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REVIEW

A bibliometric literature review in beaver management: when does the beaver become a resource?

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ABSTRACT

1. Freshwater ecosystems are some of the most biodiverse habitats, but they are among the most endangered due to human activities. In this context, beavers represent a nature-based solutions to preserve and repair freshwater ecosystem, given their important role as ecosystem engineers. However, in an environment modified by humans, beaver activities frequently create conflicts masking the positive effects of this rodent. Therefore, the management of beaver populations and human–beaver conflicts is needed.
2. This article investigates the literature about beaver management through a bibliometric analysis to understand past, current, and future response. Moreover, it quantifies the number of studies that consider beavers as a resource, and it identifies the emerging themes in the field.
3. The bibliometric analysis was performed considering a total of 415 documents with the software VOSviewer and the R web interface for bibliometrix Biblioshiny.
4. The analysis presented here provides a complete view of past, present, and future management approaches and responses at the base of beaver management strategies. Three main results emerged. Firstly, a rising tendency in the number of publications about beavers that are directly linked to the populations development and spread has detected. Secondly, only 4.3% of scientific literature has referred to beaver-related restoration. Thirdly, the 'human perceptions' has resulted in the emerging field investigated.
5. Findings suggest that there is a lot of research interest about beaver management. The beaver is still poorly managed as a tool for freshwater ecosystem restoration. The management is shifting from studies focused more so on beaver ecology to others mainly focused on the beaver effects and the human dimension.
6. This review provides a starting point for future research on beavers and suggests the development of socio-ecological management models that consider benefits and impacts of beavers. This will help the decision-making process of conservation and restoration initiatives.

INTRODUCTION

Freshwater ecosystems are among the most biodiverse habitats on Earth, but they are increasingly affected by human activities (Reid et al. 2019, Su et al. 2021). Climate change, overexploitation of resources, habitat fragmentation, pollution, and the introduction of alien species are the main drivers of biodiversity loss (Committee on the Environment Public Health and Food Safety 2021). To ensure ecosystem protection, it is necessary to address drivers of change by embracing environmental protection strategies that work with nature and prioritise its conservation (IUCN 2019, Committee on the Environment Public Health and Food Safety 2021).

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In this context, beavers represent a nature-based solution (Brown et al. 2018, Puttock et al. 2018), that is, a solution inspired and supported by nature to address socio-environmental challenges (Cohen-Shacham et al. 2016). Indeed, they help to maintain regional biodiversity, counter drivers of change, and restore freshwater ecosystems (Brown et al. 2018, Brazier et al. 2021, Jordan & Fairfax 2022). Beavers are rodent semi-aquatic mammals (Castoridae family, *Castor* genus) that play a very important role in nature as ecosystem engineers. Their behavioural activities (i.e. cutting trees, building lodges and dams, digging burrows and channels) deeply transform the environment, and produce ecosystem, hydraulic, hydrological, climatic, and socio-economic benefits (Rosell et al. 2005, Rozhkova-Timina et al. 2018). Moreover, beaver activities provide numerous ecosystem services and help to build freshwater ecosystem resilience (Puttock et al. 2018, Brazier et al. 2021, Thompson et al. 2021). Thus, beavers could have a potential role in water resource management strategies based on natural processes (Puttock et al. 2018).

However, beaver activities do not only have positive impacts in a human-made environment. The interaction between beavers and human activities often leads to the insurgence of conflicts (Taylor et al. 2017). Some of the most common human–beaver conflicts are tree damage, property flooding, and damage to crops (Campbell-Palmer et al. 2016, Taylor et al. 2017, Treves et al. 2020). Human–beaver conflicts needs to prevent, reduce, and manage because their outbreak affects people's perception and response to beaver presence (Taylor et al. 2017), leading to the point at which beavers are compared to pests (Coz & Young 2020). This conditioning of people's perception influences the positive impacts of beavers and wildlife in general, and it makes wildlife management more complex (Bhatia et al. 2020). Wildlife management encloses a wide range of responses and approaches to prevent or reduce conflicts in frequency or severity (Nyhus 2016). These responses can directly target wildlife and its habitat, or humans and their activities, changing their behaviour.

The study of scientific literature is essential to understand past, current, and future responses and approaches in beaver management. This article, for the first time, systematically investigated the state of the art of beaver management by answering four main questions: 'What are the approaches and methods used in beaver management?', 'What prevailed?' and 'In which direction is beaver management heading?', and 'How much is the beaver managed as a resource?' This investigation: 1) provides an overview of the existing literature about management of beavers; 2) highlights key topic and development trends in the research; and 3) identifies which and how many studies consider beaver as a restoration tool for freshwater ecosystems. The study was conducted through a systematic review of the literature coupled with a bibliometric analysis. Data for this study were collected from two major databases of scientific literature and they were investigated using bibliometric networks based on elements such as publishing date, co-authorship and country relations, keywords.

Overall, it was expected from the analysis an increasing trend in the number of publications about beavers due to the increase of countries with beaver occurrences, as well as to the growing interest towards this species due to recent re-colonisation. In addition, most publications were supposed to refer to the study of beaver impacts, management practises, and monitoring with the aim of managing the human–beaver conflict rather than enhancing the species. It is therefore hardly that many studies have used the beaver as a restoration tool for the freshwater ecosystem.

MATERIALS AND METHODS

To investigate methods and approach applied in beaver management, the literature review was performed with three software: Excel, VOSviewer and Biblioshiny, that is, the web interface for bibliometrix, according to the following steps.

