed the environmental effects of reintroduction of Eurasian beavers in Scotland (28). As part of the study, NatureScot (2022) provided qualitative comments on the effectiveness of management interventions, including tree guards and exclusion fencing. The study reported that tree guards and exclusion fencing were generally effective, although the effectiveness of deterrent fencing for protecting crops was yet to be determined. The study also reported that in-stream fencing was not straightforward, owing to the requirement to exclude beavers while allowing migration of fish, and may require statutory consents, flood risk assessment and a maintenance plan [Strength of evidence 4].

Other study designs

No evidence identified.

Tree protection: choice of tree species

Section summary

- Four studies were found on beavers' choice of tree species.
- The strength of evidence was moderate.
- Beavers exhibited clear preferences towards certain tree species.
- Providing beavers with a buffer of palatable trees (e.g., willow) close to the edge of waterways may be able to prevent damage to commercially or biologically important tree species deeper in the woodland.

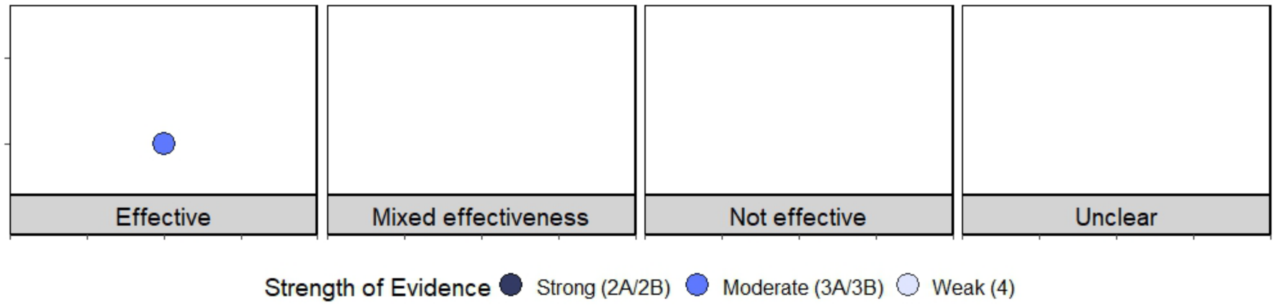

Figure 10: Dot plot showing the amount of evidence, strength of evidence, and direction of the evidence found on tree protection: choice of tree species; studies with results which could not be categorised by efficacy are not included.

Experimental evidence

The evidence review identified two experimental studies that examined beavers' preference for different tree species (44, 45).

DuBow (2000; chapter 3) conducted an experimental study that examined the efficacy of seven repellents on consumption of pacific willow (*Salix lucida),* western hemlock (*Tsuga heterophylla),* red alder (*Alnus rubra*), and cascara by North American beavers at one site in Washington State, USA (study date not reported) (45). As part of the study, DuBow (2000) conducted two two-choice, pen experiments (experiment four) with eight beavers to compare the palatability of 1) willow and alder and 2) willow and cascara. Researchers first conducted the experiment comparing willow and alder and they subsequently conducted the experiment comparing willow and cascara. The experiments used 18 cuttings of each tree species per pen (N=8 pens) presented in random order in racks to beavers daily for four days. The study found that willow was foraged significantly less than cascara (F_1=11.061; p=0.0126), but there was no significant difference between willow and alder (F_1=0.126; p>0.5) [Strength of evidence 3A].

DuBow (2000; chapter 4) conducted an experimental study between March and June 1999 that examined whether herbivore repellent reduced damage to willow and cascara by North American beavers at 17 active beaver colonies in Washington State, USA (44). As part of the study, researchers compared beavers' preference for untreated willow and cascara. At each of the 17 sites, researchers planted 24 cascara cuttings and 24 willow cuttings (height ≥75 cm) in 12 rows perpendicular to the water's edge. Half of the trees (12 of each species at each site) were treated with herbivore repellent and the other half were left untreated. Trees were monitored for 74 days after planting. Beavers foraged untreated willow significantly more often than untreated or treated cascara (F_1=7.6; p=0.03) [Strength of evidence 3A].

Mixed-method evidence

The evidence review identified one mixed-method study that examined beavers' preference for different tree species (46).

Müller-Schwarze and others (1994) conducted a mixed-method study between 1984 and 1993 that examined North American beavers' preference for different tree species in New York State, USA (number of sites was unclear) (46). In the first phase of the study, the researchers observed the number of intact trees and the number of tree stumps for 15 tree species at three sites in December 1984 and four sites in February 1985. Researchers reported that red maple was one of the least preferred species (ranking of other species was not provided). The second phase of the study involved a series of experiments conducted between March 1985 and July 1985 that tested beavers' preference for untreated logs at 20 beaver ponds at two sites. Sticks from red maple, quaking aspen, and sugar maple trees were cut to 20 cm long and placed at 10 beaver ponds at site one and 10 beaver ponds at site two (yellow birch sticks were also used at site two). Red maple logs were consumed significantly less by beavers compared with sugar maple and quaking aspen at site one (Q_6=45.9; p<0.001) and site two (Q_6=21.68; p<0.01). The researchers also tested beavers' preference for untreated trees compared with trees treated with repellents. The results are reported in section *Repellents: other* [Strength of evidence 3A].

Observational evidence

The evidence review identified one observational study that examined beavers' preference for different tree species (47).

Mikulka and others (2022) conducted an observational study in 2017 that assessed preferences of Eurasian beavers for different tree species and whether buffers could be used to reduce damage to commercial hardwood forests at two sites in the Czech Republic (47). Site one was a commercial forest focused on producing oak and ash. Site two was a nature reserve and had a broad species diversity. Researchers measured beavers' feeding preferences at pre-identified feeding hotspots along the riverside; 24 in site one and 26 in site two. The plots were 5 m x 20 m. The researchers then used a general linear model to test if a buffer of softwoods could be used to reduce damage to commercial hardwoods.

The study reported that the probability of hardwood damage (e.g., oak) was lower at stands with higher proportion of softwoods (e.g., willow) and light hardwoods (e.g., hazel and alder). The distance beavers foraged for food was 7.64 m shorter on plots with a buffer willow and/or poplar compared with plots without these species. These results suggest that softwoods highly palatable to beavers, like willow, limit beaver penetration into woodland and may be used as a buffer between beavers and hardwood plantations. [Strength of evidence 3B].

Cost-benefit analysis

No evidence identified.

Case studies

No evidence identified.

Guidance

No evidence identified.

Other study designs

No evidence identified.

Repellents: odour

Section summary

- Five studies were found on odour repellents.
- The strength of evidence was moderate.
- Odour repellents, including predator odours, Big Game Repellent, and beaver odours, reduced damage to trees caused by beavers.

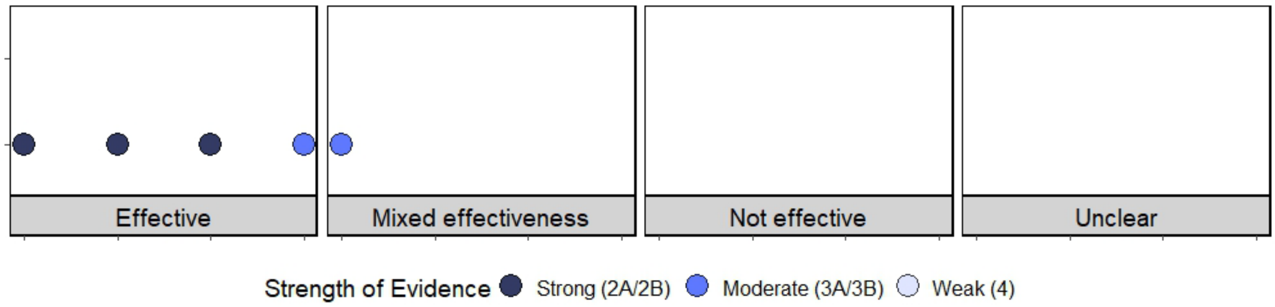

Figure 11: Dot plot showing the amount of evidence, strength of evidence, and direction of the evidence found on repellents: odour; studies with results which could not be categorised by efficacy are not included.

Experimental evidence

The evidence review identified five experimental studies that examined odour repellents (44, 45, 48-50).

Rosell and Czech (2000) conducted an experimental study in 1997 that tested the effect of applying predator odours to aspen sticks on the foraging behaviour of Eurasian beavers at 100 beaver colonies in Suwalki Lakeland, northeastern Poland (48). Predator odours were taken from the excrement of six animals (red fox *Vulpes vulpes*, river otter *Lutra canadensis*, lynx *Lynx lynx*, wolf *Canis lupus lupus*, brown bear *Ursus* arctos arctos, and dog *Canis familiaris*) and human sweat, mixed with methanol, and then applied to perforated aspen sticks. There were three control groups: perforated sticks soaked in methanol; perforated but unsoaked sticks; and unperforated and unsoaked sticks. Experimental and control sticks were placed in rows of 10 randomly sequenced sticks at 10 randomly selected beaver colonies for 10 trials. Odour treatment caused a significant decrease in the number of sticks eaten (X^2=257.6, p<0.0001). River otter odour caused the largest decrease, but sticks treated with red fox, lynx, wolf, brown bear, and human odour were also effective [Strength of evidence 2B].

Engelhart and Müller-Schwarze (1995) conducted an experimental study in 1993 that examined the effect of applying predator odours to aspen sticks on the foraging behaviour of North American beavers at 184 beaver colonies at two sites in New York state, USA (49). Researchers used seven predator odours (lynx, coyote *Cants latrons*, lion *Panthera leo,* river otter, black bear *Ursus americanus*, dog, and wolf), two non-predator odours (neem seed extract and diesel oil), and three control groups (same as Rosell and Czech

[2000]). Experimental and control sticks were placed in rows of 12 randomly sequenced sticks at 10 randomly selected beaver colonies for five trials in summer and eight trials in autumn in site one, and six trials in summer in site two. Engelhart and Muller-Schwarze (1995) found that in both sites, beavers preferentially consumed the control aspen sticks. At both sites, treating sticks with predator odour significantly reduced consumption. Beavers consumed sticks treated with river otter, coyote, and lynx the least [Strength of evidence 2B].

DuBow (2000; chapter 4) conducted an experimental study between March and June 1999 that examined whether Big Game Repellent Powder could reduce damage to willow and cascara caused by North American beavers at 17 active beaver sites in Washington State, USA (44). At each of the 17 sites, researchers planted 24 cascara cuttings and 24 willow cuttings (height ≥75 cm) in 12 rows perpendicular to the water's edge. Big Game Repellent is a sulphur-based substance and has an aversive odour to beavers. Half of the trees (12 of each species at each site) were treated with Big Game Repellent powder and the other half were left untreated. Trees were monitored for 74 days after planting. Treatment with Repellent Powder had a moderate but non-significant effect on willow and cascara damage (F_1=2.2; df=1; p=0.19). The researchers reported preference of cuttings based on mean utilisation by beavers as follows: willow > treated willow > cascara = treated cascara [Strength of evidence 3A].

DuBow (2000; chapter 3) conducted experimental studies that examined the efficacy of seven repellents on consumption of pacific willow, western hemlock, red alder, and cascara by North American beavers at one site in Washington State, USA (study date not reported) (45). The efficacy of the repellents was tested in five pen experiments that used 10 captive beavers.

- The first experiment tested seven chemical repellents acting through different mechanisms (odour, taste, and post-ingestive malaise) on the consumption of willow sticks. The authors found a significant difference in willow consumption between the seven treatments and control (F_7=5.222; p=0.0002). Pairwise comparisons showed that willow seedlings treated with Big Game Repellent Liquid and Plantskydd were foraged significantly less than control (untreated willow) (p<0.05).
- The second experiment then compared the efficacy of Big Game Repellent Powder and Plantskydd and showed that willow cuttings treated with Big Game Repellent Powder were foraged significantly less than those treated with Plantskydd (F_1=6.056; p=0.0380).
- Experiment three tested whether Big Game Repellent Powder could reduce the palatability of western hemlock. Treated western hemlock cuttings were consumed less than untreated western hemlock (F_1=6.291; p=0.0322).
- Experiment four was a choice experiment comparing the palatability of willow, alder, and cascara. The results of this experiment are discussed in Section *Tree protection: choice of tree species*).

- The final experiment tested the effect of Big Game Repellent Powder on palatability of willow and cascara through a series of two-day, two-choice tests, with the beavers receiving the different treatment combinations in random order. The researchers reported preference as: untreated willow > treated willow > untreated cascara > treated cascara [Strength of evidence 3A].

Welsh and Müller-Schwarze (1989) conducted an experimental study during 1983 and 1984 that examined whether North American beavers avoided artificially scented vacant beaver colonies at 96 sites in New York State, USA (50). The researchers constructed mounds at 47 experimental sites and scented them with homogenised castor sacs and anal glands from adult beavers. The study also included a group of 49 control sites with non-scented mounds. In total, 4% of scented sites and 16% of unscented control sites were colonised by beavers ($G_1=3.998$; $p<0.05$) [Strength of evidence 2B].

Mixed-method evidence

No evidence identified.

Observational evidence

No evidence identified.

Cost-benefit analysis

No evidence identified.

Case studies

No evidence identified.

Guidance

No evidence identified.

Other study designs

No evidence identified.

Repellents: textural

Section summary

- Four studies were identified on textural repellents.
- The strength of evidence was moderate-weak.
- Textural repellents (sand and paint mixture) can reduce foraging on trees by beavers, but toxicity of these repellents was a concern.

Figure 12: Dot plot showing the amount of evidence, strength of evidence, and direction of the evidence found on repellents: textural; studies with results which could not be categorised by efficacy are not included.

Experimental evidence

The evidence review identified two experimental studies that examined textural repellents (35, 51).

Nolte and others (2003) conducted an experimental study that examined the efficacy of five interventions, including textural repellent, for the management of North American beavers at four ponds in Arizona, USA (study dates not reported) (35). Textural repellent, consisting of sand and alkyd paint (140 g/L), was painted evenly on cottonwood stems in four test plots. Damage to the cottonwood stems was recorded weekly for four months relative to the damage of cottonwood stems in four untreated, control plots. Tree paint reduced damage to cottonwood stems, with a mean damage score of 0.89 for protected trees compared with 1.95 for control [Strength of evidence 3A][6].

The Miistakis Institute conducted an experimental study between September and December 2020 that examined the effect of a textural repellent on tree damage caused by North American beavers at one site in Alberta, Canada (51). For the experiment, park staff selected two 10 m x 10 m plots for treatment and two plots for control. In the treated plots,

[6] Damage intensity was scored from 0 to 7 for each stem by visual estimation: 0 = no damage; 1 = tooth marks; 2 = <10% bark removed; 3 = 10–25% bark removed; 4 = 25–75% bark removed or stem gnawed less than 25% through; 5 = 25–75% bark removed or stem gnawed between 25 and 50% through; 6 = >75% bark removed or stem gnawed between 50 and 75% through; 7 = stem gnawed through.

a sand and paint mix (140 g/L) was applied 1.2 m up the trunk to all saplings over 1.8 m tall. Baseline data were taken on the day of treatment (28 September 2020) and follow up data were taken in December 2020. Beavers consumed more trees at the control sites, with the number of new tree stumps increasing by 88.5% at the control sites compared with 15.5% in the treated plots. However, the researchers reported the results of toxicity testing, showing that beavers consuming the bark of three painted trees would reach a lethal dose (LD50) of titanium dioxide[7] [Strength of Evidence 3B].

Mixed-method evidence

No evidence identified.

Observational evidence

The evidence review identified one observational study that examined textural repellents (42).

NatureScot (2021) conducted an observational study that examined the cost of installing tree paint as part of three Eurasian beaver management projects in Scotland (project dates and exact locations were not reported) (42). The study did not provide details on the design or application of tree paint. The study estimated that the cost to protect two trees with tree paint is £135 (only including the cost of paint) and that one person could paint two trees in an hour [Strength of evidence 4].

Cost-benefit analysis

No evidence identified.

Case studies

The evidence review identified one publication that reported case studies on textural repellents (34).

Pollock and others (2018) reported a series of 11 case studies conducted between 1996 and 2015 that examined management interventions for mitigating impacts of North American beavers at 11 sites in six states in the USA (34). As part of one case study conducted in Martinez, California, tree paint was applied in 2007 to manage damage to urban trees. The researchers reported that tree paint was effective and relatively inexpensive, although repeated application is required [Strength of evidence 4].

Guidance

No evidence identified.

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[7] Assuming that it takes 2 gallons of paint to paint 167 trees or approximately 0.01 gallon of paint per tree.

Other study designs

No evidence identified.

Repellents: other

Section summary

- Four studies involving other types of repellents were identified.
- The strength of evidence was moderate-weak.
- Aversive conditioning reduced consumption of corn by beavers, but the beavers generalised the aversion to other foods, too.
- Painting or soaking aspen with maple extract had a limited effect on the palatability of aspen – it did not appear a good deterrent.
- Landowners reported that repellents were generally unsuccessful or only partially successful.
- Experts reported repellents as ineffective at preventing beavers from blocking culverts, but they may be used to protect riparian areas.

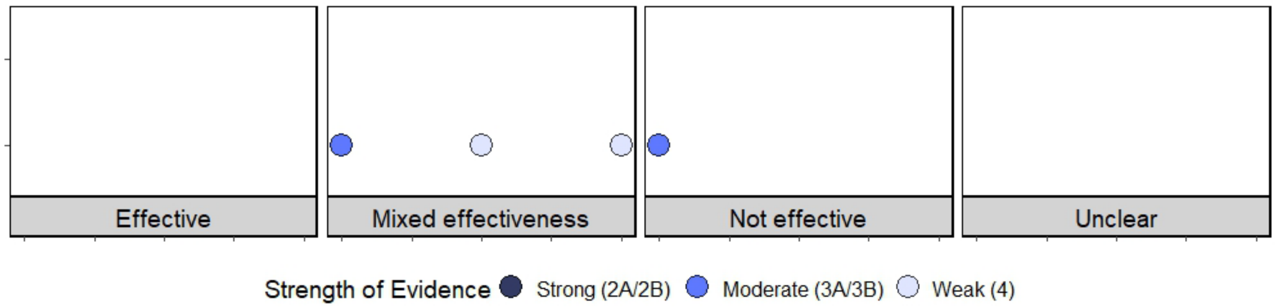

Figure 13: Dot plot showing the amount of evidence, strength of evidence, and direction of the evidence found on repellents: other; studies with results which could not be categorised by efficacy are not included.

Experimental evidence

The review identified one experimental study that examined repellents (other than those that focus on predator/beaver odours or textural repellents) (52).

Harper (2005) conducted an experimental study in November 2005 that investigated whether aversive conditioning could reduce North American beaver foraging at one field station in Washington State, USA (52). The researchers injected beavers with lithium chloride, which induced post-ingestive malaise, after eating corn to see if the association between corn and sickness would train beavers to avoid corn. The quantity of corn eaten by the beavers was then compared to a control group, who had been injected with a placebo. The experiment was performed on 17 beavers total (treatment: control group split unclear). Averse conditioning significantly reduced the consumption of corn by beavers ($p<0.001$). However, beavers generalised this aversion to other foods in their diet, meaning that the effects of aversive conditioning weren't targeted at specific foods and could potentially cause beavers to undereat in general. The researchers also suggested that in the long-term, beavers may also resample foods and resume consumption, meaning that the effects of aversive conditioning are likely to be short-lived [Strength of evidence 3A].

Mixed-method evidence

The evidence review identified one mixed-method study that examined repellents (46).

