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# Rewilding with the Beaver in Portugal - an Economic Analysis

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Master in Economics

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Department of Economics / Political Economy

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Resumo

Os rios e riachos em Portugal estão em más condições ecológicas, programas de restauração de rios são assim essenciais. Vários estudos demonstram que o castor é uma ferramenta importante para melhorar o estado ecológico dos habitats de água doce. Este estudo visa determinar o potencial dos castores para futuros programas de restauro fluvial. O trabalho compara, de uma perspetiva económica e ambiental, uma abordagem de gestão ativa na forma de ações tradicionais de restauro de rios e uma estratégia de gestão passiva na forma de reintrodução de castores.

Em primeiro lugar, é apresentado um breve panorama das condições para o castor europeu regressar à paisagem portuguesa. Em segundo lugar, é feita uma estimativa económica com base no potencial de poupança de custos relacionados com o restauro de habitats, despesas de gestão conflitos e os fundos necessários para um programa de reintrodução. Essas estimativas são comparadas com o programa de restauro de rios e ribeiras da APA que decorreu de 2018 a 2020. Em terceiro e último lugar, os prováveis efeitos na paisagem natural são analisados com base em dinâmicas documentadas para a espécie.

Os resultados indicam que existem condições para o castor regressar a Portugal. Os benefícios associados à espécie superam os custos e os efeitos na paisagem são amplamente positivos. O castor, além de poupar custos em programas de restauro fluvial, cria condições para a vida selvagem prosperar, fornece uma ampla gama de serviços ecossistémicos e desenvolve uma paisagem mais resistente às alterações climáticas.

**Palavras-chave:** Restauro de ecossistemas, Economia, Castor, Rewilding

# Abstract

Rivers and streams in Portugal are in poor ecological condition. River restoration programs are therefore seen as essential. It is well established that the beaver is an important tool for improving the ecological state of fresh water habitats. This study aims to determine the potential to use beavers has a tool in future river restoration programs. The work compares, from an economic and environmental perspective, an active management approach in the form of traditional river restoration actions and a passive management strategy in the form of beaver reintroduction.

First, a brief overview of the conditions for the European beaver to return to the Portuguese landscape is presented. Second, an economic estimation based on the potential to save on habitat restoration costs, beaver management expenditures and the funds required for a reintroduction program is provided. These estimates are compared with the APA 2018-2020 river restoration program. Third and lastly, the likely large-scale landscape effects are analysed based on documented dynamics for the specie.

The results indicate that the conditions exist for the beaver to return to Portugal. The benefits associated with the specie outweigh the costs and the landscape effects are broadly positive. The beaver, besides saving costs in river restoration programs, creates conditions for wildlife to thrive, delivers a wide range of ecosystem services and develops a landscape more resilient to climate change.



**Key words:** Ecosystem restoration, Economics, Beaver, Rewilding

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# Acronyms

**APA:** Agência Portuguesa do Ambiente.

**CBA:** Cost Benefit Analysis.

**ES:** Ecosystem Service.

**IUCN:** International Union for Conservation of Nature.

**NBS:** Nature Based Solutions.

**WEF:** World Economic Forum.

CHAPTER 1

# Introduction

Environmental problems pose an existential threat to humanity [**IPBES, 2019**] [**IPCC, 2019**]. Several planetary boundaries have already been crossed and among the more pressing problems are climate change and biodiversity loss [**Rockström et al., 2009**]. Rewilding, understood as the creation of conditions that allow natural processes to return to landscapes, has the potential to answer both challenges. The restoration of ecosystems can mitigate and adapt to the effects of climate change while creating the conditions for biodiversity to thrive [**Pereira and Navarro, 2015**] [**Rockström et al., 2009**].