Step 1 – Keywords identification, search, and sorting of results

The scientific literature was collected from Scopus and Web of Science (WoS) datasets until June 2023. The data were collected by using some selected terms and their combination as keywords to search documents according to titles, abstracts, or authors keywords. The selected terms refer to the species and to models, approaches, or purposes (Table 1).

Overall, the total number of documents collected from Scopus and WoS was 1054 and 776, respectively. These documents were checked to eliminate out of topic and duplicate by referring to title and abstract. Moreover, documents in which beaver is the primary focus of the study were considered, excluding those relating to Beaver Dam Analogs (BDAs) and other animals–beavers interactions. Furthermore, documents about beaver in Chile and Argentina were omitted from the analysis. These documents deal with management strategies specific for these countries where the beaver is an alien invasive species (Henn et al. 2016, Herrera et al. 2020). The total number of documents (415) selected to implement the bibliometric analysis is shown in the Table 2, together with the subdivision of the excluded ones.

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Step 2 – Implementation of bibliometrics review on Biblioshiny and VOSviewer

At this point, the bibliometric analysis has been performed through two software Biblioshiny and VOSviewer. These software permit to map scientific literature by importing bibliographic data from several databases. Biblioshiny is a web app included in the open-source R package bibliometrix (Aria & Cuccurullo 2017). This app for no coders was used to have an overview of data, evaluate annual scientific production, identify the most relevant sources, and consider author and country contribution. While VOSviewer is a software tool for constructing and visualising bibliometric networks based on citation, co-authorship relations, keywords, etc. (van Eck & Waltman 2010). This software was used to analyse the country network and the co-occurrence of authors' keywords. All the analysis was performed separately without merging the metadata of Scopus and WoS. They were only joined subsequently where it was possible.

Table 1. Keywords used in the search into Scopus and Web of Science database

Terms referring to the species		Terms referring to models, approaches, or purposes
Beaver	AND	Management
OR		OR
Castor fiber		Conservation
OR		OR
Castor canadensis		Restoration
OR		OR
Eurasian beaver		Reintroduction
OR		OR
American beaver		Habitat suitability
		OR
		Model distribution
		OR
		Species distribution model

Table 2. Total number of documents collected from the two database, Scopus and Web of Science, obtained after checking

	Scopus	Web of Science
Search results	1054	776
After checking	532	76*
Documents used to implement bibliometric analysis	389	26
BDAs	23	7
Beaver as invasive species	56	2
Other animals–beaver interference	64	41

*This number was obtained by excluding documents already present in Scopus, out of topic, and duplicated.

Step 3 – Classification of documents on Excel

After the bibliometric analysis, the documents were organised according to subject, that is, Eurasian beaver, American beaver, or both, and categorised based on type of approaches used in beaver management. Specifically, the documents were categorised according to title, abstract, and author keywords.

RESULTS AND DISCUSSIONS

The bibliometric analysis gives an overview of documents collected. The documents refer to a time span of 44 years. This time span corresponds to the period in which beavers re-expanded their ranges as a result of protection, natural spread, reintroductions (Halley & Rosell 2002), and lately unofficial releases (Dewas et al. 2012, Crowley et al. 2017, Pucci et al. 2021, Burón et al. 2023, Viviano et al. 2023). Moreover, the huge number of publications in the last years reveals an increased interest in the research about beaver and its management.

The first two papers were written in 1979 by Lochmiller and Zurowski. One paper deal with economic potential return of beaver ponds link to proper management (Lochmiller 1979), while the other focus on the preliminary results of beaver reintroduction in Vistula River, Poland (Zurowski 1979). In order to highlight the trend of publications over time, the graph of the annual scientific production was created (Fig. 1). Specifically, the graph shows a linear growth trend in the number of publications per year from 1979 to June 2023 for both databases and their sum. Furthermore, a maximum productivity was observed for the year 2022 with 37 publications.

Subsequently, the type of documents, sources, and authors' contribution were analysed. Overall, article and review published in peer-reviewed journals are the main document type observed. The documents are published on 220 different sources that mostly deal with management, biology, and conservation. The three sources that publish the most about beavers are *Mammal Review*, *Journal of Wildlife Management*, and *European Journal of Wildlife Research* (Fig. 2). This analysis gives an initial idea of purposes of collected studies.

Authors contribution and country production

Regarding the contribution of the authors, Rosell F., Campbell-Palmer R. and Hood G.A. results the authors who have contributed the most in the context of beaver. This result is linked to the calculation of fractional frequency that considers a uniformly contribute of co-authors to a document (Fig. 3). Fractional frequency is calculated as the ratio between the number of authored documents