Müller-Schwarze and others (1994) conducted a mixed-method study between 1984 and 1993 that examined the effect of painting trees with red maple extract on foraging behaviour of North American beavers in New York State, USA (total number of sites was unclear) (46). The study involved a series of experiments whereby the researchers tested beavers' preference to differentially treated logs (Figure 14). Treating aspen logs with red maple extract had mixed results. When all types of red maple extract treated logs were compared with all aspen controls, the authors reported red maple treated logs were consumed significantly less. Other statistically significant results were reported; however, the authors did not provide a robust rationale for grouping the treatment and control groups in this way, so this result provides weak evidence that red maple extract had an effect. Taking red maple extract from different parts of the maple tree did not affect the palatability of painted aspen. The researchers also tested beavers' preference for different tree species. The results are reported in section *Choice of Tree Species* [Strength of evidence 3A].

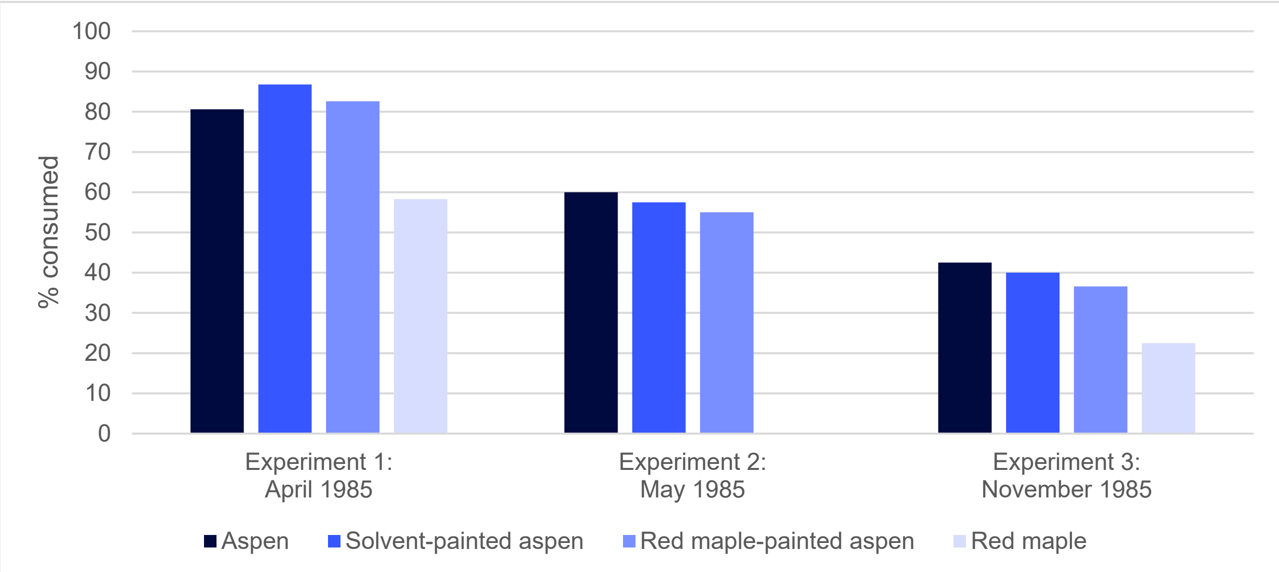

Figure 14: Consumption of painted and unpainted logs at Allegany State Park, USA.

Observational evidence

The review identified one observational study that examined repellents (other than those that focus on predator/beaver odours or textural repellents) (43).

Willging and Sramek (1989) conducted an observational study that examined residents' attitudes towards methods used to control North American beavers in one area in Texas, USA (survey date not reported) (43). Researchers sent 15-question surveys to residents of one metropolitan area in Texas who had been assisted with beaver problems between 1984 and 1988. The survey obtained information on damage estimates, type of damage, beaver control methods, and the perception of beaver control. A total of 87 surveys were sent and 63% were returned; nine respondents reported that they had used repellents. Four of the nine respondents that used repellents indicated that the method was partially successful, and the remaining five respondents reported that repellents were not successful [Strength of evidence 4].

Cost-benefit analysis

No evidence identified.

Case studies

No evidence identified.

Guidance

The review identified one guidance study that reported on repellents (53).

Nolte and others (2005) provided guidance on how to prevent North American beavers from blocking culverts (location unspecified) (53). The guidance was based on expert experience, and no empirical data were reported but they provided some comments on the efficacy of repellents. The document reported that repellents are not effective at preventing beavers from blocking culverts; however, they may be used to protect riparian areas. The study also noted that commercial repellents can be used to protect willow or cottonwood seedlings, but they were ineffective at protecting larger trees. Experts reported that a grit-paint mixture (ingredients unspecified) was more effective than standard repellents [Strength of evidence 4].

Other study designs

No evidence identified.

Scarer devices

Section summary

- Four studies were found on scarer devices.
- The strength of evidence was moderate-weak.
- Scarer devices did not prevent beavers from foraging.
- Experts reported that scarer devices were generally ineffective after a few days, although electric fencing with dangling electric loops may be effective for longer.
- In general, landowners considered scaring device an unacceptable management method for management.

Figure 15: Dot plot showing the amount of evidence, strength of evidence, and direction of the evidence found on scarer devices; studies with results which could not be categorised by efficacy are not included.

Experimental evidence

The evidence review identified one experimental study that examined scarer devices (35).

Nolte and others (2003) conducted an experimental study that examined the efficacy of five interventions, including scarer devices, for the management of North American beavers at four ponds in Arizona, USA (study dates not reported) (35). A CritterGritter (a motion-activated device that emits light and sound) was attached to a post at the centre of six test plots: four terrestrial, containing cottonwood stems and two aquatic, containing aquatic vegetation. Damage to vegetation was recorded weekly for four months and compared to the damage of vegetation in six untreated, control plots. On terrestrial plots, scarer devices did not reduce mean damage to cottonwood stems compared with control (mean damage score[8]: 2.39 vs 1.95). Aquatic plant cover increased over time, but there was no significant difference between the four aquatic treatments ($p>0.35$). The researchers suggest scaring devices may be effective in the very short term before beavers get used to them [Strength of evidence 3A].

[8] Damage intensity was scored from 0 to 7 for each stem by visual estimation: 0 = no damage; 1 = tooth marks; 2 = <10% bark removed; 3 = 10–25% bark removed; 4 = 25–75% bark removed or stem gnawed less than 25% through; 5 = 25–75% bark removed or stem gnawed between 25 and 50% through; 6 = >75% bark removed or stem gnawed between 50 and 75% through; 7 = stem gnawed through.

Mixed-method evidence

No evidence identified.

Observational evidence

The evidence review identified two observational studies that examined scarer devices (29, 43).

Morzillo and Needham (2015) conducted an observational study in 2011 that examined landowners' perceptions of methods used to control North American beavers in Oregon, USA (29). Researchers sent out 5,200 questionnaires in January 2011 and received responses from 1,204 landowners. The questionnaires asked respondents to rate the acceptability of different beaver management strategies in response to six different hypothetical beaver impact scenarios. Frightening beavers was considered unacceptable, regardless of scenario (e.g., beavers seen in area, beavers foraging trees, beavers flooding buildings, etc). Landowners who had experienced prior beaver impacts found frightening beavers significantly more acceptable compared with landowners that hadn't experienced prior beaver impacts ($t=3.47–4.24$; $p<0.001$) [Strength of evidence 3B].

Willging and Sramek (1989) conducted an observational study that examined residents' attitudes towards methods used to control North American beavers at one area in Texas, USA (survey date not reported) (43). Researchers sent a 15-question surveys to residents of one metropolitan area in Texas who had been assisted with beaver problems between 1984 and 1988. The survey obtained information on damage estimates, type of damage, beaver control methods, and perception of beaver control. A total of 87 surveys were sent and 63% were returned; eight respondents reported that they used a light/noise deterrent. Three of the eight respondents that used light/noise deterrents reported that the method was partially successful, and the remaining five respondents reported that light/noise deterrents were not successful [Strength of evidence 4].

Cost-benefit analysis

No evidence identified.

Case studies

No evidence identified.

Guidance

The evidence review identified one guidance study that reported on scarer devices (53).

Nolte and others (2005) provided guidance on how to prevent North American beavers from blocking culverts (location unspecified) (53). The guidance was based on expert experience, and no empirical data were reported. The study reported that most methods do not work for more than a few days, but an electric fence with dangling electric loops may be effective longer term [Strength of evidence 4].

Other study designs

No evidence identified.

Electric fencing and electric shock devices

Section summary

- Four studies were found on electric fencing and electric shock devices.
- The strength of evidence was weak.
- Electric fencing can sometimes repel beaver activity, but it harms beavers and other wildlife, and it is high maintenance.

Figure 16: Dot plot showing the amount of evidence, strength of evidence, and direction of the evidence found on electric fencing and electric shock devices; studies with results which could not be categorised by efficacy are not included.

Experimental evidence

The evidence review identified one experimental study that examined electric shock devices (35).

Nolte and others (2003) conducted an experimental study that examined the efficacy of five interventions, including electric fencing, for the management of North American beavers at four ponds in Arizona, USA (study dates not reported) (35). The researchers placed an electro-shock device at the centre of two aquatic test plots containing aquatic vegetation. Damage to vegetation was recorded weekly for four months and compared to the damage of vegetation in two control plots. Aquatic plant cover increased over time, but there was no statistical difference between the four aquatic treatments ($p>0.35$) [Strength of evidence 3A].

Mixed-method evidence

No evidence identified.

Observational evidence

The evidence review identified one observational study that examined electric shock devices (43).

Willging and Sramek (1989) conducted an observational study that examined residents' attitudes towards methods used to control North American beavers at one area in Texas, USA (survey date not reported) (43). Researchers sent a 15-question surveys to residents of one metropolitan area in Texas who had been assisted with beaver problems between 1984 and 1988. The survey obtained information on damage estimates, type of damage, beaver control methods, and perception of beaver control. A total of 87 surveys were sent and 63% were returned; two respondents reported that they had used electric fencing. One respondent reported that electric fencing was a success and the other reported that it was not a success [Strength of evidence 4].

Cost-benefit analysis

No evidence identified.

Case studies

No evidence identified.

Guidance

The review identified one guidance document that reported on electric shock devices (54).

Angst (2022) provided guidance on managing impacts of Eurasian beavers at sites with railroad infrastructure in Switzerland (54). As part of the guidance, Angst (2022) estimated the cost of individual management measures. The material cost of installing an electric wire over a beaver dam following dam notching was £180–270. This method requires daily checks as floating material can disable the electric device [Strength of evidence 4].

Other study designs

The evidence review identified one review that reported on electric shock devices (55).

Campbell-Palmer and Pizzi (2025) conducted a review on the use of electric fencing for management of beavers (target species and geographical focus not reported) (55). The review did not report any empirical data. However, based on expert opinion and anecdotal evidence, it suggested that electric fencing is harmful to beavers and non-target species, such as frogs, toads, common lizards, water voles and hedgehogs. No conclusive comments were made about whether electric fencing was effective at deterring beaver activity. Electric fencing requires daily maintenance. Overall, the authors conclude that electric fencing is not recommended [Strength of evidence 4].

Embankment protection

Section summary

- Two studies were found on embankment protection.
- The strength of evidence was weak.
- There is too limited evidence to make definitive conclusions, but initial evidence suggests that steel mats can prevent embankments from being damaged by beaver activity.

Figure 17: Dot plot showing the amount of evidence, strength of evidence, and direction of the evidence found on embankment protection; studies with results which could not be categorised by efficacy are not included.

Experimental evidence

No evidence identified.

Mixed-method evidence

No evidence identified.

Observational evidence

No evidence identified.

Cost-benefit analysis

No evidence identified.

Case studies

The evidence review identified one publication that reported case studies embankment protection (56).

Mandavkar and others (2017) reported three case studies conducted between 2003 and 2013 that examined techniques to protect embankments from burrowing animals, including Eurasian beavers, at three sites in Italy, Austria, and Germany (56). The case studies trialled the use of steel mesh with and without geomat protection. In case study one, steel mesh, with and without extruded geomat, was installed in 2003 along a canal in Rovigo Province, Italy. Surveys were conducted at baseline and during a follow-up in 2013. It found that steel mesh, with or without geomat, protected against burrowing rodents. However, steel mesh with geomat was more effective than steel mesh alone, which showed some evidence of soil erosion. In case study two, a double twisted steel mesh (300,000 m^2) was installed between 2008 and 2013 along a riverbank on the River March, Austria. A second section of the bank that wasn't protected with steel mesh was used as control. The case study reported that banks protected with steel mesh experienced less damage than unprotected banks. In case study three, beaver protection netting was installed along 200 m of riverbank during October and December 2013 in Brandeburg, Germany. Three different protection systems were installed:

1) Hexagonal steel wire mesh with integrated three-dimensional polymer matrix, covered by 5 cm top soil
2) Hexagonal steel wire mesh, covered with 20 cm of top soil
3) Hexagonal steel wire mesh, covered with 20 cm of top soil, connected to a stone mattress layer below in the water section

The steel wire mesh started from the top of the levee and ended by the water. The case study reported that there was no erosion when banks were protected with steel wire and geomat; however, erosion was observed where wire was used without geomat [Strength of evidence 4].

Guidance

The review identified one guidance document that reported on embankment protection (27).

The Beaver Protocol for Utrecht (2023) provides guidance on managing conflicts caused by activity of Eurasian beavers in Utrecht, Netherlands (27). As part of the protocol, authors detail the cost of different interventions used. Installation of 20 m of construction steel mat to stop beavers digging into embankments took eight hours at a cost of total cost of £1,558 [Strength of evidence 4].

Other study designs

No evidence identified.

Flow devices

Section summary

- Seventeen studies were found on flow devices.
- The strength of evidence was weak.
- Studies consistently suggested that flow devices controlled water levels and reduced costs associated with management of beaver impacts.
- Landowners that used flow devices generally reported that they were satisfied with the devices and tended to stop using more extreme methods of management (e.g., trapping) after flow devices were installed.
- Flow devices required some ongoing management effort and a small proportion failed due to beavers building secondary dams.

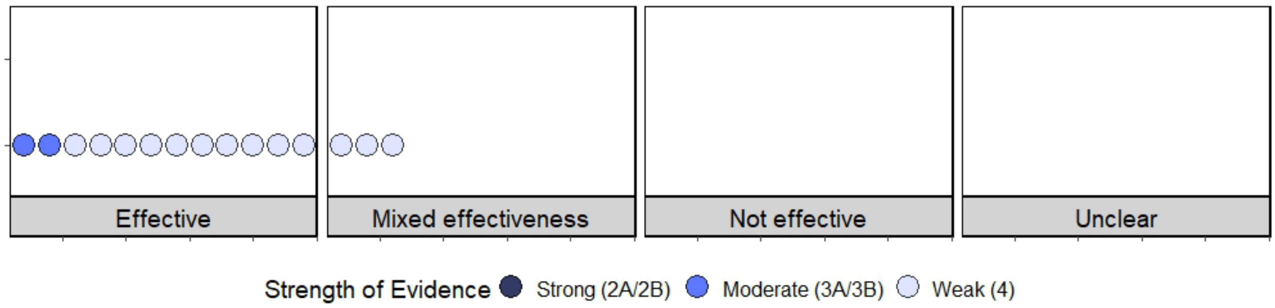

Figure 18: Dot plot showing the amount of evidence, strength of evidence, and direction of the evidence found on flow devices; studies with results which could not be categorised by efficacy are not included.

Experimental evidence

The evidence review identified four experimental studies that examined flow devices (57-60). The designs of flow devices are reported in Table 5.

Lamsodis and others (2011) conducted an experimental study between 1998 and 2006 that examined the efficacy of flow devices and dam removal on an open drain impounded by Eurasian beavers at one site in the Nevezis river basin, Lithuania (57). During the study, water levels fluctuated around the level of the flow devices, with short periods in the spring when water level exceeded the height of the flow devices. Beavers sealed the inlets and outlets of the flow devices several times during the study, but researchers unblocked them each time. After beavers failed to seal the flow devices and raise the water level at the two dams, the beavers built two new dams in autumn 1999. Two flow devices were installed in the new dams and, after failing to block these, beavers lost interest in these dams too. Water inlet holes for the flow devices were 3.5 cm, but the inlets were gradually blocked. Enlarging the inlet holes mitigated this issue [Strength of evidence 4].

Roblee (1984) conducted an experimental study between April 1978 and July 1980 that examined the efficacy of flow devices at 11 sites occupied by North American beavers in New York State, USA (58). Flow devices were installed at one beaver dam at each of the

11 sites. Tubing controlled water levels at nine of the 11 sites. Tubing was most effective when it was correctly installed. The study reported that it took 1.5 working days (eight-hour days) to install the tubing. Estimated maintenance time over the course of 10 years was 7.7 working days, with one extra day to replace wire mesh covering and support wires. The estimated annualised cost of installing the tubing was £182 (based on a 15-year life span). The estimated annualised cost of replacing wire mesh covering and support wires was £37 [Strength of evidence 4].

Callahan (2003) conducted an experimental study[9] beginning in November 1998 (end date unclear) that examined the efficacy of several interventions, including flow devices, at 213 problematic North American beaver colonies in New England and New York State, USA (59). Between November 1998 and November 2002, researchers installed a total of 116 flexible flow devices, with an average of 1.4 flow devices per dam. The study reported that 83% of the flow devices controlled water levels. Causes of flow device failure were new downstream dam (n=15), insufficient pipe capacity (n=4), and vandalism (n=1). The average cost of installation was £981 per dam. Flow devices required 0.5 hours of maintenance per year, with an average annual cost of maintenance of £54. The flow devices had an expected life of 10 years, which puts the annualised cost of flow devices at £152 per dam [Strength of evidence 4].

Callahan and others (2005) conducted a follow-up from the Callahan (2003) study. The follow-up study included data from November 1998 (beginning of the original study) to February 2005 and examined the 213 original sites plus an additional 269 sites (total: 482 sites) (60). The follow-up study examined 156 flow devices: 116 flow devices from the original study and 40 new flow devices. By February 2005, 87% of flow devices were still functioning successfully and 13% had failed. All failures happened in the first year of operation. The reasons for failure of flow devices were new downstream dam (n=11), insufficient pipe capacity (n=6), maintenance not performed (n=2), and dammed fencing (n=2). It’s unclear why fewer failures due to downstream dams were reported in this study compared with the 2003 study. The average cost of installation of a flow device was £1,118, and annual maintenance was £112. The annualised cost (assuming a 10-year lifespan) was £224 [Strength of evidence 4].

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[9] Note that the study design was unclear, but it was assumed to be experimental.

Table 5: Summary of the design of flow devices used in experimental studies. Note: some cells have been left blank.

Study	Type	Pipe				Cage		
		Pipes per dam	Dimensions	Wall design	Perforations	Caged?	Cage design	Cage materials
Lamsodis and others (2011)	Custom design	One	15 cm (diameter); pipe stretched 4m from dam to inlet	NR	Three rows of 3.5 cm holes along the bottom of inlet pipe; holes enlarged later in study	No (inlet anchored above pond floor)	-	-
Roblee (1984)	Custom design	NR	6–30 m x 10–25 cm (length x diameter)	NR	1.9–2.2 cm holes drilled over 3 m of inlet at top of pipe	Yes, along length of inlet pipe	Wrapped around entire intake	Welded wire
Callahan (2003 and 2005)	Custom design	≥1, dependent on the volume of water and desired rate of flow	6 m x 15–61 cm (length x diameter)	Single or double walled	NR	Yes, at inlet	NR	6-gauge concrete reinforcing wire with 15 cm × 15 cm mesh

Mixed-method evidence

The evidence review identified one mixed-method study that examined flow devices (20). The design of flow devices is reported in Table 6.