In recent years, there has been renewed interest in environmental problems within the economics field. The 2018 Sveriges Riksbank Prize in Economic Sciences was awarded "for integrating climate change into long-run macroeconomic analysis". Plus, the calls from society and students in the field, advocating for a practical approach, away from theoretical abstract models to real pressing problems is gaining momentum [**Raworth, 2017**] [**Fischer et al., 2017**] [**Earle et al., 2016**]. New paradigms are being drawn that move away from the standard economic narrative [**Wiedmann et al., 2020**] [**Raworth, 2017**]. The Doughnut Economy is a new sustainable development framework which can be broadly defined as the "safe and just space for humanity", where societal needs (such as water, food, health, and education) are met without overstepping planetary boundaries (climate change, land conversion, biodiversity loss, among others). It is part of the ecological economics framework which states that the economy is embedded in society and in the biosphere. This theoretical framework embraces the complexity of the problems the economy needs to consider while leaving options open of how to address them [**Raworth, 2017**].

Restoration of ecosystems is one of the relevant challenges and there is a growing interest in the topic. The United Nations recently declared the Ecosystem Restoration Decade from 2021 to 2030, to raise awareness for the need to recuperate ecosystem around the world. The European Union has plans to promote the restoration of ecosystems, indeed one of the three pillars of the recent EU 2030 Biodiversity strategy is ecosystem restoration [**European Commission, 2020**]. Portugal is one of Europe's most biodiverse countries [**Myers et al., 2000**] but also one where climate change is expected to be felt the hardest [**WWF, 2020**] [**IPCC, 2019**]. Currently, the country is not doing enough to protect its ecosystems and biodiversity. In 2019 the European Court of Justice sentenced the Portuguese State for: failing to protect its habitats and wild fauna and flora species; not designating European Union selected areas as protected; and not adopting proper management actions in designated habitats [**CJEU,** ].

From the several types of species present in the country the group that is more under threat is the freshwater and migratory fish [**Cabral et al., 2005**]. Across Europe human and ecological pressures in fresh water habitats are a prevailing scenario [**Grizzetti et al., 2017**]. Iberian rivers and streams are no different, while more irregular precipitations patterns due to climate change are making drought and flood events more frequent [**IPBES, 2019**] [**Beck et al., 2018**]. The Agência Portuguesa do Ambiente (APA), in english the Portuguese environmental agency, has developed a program to tackle these issues along with erosion from forest fires, based on bio-engineering techniques to restore rivers and streams. The goals of the program are to improve the ecological status of freshwater habitats and to mitigate the effects of erosion caused by forest fires. Yet, such interventions do not always provide the desirable outcomes and may not fix the existing gap in the ecosystem [**Beechie et al., 2010**] [**Roni et al., 2008**]. Additionally, given the current lack of funds for nature conservation, using the existing funds wisely is key to deliver long lasting benefits [**Credite Suisse et al., 2014**].

It is now well established from a variety of studies that the beaver has a transformative role in aquatic ecosystems and for this reason it is known as a ecosystem engineer. It increases the complexity of habitats, supports an expansion of the number of species present and delivers a wide range of ecosystem services [**Law et al., 2017**] [**Campbell-Palmer et al., 2016**] [**Janiszewski et al., 2014**]. Returning the animal to places where it is absent is crucial to return the ecosystem to a more complex, dynamic and resilient state [**Janiszewski et al., 2014**] [**Goldfarb, 2018**] [**Schwab, 2015**]. In some regions, beavers are used as a cost-effective way to restore river ecosystems. In the United States the beaver has been used to complement restoration programs or as the solution to restore a water body or wetland [**Pollock et al., 2015**] [**Goldfarb, 2018**] [**Pollock et al., 2007**]. In Europe, the gains for local biodiversity are also becoming clear, as the beaver recovers its former range [**Halley et al., 2012**] [**Halley et al., 2020**]. In the United Kingdom, where it is now present after centuries of absence, the gains for wildlife are clear as are the economic benefits in the form of flood prevention and tourism opportunities [**Brazier et al., 2020**] [**Puttock et al., 2018**] [**Puttock et al., 2017**].