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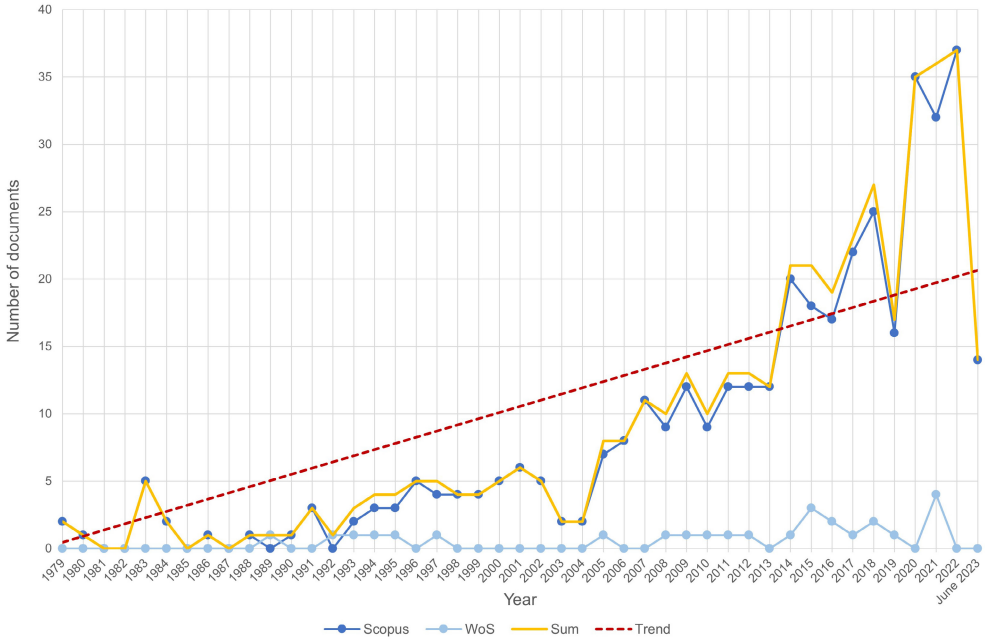


Fig. 1. Annual scientific production obtained with Biblioshiny and then elaborated with Excel to merge metadata of Scopus (dark blue) and WoS (light blue). The orange line shows the metadata merging, while the dashed red line highlights the increasing trend of documents number production. The year 2023 considers documents until June.

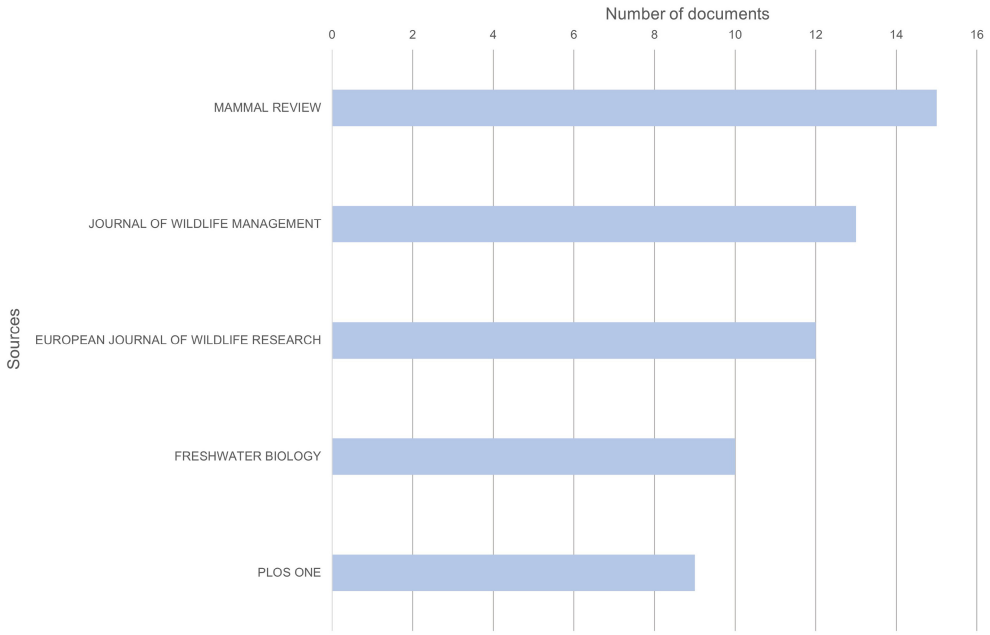


Fig. 2. Top five relevant sources based on number of documents collected from Scopus and Web of Science database until June 2023.

and the number of co-authors. It quantifies the individual author's contribution to a set of documents.

Then, the country production was analysed by considering corresponding author's country with the aim to understand which country contribute more to the scientific literature about beaver management topic. Overall, it stands out that the United States, the United Kingdom, and Canada are the countries with major production. Moreover, the United States have the largest production and the largest number of documents featuring a co-author from

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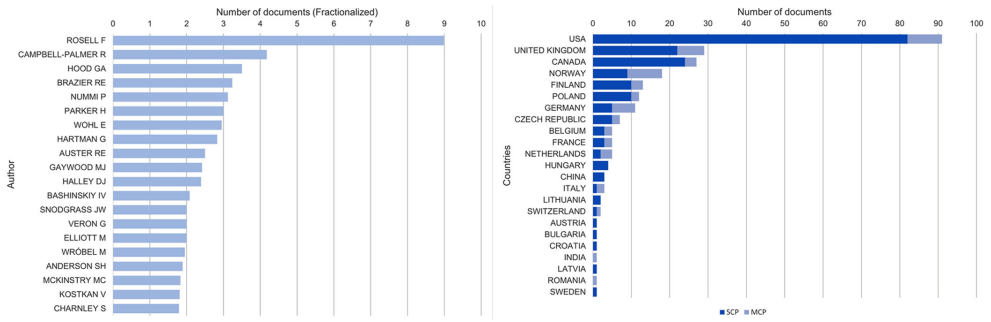


Fig. 3. Top 20 relevant authors (left) and corresponding authors' country (right). Top 20 relevant authors are determined based on fractional frequency. While corresponding authors' country is evaluated considering Single Country Publication (SCP) and Multiple Country Publication (MCP). The rate of MCP (light blue) and SCP (dark blue) represents the intensity of international collaboration.