Hood and Yarmey (2015) conducted a mixed-method study between May 2014 and August 2015 that examined the efficacy of flow devices at sites dammed by North American beavers in Alberta, Canada (number of sites unclear) (20). Between May and August 2014, 12 flow devices were installed at dams and culverts to manage the impacts of North American beavers. Hood and Yarmey (2015) reported that in June 2015 all flow devices were in good working order. Beavers tried to block one flow device, but water still flowed through it and the blockage was resolved by researchers (it was unclear how they did this). The total time spent installing nine flow devices was 57 hours (six hours per device). The total cost of installing the nine flow devices was £8,014 (£890 per device). After installation, the annual cost of monitoring was £108 [Strength of evidence 4].

Table 6: Summary of the design of flow devices used in mixed-method studies.

Study	Type	Pipe				Cage		
		Pipes per dam	Dimensions	Wall design	Perforations	Caged?	Cage design	Cage materials
Hood and Yarmey (2015)	Custom design	NR	9 m x 30 cm (length x diameter)	Single- or double-walled pipes	0.6 cm holes down the length of the pipe	Yes, at inflow and outflow	Circular	Hog fencing

Observational evidence

The review identified two observational studies that examined flow devices (29, 61). The designs of flow devices are reported in Table 7.

Morzillo and Needham (2015) conducted an observational study in 2011 that examined landowners' perceptions of methods used to control North American beavers in Oregon, USA (29). Researchers sent out 5,200 questionnaires in January 2011 and received responses from 1,204 landowners. The questionnaires asked respondents to rate the acceptability of different beaver management strategies in response to six different hypothetical beaver impact scenarios. Installing control pipes was considered acceptable by landowners, regardless of scenario. However, landowners who had experienced prior beaver impacts found installing control pipes significantly less acceptable compared with landowners that hadn't experienced prior beaver impacts ($t=2.48–3.25$; $p=0.014–0.001$) [Strength of evidence 3B].

Nolte and others (2000) conducted an observational study that examined the effectiveness of Clemson pond levellers[10] installed by Mississippi Wildlife Services to manage the impact of North American beavers in Mississippi, USA (study date and number of sites not reported) (61). Clemson pond levellers are a type of flow device commonly used in the USA. A total of 40 devices were installed between May 1995 and August 1999. Of the 40 flow devices installed, 20 were considered successful by the landowner. Failure of nine flow devices was attributed to formation of a secondary dam. Flow devices were more successful where they were installed to reduce water levels during extreme events, rather than when they were intended to constantly provide water relief [Strength of evidence 4].

[10] A brand of flow device commonly used in the USA.

Table 7: Summary of the design of flow devices used in observational studies.

Study	Type	Pipe				Cage		
		Pipes per dam	Dimensions	Wall design	Perforations	Caged?	Cage design	Cage materials
Morzillo and Needham (2015)	NR	NR	NR	NR	NR	NR	NR	NR
Nolte and others (2000)	Clemson leveller	NR	25 cm inlet pipe (diameter; length NR) and 20 cm outlet pipe (diameter; length NR)	NR	150–180, 5 cm perforations	Yes, along length of inlet pipe	Wrapped around entire inlet pipe	Galvanised weld wire

* Cage was submerged 3–6 m from the dam.

Cost-benefit analysis

The review identified one study that performed cost-benefit analyses for flow devices (62). The designs of flow devices are reported in Table 8.

Hood and others (2018) conducted a cost-benefit analysis between 2011 and 2013 that examined flow devices installed at 12 sites where North American beavers were causing flooding in Alberta, Canada (62). The total cost of installing and monitoring the 12 flow devices over the three-year study period was £10,507 (£875 per site). Based on a willingness to pay of £0 and a discount rate of 3%, the net present value (calculated as present value of benefits minus present value of costs) of installing flow devices was £68,544 over three years and £150,880 over seven years. The researchers modelled scenarios with willingness to pay values of £0 and £5 and discount rates of 3% and 6%; all scenarios showed a net benefit of installing flow devices [Strength of evidence 3B].

Table 8: Summary of the design of flow devices used in cost-benefit analyses.

Study	Type	Pipe				Cage		
		Pipes per dam	Dimensions	Wall design	Perforations	Caged?	Cage design	Cage materials
Hood and others (2018)	Custom design	Unclear	One pipe 6.1 m x 30 cm coupled with* another pipe 6.1 m x 30 cm (length x diameter)**	One double-walled pipe coupled with* a single-walled pipe	NR	Yes, at the inlet and outlet	Circular cage (1.22 m x 1 m; diameter x height) at the inlet and a small cage or fence (dimensions NR) at the outlet	Galvanised hog fencing

* It was unclear how the pipes were coupled.

** A 20 cm pipe was used at shallower sites.

Case studies

The review identified five publications that reported case studies on flow devices (5, 34, 42, 63, 64). The designs of flow devices are reported in Table 9.

Pollock and others (2018) reported a series of 11 case studies conducted between 1996 and 2015 that examined management interventions for mitigating impacts of North American beavers at 11 sites in six states in the USA (34). Flow devices (Castor Masters[11]) were installed as part of two case studies (one in California and the other in Oregon). Flow devices were generally effective, although expensive, but did not always reduce water to the desired level or eliminate all stakeholder concerns. The study reported that the cost to install a Castor Master was £8,613, including labour, materials, and travel. Castor Masters took one month to install [Strength of evidence 4].

Wood and Woodward (1992) reported nine case studies conducted between 1988 and 1991 that examined Clemson pond levellers installed to manage the impacts of North American beavers at 25 sites in South Carolina and Georgia, USA (63). A total of 25 were installed flow devices through dams and culverts during the nine case studies. Across the case studies, only one flow device was disabled by beavers. Two flow devices were disabled by silt. Qualitative results confirmed that flow devices were 'useful' at most sites [Strength of evidence 4].

Brazier and others (2020) presented a case study conducted between autumn 2016 and autumn 2018 that examined the efficacy of a flow device installed to reduce flooding caused by Eurasian beavers at a pastoral site on the River Otter, UK (5). Beavers were first noticed in September 2016 and a flow device was installed in December 2016. At the flood site, flooding upstream of the beaver dam was reduced from 0.89 ha to 0.054 ha. Activity of beavers around the flood site decreased following intervention with the flow device, but subsequently beavers created a new dam 20 m downstream of the piped dam. Installation of the flow device cost £615 [Strength of evidence 4].

NatureScot (2021) reported a case study conducted between December 2020 and May 2021 that examined the efficacy of a flow device used to mitigate against damming by Eurasian beavers under a railway arch (location was not reported) (42). The device was installed on 1st December 2020, and maintenance was conducted on the flow device in May 2021, but otherwise the flow device successfully allowed a steady flow of water past the dam [Strength of evidence 4].

NatureScot (2021) also provided data on the costs and maintenance of eight flow devices installed as part of the Scottish Beaver Mitigation Scheme (study design, location, and dates not reported) (42). The study reported that the average cost of installing a flow device was £1,374, £451 of which was for materials. Flow devices generally require some

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[11] A brand of flow device commonly used in the USA.

maintenance and adjustment after installation. No comments were provided on whether water levels were successfully controlled by the devices [Strength of evidence 4].

Bailey and others (2018) examined three case studies conducted between 1997 and 2014 that examined mitigation strategies used as part of landscape engineering projects to alleviate impacts of North American beavers at three sites in Washington State, USA (64). Two of the case studies used flow devices (design and method of implementation not reported) as part of the mitigation strategy. The study reported that the landscape engineering projects can accommodate beaver colonisation through mitigation of their impacts, while leveraging the beaver’s role as ecosystem engineers [Strength of evidence 4].

Table 9: Summary of the design of flow devices used in case studies.

Study	Type	Pipe				Cage		
		Pipes per dam	Dimensions	Wall design	Perforations	Caged?	Cage design	Cage materials
Pollock and others (2018)	Castor master in one case study; NR in other case study	NR	NR	NR	NR	NR	NR	NR
Wood and Woodward (1992)	Clemson levellers	NR	3 m x 25 cm inlet pipe (length x diameter) and 20 cm outlet pipe (diameter; length NR)	NR	160, 5 cm perforations	Yes, along length of inlet pipe	Wrapped around entire inlet pipe	Galvanised weld wire
Brazier and others (2020)	NR	NR	NR	NR	NR	Yes, at the inlet	NR	Wire

Study	Type	Pipe				Cage		
		Pipes per dam	Dimensions	Wall design	Perforations	Caged?	Cage design	Cage materials
NatureScot (2021) (case study with a single flow device)	Custom design	Two (pipes placed side by side)	6 m x 300 mm (length x diameter)	NR	NR	Yes, at the inlet	Circular	Weldmesh
NatureScot (2021) (case study with eight flow devices)	NR	One or two	NR	NR	NR	Yes, at the inlet	NR	Wire mesh
Bailey and others (2018)	NR	NR	NR	NR	NR	NR	NR	NR

Guidance

The review identified four guidance documents that reported on flow devices (27, 28, 53, 54).

Nolte and others (2005) provided guidance on how to prevent North American beavers from blocking culverts (location unspecified) (53). The guidance was based on expert experience, and no empirical data were reported. The document reported that using perforated tubing or Clemson pond leveller can prevent beavers from blocking culverts, but routine maintenance is required to prevent the intake from being blocked by debris [Strength of evidence 4].

Angst (2022) provided guidance on managing impacts of Eurasian beavers at sites with railroad infrastructure in Switzerland (54). As part of the guidance, Angst (2022) estimated the cost of individual management measures. Installing flow devices required two people for two hours (labour costs not reported). Material costs were between £360 and £720. After installation, the system had to be monitored every one to two weeks [Strength of evidence 4].

The Beaver Protocol for Utrecht (2023) provides guidance on managing conflicts caused by activity of Eurasian beavers in Utrecht, Netherlands (27). As part of the protocol, authors provide the cost of management options used in the Netherlands. Preparation and installation of a Beaver Deceiver took 10 hours at a cost of £418. The Beaver Deceivers required two adjustments, which took three hours at an additional cost of £157. Installation of other flow devices took 24 hours and cost between £261 and £1,204 [Strength of evidence 4].

NatureScot (2022) reviewed the environmental effects of reintroduction of Eurasian beavers in Scotland (28). As part of the study, NatureScot (2022) provided qualitative comments on the effectiveness of management interventions, including flow devices. The study reported that flow devices generally resolved flooding impacts, although they sometimes require adjustment to increase water flow and often require maintenance (e.g., removal of debris from inlet) [Strength of evidence 4].

Other study designs

No data identified.

Culvert protection

Section summary

- Eight studies were found on culvert protection.
- The strength of evidence was weak.
- The studies found that culvert fences and T-culverts reduced damming / blockage of culverts.
- Landowners who had used culvert exclusion fencing were generally satisfied with the intervention.
- Routine maintenance is required to prevent the intake/fencing from being blocked by debris.

Figure 19: Dot plot showing the amount of evidence, strength of evidence, and direction of the evidence found on culvert protection; studies with results which could not be categorised by efficacy are not included.

Experimental evidence

The review identified two experimental studies that examined culvert protection (59, 60).

Callahan (2003) conducted an experimental study[12] beginning in November 1998 (end date unclear) that examined the efficacy of several interventions, including culvert exclusion fencing, at 213 problematic North American beaver colonies in New England and New York State, USA (59). Culvert exclusion fencing was installed between November 1998 and November 2002 at 161 sites; 30 sites had cylindrical fences and 131 had trapezoidal fences (dimensions and materials were not reported). The study reported that nine of the 30 cylindrical culvert fences had failed following installation, leading to this design being abandoned. Trapezoidal fences were installed after failure of the cylindrical fences. In total, 126 of the 131 trapezoidal fences prevented damming of culverts. Causes of failed trapezoidal fences were dammed fences (n=2), maintenance not performed (n=2), and new downstream dam (n=1). The average cost of installation of culvert fences was £751. Culvert fences only required one hour of maintenance per year, with an average

[12] Note that the study design was unclear, but it was assumed to be experimental.

annual cost of maintenance of £144. Culvert fences had an expected life of 10 years, which puts the annualised cost of culvert fences at £218 [Strength of evidence 4].

Callahan and others (2005) conducted a follow-up from the Callahan (2003) study. The follow-up study included data from November 1998 (beginning of the original study) to February 2005 and examined the 213 original sites plus an additional 269 sites (total: 482 sites) (60). In this study, culvert exclusion fencing was installed between November 1998 and February 2005 at 257 sites; 30 sites had cylindrical fences and 227 had trapezoidal fences. By February 2005, 40% of the cylindrical culvert fences had failed and 3% of the trapezoidal fences had failed. The majority of failures happened in the first year of operation. The reasons for failure of trapezoidal fences were dammed fences (n=2), maintenance not performed (n=4), and vandalism (n=1). The average cost of installation of culvert fencing was £839, and annual maintenance was £224. The annualised cost (assuming a 10-year lifespan) was £308. [Strength of evidence 4].

Mixed-method evidence

No evidence identified.

Observational evidence

The review identified two observational studies that examined culvert protection (65, 66).

Bruinsma (2020) conducted an observational study between September 2014 and September 2019 that examined the efficacy of flow devices and culvert protection at managing damage caused by North American beavers to infrastructure at 17 sites in Alberta, Canada (65). Researchers installed two culvert exclusion fences and 15 flow devices. Culvert exclusion fences were typically trapezoidal and measured at least 12 m in perimeter (materials used were not reported). They were installed at the inlet of the culvert. The time it took to install culvert fences averaged 24 hours. The devices only required two hours of annual maintenance. The cost of materials was £897, and the projected five-year annualised cost was £304 (assuming a wage of £18 per hour) [Strength of evidence 4].

Jensen and others (2001) conducted an observational study in 1997 and 1998 to determine the factors that affect the likelihood of culverts being plugged by North American beavers at 216 sites in New York State, USA (66). The study examined sites where a stream passes under a road through a culvert and where an active beaver colony was present. In total, researchers sampled 113 plugged and 113 unplugged sites. At each site, researchers recorded variables that may affect the likelihood of culverts being plugged by beavers and then tested for differences in these variables between plugged and unplugged sites. The probability that a highway culvert became blocked increased significantly with increasing culvert area ($p<0.0001$) and stream gradient ($p<0.001$). The following types of culvert were blocked more: pipe culverts (rather than box or bridge designs), sites with only one culvert (rather than several culverts), sites with narrower and shallower streams, sites with topographic constrictions, sites with substrate and streamside material suitable for plugging culverts, culverts with debris (rocks and sticks) inside them, culverts with less pipe submerged, and round shaped culverts (rather than arch, ellipse or pipe-arch shapes) (no statistical tests reported). The smoothness of culvert materials used, amount of adjacent shrub coverage, plane that the pipes were installed (flush or projecting), and presence of a man-made depression at the inlet had no clear effect [Strength of evidence 3B].

Cost-benefit analysis

No evidence identified.

Case studies

The evidence review identified two publications that reported case studies on culvert protection (67, 68).

Oel and Gallant (2019) reported a case study conducted from 2012 to 2013 that examined the efficacy of two culverts installed to manage flooding caused by North American beavers in Alberta, Canada (67). The case study reported on two culverts with new end designs which replaced an original culvert under a road that had been repeatedly blocked by beavers. The new culverts were designed in a T configuration, using 60 cm diameter pipes with a grates to cap the ends. The culverts performed well during floods in 2013, and seven years after installation of the new culverts, municipal infrastructure and private roads were still intact. The study reported that the original culvert had to be unblocked using heavy equipment two to three times per year at a total cost of £3,858 to £7,717 per summer season. The initial cost of installing the two new culverts was £27,009, but the authors reported that the new culverts solved the blockage issues [Strength of evidence 4].

Roblee (1987) reported a case study conducted from May 1984 to February 1987 that examined four T-culverts installed to manage damage caused by North American beavers at four sites in New York State, USA (68). The study installed four T-culverts to protect road culverts. A large culvert was used as an inlet (1.2–1.8 m diameter, 2.4–3.7 m length). This large culvert was connected at 90 degrees with smaller diameter culvert (30–61 cm diameter, 1.8–2.4 m length) – forming a T shape. The smaller culvert was connected with the road culvert (36–91 cm diameter). The two culverts used for construction of a T-culvert could be made from either corrugated aluminium or corrugated galvanised steel. The ends of the large culvert were covered with No. 6 gauge reinforced wire mesh. The researchers reported that T-culverts prevented detection of water flow into the culvert, which alleviated damage to road culverts. T-culverts took an average of 2.94 working days to install and required 0.27 days of maintenance per year. The average cost of materials for the T-culvert was £305. The cost to rent heavy equipment (one backhoe) for installation of the T-culvert averaged £216. Labour costs were not reported [Strength of evidence 4].

Guidance

The review identified two guidance documents that reported on culvert protection (28, 53).

Nolte and others (2005) provided guidance on how to prevent North American beavers from blocking culverts (location unspecified) (53). The guidance was based on expert experience, and no empirical data were reported. The document reported that T-culverts with or without grates, rebar, or wire mesh protection can prevent beavers from blocking culverts, but routine maintenance is required to prevent the intake from being blocked by debris. Coated mesh or chain link fencing excluding beavers from the culvert can also be prevent blockage, provided that the fencing is tight against the ground or buried a few inches deep [Strength of evidence 4].

NatureScot (2022) reviewed the environmental effects of reintroduction of Eurasian beavers in Scotland (28). As part of the study, NatureScot (2022) provided qualitative comments on the effectiveness of management interventions, including culvert protection. The study reported that culvert protection/grilles were effective, but required regular maintenance (e.g., removal of debris) [Strength of evidence 4].

Other study designs

No evidence identified.

Flow devices and culvert protection: combined

Section summary

- Six studies reported on the effectiveness of flow devices and culvert fences together, without separating out the effect of each.
- The strength of evidence was weak.
- The evidence suggested that flow devices and culvert fences controlled flooding caused by beavers, resulting in a net cost savings.

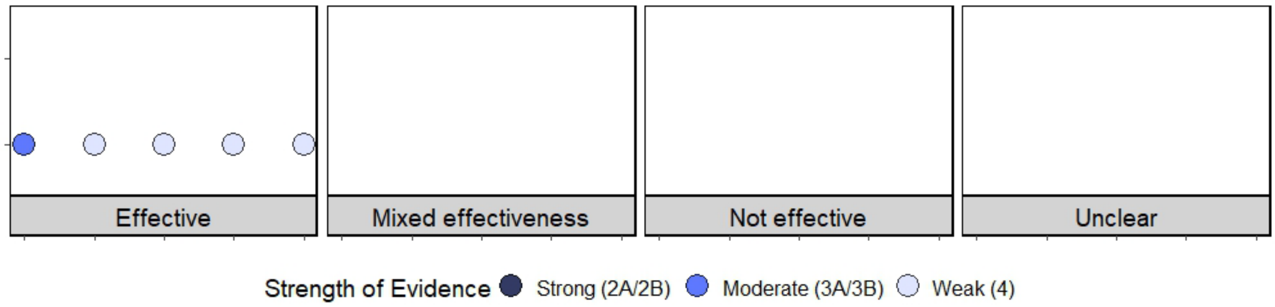

Figure 20: Dot plot showing the amount of evidence, strength of evidence, and direction of the evidence found on flow devices and culvert protection: combined; studies with results which could not be categorised by efficacy are not included.

Experimental evidence

The evidence review identified two experimental studies that examined flow devices (60, 69). The designs of flow devices and culvert fences are reported in Table 10 and Table 11.