Up to now, far too little attention has been paid to the possibility of beaver reintroduction in Portugal, although some research has been done to understand the status of the beaver in historical times in the Iberian Peninsula [**Antunes, 1989**] [**Cuenca-Bescós et al., 2017**]. No study analyses the suitability of the beaver to return to the Portuguese territory based both on environmental and economic terms. The literature around beavers has highlighted the potential for beavers in river restoration actions yet a detailed economic analysis of possible restoration actions and respective costs, based on a practical case, has not been performed. This has been noted in other works [**Campbell-Palmer et al., 2016**] [**Pollock et al., 2015**].

There is one key goal of this dissertation and two complementary ones. The key goal is to analyse through a case study if the beaver can be a sound economic solution based on its potential to save river restoration costs. The two complementary ones are: to examine the suitability of the beaver to return to Portuguese territory based on historical records, habitat requirements, social attitudes and legal aspects and lastly, to examine the beaver potential to deliver ecosystem services beyond river restoration and its capacity to improve the resilience and climate adaptability of the landscape.

This study explores the beaver status in Portugal and opens the debate about a possible return to the Portuguese territory. It is important to highlight that only another paper, from 1989, discussed the beaver in a Portuguese context [**Antunes, 1989**]. The findings should additionally provide important contributions to the field of economics and ecology by exploring: the economic part of having keystone species back in the landscape and the benefits of a passive managed conservation approach, commonly known as rewilding. The experimental work presented here provides one of the first practical investigations into how rewilding measures, in the form of reintroductions or translocations, might save habitat management costs.

It is beyond the scope of this study to assess in detail the conditions required to reintroduce the beaver. Such a process is always dependent on a detailed analysis of human attitudes, habitat suitability models and detailed research [**IUCN/SSC, 2013**]. This study is also unable to encompass all indirect potential costs and benefits in monetary terms that the return of the beaver might create. The majority of such studies are done after reintroduction, by comparing the based level with the changed one [**Seddon et al., 2007**]. Nonetheless, this work presents likely results based on other studies for the beaver, of which some were undertaken in different climate conditions.

This dissertation is divided into several chapters. The literature review analyses the main concepts, presents current knowledge in the field of river restoration, explores the economic analysis of nature based solutions, stresses the importance of restoring ecosystems and provides a critical analysis of the APA program. The methodology explains the reasoning behind the structure of this study and it is followed by a chapter exploring the conditions for the beaver to return to the Portuguese landscape. Then, the case Study compares from an economic perspective the active management strategy, in the form of direct river restoration actions based on the APA guide and program, and a passive management approach in the form of a beaver reintroduction. After the Beaver Landscape effects were explored in the from of an ecosystem service analysis. Lastly, the conclusion highlights the main findings of this work and presents possible areas for future research.

CHAPTER 2

# Literature Review

The literature review begins with a presentation of the main concepts and terms used throughout this dissertation, namely: Nature Based Solutions (NBS), Ecosystem Restoration, and Rewilding while providing a economic perspective on each one. Second, the role of apex predators and keystone species in the ecosystem, and their economic benefits, are discussed. Third, a review of the river restoration literature including economic valuation, a analysis of APA's river restoration guide and general insights about the beaver are provided. Lastly, philosophical and ethical considerations about ecosystem restoration and the economic valuation of nature are rendered.

APA names the restoration actions undertaken in the 2018 - 2020 program as nature-based solutions for river restoration (NBS). It is therefore important to understand the concept of NBS. Besides the definitions, economic perspectives and policy cases will also be studied. Since the main focus of this study is on river restoration, the following topics are explored: the basic principles of freshwater restoration, main economic valuation methods of such rehabilitation actions, critical analysis of the APA program and why the beaver can be used as a tool in river restoration projects.