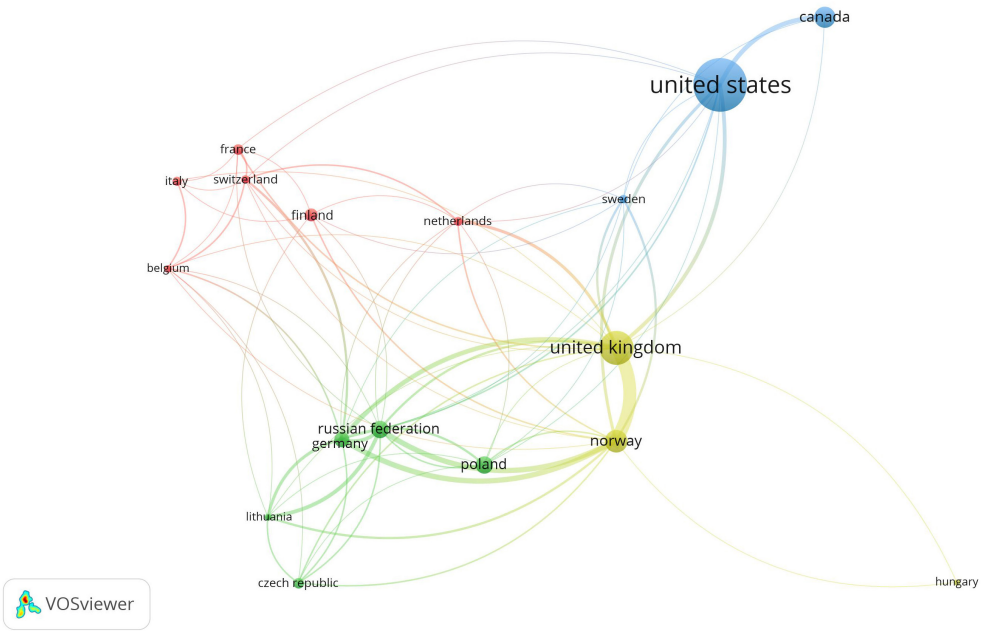


Fig. 4. Co-authorship network map of countries obtained with VOSviewer with Scopus data. The circle size is related to the weight based on total link strength, while the line thickness represents the strength of the link. Moreover, the colour identifies four clusters of countries that cooperate.

another country. These findings seem to be due to the country extension and the presence of the beaver in terms of timing and population size. However, this explanation is not enough to justify the result obtained. The result might be even linked to the growing interest towards beaver management as consequences of re-colonisation and rewilding movement, human perceptions, and related ecosystem restoration measures. The latter yet widely applied in the United States and Canada.

Further analysis show that, in the top 20 countries, Norway has the higher intensity of international collaboration due to the rate between Multiple Country Publication and Single Country Publication. Germany and the United Kingdom follow it. This finding is supported by the co-authorship network map (Fig. 4). This map was obtained through VOSviewer and shows 19 countries that collaborate each other, considering at least five publications for each country. It subdivides countries into four clusters identified by four colours (i.e. red, yellow, blue, and green) and highlights that developed cooperation arise mostly between neighbouring countries.

Authors' keywords and co-occurrence analysis

The analysis of authors' keywords provides a clearer snapshot of topic literature. Specifically, the co-occurrence analysis is one of the most effective to discover trends

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and emerging research streams creating a thematic map and a temporal map (Fig. 5). The thematic map permit to cluster author keywords by topic based on links. The temporal map refers to same keywords and connection, but underscore their used over time.

Overall, three interconnected clusters are identified. They refer to three main topics: the reintroductions, the freshwater restoration, and the role of beavers as ecosystem engineer. The first encloses publications about beaver management, human dimensions, population distribution, and dynamics. The second one concerns studies about beaver dam presence, effects on riparian habitat, and hydraulic and hydrological sphere. The last covers issues related to biodiversity and conservation.

The temporal map shows when a substantial research interest for the several issues has indicatively started to emerge. Specifically, it would seem that earlier research has focused more on population distribution and dynamics, while only later there was an interest on restoration links to beaver dams and on the figure of the beaver as an ecosystem engineer. The thematic of beaver as ecosystem engineer has developed since 2018 and seems to be growing within the scientific literature as well as hydrology thematic. Perhaps, the most significant findings are two emerging themes: human dimensions and perceptions. These themes have developed since 2020 and results strongly linked to reintroduction and management issues. This interesting result may reflect the recent tendency to undertaken policies and management approaches actively involving citizen.

Target subject

The main subject of beaver existing literature was investigated through the analysis of metadata. There was a clear partition of the studies according to the target subject: Eurasian beaver, American beaver, or both species (Fig. 6). The term 'both' refers to documents about review of beavers effects or case studies of areas where both species are present. Moreover, when the species could not be identified on the basis of the information contained in the metadata (i.e. title, abstract, and keywords), the subject of the document was identified as 'not clearly identifiable'.