Boyles and Savitzky (2008) conducted an experimental study between June 2004 and August 2007 that examined the efficacy of flow devices and culvert fences (Beaver Deceivers) for managing impacts of North American beavers at 21 sites in Virginia, USA (69). From June 2004 to November 2005, investigators installed 18 culvert fences and 15 flow devices at 14 sites near roads with chronic damage caused by North American beavers. Between November 2005 and March 2006, they installed a further seven devices (type of device not reported) at seven additional sites. The brand of flow devices used was Castor Master. The study reported that all 21 sites experienced flooding before intervention, whereas only one of the 21 sites experienced flooding after installation of flow devices. The total cost of beaver management before the installation of flow devices at the 14 initial sites was £246,796/year. The total cost for managing the 14 sites was reduced to £36,524/year after the installation of flow devices [Strength of evidence 3A].

Callahan and others (2005) conducted an experimental study[13] between November 1998 and February 2005 that examined the efficacy of several interventions, including flow

[13] Note that the study design was unclear, but it was assumed to be experimental.

devices and culvert fencing, at 482 North American beaver colonies in New England and New York State, USA (60). The researchers trialled different interventions to resolve human-beaver conflicts around water levels. Flow devices were used as a first resort, and trapping was used at 12 ‘no tolerance’ sites. At some sites, culvert fences were installed in conjunction with a flow device. The average cost of installation of culvert fencing with a flow device was £1,566, and annual maintenance was £168. The annualised cost (assuming a 10-year lifespan) was £324 [Strength of evidence 4].

Table 10: Summary of the design of flow devices used in experimental studies.

Study	Type	Pipe				Cage		
		Pipes per dam	Dimensions	Wall design	Perforations	Caged?	Cage design	Cage materials
Boyles and Savitzky (2008)	Castor Masters	NR	6 m x 30 cm (length x diameter)	NR	NR	Yes, at the inlet and outlet	Round Fence, 0.6–1.2 m x 1.2–2.4 m (height x diameter)	4-guage steel mesh
Callahan and others (2005)	Custom design	≥1, dependent on the volume of water and desired rate of flow	6 m x 15–61 cm (height x diameter)	Single or double walled	NR	Yes, at inlet	NR	6-gauge concrete reinforcing wire with 15 cm × 15 cm mesh

Table 11: Summary of the design of culvert protection used in experimental studies.

Study	Type	Shape	Dimensions	Materials
Boyles and Savitzky (2008)	Beaver Deceivers	Shaped as a square, rectangle, pentagon, or trapezoid	12 m to 37 m (perimeter)	4-gauge steel mesh
Callahan and others (2005)	Culvert fences	Cylindrical or trapezoidal	NR	NR

Mixed-method evidence

No evidence identified.

Observational evidence

The evidence review identified two observational studies that examined flow devices (65, 70). The designs of flow devices and culvert fences are reported in Table 12 and Table 13.

Bruinsma (2020) conducted an observational study between September 2014 and September 2019 that examined the efficacy of flow devices at managing damage caused by North American beavers to infrastructure at 17 sites in Alberta, Canada (65). Researchers installed 15 flow devices. Flow devices were either flexible levellers, self-start syphons, or double-filter flexible levellers, which were a hybrid of a flexible leveller and a culvert fence. Of the 15 flow devices installed at conflict sites, 13 were functional as of September 2019. Qualitative comments suggest flexible levellers were effective, with a good longevity (typically >5 years), relatively low material and labour costs, high flow capacity, and good aesthetic appeal (mostly submerged and visually unobtrusive). Self-start syphons worked well on low-flow sites, but repeated unblocking of the intake was necessary. The projected five-year annualised cost was £181 for self-start siphon, £156 for flexible levellers, and £175 for double-filter flexible levellers, including material costs and labour costs associated with installation and maintenance of flow devices (assuming a wage of £18 per hour). The annual cost saving associated with installing a flexible leveller was £257 per site (annual cost of site visits minus annualised cost of flow devices) [Strength of evidence 4].

Simon (2006) conducted an observational study in April 2002 that assessed the efficacy of culvert fences and flow devices at managing impacts of North American beavers at 482 conflict sites in New England and New York State, USA (70).[14] Researchers interviewed 36 people who had a combined total of 54 flow devices installed to manage conflict with beavers. 89% of participants were satisfied and 61% of participants were very satisfied with their flow device. 89% of participants would use a flow device again and 94% of participants would recommend flow devices to others. Before intervention with flow devices, 33% of participants trapped beavers. This reduced to 3.7% of participants after intervention. In total, 11% of flow devices failed (either the respondent was dissatisfied with the device or the device didn't work properly after three attempts to fix it). 13% of the devices were vandalised after installation. Flow devices were comprised of one or more pipes inserted through a dam, with a protective cage at the inlet, but no further details were provided of the interventions [Strength of evidence 4].

[14] Note: the researchers stated that the study used a design similar to Callahan (2003 and 2005). The design details have been copied from those publications.

Table 12: Summary of the design of flow devices used in observational studies.

Study	Type	Pipe				Cage		
		Pipes per dam	Dimensions	Wall design	Perforations	Caged?	Cage design	Cage materials
Bruinsma (2020)	Custom design: flexible levellers	NR	Flexible levellers: 15–30 cm	NR	NR	Yes, at the inlet	NR	Wire
	Custom design: self-start syphons	NR	~5 cm (diameter; length NR)	NR	NR	NR	NR	NR
Simon (2006)*	Custom design	≥1, dependent on the volume of water and desired rate of flow	6 m x 15–61 cm (height x diameter)	Single or double walled	NR	Yes, at inlet	NR	6-gauge concrete reinforcing wire with 15 cm × 15 cm mesh

*Note: the researchers stated that the study used a design similar to Callahan (2003 and 2005). The design details have been copied from those publications.

Table 13: Summary of the design of culvert protection used in observational studies.

Study	Type	Shape	Dimensions	Materials
Bruinsma (2020)	Culvert fences	Typically trapezoidal	12 m perimeter	NR
Simon (2006)*	Culvert fences	Cylindrical or trapezoidal	NR	NR

*Note: the researchers stated that the study used a design similar to Callahan (2003 and 2005). The design details have been copied from those publications.

Cost-benefit analysis

The evidence review identified one study that performed a cost-benefit analysis for flow devices (71).

Callahan and others (2019) conducted a cost-benefit analysis between 2000 and 2019 that compared non-lethal control (flow devices and culvert exclusion fencing) with lethal control of North American beavers at 55 beaver conflict sites in Massachusetts, USA (71). The study did not report the design of the culvert fences and flow devices, but an illustration indicated that the flow device intake was protected by a circular cage. The study reported the cost of flow devices and culvert exclusion fencing together. The average cost of installation of flow devices was £1,340, and the annual cost of maintenance was £71. The annualised cost was £205 (assuming a 10-year lifespan). The average annual cost saving from using non-lethal interventions compared with lethal interventions was £161 per site [Strength of evidence 4].

Case studies

No evidence identified.

Guidance

The evidence review identified one guidance study that reported on flow devices (72).

Lisle (2001) provide expert commentary on the use of flow devices and culvert exclusion fencing to manage the impacts of North American beavers in Maine, USA (72). Lisle (2001) reported that installation of 18 devices eliminated beaver-related road maintenance costs over a five-year period. The methods for this study are unclear [Strength of evidence 4].

Other study designs

No evidence identified.

Water level changes

Section summary

- Five studies reported on the effect of natural water level fluctuations and river flow changes on beaver behaviour and population dynamics.
- The strength of evidence was moderate.
- The evidence suggested that water level variations are harmful to beavers, causing lodge abandonment and stress.
- There was not enough evidence to make conclusions about the effect of river flow changes.

Five studies reported on the effect of natural water level fluctuations and river flow changes on beaver behaviour and population dynamics. As beavers return to British landscapes, it is likely that humans will have to intervene to alter water levels both at individual beaver territories and at the catchment scale to manage water systems. Whilst the intervention reported here was natural rather than human-induced, this review has included these studies as their results can be used to make initial suggestions about what effects human alteration of water levels and flow could have on beavers.

No visual summary has been provided as it was not possible to classify any of the study results in categories of effectiveness.

Experimental studies

No evidence identified.

Mixed-method studies

No evidence identified.

Observational studies

The review identified five observational studies reporting on the effects of naturally occurring water level fluctuations and river flow changes on beavers (73-77).

Feldman and others (2020) conducted an observational study between February 2012 and March 2014 which investigated the factors affecting lodge abandonment by North American beavers in 47 lodges in Tierra del Fuego, Argentina (73). The researchers conducted longitudinal surveys of lodges in two study areas: one area of forest habitat containing 22 beaver lodges and one area of steppe habitat containing 25 beaver lodges. Variables considered were water level variation, stream gradient, vegetation cover adjacent to shore, and forest structure. Water level variation was the most significant factor in successfully predicting lodge abandonment by beavers in both forest and steppe habitats. The water level at the entrance of the lodge was lower in abandoned lodges, although the researchers do not know if dropping water levels were a cause or consequence of beaver lodge abandonment. These results suggest water level variation causes beaver lodge abandonment, and water level decrease either causes or follows beaver lodge abandonment [Strength of evidence 3B].

Smith and Peterson (1988) conducted an observational study from 1984 to 1987 which assessed the effects of water level fluctuations on North American beavers at three sites in Minnesota, USA (74). Water drawdown behind hydroelectric dams causes one metre yearly fluctuations to site 1 and three metres yearly fluctuation to site 2. Inland ponds with no drawdown were used as a control (site 3). Lodge abandonment was much higher at site 2: 80% abandonment compared to 38% abandonment at site 1 and 20% at site 3. Lodge abandonment, and subsequent lack of access to shelter and winter caches, appeared to adversely affect beaver condition, particularly in kits. At site 2, colony instability and failure to reproduce was highest. Beaver mortality due to water drawdowns did occur but it was not sufficient to prevent population increases. The researchers noted water drawdown timing is the critical concern for managing water levels to reduce impacts on beavers [Strength of evidence 4].

Breck and others (2001) conducted an observational study between September 1997 and November 1999 which assessed the effects of river flow regulation on North American beavers at two sites in Colorado, USA (75). The researchers compared the health and demography of beavers at site 1, where the river contained man-made dams and natural river flow was interrupted, to beavers at site 2, where the river had no man-made dams. The researchers found that mean body mass and tail thickness of adult and subadult beavers was significantly higher at site 1 compared to site 2 ($p<0.05$). Beaver colonies were denser at site 1 than site 2. There was no significant difference in home-range size between beaver colonies on site 1 compared to site 2. The researchers suggested that beavers were in better health and more densely populated at site 1 than site 2 because the regulation of water levels at site 1 had led to geomorphological changes that increased beaver food availability. At site 2, unregulated water flow led to the formation of sandy flats and bars, which possibly increased beaver energy expenditure when trying to obtain food and the risk of beaver predation [Strength of evidence 3B].

Pașca and others (2011) conducted an observational study between June and August 2010 which assessed Eurasian beaver response to extremely variable rainfall at one site in Covasna County, Romania (76). The researchers directly observed beaver behaviour for over a hundred hours. They found that temporary water level fluctuations can force beavers to leave their lodges and make temporary resting and feeding shelters above ground. This period is very stressful for beavers and causes them to exhibit exceptional behaviours, such as co-habiting with other family groups and tolerating unusual levels of human presence [Strength of evidence 4].

Ahlers and others (2010) conducted an observational study between June 2008 and July 2009 which examined the effect of flooding on muskrat survival at one site in Illinois, USA (77). The study used known-fate models and an information–theoretic approach to examine effects of age, season, hydrology, and riparian width on weekly survival rates of 27 radio-marked riparian muskrats in small streams and agricultural ditches. Riparian buffer width was the most significant factor at explaining muskrat survival rates. Every

50 m increase in riparian buffer width increased the chance of muskrat survival by 3.7% [Strength of evidence 3A].

Cost-benefit analysis

No evidence identified.

Case studies

No evidence identified.

Guidance

No evidence identified.

Other study designs

No evidence identified.

Dam removal

Section summary

- Seven studies were found on dam removal.
- The strength of evidence was weak.
- Dam removal was generally successful, but usually involved multiple efforts as beavers rebuild the dams.
- Dam removal was cost-effective.

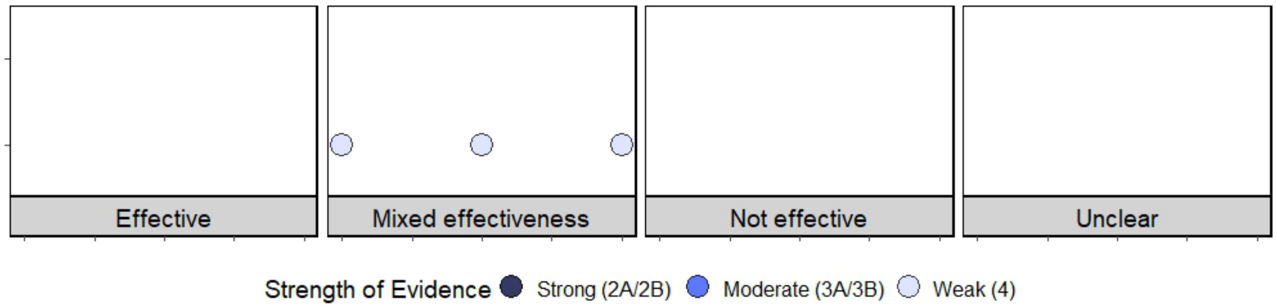

Figure 21: Dot plot showing the amount of evidence, strength of evidence, and direction of the evidence found on dam removal; studies with results which could not be categorised by efficacy are not included.

Experimental evidence

The evidence review identified one experimental study that examined dam removal (57).

Lamsodis and others (2011) conducted an experimental study between 1998 and 2006 that examined the efficacy of pond levellers and dam removal on an open drain impounded by Eurasian beavers at one site in the Nevezis river basin, Lithuania (57). Researchers removed a total of three dams during the study. One dam was removed a total of six times, but beavers rebuilt it each time. The other two dams were successfully removed [Strength of evidence 4].

Mixed-method evidence

No evidence identified.

Observational evidence

The evidence review identified one observational study that examined dam removal (29).

Morzillo and Needham (2015) conducted an observational study in 2011 that examined landowners' perceptions of methods used to control North American beavers in Oregon, USA (29). Researchers sent out 5,200 questionnaires and received responses from 1,204 landowners. The questionnaires asked respondents to rate the acceptability of different beaver management strategies in response to six different hypothetical beaver impact scenarios. Landowners considered removing dams and lodges unacceptable when beavers had only been seen (and not caused damage) or when beavers had been foraging on trees. However, removing dams and lodges was considered acceptable when beaver impact severity increased, such as when beavers plugged culverts and when beavers caused flooding of property and fields. Landowners who had experienced prior beaver impacts found removing beaver dams and lodges significantly more acceptable compared with landowners that hadn't experienced prior beaver impacts ($t=3.63$–5.71; $p<0.001$) [Strength of evidence 3B].

Cost-benefit analysis

The evidence review identified one cost-benefit analysis of dam removal (78).

Shwiff and others (2011) performed a cost-benefit analysis from 2005 to 2009 of a beaver control programme operating in all 82 counties of Mississippi, USA (78). The program included two interventions: beaver trapping on the properties of interested landowners and the removal of beaver dams from flooded properties. The study did not separate the cost-benefit analysis of the two different interventions. The total programme costs averaged £987,037 annually over the study period. Cost-benefit analysis found that the program was economically efficient, with the net benefits ranging from £30,975,114 to £69,121,060 (maximum damage and lowest benefit estimate – minimum damage and highest benefit estimate) [Strength of evidence 3A].

Case studies

The evidence review identified one publication that reported a case study on dam removal (26).

Bos and others (2022) reported on a case study conducted between August and November 2021 where researchers managed activity of a Eurasian beaver near a railway in Taarlo, Netherlands (26). A Eurasian beaver burrowed under a railroad track, flooded a culvert, and built dams at one site near a railway and the activity was deemed intolerable. In October, the local water board lowered the beaver dam, but the beaver quickly rebuilt it. The water board subsequently removed the dam, and by the end of the monitoring period (November 2021), the beaver had stopped attempting to rebuild the dam [Strength of evidence 4].

Guidance

The review identified three guidance documents that reported on dam removal (27, 28, 54).

The Beaver Protocol for Utrecht (2023) provides guidance on managing conflicts caused by activity of Eurasian beavers in Utrecht, Netherlands (27). As part of the protocol, authors provide the cost of management options used in the Netherlands. Removing beaver dams took between 1 and 63 hours at a cost of £52 to £4,411. There was no information of the methods used for removing dams that could explain the variance in cost [Strength of evidence 4].

Angst (2022) provided guidance on managing impacts of Eurasian beavers at sites with railroad infrastructure in Switzerland (54). As part of the guidance, Angst (2022) estimated the cost of individual management measures. Removing a dam with a crane or other heavy equipment had an approximate cost of £900 [Strength of evidence 4].

NatureScot (2022) reviewed the environmental effects of reintroduction of Eurasian beavers in Scotland (28). As part of the study, NatureScot (2022) provided qualitative comments on the effectiveness of management interventions, including dam removal or dam notching. The study reported that dam removal can be effective, but beavers often rebuild dams, leading to escalating costs associated with repeated removal. The study also reported that dam notching can provide short-term flooding relief, but beavers often repair the dam [Strength of evidence 4].

Other study designs

No evidence identified.

Lodge removal and infilling burrows

Section summary

- Two studies were found on lodge removal or burrow infilling.
- The strength of evidence was weak.
- Landowners deemed lodge removal as acceptable when beaver impacts were severe, such as when beavers plugged culverts and when beavers caused flooding of property and fields
- None of the studies found commented on the efficacy of lodge removal or burrow infilling.
- Infilling burrows was costly to landowners.

No visual summary has been provided as it was not possible to classify any of the study results in categories of effectiveness.

Experimental evidence

No evidence identified.

Mixed-method evidence

No evidence identified.

Observational evidence

The evidence review identified one observational study that examined lodge removal (29).

Morzillo and Needham (2015) conducted an observational study in 2011 that examined landowners' perceptions of methods used to control North American beavers in Oregon, USA (29). Researchers sent out 5,200 questionnaires and received responses from 1,204 landowners. The questionnaires asked respondents to rate the acceptability of different beaver management strategies in response to six different hypothetical beaver impact scenarios. Landowners considered removing dams and lodges unacceptable when beavers had only been seen (and not caused damage) or when beavers had been foraging on trees. However, removing dams and lodges was considered acceptable when beaver impact severity increased, such as when beavers plugged culverts and when beavers caused flooding of property and fields. Landowners who had experienced prior beaver impacts found removing beaver dams and lodges significantly more acceptable compared with landowners that hadn't experienced prior beaver impacts ($t=3.63–5.71$; $p<0.001$) [Strength of evidence 3B].

Cost-benefit analysis

No evidence identified.

Case studies

No evidence identified.

Guidance

The review identified one guidance documents that reported on infilling burrows (27).

The Beaver Protocol for Utrecht (2023) provides guidance on managing conflicts caused by activity of Eurasian beavers in Utrecht, Netherlands (27). As part of the protocol, authors provide the cost of management options used in the Netherlands. Infilling burrows and restoration of collapsed riverbanks took between 8 and 105 hours to complete and costs ranged from £696 to £7,073, depending on site and severity of damage. There was no information of the methods used for infilling burrows that could explain the variance in cost [Strength of evidence 4].

Other study designs

No evidence identified.