Although there are several definitions of nature-based solutions, the one from the International Union for Conservation of Nature (IUCN) which works as an umbrella concept [**Cohen-Shacham et al., 2016**]. Nature-based solutions (NBS) are "actions to protect, sustainably manage and restore natural or modified ecosystems, which address societal challenges effectively and adaptively, while simultaneously providing human well-being and biodiversity benefits" [**Cohen-Shacham et al., 2016**]. Besides the IUCN, other international organizations use the concept, such as the United Nations and the European Commission [**Faivre et al., 2017**]. To implement and design NBS, it is important to consider knowledge from a wide range of disciplines and fields of study [**Nesshöver et al., 2017**]. NBS can be implemented in many situations, such as restoring forests to prevent soil erosion, creation of wetlands to prevent flooding or installation of green roofs in urban areas to mitigate the effect of urban heat waves [**Cohen-Shacham et al., 2016**]. NBS tend to offer a cost-effective long term solution for mitigating and restoring land affected by degradation processes, as is the case of soil erosion from intensive agriculture or overgrazing [**Keesstra et al., 2018**] [**Faivre et al., 2017**]. Moreover, NBS can be used to perform ecosystem restoration actions, as in the case of the APA River Restoration 2018 - 2020 Program which is going to be analysed in the case study [**APA, 2020**]. Many of the benefits from

NBS are in the form of ecosystem services [**Keesstra et al., 2018**] [**Cohen-Shacham et al., 2016**], which are benefits that humans directly and indirectly receive from nature. Ecosystem services can take many forms, from the provision of resources to regulating services and cultural benefits [**Leemans and De Groot, 2003**].

Regarding the concept of Ecosystem Restoration, according to the UN: "Ecosystem restoration is understood as assisting the recovery of degraded, damaged and destroyed ecosystems to regain ecological functionality and provide the goods and services that people value" [**United Nations, 2018**]. It is important to note that conservation must always be the priority, since ecosystems do not recover fully after disturbance (logging, dams, agriculture, or other practices) [**Jones et al., 2018**]. Even after the the disturbance has finished, letting ecosystems recover in a passive way is sometimes the best approach to restoration, for example allowing natural regeneration instead of planting new trees [**Jones et al., 2018**]. Moreover, restoration should be considered only where species or processes will not return without human intervention, as in the case of regional extinction of species [**Jones et al., 2018**]. To conclude, it is important to understand ecosystems as dynamic and ever evolving. The goal is to recover an ecosystem to a more complex and resilient state, thus the historical state of a ecosystem should be used as a guide, not as a rigid template [**Higgs et al., 2014**]. Lastly, it is relevant to note that ecosystem restoration actions can be consider as nature based solutions [**Keesstra et al., 2018**].

Several reports have showed the potential economic benefits that can emerge from the restoration of ecosystems. The World Economic Forum Report (WEF) on "The Future of Nature and Business" focuses on the need to preserve and restore ecosystems. It states that "half of the global GDP, 44 trillion dollars, is potentially threatened by nature loss", making a clear connection between the economy and the natural world. [**WEF, 2020**]. It also makes the case for the potential of nature based solutions to be used to tackle climate change and biodiversity loss. Plus, there are business opportunities for protecting the planet and a big potential for job creation in the transition to a "nature-positive economy" [**WEF, 2020**]. Another document this time by the World Wide Fund for Nature (WWF) in partnership with Global Trade Analysis Project and the Natural Capital Project titled "Global Futures - Assessing the Global Economic Impacts of Environmental Change to Support Policy-Making". Predicts that "trillions of dollars will be wiped off the world's economies" unless nature loss is dealt urgently [**WWF, 2020**]. Regarding Portugal, the study predicts that it will be one of the most affected countries by the loss of nature and destruction of life-sustaining systems [**WWF, 2020**]. The conclusion of both reports is that improving the state of ecosystems is good to business and to the overall economy [**WEF, 2020**] [**WWF, 2020**]. Yet economic case to protect nature is not a new argument. In 2006 the Stern Review, a 700 page report commissioned by the UK government, made this point clearly [**Stern et al., 2006**]. Despite the increasing awareness around the benefits of protecting and restoring nature, so far our collective actions and economic choices are still beyond planetary boundaries [**Rockström et al., 2009**].