The subject target of collected studies is mostly Eurasian beaver (49%), but also for the American beaver there is a considerable number of documents (39%). Although the first publications are from the United States and the countries that contribute most to the scientific literature of this field present in their territories *Castor canadensis* or American beaver, this finding reveal more studies focusing on the Eurasian beaver. This is probably linked to the fact that the third country that contributes the most is the United Kingdom. This country has produced a lot of publications in recent years due to large amount of data collected during the beaver reintroduction trials in Scotland and England (Crowley et al. 2017, Goodman et al. 2017, Gaywood 2018, Girling et al. 2019a). This increasing trend in publications focusing on Eurasian beaver is confirmed in Fig. 6.

Categorisation of responses and approaches in beaver management

The last step of the literature review provides a categorisation of collected documents based on title, abstract, and keywords. This categorisation highlights management approaches and response applied in the context of beaver. Concerning the thematic addressed in the 415 selected studies, 10 methodological categories resulted from the analysis: 1) beaver-related restoration; 2) biopolitics; 3) effects of beavers; 4) genetic conservation; 5) habitat suitability; 6) health surveillance and management; 7) human perceptions; 8) monitoring behaviour and demography; 9) population dynamic and distribution; 10) practical management measures. These categories are briefly described and exemplified next, while Fig. 7 shows the percentage of studies falling into each category.

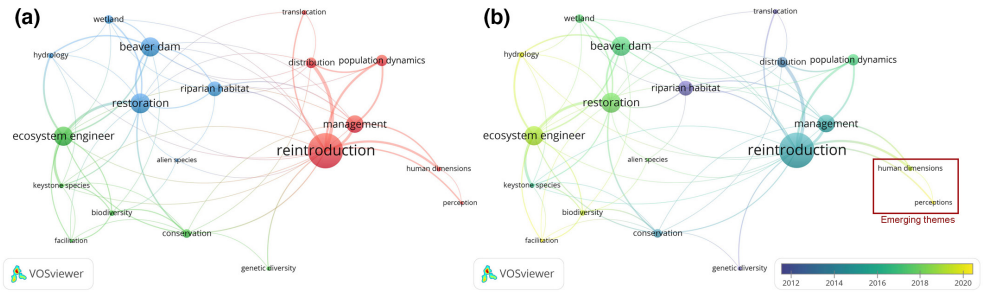


Fig. 5. Co-occurrence network map of authors' keywords: (a) the thematic map and (b) the temporal map. The thematic map shows the most used keywords divided by cluster. The temporal map on the right shows the use of keywords over time, highlighting emerging themes (red box).

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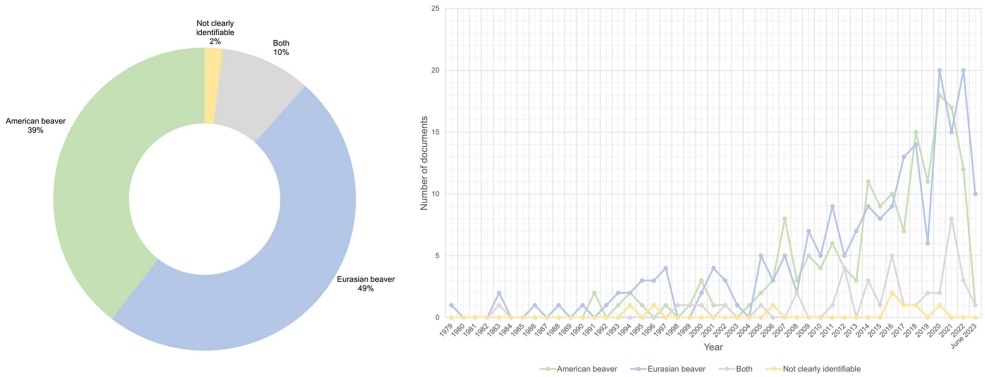


Fig. 6. Target subject investigated in beaver scientific literature: Partition of documents (left) and annual scientific production (right) according to species, that is, American beaver (green), Eurasian beaver (blue), both species (grey), not clearly identifiable (yellow).