Trapping and translocation

Section summary

- Ten studies were found on trapping and/or translocation.
- The strength of evidence was moderate to weak.
- Trapping can help control beaver populations.
- However, trapping rates (using US- and EU-approved traps) were relatively low; beavers often recolonise trapped areas; and trapping can cause beaver mortality.
- Translocation has been used to populate target areas.
- However, translocation can cause beaver mortality, albeit at a low rate; relocated beavers are also vulnerable to predation and often leave the designated target area; it can therefore be difficult to get a pair to establish in a target area.
- Landowners perceived trapping and translocation as an acceptable method for managing beavers, but when they conducted trapping on their land, they generally found it to be unsuccessful.

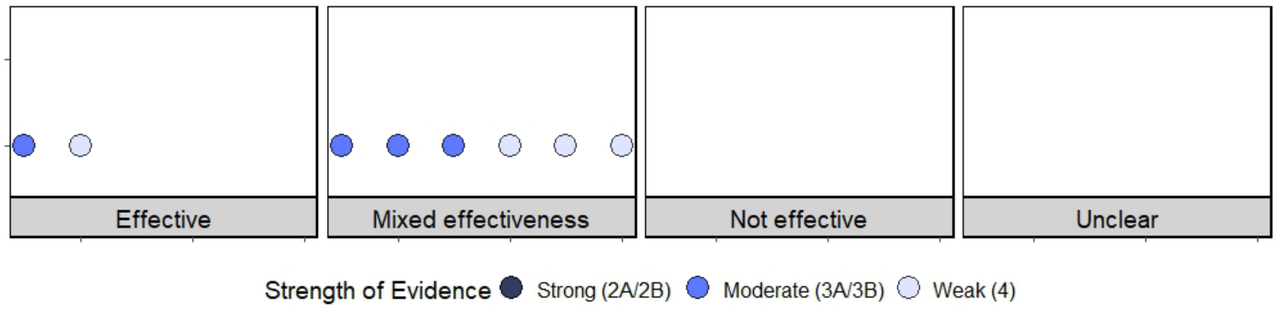

Figure 22: Dot plot showing the amount of evidence, strength of evidence, and direction of the evidence found on trapping and translocation; studies with results which could not be categorised by efficacy are not included.

Experimental evidence

The evidence review identified three experimental studies that examined trapping and/or translocation of beavers (60, 79, 80).

McKinstry and Anderson (2002) conducted an experimental study between 1994 and 1997 that examined the effect of trapping and translocation on survival and migration of North American beavers at 33 sites in Wyoming, USA (79). Across four Spring–Autumn trapping seasons, 277 beavers were trapped using snares[15] and Hancock traps[16]. After capture, beavers were fitted with Monel ear tags to both ears. A subset of 114 beavers were implanted with transmitters: 46 received Advanced Telemetry Systems model, 17 internal transmitters and 67 received tail collars or modified ear tag transmitters attached to the tail[17].15 beavers died during trapping: 11 entangled in snares and four killed by predators while caught in snares or Hancock traps. 15 of the trapped beavers were lactating females and were not translocated.

The remaining 247 beavers were transported. 13 beavers died during translocation, so a total of 234 beavers were released at 14 sites. All beavers aged less than two years either died or moved outside of the transplant areas before 180 days. Across all age classes, 51% of beavers migrated more than 10 km away from the release site within the first six months. This meant it took researchers an average of ’7 beavers to get a pair to establish and reproduce at the chosen sites. In September of 2001, 13 of the 14 sites were still occupied by beavers. Examination of variables predicting success of releases failed to identify any variables that significantly impacted the likelihood of success (data not shown). Of the 114 beavers equipped with transmitters, 30% died within 180 days and the fate of 51% was unknown due to emigration or loss of transmitter. The Kaplan-Meier survival estimate for beavers aged ≥2.5 years was 49% at 180 days and 43% at 360 days [Strength of evidence 3A].

Jusim and others (2020) conducted an experimental study in April and May 2015 that examined the effectiveness of trapping at 38 beaver colonies North American beavers in Tierra del Fuego, Argentina (80). The hunters used kill body-grip traps and live traps (snares). The study set a total of 676 traps over 864 trapping nights: 473 body grips[18] and 203 snares. Body grip traps were significantly captured significantly more beavers than snares ($p<0.01$), but both were less than 20% efficiency at capturing beavers. Both were frequently activated without securing capture and had a total injury rate of 10/115 beavers. Both traps captured significantly more beavers when placed in slides than channels

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[15] A type of animal trap consisting of thin wire noose which tightens as the animal wriggles in it. Can be lethal or non-lethal depending on the snare design.

[16] The main brand of trap used to catch beavers live in North America. Like a Bavarian beaver trap, it consists of a large cage, the door closing as the animal walks inside and triggers the release of a weighted spring.

[17] It’s unclear why these do not add up to 114.

[18] A type of lethal trap used in North America. It consists of two rectangular frames with a trigger, that when activated, slam shut on the body.

(p<0.01). Trap location was the most important factor in explaining trap success [Strength of evidence rating 3B].

Callahan and others (2005) conducted an experimental study[19] between November 1998 and February 2005 that examined the efficacy of several interventions, including trapping, at 482 North American beaver colonies in New England and New York State, USA (60, 70). The researchers trialled different interventions to resolve human-beaver conflicts around water levels. Different flow devices were used as a first resort, and trapping was used at 12 'no tolerance' sites. By February 2005, 16% of trapping interventions succeeded and 84% failed (definition of success/failure presumably meant ability of traps to capture beavers) [Strength of evidence 4].

Mixed-method evidence

No evidence identified.

Observational evidence

The evidence review identified five observational studies that examined the effectiveness of trapping and/or translocation of beavers (24, 29, 43, 75, 81).

Ribic and others (2017) conducted an observational study between 1983 and 2003 that examined the effect of a monitoring and trapping management programme on density of North American beaver colonies at two sites in Wisconsin, USA (24). Trapping began at site one in 1987 and at site two in 1997. Beaver colony density was then compared between streams from which beavers had been trapped and streams where no trapping had occurred. At both sites, beaver colony density was ≥60% lower at trapped streams compared with the non-trapped stream [Strength of evidence 3B].

Breck and others (2001) conducted an observational study between September 1997 and November 1999 that assessed how North American beaver populations have responded to changes in flow regulation at two river systems in Colorado, USA (75). As part of the study, researchers captured beavers using Hancock traps and snares and implanted transmitters into 18 beavers (total number of beavers trapped was not reported). The study reported that there were three trapping-related mortalities between 1997 and 1999. All mortalities were caused by snares [Strength of evidence 3B].

González-Calderón and Schiavini (2022) conducted an observational study between 2016 and 2018 that examined the effect of historic population management strategies on the reproduction of female North American beavers at seven sites in Isla Grande, Argentina (81). Trappers captured beavers before culling them and collecting the reproductive tract of female beavers to examine the reproductive signs. Beavers were trapped from areas subject to four different management regimes: intensive population management with very

[19] Note that the study design was unclear, but it was assumed to be experimental.

high historic rates of trapping; focused trapping targeted at specific locations; total eradication (with later invasion); and very limited historic population management[20]. The different management regimes had no significant effect on the fertility rates of female beavers across different age classes ($p>0.05$). However, areas subject to population management had higher overall reproductive rates than areas not subject to management ($p<0.05$) [Strength of evidence 4].

Morzillo and Needham (2015) conducted an observational study in 2011 that examined landowners' perceptions of methods used to control North American beavers in Oregon, USA (29). Researchers sent out 5,200 questionnaires and received responses from 1,204 landowners. The questionnaires asked respondents to rate the acceptability of different beaver management strategies in response to six different hypothetical beaver impact scenarios. Landowners considered trapping an acceptable strategy for management across all impact scenarios. Landowners that had experienced prior beaver impacts found capturing and relocating beavers more acceptable than landowners that hadn't experienced prior beaver impacts ($t=1.63$–2.91; $p=0.104$–0.004) [Strength of evidence 3B].

Willging and Sramek (1989) conducted an observational study that examined residents' attitudes towards methods used to control North American beavers in Texas, USA (survey date not reported) (43). Researchers sent a 15-question surveys to residents of one metropolitan area in Texas who had been assisted with beaver problems between 1984 and 1988. The survey obtained information on damage estimates, type of damage, beaver control methods, and perception of beaver control. A total of 87 surveys were sent and 63% were returned; 21 respondents reported that they had used trapping. All non-lethal trapping methods used (including snares, leghold, and livetraps) were perceived as unsuccessful. Body grip traps (lethal) were the only trapping method perceived as partially successful [Strength of evidence 4].

Cost-benefit analysis

The evidence review identified one cost-benefit analysis of trapping and/or translocation of beavers (78).

Shwiff and others (2011) performed a cost-benefit analysis from 2005 to 2009 of a beaver control program operating in all 82 counties of Mississippi, USA (78). The program included two interventions: beaver trapping on the properties of interested landowners and the removal of beaver dams from flooded properties. The study did not separate the cost-benefit analysis of the two different interventions. The total program costs averaged £987,037 annually over the study period. Cost-benefit analysis found that the program was economically efficient, with the net benefits ranging from £32,636,761 to £72,829,029

[20] Listed from the most intensive method of management to the least intensive method of management.

(maximum damage and lowest benefit estimate – minimum damage and highest benefit estimate) [Strength of evidence 3A].

Case studies

No evidence identified.

Guidance

The evidence review identified one study that that provided guidance on trapping and/or translocation of beavers (28).

NatureScot (2022) reviewed the environmental effects of reintroduction of Eurasian beavers in Scotland (28). As part of the study, NatureScot (2022) provided qualitative comments on the effectiveness of management interventions, including trapping. The study reported that trapping was effective and has seen more uptake owing to a desire to reduce use of lethal control [Strength of evidence 4].

Other study designs

No evidence identified.

Lethal control

Section summary

- Six studies were identified on lethal control.
- The evidence strength was moderate-weak.
- Lethal control can reduce beaver numbers or prevent colonisation at particular sites, but it but if there is a local beaver population, beavers often re-establish at the culled site.
- If beavers reestablish at culled sites, the ongoing cost of culling can be high compared to non-lethal management options.
- Landowners report that culling generally resolves beaver-related impacts but is unacceptable in most scenarios.

Figure 23: Dot plot showing the amount of evidence, strength of evidence, and direction of the evidence found on lethal control; studies with results which could not be categorised by efficacy are not included.

Experimental evidence

No evidence identified.

Mixed-method evidence

No evidence identified.

Observational evidence

The evidence review identified three observational studies that examined lethal control of beavers (29, 42, 43).

Morzillo and Needham (2015) conducted an observational study in 2011 that examined landowners' perceptions of methods used to control North American beavers in Oregon, USA (29). Researchers sent out 5,200 questionnaires and received responses from 1,204 landowners. The questionnaires asked respondents to rate the acceptability of different beaver management strategies in response to six different hypothetical beaver impact scenarios. Lethal control was considered unacceptable, regardless of scenario. Landowners who had experienced prior beaver impacts found lethal control significantly more acceptable compared with landowners that hadn’t experienced prior beaver impacts ($t=6.04–6.85$; $p<0.001$) [Strength of evidence 3B].

Willging and Sramek (1989) conducted an observational study that examined residents' attitudes towards methods used to control North American beavers in Texas, USA (survey date not reported) (43). Researchers sent a 15-question surveys to residents of one metropolitan area of Texas who had been assisted with beaver problems between 1984 and 1988. The survey obtained information on damage estimates, type of damage, beaver control methods, and perception of beaver control. A total of 87 surveys were sent and 63% were returned; 18 respondents reported that they had used lethal control. Of these, 12 reported that lethal control was successful and six reported that it was a partial success [Strength of evidence 4].

NatureScot (2021) conducted an observational study of the effect of licencing trapping and culling on the number of Eurasian beaver territories between 2017 and 2019 in the Forth and Tay catchment (total number of sites examined was not clear) (42). The study examined beaver licence returns in 2020 and 2021 compared with licence returns from previous years. The method used to collect and analyse licence data was unclear. The study reported that licencing beaver trapping and culling resulted in culling of 115 beavers in 2020 and prevented the establishment of nine territories in 2020 and 2021. Four territories disappeared in the same period. However, the local effects of trapping and culling did not negatively impact on the total beaver population at the Forth and Tay catchment, with the total number of beaver territories increasing from 114 in 2017/18 to 251 in 2020/21 [Strength of evidence 4].

Cost-benefit analysis

The review identified one study that performed cost-benefit analyses for lethal control of beavers (71).

Callahan and others (2019) conducted a cost-benefit analysis between 2000 and 2019 that compared non-lethal control (flow devices and culvert exclusion fencing) with lethal control (lethal trapping) of North American beavers at 55 beaver conflict sites in Massachusetts, USA (71). Beaver trapping (type not reported) was conducted at ‘no tolerance zones’ (N=12), which are regularly monitored for evidence of beavers. By law, all trapped beavers had to be killed. Dam breaching was also conducted at trapping sites. A total of 222 beavers were trapped – an average of 18.5 per year and 1.5 per site per year. The total cost of trapping and breaching beaver dams was £45,872, with an average annual cost of £201 per conflict site. Conflict sites were monitored as part of the trapping programme. Monitoring cost £164 per site per year, bringing the annualised cost per site to £365 per site. The average annual cost saving from using non-lethal interventions compared with lethal interventions was £161 per site [Strength of evidence 4].

Case studies

No evidence identified.

Guidance

The review identified one guidance document that reported on lethal control of beavers (53).

Nolte and others (2005) provided guidance on how to prevent North American beavers from blocking culverts (location unspecified) (53). The guidance was based on expert experience, and no empirical data were reported. The study reported that trapping and shooting can be effective but only in the short term as beavers will often repopulate trapped sites [Strength of evidence 4].

Other study designs

The review identified one modelling study that examined the effect of lethal control of beavers (82).

Pietrek and others (2017) used a modelling study to explore the effect of different management regimes on the spread of North American beavers in Patagonia – both in Argentina (where beavers were first released) and Chile (where beavers were subsequently recorded) (82). The model tested the effect of buffer zones (a strip of land aligned perpendicular to the direction of spread within which a proportion of migrating beavers are culled) on the estimated dispersal of beavers. The study investigated two buffer zone widths (50 km and 100 km) and three different culling rates within the buffer zones (90% vs 60% vs 0% [control]). Culling caused a large reduction in the number of beaver colonies within buffer zones at the end of the 10-year simulation. For both buffer widths, the 90% culling rate resulted in seven beaver colonies in the buffer zone and the 0% culling scenario resulted in 1,000 beaver colonies in the buffer zone. Regardless of culling scenario, the average time for the first beaver to arrive on other side of the 100 km buffer zone was 4 years. [Strength of evidence 2B].

Ecological mitigation and compensation measures

Section summary

- One study was found on ecological mitigation and compensation measures.
- It was moderate strength.
- Exclusion measures can reduce the fatalities of coypu on roads.
- This review cannot make conclusions about the efficacy of ecological mitigation and compensation measures for beavers based on such limited evidence.

Figure 24: Dot plot showing the amount of evidence, strength of evidence, and direction of the evidence found on ecological mitigation and compensation measures; studies with results which could not be categorised by efficacy are not included.

Experimental evidence

No evidence found.

Mixed-method evidence

No evidence found.

Observational evidence

The evidence review identified one observational study that examined ecological mitigation and compensation measures (83). The design of measures are reported in Table 14.

Bager and others (2013) conducted an observational study between 1995 and 2002 that examined the effectiveness of measures designed to reduce the numbers of coypu killed on three sections of a highway road that crossed a federal protection area in Rio Grande do Sul, Brazil (83). The study investigated the change in coypu roadkill rates (number of individuals/km/day) before and after the installation of exclusion fencing and stock guards on two of three sections of road in 1998. The authors reported that roadkill rates of coypu reduced from 8.25/100 km/day to 3.60/100 km/day after the installation ($H_{1,1190}$=31.282; p<0.001), although there was no difference in overall roadkill rates excluding coypu ($H_{1,1190}$=1.769; p=0.184) [Strength of evidence rating 3B].

Table 14: Summary of the design of compensation measures used in observational studies.

Study	Type	Dimensions	Materials
Bager and others (2013)	Road fences	3.4 km fence at section one and 6.8 km at section three (section two [5.5 km] was unfenced); 1.1 m high	Square, 50 mm mesh on bottom 0.65 m and square 100 mm mesh on top 0.45 m of fence

Cost-benefit analysis

No evidence found.

Case studies

No evidence found.

Guidance

No evidence found.

Other study designs

No evidence found.

Discussion

Once native to Britain, beavers provide ecosystem services to humans and other wildlife (1, 2). Their return has been hailed a success by some stakeholders, but others are concerned about the potential for negative impacts caused by beaver activity. This has raised concerns about how negative beaver impacts will be managed, and whether management techniques are effective. This report presents the scientific evidence on beaver management, analyses the strength of the scientific evidence, and identifies areas requiring further research. By assessing the empirical evidence, this project makes science-based conclusions about the effectiveness of management and mitigation actions. The aim of this work is to promote evidence-led management, increased trust from stakeholders, and promote more successful human-beaver coexistence in the medium-long term.

Caveats

This report summarises the results of the evidence review. As such, it presents an objective summary of the scientific evidence. It does not provide guidance around what management option to take or advise about the legal context in specific countries.

Readers in England should note that beavers are a European Protected Species. As such, the conclusions made below should therefore be considered within the legislative context in England. It is also important to consider that when undertaking beaver management, Natural England recommends a hierarchical approach, with the least severe management options being tried first. Management is discussed below in the same order as the hierarchy in Natural England's Beaver Management Framework. Lastly, some management actions require additional environmental permits from the relevant Risk Management Authority. More information on all of the above can be found here: Protection and management of beavers in England - GOV.UK (www.gov.uk).

Readers should also note that this evidence review focuses solely published scientific literature and published or unpublished grey literature. There is extensive knowledge around the efficacy of different beaver management techniques held in practitioner experience. However, the systematic process of producing evidence reviews is not designed to capture these types of evidence; it is only designed to capture documented evidence.

Monitoring

Depending on the time of year and level of activity, beavers can often leave obvious signs of impact on the landscape (4). Monitoring is the first step in Natural England's Beaver Management Framework (84). It can be a valuable tool to assess and manage beaver activity. Evidence suggested that monitoring allowed potential sources of human-beaver conflict to be identified before they occurred. This meant pre-emptive measures could be put in place to prevent those conflicts arising.

Field surveys (foot and canoe), GIS-based monitoring, and remote sensing (e.g., aerial surveys) in particular allowed successful identification of beaver distribution, beaver territory location, and potential management issues. However, there were some limitations. Field surveys were time intensive (27) and remote-sensing imagery had difficulty determining whether lodges were occupied or abandoned (20).

Some monitoring methods were less effective. Camera trapping can be used to track beaver activity, but it had limited success in published studies (26, 28). Thermal imaging was only successful at identifying active beaver lodges under a niche set of conditions (25). Tail-mounted transmitters had poor retention rates and caused negative impacts on beavers' health (18, 19, 21).

Education and stakeholder engagement

It has been 400 years since beavers went extinct in Britain, and most people today lack understanding or experience of living alongside them. This evidence review found that engagement between wildlife managers and stakeholders, and education on how to live alongside beavers helped to resolve human-beaver conflicts. Education and stakeholder engagement increased stakeholder knowledge, promoted successful management techniques, and facilitates better communication and more collaborative decision-making (30-33). This led to more peaceful human-beaver coexistence. However, education and stakeholder engagement was resource intensive and required ongoing commitment (31, 34).

Alongside monitoring, education and stakeholder engagement are the first stage in Natural England's Beaver Management Framework. The evidence found here suggested that they are effective management techniques.