In terms of policy applications of the concept of ecosystem restoration, the EU Biodiversity Strategy for 2030 *An EU Nature Restoration Plan: restoring ecosystems across land and sea*, highlights: first, the urgent need to tackle biodiversity loss; second, the role safeguarding biodiversity has in preventing future diseases; third, the high costs of inaction when compared to a proactive approach regarding environmental protection [**European Commission, 2020**]. One of the goals of this policy document is to "restore freshwater ecosystems and the natural functions of rivers" and to have by 2030 "at least 25,000 km of free-flowing rivers" mainly through the "removal of obsolete barriers and the restoration of floodplains and wetlands" [**European Commission, 2020**].

Rewilding can also be described as a process-based passive management approach to ecosystems and can be considered as nature based solution [**Keesstra et al., 2018**]. The initial focus of Rewilding, in the 90s, was on the restoration of big wilderness areas. This vision was inspired by the effects of the reintroduction of wolves in Yellowstone National Park in the United States [**Soule and Noss, 1998**]. Wolves started a cascade of effects: by controlling the number of herbivores and changing their grazing behaviours, trees and shrubs could grow close to river streams, beavers had materials to create wetlands and this created habitat for a number of amphibians, birds and fish [**Beschta and Ripple, 2019**] [**Ripple and Beschta, 2012**]. Plus, wolves prey on coyotes, which led to an increase in small mammal species and to a greater variety of small predators such as foxes and hawks [**Ripple and Beschta, 2012**]. The animals wolves killed provided more food for bears, ravens and eagles [**Ripple and Beschta, 2012**] [**Wilmers et al., 2003**]. The original concept focused on three ideas: core protected areas of wilderness, nature corridors between protected areas to allow animals to colonize new territories and to prevent inbreeding by facilitating genetic flow, and presence of carnivores, to provide the checks in the ecosystem by the processes exemplified above [**Soule and Noss, 1998**]. Since then the concept has evolved to become more flexible. It is understood now as "passive management of ecological succession with the goal of restoring natural ecosystem processes and reducing human control of the landscapes" [**Gillson et al., 2011**] [**Pereira and Navarro, 2015**]. Yet, active interventions may still be necessary, for example to restore regionally extinct species or reinforce populations of depleted animals, control invasive species or regulate hunting [**Pereira and Navarro, 2015**]. The present focus of Rewilding is on restoring ecological functions and on autonomy of natural processes, not on wilderness as a total absence of human dynamics [**Perino et al., 2019**]. The ultimate goal is to restore a ecosystem to a state where it can sustain itself and evolve without the need for human intervention or management [**Pereira and Navarro, 2015**] [**Terborgh and Estes, 2013**].

Rewilding has the potential to deliver a wide range of ecosystem services such as flood prevention or recreation opportunities in the form of tourism and can lead to biodiversity gains [**Sandom et al., 2020**] [**Pereira and Navarro, 2015**]. Like the ecosystem restoration concept, it sees the historical state as not as a rigid image but as a template to restore nature [**Perino et al., 2019**], albeit selecting older baselines [**Pereira and Navarro, 2015**]. The issue of baselines is important. Shifting baseline syndrome (SBS) describes a gradual change in human perception of the state of the natural environment, due to lack of past information or awareness of historical conditions [**Papworth et al., 2009**]. The term was first used to describe the changing perceptions of the size of fisheries among fishermen, who take into account their knowledge of only a few decades back; since fishery decreases have been happening for centuries, fishermen did not grasp the decline in fish species and their abundance accurately [**Pauly, 1995**]. The SBS has a big influence in nature conservation, conditioning both planning and implementation of nature restoration programs [**Papworth et al., 2009**].

There have been critics of the Rewilding concept, using arguments such as: the concept is not well defined and has several meanings to different people [**Jørgensen, 2015**]; it adds nothing to the concept of ecosystem restoration; it still requires, most of the time, active human interventions [**Hayward et al., 2019**]. Yet Rewilding offers an opportunity to rethink the restoration of ecosystem, this is specially true in the case of agriculture abandonment in Europe. This presents a chance to reimagine the restoration of ecosystems on a landscape scale with core protected areas, corridors and carnivores, to critically evaluate the role of agriculture in safeguarding biodiversity, and to imagine new economic models in rural areas around Europe [**Pereira and Navarro, 2015**].