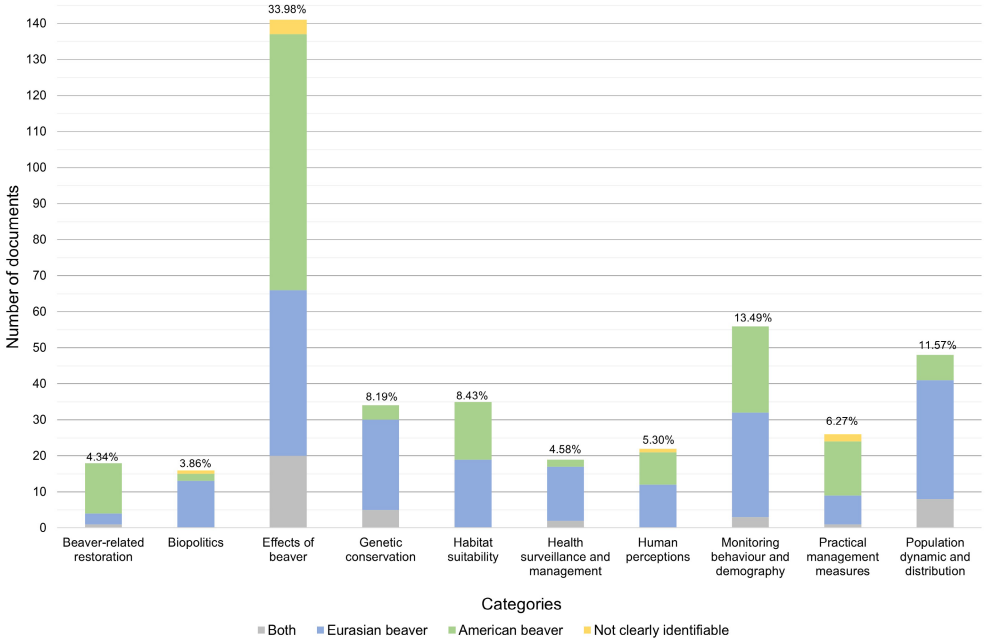


Fig. 7. Selected documents subdivided in methodological categories. Each column represents a category, and it is partitioned according to the species analysed by the studies (i.e. 'Eurasian beaver' in green, 'American beaver' in blue, 'both' in grey, and 'not clearly identifiable' in yellow). The percentage above the columns indicates the number of documents concerning a specific topic compared to the total number (415).

BEAVER-RELATED RESTORATION

This category consists of 18 documents regarding ecological stream restoration operated by beaver activities and behaviour. Specifically, these documents present restoration case studies that use the presence of the beaver and the effect of their dams for the ecological restoration of entire areas. They describe the outcome of beaver-related restoration projects at several levels (Pollock et al. 2014, Holthuijzen 2021, Stevenson et al. 2022) dwelling on challenges and opportunities (Abrams et al. 2019), also questioning to ranchers and land managers (Fountain 2014, Charnley 2019, Charnley et al. 2020).

Most of the studies collected in this category concern a time span from 2014 to 2022. The two first published papers in this framework were written in 1983 and 1991. The first concerns a case study that shows of how beavers have influenced riparian plants and restored aquatic habitat (Apple 1983). The second one highlights beaver management techniques to enhance their potential as habitat for waterfowl (Ringelman 1991).

BIOPOLITICS

This category collects 16 documents related to governance, environmental policy, and legislation. They focus

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on the set of rules and practices adopted by a state to regulate the biological life of beavers and protect their populations (Albrecht 2016, Mills 2019). Moreover, they discuss about models of governance applied to rewild beavers (Gow 2006, Ward & Prior 2020) and at the same time restore river (Törnblom et al. 2011, Carver 2016). These studies are all post-2006 except one from 1997, written by Dennis R., who was one of the leaders of the campaign to reintroduce beavers in Scotland (Dennis 1997). Instead, the more recent document is from 2023 and discussed about the use of beaver management groups as an adaptive process in the United Kingdom management policies.

Furthermore, the only publication who clearly uses the term biopolitics was written in 2020 and it argued about the implementation of governance models in Scotland to implement beaver rewilding strategies that do or do not consider animal autonomy (Ward & Prior 2020).

EFFECTS OF BEAVERS

This category consists of 141 documents regarding positive and negative impacts of beaver. Specifically, they describe and investigate the effects of beaver activities on ecosystem, hydraulic and hydrological sphere, climate and socio-economic sphere, related to specific case study area. However, several documents on this topic are reviews and they investigate on a wide scale effects of beaver activities (Brazier et al. 2021), also on specific compart as biomes stream conservation (Grudzinski et al. 2022), structure and function of river corridor (Larsen et al. 2021), lakes (Bashinskiy 2020), and biodiversity (Stringer & Gaywood 2016). Another aspect considered in this topic are ecosystem services offered by beaver and its habitat that was quantified by Thompson et al. (2021). Finally, two reviews about beaver effects that also address management practices to be implemented in response to beaver impacts are highlighted in this category (Hammerson 1994, Gibson & Olden 2014).

GENETIC CONSERVATION

This category collects 34 documents related to non-invasive control and genetic monitoring of the species. They control genetic structure and variability of population mostly through DNA-based methods (Fedorca et al. 2021, Iso-Touru et al. 2021, Munclinger et al. 2022), skeleton (Fandén 2005), and anal gland secretions (Schulte et al. 1995). The analysis of anal gland secretions is also used to distinguish the two species, that is, American and Eurasian beavers (Rosell & Sun 1999, Rosell et al. 2019, 2020). Furthermore, the genetic analyses are used to source beaver for successful reintroductions (Halley 2011, Senn et al. 2014). These types of studies are well distributed in time span, with a first publication in 1986 (Heidecke 1986).

HABITAT SUITABILITY

This category consists of 35 documents that applied habitat suitability model to guide beaver reintroduction, conservation, and management actions. Specifically, these documents present the application of different methods and algorithms to predict the suitability of a location for this rodent based on its needs and environmental conditions (Maringer & Slotta-Bachmayr 2006, Francis et al. 2017, Smeraldo et al. 2017, Swinnen et al. 2017, Dittbrenner et al. 2018, Stringer et al. 2018, Treves et al. 2020, 2022, Fitch et al. 2022, Serva et al. 2023). Moreover, habitat suitability models are used to 1) predict beaver dam occurrences, better understand dam site characteristics, and evaluate beaver dam carrying capacity (Macfarlane et al. 2017, Petro et al. 2018, Graham et al. 2020, Kornse & Wohl 2020, Scamardo et al. 2022); 2) predict beaver abundance (Beck et al. 2010, St-Pierre et al. 2017, Thompson et al. 2022); 3) link riparian vegetation and beaver occurrence (Breck et al. 2012); 4) identify potential threats for the beaver (Romanowski et al. 2008). Despite the large number of applications, there are no publications reviewing methods or algorithms used to assess habitat suitability in the context of beavers.