Management of damage to individual trees

Beavers forage plants, including trees and shrubs, feeding on the leaves and bark. Beavers sometimes fell trees to access foliage on higher branches or use tree parts for dam and lodge construction (85). Human-beaver conflict can arise if beavers damage commercially or culturally important trees, ornamental trees, or rare tree species (42, 85). There are, however, a number of interventions, including tree guards and repellents, that can reduce beavers' impact on individual trees.

Tree guards can protect valuable trees. Scientific evidence suggests that tree guards prevent beavers from foraging bark, felling, or otherwise damaging trees (36, 38, 41). Landowners generally support these findings, reporting that tree guards are satisfactory in most scenarios (29, 43). Installing tree guards according to manufacturer guidelines is important to success, and trees with incorrectly installed guards are more easily damaged (41). Efficacy is also better when using heavyweight materials, such as high-density textile tubes or wire mesh/chain link mesh, compared with lighter materials (36, 41). However, lightweight materials, such as elastic mesh, are often less expensive than their heavyweight counterparts, such as plastic or textile tubes. Lightweight materials may therefore be useful in cost-prohibitive scenarios, whereas heavyweight materials may be more appropriate when beavers threaten particularly valuable trees (36). Overall, tree guards offer a useful tool for preventing damage to individual trees.

Repellents can protect trees by leveraging mechanisms that are aversive to beavers. Odour deterrents prevented consumption of sticks (used as a proxy for tree damage) in choice experiments. River otter odour was the most effective but other predator odours were also successful, including red fox, lynx, wolf, brown bear, and human odour (48, 49). Commercial repellents were also effective. Big game repellent liquid/powder, which mimics the scent of predator urine, was the most successful at reducing tree damage. Plantskydd, which acts through a similar mechanism, also reduces tree damage but to a lesser extent (44, 45). Textural repellents (sand and paint mixture) reduced beaver foraging on trees, although one study noted concerns with the toxicity of sand and paint mixtures for beavers (35, 51). Soaking palatable tree species (e.g., aspen) with extract from less palatable trees (e.g., maple) proved ineffective (46). Together this evidence suggests odour and textural repellents protects trees from beaver foraging, but taste deterrents are ineffective. It's unclear whether these methods were cost effective.

Readers in England should note that whilst tree guards can be used by anyone, the majority of the studies on repellents were from the US. As such, the substances used may not be legal in England. More information can be found: Check your product is regulated as a biocidal product - Biocides - HSE. English audiences should also be mindful of the use of pollutants near a watercourse, as per the government guidance: Flood risk activities: environmental permits - GOV.UK (www.gov.uk).

Management of damage to groups of trees

While tree guards and repellents reduced or prevented damage to trees, using these methods over large areas may prove impractical. There are other options for protecting large groups of trees. These include exclusion fencing, buffer zones, and scarer devices.

Exclusion fencing can be constructed around areas of valuable trees. If constructed properly, exclusion fencing can completely prevent beavers from accessing trees within. Evidence suggested that this is the case, with studies reporting that trees within fenced areas sustained no beaver-related damage (35, 37). Landowners corroborated these findings, reporting that exclusion fencing generally prevented tree damage and was an acceptable method of management in most scenarios (29, 43). There were limited data on the cost of exclusion fencing, but NatureScot reported that exclusion fencing cost £27–30/m (including labour), which may make exclusion fencing cost prohibitive in some scenarios or for some landowners (42). Nevertheless, exclusion fencing offers an effective method of managing human-beaver conflicts if budget allows.

Buffer zones consisting of tree species palatable to beavers (e.g., willow) can be used as a barrier between beavers and commercially valuable trees (e.g., oak). Only one study was found on buffer zones. It showed that a buffer of softwoods highly palatable to beaver significantly reduced beaver penetration into commercial hardwood plantations (47). More evidence is needed on this to confirm the efficacy of buffer zones.

Scarer devices that emit light, sound, or an electric shock may offer an alternative method of management. However, experts reported that most scarer devices do not work for more than a few days (53), and landowners found frightening beavers unacceptable (29). Evidence, albeit limited, suggests that light and sound scarer devices do not reduce damage to trees (35). There was limited empirical evidence on electric fencing. Anecdotal evidence and expert opinion suggested that electric fencing is harmful, and often lethal, to beavers and other wildlife (55). It also may not be practical due to the need for daily maintenance (55).

Evidence suggests that beaver-related damage to areas of trees can be reduced using exclusion fencing, and possibly buffer zones. In England, both techniques can be implemented by stakeholders without a licence. Scarer devices do not prevent damage to trees for more than a few days, nor are they recommended for long term use by Natural England due to their harmful effects on wildlife. For more information on the use of scarer devices, including electric fencing, in England, please see: Beavers: how to manage them and when you need a licence - GOV.UK (www.gov.uk).

Management of damage to embankments

Beaver burrowing can cause damage to embankments found alongside waterways or human infrastructure (56). This can cause conflict with humans if it results in flooding or unstable or damaged infrastructure (e.g., railroad tracks). The review identified limited evidence on embankment protection, but initial findings suggest that steel mesh with geomat protects against beaver-related damage to embankments (56). Overall, it is difficult to make conclusions about the effectiveness of this management technique based on limited scientific evidence. English readers should be aware that activities which affect the bank of a watercourse may require an environmental permit from the relevant risk management authority. More information can be found here: Flood risk activities: environmental permits - GOV.UK (www.gov.uk).

Management of flooding

Where water depths are insufficient for beavers to dive away from predators or build underwater entrances to their lodges and burrows, beavers will create dams to raise the water level. This can cause conflict with humans if it results in flooding of human infrastructure or farmland.

Flow devices can maintain the water level at dammed streams or beaver ponds, without negatively affecting beavers' activity. Studies consistently showed that flow devices controlled water levels in most scenarios (5, 20, 34, 42, 57, 58, 65, 69). Landowners supported these findings, reporting that they were generally satisfied with the performance of flow devices (29). Landowners also reported that after the installation of flow devices, they were less likely to turn to more extreme management options (e.g., lethal control) (70). This suggests flow devices alleviate human-beaver conflict and landowners find the solution satisfactory.

Flow devices did fail on occasion. This was most often caused by beavers building secondary dams, which causes higher water levels at the outlet of the flow devices (60). Failures can also be caused by beavers blocking flow devices, insufficient pipe capacity, and lack of routine maintenance also caused flow device failure (53, 60, 63, 70). Where beavers blocked flow devices, this was resolved in most instances by installing a cage over the tube inlet to protect it from beavers (20, 65). The cost of flow devices varied widely across studies, which is likely due to differences in the date and country that flow devices were installed, as well as the different designs of the flow devices. However, results of cost-benefit analyses suggested that flow devices were associated with a net cost saving, as flow devices prevented damage to infrastructure and buildings and reduced costs associated with beaver management (trapping, dam removal, etc) (69, 72). Overall, flow devices manage flooding well in most situations and results in a net cost saving over time. It's unclear which flow device designs are the most effective, and this should be addressed in future research.

Installing flow devices may be undesirable in some situations. For example, the reduction in water levels caused by flow devices may not be enough to resolve human-beaver conflicts or the presence of a dam may be intolerable to a land manager. In these instances, dam removal may be a suitable option. Dam removal can relieve beaver-related impacts (e.g., flooding) in the short term, but as beavers habitually rebuild dams, researchers often reported a recurrence of beaver impacts in the medium-to-long term (26, 57). To permanently remove the dam, humans often had to remove it several times until beavers stop rebuilding (26, 57). Accordingly, landowners had mixed perceptions of dam removal. They found it unacceptable when beaver impacts were minor but more desirable as the severity of beaver impacts increased (29).

Dam notching may provide an alternative to dam removal. It allows water to flow through a gap in the dam and water levels to drop. However, notching is a short-term solution, as beavers will often repair the dam (28).

Both flow devices and dam removal play a role in management of flooding. Flow devices are generally more successful and are deemed more acceptable by landowners than dam removal. Therefore, installation of a flow device is the better first-line defence against flooding. If flow devices fail, dam removal may be a suitable alternative.

For guidance around the use of these interventions in England, readers should refer to: Protection and management of beavers in England - GOV.UK (www.gov.uk), Flood risk activities: environmental permits - GOV.UK (www.gov.uk), and Fisheries offences - GOV.UK (www.gov.uk).

Management of culvert plugging

Beavers sometimes plug culverts, preventing water from flowing effectively. The review identified a number of possible solutions to this problem. These included the installation of culvert fencing, T-culverts, and/or flow pipes.

Culvert exclusion fences aim to prevent beavers from accessing culverts, while also covering a sufficient area to prevent beavers from perceiving movement of water through the culvert. Empirical evidence suggested that culvert exclusion fencing was generally successful at preventing beavers from blocking culverts (60, 70). These findings were supported by comments from experts (28, 72) and landowners (70). One study noted that cylindrical designs were less effective than trapezoidal ones (59). Where culvert exclusion fences failed, this was mainly due to beavers damming the fences, maintenance not being performed, and vandalism (60). As with flow devices, the cost of exclusion fencing varied by study. Results of cost-benefit analyses suggested that erecting culvert exclusion fencing resulted in a net cost saving, by reducing management costs associated with unblocking and repairing culverts and infrastructure (e.g., roads, etc) (69, 72). The evidence suggests that culvert exclusion fences are an effective management method.

T-culverts play a similar role to exclusion fencing: preventing beavers from accessing culverts and perceiving movement of water through culverts. T-culverts weren’t examined in any robust experimental or observational studies. However, the results of several case studies suggested that they prevent plugging of culverts by beavers (53, 67, 68). T-culverts required routine maintenance to prevent the intake/fencing from being blocked by debris (53).

For guidance around the use of these interventions in England, readers should refer to: Protection and management of beavers in England - GOV.UK (www.gov.uk), Flood risk activities: environmental permits - GOV.UK (www.gov.uk), and Fisheries offences - GOV.UK (www.gov.uk).

Management of water systems

During beavers’ absence from Britain, humans have made significant changes to natural waterways. Humans have drained areas of land below sea level, built on flood plains, and developed complex water infrastructure systems. As beavers colonise these highly modified landscapes, humans need to be able to continue to manage water at catchment scales. For instance, water companies can be required by regulators to periodically release large volumes of water into water courses to test storm drainage infrastructure capability. However, since modern systems of water management have not coexisted with beavers in Britain, the effects of these systems on beavers are unknown.

Empirical evidence from other countries suggested that water level fluctuations are harmful to individual beaver families but are unlikely to impact upon beavers at the population scale. Water level variations caused lodge abandonment, stress, loss of condition (particularly in beaver kits), and decreased reproduction (73, 74, 76). However, whilst water level fluctuations caused some beaver mortality and reproductive failure, beaver populations were resilient and continued to grow (74). This suggests that water level management at large scales affects individual beaver welfare, but it is unlikely to impact upon their favourable conservation status as a population.

Initial scientific evidence suggests that there are adjustments water managers could make to reduce the impacts of water level management on beavers. One study noted that the timing of water level fluctuations was crucial. The researchers recommended spreading water level changes out over a longer period of time to make changes less abrupt (74). The researchers also recommended timing water changes so that they did not exacerbate natural fluctuations (74). For example, land managers should not significantly reduce water levels in summer, when water levels are already low and beaver lodge entrances risk being exposed. Conversely, land managers should not significantly raise water levels during flood events in winter, when beavers are at risk of having their lodges flooded and dams washed away. A study on muskrats found that where human alteration of water levels was unavoidable, riparian buffers significantly improved the chance of muskrat survival because it gave them land to escape to when water levels were raised (77). Beavers have similar behaviour to muskrats and riparian buffers could help reduce the impact of water fluctuations on beavers.

Overall, early scientific research indicates that large-scale water level management might harm individual beaver welfare, but it is unlikely to affect their conservation status as a species. There are potential adjustments water managers can make to reduce the impacts on beavers, although further research is needed on this.

Translocation and lethal control

If land managers are unable to employ the management methods described above, it may be necessary to use more extreme methods of management. These include trapping, translocation, and lethal control. In England, these activities can only be carried out by a specially trained and licensed person. They can only occur when there is no suitable alternative and they do not affect the favourable conservation status of beavers. English readers should note that most of the studies the review identified on trapping came from the US. These studies used a mixture of trapping methods, the majority of which are not legal in England. The only type of trap which is legal for beavers in England is the Bavarian beaver trap[21]. However, the Hancock trap, a type of live trap used in the US, is a very similar design to the Bavarian beaver trap.

In the studies reviewed, live trapping was generally carried out using Hancock traps and/or snares. Most empirical evidence suggested that traps had a low capture rate (60, 70, 80). Additionally, experts report that trapping is only effective in the short term, as beavers will often repopulate trapped sites (53). Initial evidence also suggests that widespread trapping results in increases overall reproductive rates of beavers, leading to a subsequent resurgence in their population (81). Trapping also caused unintended mortality of 5–16% of captured beavers (75, 79). However, landowners still found trapping an acceptable form of management in most scenarios

If beavers have been successfully trapped, they can be moved to a more suitable area. Transporting beavers can cause mortality, although the rate is relatively low at approximately 5%. Beavers are also at an increased risk of predation when they are moved to unfamiliar areas. There was limited evidence on this topic, but initial data from the US suggest that ~30% of translocated beavers died within six months (79)[22]. Beavers that survived often moved outside of the target area (79). Due to death and beaver emigration, one study found that it took 17 beavers to get one pair of beavers to successfully colonise a designated site following translocation (79). This study also found that the translocation of kits and yearlings was unsuccessful. All kits and yearlings either died or moved outside of the target area (79).

If trapped beavers are not translocated, the other option is that they are culled. Culling appears to have limited success as a management strategy. Evidence from scientific studies suggests that beaver colonies can be successfully removed from sites, but if there is a local beaver population, beavers often re-establish at the culled site (52). Therefore, land managers need to continuously cull beavers as new beavers recolonise their sites (71). Landowner opinion on the efficacy and acceptability of culling was divided, with landowners reporting that culling generally resolves beaver-related impacts but is unacceptable in most scenario (29, 43). Evidence suggests that culling was not cost-effective compared with non-lethal management interventions (e.g., culvert protection and flow devices) (71). This is likely because culling is a short-term solution and requires sustained efforts as beavers recolonise no tolerance sites.

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[21] The main brand of trap used to catch beavers live in Europe. It consists of a large cage, the door closing as the animal walks inside and triggers the release of a weighted spring.

[22] Most evidence on the mortality of beavers after translocation is from the USA, where there are more apex predators that hunt beavers (coyote, bears, etc) than in Britain. Post-translocation mortality may therefore be lower in the Britain than the USA.

Readers in England should note that trapping, translocation, and lethal control are strongly discouraged by Natural England's licensing regime and are considered a last resort. Guidance on the use of these interventions can be found here: [Protection and management of beavers in England - GOV.UK (www.gov.uk).]

Mitigation of the impacts of development on beavers

No scientific evidence was found on how best to mitigate the impact of infrastructure development on beavers, aside from one study that showed that exclusion fencing and stock guards can reduce fatalities of coypu on roads (83). This review can therefore make no conclusions about whether ecological mitigation and compensation measures work for beavers based on such limited evidence. This evidence gap should be addressed through future research.

Data gaps

The evidence review identified several gaps in the empirical evidence for the following management methods:

- Scarer devices,
- Electric fencing,
- Buffers of preferred tree species,
- Embankment protection,
- Lodge removal and burrow infilling,
- Measures to mitigate for the impacts on infrastructure development on beavers.

Note that the list above refers to gaps in the empirical data. There may be expert knowledge or guidance that addresses these gaps, but the systematic process of producing evidence reviews is not designed to capture these types of evidence.

Future research is needed to fill in these empirical evidence gaps. This can be achieved through further primary studies of management interventions, as well as surveys of experts to capture their existing knowledge.

Limitations of included studies

Critical appraisal of the strength of evidence showed that most of the studies included in the review were weak strength. Most management interventions had at least one strong strength study, but studies on flow devices and dam removal were all weak-to-moderate strength.

There were some areas of consistent weakness:

- Many studies did not fully report their findings – sometimes focusing only on significant results – which made it difficult to interpret the studies.
- Most studies did not report the effect of management on non-target species.
- Most studies did not use (or did not report methods for) randomised sampling.
- Studies that used questionnaires either did not pre-test/pilot the questionnaire or did not report pre-test/pilot the questionnaire.
- Most studies did not report confounding factors and their effect on the dependent variable. This was particularly an issue with uncontrolled studies, which generally struggle to provide a concrete link between intervention and outcome.
- Most studies did not report the short-term and long-term effect of management.

Limitations of the review

This rapid evidence review has limitations, and the results of the review should be interpreted with these in mind.

Screening and data extraction were carried out by a single reviewer. Including a second reviewer in the screening process may have yielded additional relevant studies. However, quality control checks were carried out on 10% of papers by a second reviewer and screening decisions found to be consistent.

While the review did not have restrictions on the publication language, the searches were carried out in English, which make it less likely that relevant, non-English language publications would be identified. This was, in part, mitigated by supplementary searches of reference lists of eligible publications and foreign databases, but it is likely that some relevant foreign-language publications were missed.

Inter-study heterogeneity may have affected the interpretation of the findings. However, as the study and intervention characteristics and baseline data were often underreported, it was difficult to assess the impact of heterogeneity on the results.

This review converted all cost data to 2023 GBP. Some studies did not accurately report the date of the reported currency (e.g., 2018 USD, 2012 Euros). In these cases, the reviewers estimated the date of the reported currency using median of the trial dates (i.e., point between the start date and end date) or, if this information was not available, the publication date. The estimates may have been inaccurate in some cases, and this could lead to an conversion error from the original currency to 2023 GBP.

Lastly, like many other fields in conservation, beaver management has a lot of knowledge which is held in practitioner experience and not documented in scientific literature. There are experts who have spent decades successfully managing beaver impacts. However, where this knowledge has not been tested by science and published in peer-reviewed literature, the review has been unable to consider it. An evidence review is not able to assess expert opinion or undocumented evidence. This means that there are management areas which look like they have a knowledge gap, but in fact a significant amount is known by practitioners, it just hasn’t been scientifically researched.

Conclusions

This report reviews the scientific evidence on beaver management.

Monitoring and education detect and pre-empt challenges and conflict between humans and beavers. Education also corrects misinformation and teaches stakeholders about the benefits and disbenefits of beavers, which improves human-beaver co-existence. Given that education and monitoring are the first step in Natural England's Beaver Management Framework and have a minimal impact on beaver welfare, most land landowners' will be able to incorporate these methods into their beaver management strategy.

If monitoring reveals that beavers are causing undesirable effects, such as tree damage, blocked culverts, and increased water levels, land/water managers can use various techniques to manage beavers' impacts. The review found that flow devices, odour and textural repellent, tree guards, exclusion fencing, culvert fencing, and beaver-proof culvert ends (e.g., T-culverts) reduce beaver-related impacts. Dam removal may also be effective in some scenarios, although beavers often try to rebuild removed dams.

If the former methods fail to resolve conflict between humans and beavers, trapping and culling can be used to manage beavers. However, these methods have limited success as beavers often repopulate trapped and culled areas, and there are restrictions on the use of these interventions in England and Natural England's licensing regime recommends that they are only used as a last resort.

The review also identified several interventions that had no effect – or at best a short-term effect – on beaver foraging behaviour. These include repellents that do not rely on odour or texture, electric shock devices, and scarer devices.

Some interventions were potentially effective but lack scientific evidence to support their use. These include tree buffers, embankment protection with steel mesh mats, lodge removal and infilling burrows, and ecological compensation measures.

Most of the management interventions identified in this review would benefit from further research. As already mentioned, several interventions lacked sufficient evidence on their efficacy. Furthermore, some of the interventions that had been researched extensively were supported by weak evidence (Figure 5). In areas where there is either a lack of scientific evidence or a lack of robust evidence, further well-designed studies would aid decision making in the future.