One key message of the concept is the need to be creative. "The greatest impediment to rewilding is an unwillingness to imagine it" [**Gillson et al., 2011**]. Can be something small and local such as allow marginal agriculture land to develop without human intervention or reconnecting a river with its flood plain, meandering through the landscape instead of straight paths or letting a suburban garden grow wild meadow instead of the classic green lawn or restore locally extinct species after centuries of absence [**Perino et al., 2019**].

In Rewilding the presence of apex predators and keystone species is crucial [**Pereira and Navarro, 2015**] [**Terborgh and Estes, 2013**]. Apex predators are species at the top of the food chain that create top-down direct and indirect impacts in the ecosystem in the form of trophic cascades, such as the wolves in Yellowstone [**Terborgh and Estes, 2013**]. Keystone species are species that have a disproportionate effect on the ecosystem where they are present, providing checks in the ecosystem or creating the conditions for many other species to thrive [**Bond, 1994**].

There are several types of keystone species with different modes of action. Some of those are: predators like wolves, large herbivores such as horses, pathogens and parasites, earth-movers like rabbits and marmots, or system processors like beavers [**Bond, 1994**]. Several examples of keystone species were found to provide both gains for biodiversity and to humans, in the form of ecosystem services. In France, an increase in deer numbers led to a spike in road accidents due to collisions with the animals. Wolves are commonly known for the economic losses in animal husbandry, yet when the indirect benefits such as decreasing car accidents from deer collisions are accounted for, wolves can have surprising economic benefits [**Martin et al., 2020**]. Another case is the sea otter in the United States West Coast. Sea otters control the number of sea urchins that feed on kelp plants, thus ensuring that the aquatic forest is in a good ecological state. Despite the costs from the loss of invertebrate fisheries, the gains in tourism, carbon storage among other ecosystem services gains, outweigh the costs by seven times [**Gregr et al., 2020**].

When the ecosystem is not complete humans need to compensate for a missing ecological role, to perform an action or dynamic that would naturally occur in the presence of a species that due to hunting, loss of habitat or another reason is now absent [**Pereira and Navarro, 2015**]. Some examples are: the need to clean vegetation to prevent forest fires in the absence of grazing by herbivores; the need to control herbivore numbers through hunting to prevent overgrazing due to the lack of predators; or the costs of processing animals who die in extensive grazing when scavengers in the ecosystem, such as vultures, are not present [**Pereira and Navarro, 2015**].

Turning now to river restoration. European rivers face several threats: increased pressure from climate change [**Markovic et al., 2017**], fragmentation by dams and weirs [**Markovic et al., 2017**], invasive species of both fauna and flora, with serious environmental, economic and social consequences [**Keller et al., 2011**]; pollution from industry, agriculture and urban areas [**Grizzetti et al., 2017**]; and unsustainable levels of water abstraction [**Kristensen et al., 2018**]. As a consequence, river restoration is a European Union priority as stated by the EU Biodiversity Strategy [**European Commission, 2020**]. The main goals of river restoration are to improve ecological state, restore and protect fish populations and increase resilience to climate change [**Roni et al., 2008**].

One important document for river restoration is the EU Water Framework Directive, which pushes for good ecological status of river and streams across the continent [**European Commission, 2000**]. Even with implementation problems, with its ambitious target of good status for all EU waters not achieved, the WFD generated a good amount of monitoring data that can be used in future river restoration programs, although data access needs improvement [**Voulvoulis et al., 2017**] [**Hering et al., 2010**]

Moving on now to consider the economic analysis of river restoration programs. There are several methods to assess the economic value of river restorations, but stated preference methods, including contingent valuation and choice experiments, are the more common [**Bergstrom and Loomis, 2017**]. Cost-benefit analysis is not widely used and tends to undervalue river restoration potential. Another important aspect to consider is that the economic potential of river restoration tends to increase with the number of kilometers restored [**Bergstrom and Loomis, 2017**]. Lastly, although an ecosystem services analysis provides valuable economic insights into the benefits of restoration of fresh water habitats, often it is not able to grasp the full economic value of a river restoration given the complexity of the task. Still, it provides a holistic analysis, that accounts for several factors, not only direct economic ones [**Vermaat et al., 2016**].