HEALTH SURVEILLANCE AND MANAGEMENT

This category includes 19 documents referring to health screen procedure, analysis of parasites, and mortality. In particular, they report non-invasive analysis (O'Brien et al. 2018, Benovics et al. 2022, Szekeres et al. 2022) and analyses of beaver deaths to assess population status (Stefen 2019, Lazár et al. 2023). Moreover, Girling et al. (2019b) carried out a disease risk analysis for the selection and health screening of Eurasian beavers before their release in Britain.

HUMAN PERCEPTIONS

This category consists of 22 documents concerning the perception, attitude, and involvement of citizens in beaver conservation and management. Specifically, these documents investigate concerns about beavers' damage, perceived benefits, and interest in a beaver management programme from citizen and stakeholders. The investigations are carried out through several different methods such as interviews (Ulicsni et al. 2020, Yarmey & Hood 2020, Auster et al. 2021b), survey (McKinstry & Anderson 1998, Jonker et al. 2009, Siemer et al. 2013, Auster et al. 2020, 2022a), Q-methodology (Auster et al.

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2021a, 2022b), and mental models (Blewett et al. 2021, 2022). Furthermore, these studies aim to assess citizen engagement (Jonker et al. 2009, Auster et al. 2021b) and public-land managers (McKinstry & Anderson 1998) to address the perception gap and involve stakeholders in the identification of appropriate management actions for human–beaver conflicts (Wohl 2015). The documents in this category are mostly from 2020 to 2023, though the first article to discuss the need to structure citizen participation approaches to address beaver management issue was written in 1996 by Enck and Brown. Moreover, the first documents focusing on the topic of human perceptions regard American beaver (*Castor canadensis*), while the most recent ones refer to Eurasian beaver (*Castor fiber*), and they are strictly linked to the reintroduction trails carried out in Britain.

MONITORING BEHAVIOUR AND DEMOGRAPHY

This category collects 56 documents on beaver ethology. Specifically, they investigate through the analysis of case study beaver behaviours and needs. The investigations dwell on: 1) habitat and lodge site selection (Du et al. 2017, Zhen et al. 2017); 2) food preference (Urban et al. 2008, John & Kostkan 2009, Law et al. 2014, Piton et al. 2020, Juhász et al. 2023); 3) activity pattern (Johnston & Windels 2015, Swinnen et al. 2015, Viviano et al. 2022); 4) family composition and colony density (McTaggart & Nelson 2003, Rosell et al. 2006); 5) beaver behaviour in relation with other species (Hood & Bayley 2008, Ruys et al. 2011); and 6) peer relationships (England & Westbrook 2021).

PRACTICAL MANAGEMENT MEASURES

This category consists of 26 documents concerning practical proposals for the management of individuals or conflicts. Specifically, they propose several measures such as trapping (Safonov 2016), captive care (Campbell-Palmer & Rosell 2015), hunting (Janiszewski & Hanzal 2021), installation of pond-levelling devices (Taylor & Singleton 2014, Hood et al. 2021), tree guard (Loeb & Garner 2022, Westbrook & England 2022), and incentives (Morzillo & Needham 2015).

POPULATION DYNAMIC AND DISTRIBUTION

This category consists of 48 documents concerning spatial spread, dynamics, and estimation of beaver population. Specifically, these documents investigate beaver current expansion and historical distribution (Lanman et al. 2013), estimate total population (Chu & Jiang 2009, Wróbel 2020), and assess colony density (Ribic et al. 2017). Moreover, these studies refer to specific area, like France (Lecomte et al. 1990, Steinmetz 2014), Czech Republic (Šimůnková & Vorel 2015), Finland (Brommer et al. 2017), Italy (Mori et al. 2021, Capobianco et al. 2023), Spain (Calderón et al. 2022), or macro region such as Eurasia (Nolet & Rosell 1998, Halley & Rosell 2002, Halley et al. 2021). The first article to concentrate to this topic was written in 1979 and it focuses on the preliminary results of the reintroduced beaver population in Vistula River, Poland (Zurowski 1979). In addition, a document deals with population trends according to the types of management actions (Yanuta et al. 2022).

As can be seen from the number of documents, the most investigated aspect within the context of beaver management concerns the effects of this rodent behaviour on territory. This topic deals mainly with the American beaver (Fig.7), but it is fundamental for understanding conflicts and benefits strictly connected to the beaver presence regardless of the species. Moreover, it represents a starting point for any species management policy.

Biopolitics is instead the topics for which there are fewer studies. The limit number of this topic in the scientific literature reveals a scarce consideration of a fundamental aspect for management: the set of guidelines and practices to be implemented at an international and, above all, national level for the protection and management of the species. This aspect is a key element for planning efficient species management strategies.

The second least investigated topic is beaver-related restoration with only 18 out of 415 documents, mostly focused on American beaver (14 out of 18) (Fig. 7). This result shows how many studies to date (2023) have considered the beaver as a resource and used it as a watercourse restoration tool. This topic substantially appears in publications over the last 6 years (Fig. 8).

Another finding that stands out from the analysis of the literature is the use of habitat suitability models as the main territorial assessment tool to support decision makers, especially as regards reintroductions. Although these methods increasingly use environmental variables linked to the anthroposphere in order to limit conflicts (Treves et al. 2020), these models do not take into account the perception and attitude of stakeholders increasingly taken into consideration given the growing number of studies (12 out of 23 studies in the last 3 years, for more detail, see the Appendix S1). These aspects are generally evaluated, instead, with interviews, mental models, etc.