In summary, the evidence presented in this review improves our understanding of beaver management – and shows areas where evidence gaps still exist. Natural England hopes this knowledge can be used to support successful human-beaver co-existence.

References

1. BRAZIER, R. E., PUTTOCK, A. K., GRAHAM, H. A., AUSTER, R. E., DAVIES, K. & BROWN, C. 2020. Beaver: Nature's ecosystem engineers. *WIREs Water,* 8**,** e1494.

2. COLES, B. J. 2006. Beavers in Britain's Past.

3. HEYDON, M. J. A., POUGET, D. A., GRAY, S. A., WAGSTAFF, G. A., ASHTON, M. E. M. A. & ANDISON, E. B. Natural England. 2021. Beaver reintroductions in England: 2000–2021 (JP036).

4. CAMPBELL-PALMER, R., PUTTOCK, A., NEEDHAM, R. N., WILSON, K., GRAHAM, H. & BRAZIER, R. E. 2021. Survey of the Tayside Area Beaver Population 2020–2021 (NatureScot Research Report 1274).

5. BRAZIER, R. E., ELLIOTT, M., ANDISON, E., AUSTER, R. E., BRIDGEWATER, S., BURGESS, P., CHANT, J., GRAHAM, H., KNOTT, E., PUTTOCK, A. K., SANSUM, P. & VOWLES, A. 2020. River Otter Beaver Trial: Science and Evidence Report.

6. PUTTOCK, A., GRAHAM, H. A., ASHE, J., LUSCOMBE, D. J. & BRAZIER, R. E. 2020. Beaver dams attenuate flow: A multi-site study. *Hydrological Processes***,** e14017.

7. PUTTOCK, A., GRAHAM, H. A., CARLESS, D. & BRAZIER, R. E. 2018. Sediment and nutrient storage in a Beaver engineered wetland. *Earth Surface Processes and Landforms,* 43**,** 2358-2370.

8. LAW, A., GAYWOOD, M. J., JONES, K. C., RAMSAY, P. & WILLBY, N. J. 2017. Using ecosystem engineers as tools in habitat restoration and rewilding: Beaver and wetlands. *Science of the Total Environment***,** 605-606, 1021-1030.

9. VERISSIMO, D. & ROSETA-PALMA, C. 2023. Rewilding with the Beaver in the iberian peninsula – Economic potential for river restoration. *Nature-Based Solutions,* 3**,** 100055.

10. O'MAHONEY, K. 2020. Blurring Boundaries: Feral rewilding, biosecurity and contested boar belonging in England. *Conservation & Society,* 18**,** 114–125.

11. 2023. *Protected Species* [Online]. NatureScot. Available: https://www.nature.scot/professional-advice/protected-areas-and-species/protected-species/protected-species-z-guide/protected-species-Beavers [Accessed 22/05/2023].

12. WALES, N. R. 2023. *Beaver licensing* [Online]. Available: https://naturalresources.wales/permits-and-permissions/species-licensing/list-of-protected-species/Beaver-licensing/?lang=en [Accessed 31/05/2023].

13. HALLEY, D. J., SAVELJEV, A. P. & ROSELL, F. 2020. Population and distribution of Beavers, Castor fiber and Castor canadensis in Eurasia. *Mammal Review*.

14. HOWE, C. V. Natural England. 2020. A review of the evidence on the interactions of Beavers with the natural and human environment in relation to England (NEER017).

15. AUSTER, R. E., PUTTOCK, A. & E., B. R. 2019. Unravelling perceptions of Eurasian Beaver reintroduction in Great Britain. *Area,* 52**,** 364–375.

16. INMAN, A. Natural England. 2021. Social dimensions of Beaver reintroduction in England: qualitative research pilot (NECR323).

17. MUPEPELE, A. C., WALSH, J. C., SUTHERLAND, W. J. & DORMANN, C. F. 2016. An evidence assessment tool for ecosystem services and conservation studies. *Ecological Applications,* 26**,** 1295-1301.

18. WINDELS, S. K. & BELANT, J. L. 2016. Performance of tail-mounted transmitters on American beavers Castor canadensis in a northern climate. *Wildlife Biology*.

19. SMITH, J. B., WINDELS, S. K., WOLF, T., KLAVER, R. W. & BELANT, J. L. 2016. Do transmitters affect survival and body condition of American beavers Castor canadensis? *Wildlife Biology*.

20. HOOD, G. A. & YARMEY, N. Edmonton: University of Alberta. 2015. Mitigating Human–Beaver Conflicts Through Adaptive Management.

21. MORTENSEN, R. M. & ROSELL, F. 2020. Long-term capture and handling effects on body condition, reproduction and survival in a semi-aquatic mammal. *Scientific Reports,* 10.

22. CAMPBELL-PALMER, R., PUTTOCK, A., WILSON, K. A., LEOW-DYKE, A., GRAHAM, H. A., GAYWOOD, M. J. & BRAZIER, R. E. 2021. Using field sign surveys to estimate spatial distribution and territory dynamics following reintroduction of the Eurasian Beaver to British River catchments. *River Research and Applications,* 37**,** 343-357.

23. ZHANG, W., HU, B., BROWN, G. & MEYER, S. 2023. Beaver pond identification from multi-temporal and multi- sourced remote sensing data. *Geo-Spatial Information Science*.

24. RIBIC, C. A., DONNER, D. M., BECK, A. J., RUGG, D. J., REINECKE, S. & EKLUND, D. 2017. Beaver colony density trends on the Chequamegon Nicolet National Forest, 1987–2013. *PLoS ONE,* 12**,** e0170099.

25. JANUSZEWICZ, M., MISIUKIEWICZ, W., JANISZEWSK, P. & FOLBORSKI, J. 2018. Methodological requirements for identifying lodges colonized by european beavers castor fiber l. With the use of thermal imaging technology - preliminary results. *Polish Journal of Natural Sciences,* 33**,** 7-16.

26. BOS, D., DIJKSTRA, V. & DE JONGE, C. 2022. Ecological working protocol beaver excavation railway embankment Taarlo.

27. Water board De Stichtse Rijnlanden; Water board Amstel Gooi; Vecht Water board; Vallei and Veluwe Rivierenland water board; Rijkswaterstaat Union of Water Boards; Fauna Management Unit; and Utrecht Mammal Society. 2023. Beaver protocol for water managers in the province of Utrecht.

28. NatureScot. 2022. Beavers in Scotland - Environmental Report Addendum 2022.

29. MORZILLO, A. T. & NEEDHAM, M. D. 2015. Landowner Incentives and Normative Tolerances for Managing Beaver Impacts. *Human Dimensions of Wildlife,* 20, 514-530.

30. AUSTER, R. E., BARR, S. W. & BRAZIER, R. E. 2022. Beaver Management Groups: Capturing lessons from the River Otter Beaver Trial and River Tamar Catchment. London: Department for Environment and Rural Affairs (DEFRA).

31. AUSTER, R. E., PUTTOCK, A. K., BARR, S. W. & BRAZIER, R. E. 2023. Learning to live with reintroduced species: beaver management groups are an adaptive process. *Restoration Ecology*.

32. AUSTER, R. E., BARR, S. W. & BRAZIER, R. E. 2021. Improving engagement in managing reintroduction conflicts: learning from beaver reintroduction. *Journal of Environmental Planning and Management,* 64, 1713-1734.

33. CHARNLEY, S., GOSNELL, H., DAVEE, R. & ABRAMS, J. 2020. Ranchers and beavers: understanding the human dimensions of Beaver-related stream restoration on western rangelands. *Rangeland Ecology & Management,* 73, 712-723.

34. POLLOCK, M. M., LEWALLEN, G. M., WOODRUFF, K., JORDAN, C. E. & CASTRO, J. M. 2018. The Beaver Restoration Guidebook.

35. NOLTE, D. L., LUTMAN, M. W., BERGMAN, D. L., ARJO, W. M. & PERRY, K. R. Feasibility of non-lethal approaches to protect riparian plants from foraging beaver in North America. Rats, Mice and People: Rodent Biology and Management, 2003.

36. RUNDE, D. E., NOLTE, D. L., ARJO, W. M. & PITT, W. C. 2008. Efficacy of individual barriers to prevent damage to Douglas-fir seedlings by captive mountain beavers. *Western Journal of Applied Forestry,* 23, 99-105.

37. KAMCZYC, J., BIELACHOWICZ, M. & PERS-KAMCZYC, E. 2016. Damages caused by European beaver (Castor fiber L., 1758) in broadleaved stands. *Forestry Letters,* 109, 7-10.

38. SHEFFELS, T. R., SYTSMA, M. D., CARTER, J. & TAYLOR, J. D. 2014. Efficacy of plastic mesh tubes in reducing herbivory damage by the invasive nutria (Myocastor coypus) in an urban restoration site. *Northwest Science,* 88, 269-279.

39. BRETON, V., FORESTIER, O., GUINDON, O. & EVETTE, A. 2014. Ecological restoration under pressure from invasive animal species: use of Salicaceae cuttings in a river bank overrun by coypu. *River Research and Applications,* 30, 1002-1012.

40. LOEB, R. E., KING, S. & HELTON, J. 2014. Human pathways are barriers to beavers damaging trees and saplings in urban forests. *Urban Forestry & Urban Greening,* 13, 290-294.

41. WESTBROOK, C. J. & ENGLAND, K. 2022. Relative effectiveness of four different guards in preventing Beaver cutting of urban trees. *Environmental Management,* 70, 97-104.

42. NatureScot. 2021. Beaver Management Report for 2020.

43. WILLGING, B. & SRAMEK, R. Urban Beaver Damage and Control in Dallas-Fort Worth Texas. Ninth Great Plains wildlife damage control workshop proceedings, April 17-20 1989 Fort Collins, Colorado.

44. DUBOW, T. J. 2000. *Reducing beaver damage to habitat restoration sites using palatable tree species and repellents | Chapter 3 Reducing beaver damage to habitat restoration sites using less palatable tree species and repellents.* Utah State University.

45. DUBOW, T. J. 2000. *Reducing beaver damage to habitat restoration sites using palatable tree species and repellents | Chapter 4 Protecting trees planted for stream habitat restoration from beaver.* Utah State University.

46. MÜLLER-SCHWARZE, D., SCHULTE, B. A., SUN, L., MÜLLER-SCHWARZE, A. & MÜLLER-SCHWARZE, C. 1994. Red maple (Acer rubrum) inhibits feeding by beaver (Castor canadensis). *Journal of Chemical Ecology,* 20**,** 2021-2034.

47. MIKULKA, O., ADAMEC, Z., KAMLER, J., HOMOLKA, M., DRIMAJ, J., PLHAL, R. & PETR, P. 2022. Using deciduous softwoods to protect commercial forest stands against damage by Eurasian beaver (Castor fiber L.). *Forest Ecology and Management,* 520.

48. ROSELL, F. & CZECH, A. 2000. Responses of foraging Eurasian beavers Castor fiber to predator odours. *Wildlife Biology,* 6**,** 13-21.

49. ENGELHART, A. & MÜLLER-SCHWARZE, D. 1995. Responses of beaver (Castor canadensis Kuhl) to predator chemicals. *Journal of Chemical Ecology,* 21**,** 1349-1366.

50. WELSH, R. G. & MÜLLER-SCHWARZE, D. 1989. Experimental habitat scenting inhibits colonisation by beaver, Castor canadensis. *Journal of Chemical Ecology,* 15**,** 887-893.

51. Miistakis Institute. Textural Beaver Repellent for Tree Protection – Toxicity Research Update.

52. HARPER, J., NOLTE, D. L., DELIBERTO, T. J. & BERGMAN, D. Conditioning beaver to avoid desirable plants. Proceedings of the 11th Wildlife Damage Management Conference, 2005.

53. NOLTE, D., ARNER, D. H., PAULSON, J., JONES, J. C. & TRENT, A. Missoula Technology and Development Center. 2005. How to keep beavers from plugging culverts.

54. ANGST, C. Swiss Federal Railways SBB. 2022. Beaver and SBB railroad infrastructure: Measures and prevention.

55. CAMPBELL-PALMER, R. & PIZZI, R. 2025. Considerations for the use of Electric Fencing in Beaver Mitigation.

56. MANDAVKAR, S., DI PIETRO, P. & WELDU, M. Steel wire mesh reinforced Geomat for embankment damage protection from rodents and burrowing animals. 2017. Association of State Dam Safety Officials, 383-392.

57. LAMSODIS, R. 2011. Attempt to manage after-effects of beaver impounding activities in drainage systems: one trial assay. *Irrigation and Drainage,* 60**,** 207-215.

58. ROBLEE, K. J. 1984. Use of corrugated plastic drainage tubing for controlling water levels at nuisance beaver sites. *New York Fish and Game Journal*.

59. CALLAHAN, M. 2003. Beaver management study.

60. CALLAHAN, M. 2005. Best management practices for beaver problems.

61. NOLTE, D., SWAFFORD, S. R. & SLOAN, C. A. Survey of factors affecting the success of Clemson beaver pond levellers installed in Mississippi by Wildlife Services. Proceedings of Wildlife Damage Management Conference, 2000. 120-125.

62. HOOD, G. A., MANALOOR, V. & DZIOBA, B. 2018. Mitigating infrastructure loss from beaver flooding: A cost–benefit analysis. *Human Dimensions of Wildlife,* 23**,** 146-159.

63. WOOD, G. W. & WOODWARD, L. A. The Clemson beaver pond leveller. Proceedings of Annual Conference of Southeastern Association of Fish and Wildlife Agencies, 1992. 179-187.

64. BAILEY, D. R., DITTBRENNER, B. J. & YOCOM, K. P. 2018. Reintegrating the North American Beaver (Castor canadensis) in the urban landscape. *Wiley Interdisciplinary Reviews: Water,* 6.

65. BRUINSMA, D. 2020. Human-Beaver Conflict Management: Water Level Control Device Summary. Elk Island National Park.

66. JENSEN, P. G., CURTIS, P. D., LEHNERT, M. E. & HAMELIN, D. L. 2001. Habitat and structural factors influencing beaver interference with highway culverts. *Wildlife Society Bulletin,* 29**,** 654-664.

67. OEL, S. & GALLANT, M. 2019. Foothills County Beaver Mitigation Projects.

68. ROBLEE, K. J. The use of the T-culvert guard to protect road culverts from plugging damage by beavers. Proceedings of the Eastern Wildlife Damage Control Conference, 1987. 25-33.

69. BOYLES, S. L. & SAVITZKY, B. A. An analysis of the efficacy and comparative costs of using flow devices to resolve conflicts with North American beavers along roadways in the coastal plain of Virginia. Proceedings of the Vertebrate Pest Conference 23, 2008.

70. SIMON, L. J. Solving beaver flooding problems through the use of water flow control devices. Proceedings of the 22nd Vertebrate Pest Conference, 2006 University of California.

71. CALLAHAN, M., BERUBE, R. F. E. & TOURKANTONIS, I. P. W. S. 2019. Billerica Municipal Beaver Management Program 2000 - 2019 Analysis.

72. LISLE, S. Beaver management at the Penobscot nation, USA: using flow devices to protect property and create wetlands. Proceedings of the 2nd European Beaver Symposium, 2001. 147-156.

73. FELDMAN, M. J., GIRONA, M. M., GROSBOIS, G. & PIETREK, A. G. 2020. Why do beavers leave home? Lodge abandonment in an invasive population in Patagonia. *Forests,* 11.

74. SMITH, D. W. & PETERSON, R. O. Omaha: US Department of the Interior, National Park Service, Midwest Regional Office. 1988. The Effects of Regulated Lake levels on Beaver in Voyageurs National Park Minnesota.

75. BRECK, S. W., WILSON, K. R. & ANDERSEN, D. C. 2001. The demographic response of bank-dwelling beavers to flow regulation: a comparison on the Green and Yampa rivers. *Canadian Journal of Zoology,* 79**,** 1957-1964.

76. PAȘCA, C., IONESCU, G., POPA, M., IONESCU, O. & IONESCU, D. T. 2011. Aspects regarding water level fluctuation influence on European beaver (Castor fiber) eco-ethology - case study. Brașov: Transilvania University Press.

77. AHLERS, A. A., SCHOOLEY, R. L., HESKE, E. J. & MITCHELL, M. A. 2010. Effects of flooding and riparian buffers on survival of muskrats (Ondatra zibethicus) across a flashiness gradient. *Canadian Journal of Zoology,* 88**,** 1011-1020.

78. SHWIFF, S. A., KIRKPATRICK, K. N. & GODWIN, K. 2011. Economic evaluation of beaver management to protect timber resources in Mississippi. *Human-Wildlife Interactions,* 5**,** 306-314.

79. MCKINSTRY, M. C. & ANDERSON, S. H. 2002. Survival, fates, and success of transplanted beavers, Castor canadensis, in Wyoming. *Canadian Field-Naturalist,* 116**,** 60-68.

80. JUSIM, P., GOIJMAN, A. P., ESCOBAR, J., CARRANZA, M. L. & SCHIAVINI, A. 2020. First test for eradication of beavers (Castor canadensis) in Tierra del Fuego, Argentina. *Biological Invasions,* 22**,** 3609-3619.

81. GONZÁLEZ-CALDERÓN, A. & SCHIAVINI, A. 2022. Reproductive rates of invasive Castor canadensis respond to management in Tierra del Fuego, Argentina. *Mammalian Biology,* 102**,** 1867-1878.

82. PIETREK, A. G., BOOR, G. K. H. & MORRIS, W. F. 2017. How effective are buffer zones in managing invasive beavers in Patagonia? A simulation study. *Biodiversity and Conservation,* 26**,** 2591-2605.

83. BAGER, A. & FONTOURA, V. 2013. Evaluation of the effectiveness of a wildlife roadkill mitigation system in wetland habitat. *Ecological Engineering,* 53**,** 31-38.

84. Beaver management regulation and licensing in England using Class Licence 52 or 51 (CL52 / CL51). Natural England.

85. *Protecting trees from beavers using wire mesh* [Online]. NatureScot. . [Accessed 15/04/2024].

Glossary

Term	Definition
95% confidence interval	A range of values, spanning the estimated mean, that is 95% likely to contain the actual population mean.
Academic databases	Online databases that contain records of academic literature (e.g., academic articles, conference abstracts, etc).
Academic literature	Peer-reviewed papers from scientific journals or books.
Agri-environment schemes	Programs that incentivize land managers to look after and improve the countryside.
Bavarian beaver trap	The main brand of trap used to catch beavers live in Europe and the only legal method of trapping beavers in the UK. It consists of a large cage, the door closing as the animal walks inside and triggers the release of a weighted spring.
Beaver burrow	A series of underground channels and chambers occupied by beavers. Burrows are usually dug into a riverbank and have one or more entrances below the level of the water.
Beaver channel	A narrow groove dug by a beaver to provide safe access to feeding sites.
Beaver lodge	A 'home' occupied by beavers, dome shaped and made of sticks, branches, mud, etc. They are usually located beside a beaver pond and have an underwater entrance.
Beaver slide	A slick muddy trail where a beaver has slid from a riverbank into the water. A 'slide' can form part of a beaver channel.
Biodiversity	The variety of organisms in a particular habitat or area.

Term	Definition
Body grip trap	A type of lethal trap used in North America. It consists of two rectangular frames with a trigger, that when activated, slam shut on the body.
Carbon sequestration	The process by which carbon dioxide is removed from the atmosphere and held in solid or liquid form.
Case study	A detailed description of a particular person, group, or situation.
Castor Master	A brand of flow device commonly used in the USA.
Clemson pond leveller	A brand of flow device commonly used in the USA.
Cost-benefit analysis	The process of comparing the projected or estimated costs and benefits of an intervention.
Critical appraisal	A systematic method used to assess the strength of a study and its results.
Ecological mitigation and compensation measures	Interventions meant to moderate the conflict between conservation and development objectives.
Ecological niche	The environmental conditions a species inhabits and the role it plays within an ecosystem.
Ecosystem	A biological community of interacting organisms and their environment.
Ecosystem engineer	An organism that creates, modifies, or destroys a habitat.
Effect estimate	A value measuring the magnitude of the intervention effect.
Effective	A medium-long term situation which minimises cost, time, and other resource requirements; supports the development of healthy and sustainable beaver populations; maximises the benefits of beavers to other

Term	Definition
	species (including humans); minimises the costs of beavers to other species (including humans); responds to risks and/or conflicts early and reasonably from the perspective of all stakeholders (human and non-human); and therefore facilitates the successful coexistence of humans and beavers.
Eligibility criteria	A set of requirements that can be used by researchers to determine whether a study should be included in or excluded from review.
Empirical evidence	Information gathered through observation or experimentation that is used to prove or disprove a hypothesis.
Exclusion fence	A fence or barrier that denies beavers access to a group of trees or an area of land.
Experimental study	Any study in which an intervention (treatment, procedure, or programme) is intentionally introduced by researchers, who then observe the results.
Explanatory variable	A variable that explains variation in the outcome variable.
Flow device	A tool used to control the depth of water upstream of a beaver dam. They usually consist of a flow pipe, with or without a protective cage.
Genetic management	Actions to ensure the genetic health of a population.
Geographic information system-based monitoring	A system designed to capture, store, manage, analyse, manipulate, and present geographical and spatial data.
Geospatial analysis	A form of computational analysis that leverages geographic information, spatial data, location data, high-resolution imagery, computer vision, and AI.

Term	Definition
Grey literature	Published or unpublished data produced outside of academic channels.
Habitat	The natural home of an animal, plant, or other organism.
Hancock trap	The main brand of trap used to catch beavers live in North America. Like a Bavarian beaver trap, it consists of a large cage, the door closing as the animal walks inside.
Herbivory	The consumption of plant material by animals.
Impact scenario	A situation where a beaver (or other species) is causing an impact on humans, the environment, or other species.
Intervention	A treatment, project, programme, or procedure intended to change, improve, or maintain the current state of a person, organism, habitat, etc.
Kaplan-Meier survival analysis	A statistical approach that estimates the proportion of subjects surviving for a given time after intervention.
Longitudinal study	A study in which subjects are followed over time.
Management of beaver impacts	Activities undertaken to reduce the occurrence and severity of beaver impacts that cause conflicts with humans. It is associated with any attempts to avoid, reduce, minimise, or contain negative beaver impacts.
Meta-analysis	A quantitative review, involving the statistical combination of results from multiple studies to determine overall effect size.
Mixed-method study	A study that uses two or more research methods (observational, experimental, cost-benefit, etc).

Term	Definition
Modelling study	An investigation of a scientific phenomenon through the construction of a mathematical model.
Monitoring	Any method used to observe beavers, beaver habitats, behaviours, or beaver impacts.
Negative beaver impact	A situation where a beaver impact causes an undesirable effect for humans.
Observational study	Any study where researchers observe the effect of an intervention or exposure – without trying to change who or what is exposed.
P value	A measure that describes the probability of the outcome observed being the result of chance. $P < 0.05$, for example, means a less than 5% probability the outcome would have been observed by chance.
Peer-reviewed literature	Literature that is assessed by other scientists or experts working in the subject area.
Pond leveller	The common term for a flow device in North America.
Positive multiplier effect	When an initial change triggers a series of changes that lead the size of the outcome to be bigger than the size of the initial change.
Primary publication	Publication of trial or study results for the first time.
Rapid evidence assessment/review	A systematic method of finding and synthesising evidence on a topic.
Remote sensing	The process of detecting and monitoring the characteristics of an area or habitat by satellite or aircraft.

Term	Definition
Repellent	A compound with an aversive taste, texture, odour, etc, that is designed to dissuade beavers from occupying an area or felling trees.
Riparian	The area next to a natural watercourse.
Science	The systematic study of something through observation, experimentation, and the testing of theories against evidence.
Scientific	Based on the principles of science.
Snare	A type of animal trap consisting of thin wire noose which tightens as the animal wriggles in it. Can be lethal or non-lethal depending on the snare design.
Snowballing approach	Where current subjects (e.g. scientific papers) are used to identify additional subjects.
Stakeholder	An individual or group involved with or with an interest in, a system, project, organisation, etc.
Standard deviation	Quantifies the variation within a set of measurements.
Standard error	A measure of how spread out the data are around the mean.
Strength of the evidence	A measure of the quality of a study, method, or outcome.
Telemetry device	A device that automatically collects, transmits, and measures data from remote sources.
Thermographic measurement	The use of equipment to study the heat distribution of a habitat, organism, structure, etc.
Translocation	Movement of living organisms from one area to another by humans.

Term	Definition
Tree buffer	A group of trees that separates beavers from commercial land, important trees, etc. Tree buffers generally contain palatable tree species, such as willow, to attract beavers' attention.
Tree guard	A device, usually made from wire mesh, plastic, or fabric, that is wrapped around a tree to protect from herbivory.
Tree paint	A paint mixture, usually paint and sand, with a texture that beavers find aversive that is applied to trees.
Trophic cascade	The progression of indirect effects by predators across successively lower levels in the food web.
Willingness to pay	The motivation of stakeholders to pay for the benefit of an intervention or to avoid the cost of an impact.

Appendices

Appendix A: Search strategy

Scopus search strategy:

((((((TITLE-ABS-KEY ((beaver* OR "Castor canadensis" OR "Castor fiber" OR muskrat* OR “Ondatra zibethicus” OR coypu* OR nutria OR “Myocastor coypus”))) AND (TITLE-ABS-KEY (manag* OR mitigat* OR compensat* OR control* OR notch* OR remov* OR destr* OR alter* OR fenc* OR electric* OR barrier* OR wir* OR mesh* OR piling* OR "rock armour" OR "artificial burrow" OR filter* OR drain* OR pipe* OR guard* OR grill* OR camera* OR infil* OR trap* OR ripar* OR plant* OR "flood bank" OR deter* OR scar* OR fright* OR repel* OR educat* OR captur* OR move* OR translocat* OR kill* OR "in stream" OR "tree guard*" OR "area fenc*" OR "exclusion fenc*" OR "electric fenc*" OR "tree paint" OR "scar device*" OR "dam alter*" OR "dam remov*" OR "bank wall prot*" OR burrow* OR lodge* OR "riparian buffer*" OR "protection of water" OR "human toleranc*" OR organism* OR frequenc* OR flood* OR river* OR erosion* OR "tree fell*" OR trout OR salmon OR cost* OR crop* OR welfare OR population* OR conservation* OR shoot* OR cull* OR lethal OR euthani?e OR pay* OR recompense OR reimburs* OR remunerat* OR redress* OR avoid* OR protect* OR licen?* OR (burrow* W/5 prevent*) OR (level* W/5 water) OR (water W/5 monitor*) OR (water W/5 manag*) OR (flow W/5 device*) OR (pond* W/5 level*) OR (culvert* W/5 protect*) OR (tree* W/5 protect*))))) AND NOT (TITLE-ABS-KEY ({Beaver County} OR (beaver* W/2 joseph) OR {beaver blade} OR {Beaver Falls} OR {Beaver Creek} OR liver OR (beaver W/2 multiplication) OR (beaver W/2 triples) OR {Beaver Island} OR {Beaver et al} OR {Beaver 96} OR beaveria OR beaverhill OR {Eager-Beaver} OR {Beaver Brook} OR {Beavers Bend} OR alfalfa OR karttunen*))) AND NOT (AUTHOR-NAME (beaver*))) AND NOT (AFFILCITY (beaver))) AND NOT (TRADENAME (Beaver*))) AND NOT (TITLE-ABS-KEY("beaver dam offspring study")) AND (LIMIT-TO (LANGUAGE,"English"))

CABI search strategy:

((((((manag* OR mitigat* OR compensat* OR control* OR notch* OR remov* OR destr* OR alter* OR fenc* OR electric* OR barrier* OR wir* OR mesh* OR piling* OR "rock armour" OR "artificial burrow" OR filter* OR drain* OR pipe* OR guard* OR grill* OR camera* OR infil* OR trap* OR ripar* OR plant* OR "flood bank" OR deter* OR scar* OR fright* OR repel* OR educat* OR captur* OR move* OR translocat* OR kill* OR "in stream" OR "tree guard*" OR "area fenc*" OR "exclusion fenc*" OR "electric fenc*" OR "tree paint" OR "scar device*" OR "dam alter*" OR "dam remov*" OR "bank wall prot*" OR burrow* OR lodge* OR "riparian buffer*" OR "protection of water" OR "human toleranc*" OR organism* OR frequenc* OR flood* OR river* OR erosion* OR "tree fell*" OR trout OR salmon OR cost* OR crop* OR welfare OR population* OR conservation* OR shoot* OR cull* OR lethal OR euthani?e OR pay* OR recompense OR reimburs* OR remunerat* OR redress* OR avoid* OR protect* OR licen?* OR (burrow* near/5 prevent*) OR (level* near/5 water) OR (water near/5 monitor*) OR (water near/5 manag*) OR (flow near/5 device*) OR (pond* near/5 level*) OR (culvert* near/5 protect*) OR (tree* near/5 protect*))) AND ((beaver* OR "Castor canadensis" OR "Castor fiber" OR muskrat* OR “Ondatra zibethicus” OR coypu* OR nutria OR “Myocastor coypus”))) NOT (("Beaver County" OR (

beaver* near/2 joseph) OR "beaver blade" OR "Beaver Falls" OR "Beaver Creek" OR liver OR (beaver near/2 multiplication) OR (beaver near/2 triples) OR "Beaver Island" OR "Beaver et al" OR "Beaver 96" OR beaveria OR beaverhill OR "Eager-Beaver" OR "Beaver Brook" OR "Beavers Bend" OR alfalfa OR karttunen*))) NOT (author:(Beaver*))) NOT (aa:(Beaver*))) NOT (("Beaver Xstar" OR "Beaver-Visitec" OR "Beaver Beads" OR "Beaver Dam Offspring Study"))
Refinements:
Language = English

Appendix B: Data extraction table

The DET is available as a separate downloadable file.

Appendix C: Critical appraisal tool

Overview

What is critical appraisal? This is a clearly defined process of analysing each part of a scientific paper (method, analysis of results, conclusions etc.) to assess if the data within can be considered robust and reliable, and how strongly a piece of evidence answers the question it addresses.

Why is it needed? As an evidence-led organisation, we need to be aware of how robust the data we collect and report on are. Critical appraisal helps us know the strength of conclusions we could draw from a paper, leading to better-supported decision making.

How do the Synthesis and Learning team carry out critical appraisal? We currently use a version of the Hierarchy of Evidence and Critical Appraisal Tool designed by Mupepele and others (2016) which we have adapted based on reviews of the original tool and for ease of use. Each paper is placed into a Study Design and Focus category and given an initial Level of Evidence ranking. Then a downgrading score is applied, based on the answers to a series of questions, resulting in a final Level of Evidence score.

Hierarchy of Evidence

The hierarchy of evidence, described by Mupepele and others (2016), is used to give studies an initial quality rating (Figure 24). The hierarchy appraises studies based on their design; systematic reviews appear at the top with a score of 1 (very strong evidence) and studies without underlying data are at the bottom with a score of 4 (weak evidence) (Table 15).

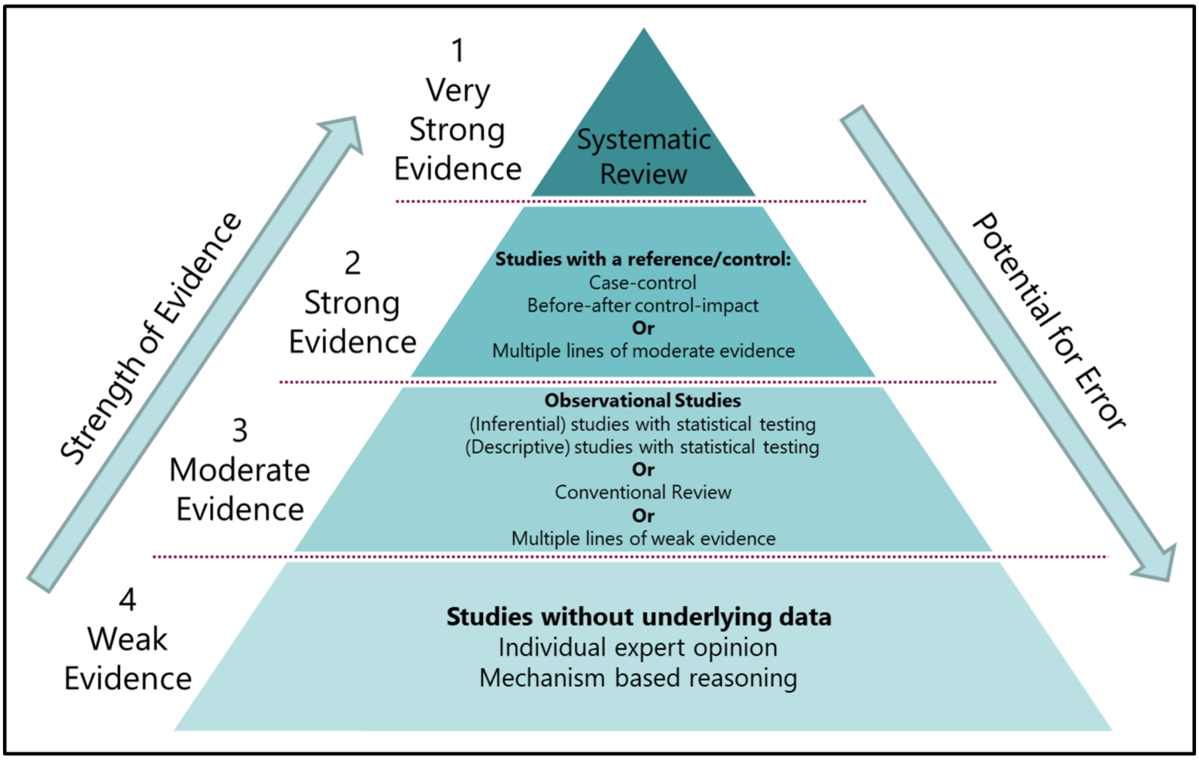

Figure 2425: Hierarchy of Evidence based on Mupepele and others (2016).

Adaptations to Hierarchy of Evidence

Since Mupepele and others (2016) was published, the field of critical appraisal has progressed. Conventional reviews have been recognised to contain limitations not acknowledged in the original paper, where they were given a “very strong evidence” weighting (section 1b). It is now accepted that these reviews carry risks of bias such as the potential for authors to ‘cherry pick’ data that fit a certain narrative, and thus might not be as robust as originally thought. As such we have chosen to place conventional literature reviews under “moderate evidence” (section 3c) for the initial ranking.

Table 15: Synthesis and Learning hierarchy, modified from Mupepele and others (2016). Note: some cells have been left blank.

Strength of Evidence		Associated studies
1. Very strong Evidence		**Review:** A. Systematic review & meta-analysis
2. Strong Evidence		**Studies with a reference/control:** A. Case-control / Before-after control-impact B. Multiple lines of moderate evidence

Strength of Evidence		Associated studies
3. Moderate Evidence		**Observational Studies:** A. (Inferential) studies with statistical testing B. (Descriptive) studies without statistical testing C. Conventional Review D. Multiple lines of weak evidence
4. Weak Evidence		**Studies without underlying data:** Individual expert opinion / Mechanism-based reasoning

Critical Appraisal Tool

The Critical Appraisal Tool (CAT) proposed by Mupepele and others (2016) consists of a checklist of questions where the reviewer answers "Yes", "No" or "Blank" resulting in an overall score which is used to downgrade (or not) the initial ranking given to the paper.

Although the tool comprises 43 questions, a subset of questions (17 to 43) only apply depending on the Study Design and the Focus of the study (Table 16).

The Synthesis & Learning team have considered reviews of the Mupupele and others' CAT and have removed question 14 to ensure that our critical appraisal focuses on the quality of studies alone, without unfairly rating studies with strong relationships.

A point to note is that the CAT does not weight questions by importance, which might lead to over-estimations of the true impact of bias present within a paper. While we recognise this limitation, we feel that at the current time, our modifications of Mupepele and others' CAT tool are sufficient to produce rapid evidence reviews of comparable quality to published literature.

Table 16: Critical appraisal tool checklist questions.

Critical Appraisal Tool - Checklist Questions
Research Aim
1**.** Does the study address a clearly focussed research question?
2**.** Does the question match the answer?
Data Collection

3. Was the population/area of interest defined in space, time and size?	
4. Selection bias: was the sample area representative for the population defined?	
5. Was the sample size appropriate?	
6. Was probability/random sampling used for constructing the sample?	
7. If secondary data were used, did an evaluation of the original data take place	
8. If data collection took place in the form of a questionnaire, was it pre-tested/piloted?	
9. Were the data collection methods described in sufficient detail to permit replication?	
Analysis	
10. Were the statistical/analytical methods described in sufficient detail to permit replication?	
11. Is the choice of statistical/analytical methods appropriate and/or justified?	
12. Was uncertainty assessed and reported?	
Results and Conclusions	
13. Do the data support the outcome?	
14. ~~Magnitude of effect: Is the effect large, significant and/or without large uncertainty?~~	
15. Are all variables and statistical measures reported?	
16. Attrition bias: Are non-response/dropouts given and is their impact discussed?	
Design-Specific Aspects	
Q17-Q24 apply if Study Design = Review (Systematic or Conventional)	
17. Is there a low probability of publication bias?	
18. Is the review based on several strong-evidence individual studies?	
19. Do the studies included respond to the same question?	

20. Are results between individual studies consistent and homogenous
21. Was the literature searched in a systematic and comprehensive way?
22. Was a meta-analysis included?
23. Were appropriate a priori study inclusion/exclusion criteria defined?
24. Did at least two peopled select and studies and extract data?
Q25-Q29 apply if Study Design = Study with a reference/control
25. Allocation bias: was the assignment of case-control groups randomised?
26. Were groups designed equally, aside from the investigated point of interest?
27. Performance bias: was the sampling blinded?
28. Were there sufficient replicates of treatment and reference groups
29. Detection bias: were outcomes equally measured and determined between groups?
Q30 applies if Study Design = Observational studies
30. Were confounding factors identified and strategies to deal with them stated?
Q31-Q32 apply if Focus = Quantification
31. Is the unit of quantification measurement appropriate?
32. Was temporal change of quantities (e.g. species abundance) measured discussed?
Q33-Q34 apply if Focus = Valuation
33. If discounting of future costs and outcomes is necessary, was it performed correctly?
34. If aggregate economic values for a population were estimated, was this estimation consistent with the sampling and the definition of the population?
Q35-Q39 apply if Focus = Management

35. Was the aim of the management intervention clearly defined?
36. Were side effects and trade-offs on other non-target species, ecosystem services or stakeholders identified?
37. Were both long- and short-term effects discussed?
38. Did monitoring take place for an appropriate time period?
39. Appropriate outcome measures: are all relevant outcomes measured in a reliable way?
Q40-43 apply if Focus = Governance
40. Were long-term effects discussed?
41. Was the policy instrument that was used described?
42. Was the influence of the applied policy instrument (incentive/law) on the society discussed?
43. Appropriate outcome measures: Are all relevant outcomes measured in a reliable way?