Finally, it is observed that the publications of the last 3 years (i.e. 2020, 2021, 2022) covered all the 10 categories as shown in Fig. 8.

Taken together, these results suggests that there was a huge growth in scientific literature about beaver management due to an increased research interest over time, but

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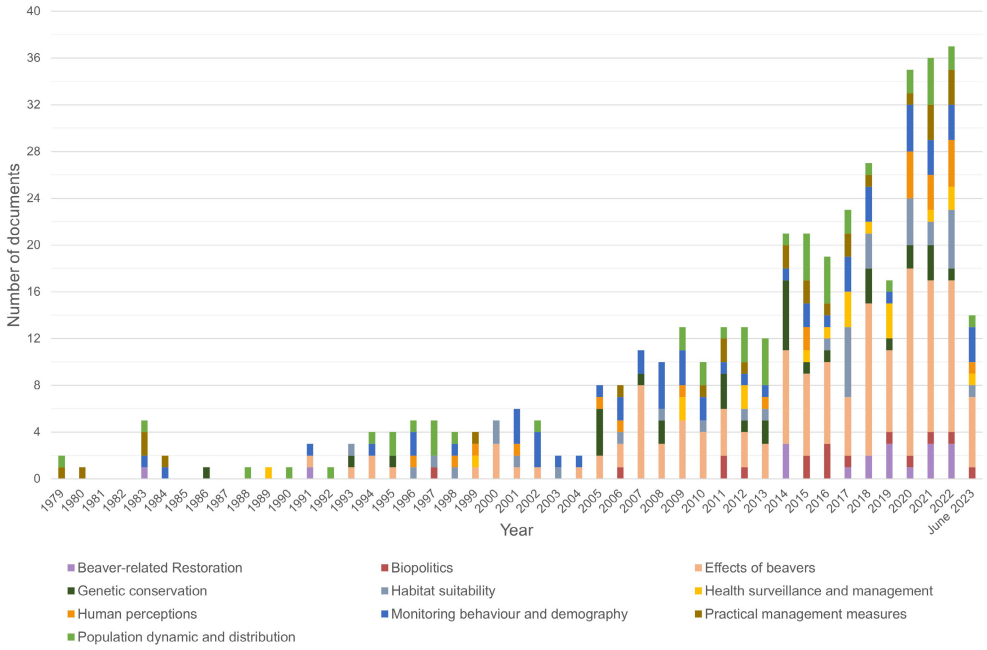


Fig. 8. Annual scientific production according to the 10 methodological categories: beaver-related restoration (violet), biopolitics (red), effects of beavers (pink), genetic conservation (dark green), habitat suitability (grey), health surveillance and management (yellow), human perception (orange), monitoring behaviour and demography (blue), practical management measures (brown), and population dynamic and distribution (light green).

there was also a motivational shift towards reintroductions for ecosystem restoration. This recent shift may have influenced the main topics investigated by research. There was a transition from studies focused more so on beaver ecology (e.g. population distribution and behaviour) to others mainly focused on the beaver effects and the human dimension around restoration.

CONCLUSIONS

This study set out an overview of past and present beaver management and shows a complete view of approaches and responses used. Moreover, it highlights changes in the literature over time with the aim of identifying future trends towards which beaver management is heading and determining how far the beaver is considered a restoration tool.

Overall, the study has identified an increasing trend of publications number about beavers closely related to the growth and expansion of beaver population, as well as to management measures implemented over the years and unofficial releases by rewilding movements (especially in Eurasia). Moreover, the co-occurrence analysis of author keywords has identified the human perceptions as the emerging field investigated and the categorisation of the documents has shown that only 4.3% of the studies describe the implementation of beaver-related restoration projects.

These results indicate that the management of beaver is of a great interest in research. But this species is still little used as an active tool, though this rodent is often described in the literature as an ecosystem engineer capable of positively modifying the environment and has a proven role in freshwater ecosystem restoration. Furthermore, the emerging trend related to human perceptions highlights a change in the management. Species management is no longer aimed at pure conflict control, but is projected towards a participatory perspective that leads to a co-existence between human and beaver. Thus, the future of beaver management is represented by the integration of management strategies and participatory approaches that combine ecological and socio-economic aspects. This integration promotes the raising awareness of benefits and impacts generated by the species highlighting the multiple dimensions that influence human–wildlife relationships.

However, to continue in this direction, it is necessary that the institutions understand the importance of acting within a socio-ecological model through a wildlife conservation approach that embraces the social dimension of the phenomenon (Decker et al. 2016). The imposing of strong management actions, as the removal of beavers unofficially released, without considering local perception could create misunderstanding, affect the perception of the species (Viviano et al. 2023), and make the management of 'legal beaver' more difficult.

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In conclusion, this study suggests undertaking species management policies that enhance the role of the beaver in the freshwater ecosystem and its restoration, stimulating stakeholder involvement and stewardship as a form of collaborative planning and responsible management. From this point of view, restoration practices will play an important role in the sustainable management of watercourses, allowing the construction of strong communities closely connected to the territory in which they live and with a strong sense of stewardship.

Future studies should develop socio-ecological management models that consider benefits and impacts generated by the beaver with the aim to support the decision-making process of restoration and conservation actions.

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DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available in the Appendix S1 as supplementary material of this article.

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Appendix S1. Data of publications analysed into the literature review.

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