As noted above, the APA 2018 - 2020 river restoration program's main goals are to mitigate the effects of forest fires and improve the ecological state of rivers and streams across Portugal [**APA, 2020**]. It is the first medium-scale program aiming at restoring rivers and streams in Portugal, and the bio-engineering techniques it proposes are an improvement from the "classic" cleaning vegetation or building dams and weirs interventions and it is also helping to raise awareness for the need to restore freshwater ecosystems in Portugal.

Still, one major drawback of the approach is that it does not address the root causes of degradation or aim to restore missing processes [**Beechie et al., 2010**]. Process-based restoration intends to recover functions and dynamics that are absent from the ecosystem., delivering results that are more resilient than engineered channels or habitats [**Beechie et al., 2010**]. Even thought the program includes intervention in weirs, it does not specify if such interventions include the creation of fish passages to improve river connectivity. Plus, the program does not include dam removal, although that is a clear process-based river restoration tool [**APA, 2020**] [**Moran et al., 2018**] [**Beechie et al., 2010**]. Another shortcoming is that despite intending to control invasive plant species, the program does not aim to control invasive fishes or restock native ones. Lastly, it does not consider one long missing process in the Portuguese rivers and streams, the beaver, which has been extinct in the country since the XVth century [**Antunes, 1989**].

"Extinction breeds Extinctions", that is, species are links in the ecosystem and one missing link can have a domino effect. Thus restoring a missing link can mean the return and increase in abundance of many more, specially for keystone species such as the beaver [**Ceballos et al., 2020**] [**Janiszewski et al., 2014**]. The benefits this species create for biodiversity are hard to replicate through human processes and the gains in ecosystem functioning and habitat gains tend to increase with time as their engineered habitats get more complex and as the population grows [**Law et al., 2017**] [**Pollock et al., 2015**]. In the United States, beavers are used as a tool to restore streams and wetlands [**Pollock et al., 2015**]. This can be complemented with active restoration techniques such as beaver dam analogues, which is "the fastest growing solution to recover streams in poor ecological condition in the west of the United States", in states from California and Oregon to Wyoming and Utah [**Goldfarb, 2018**]. The potential to use reintroduction of the beaver to save on habitat restoration costs has already been highlighted in another studies [**Campbell-Palmer et al., 2016**] [**Pollock et al., 2015**]. Yet, beaver conflicts with human activities are likely, specially for infrastructure and agriculture [**Valachovič, 2014**] [**Schwab, 2015**]. So mitigation and adaptation measures are key to create the right conditions for a harmonious coexistence, especially since the people who benefit from the beaver may not be the same that bear the costs, as when a downstream town benefits from flood prevention at the expense of flooded agriculture fields upstream [**Campbell-Palmer et al., 2016**].

No study has analysed which bio-engineering river restoration actions can be replicated by the beaver nor estimated avoided costs if the beaver is used instead. Furthermore, the literature around the Eurasian beaver in Portugal is very limited. Therefore this work explores the case for its return to Portuguese landscape and its potential biodiversity effects. Lastly, it adds a case study to the literature about rewilding with a economic lens.

Human beings are able to influence ecosystems in a way that no other species can. We have used our power to destroy ecosystems and actively contribute to the extinction of species. But we also have the potential to create and influence ecosystems in a positive way. The Yellowstone story, among others, offers hope for the restoration of ecosystems. Human activities, through hunting and destruction of habitats, eliminated the beaver from the Iberian Peninsula [**Antunes, 1989**] [**Halley et al., 2012**]. But we can now play an active role by returning the species to its former range. The value of such an action could be assessed in two ethical frameworks: "Ecocentrism, valuing nature for its own sake and / or anthropocentrism, valuing nature because of material or physical benefits it can provide for humans" [**Thompson and Barton, 1994**]. In this work, as in most of Economics, the anthropocentric approach will be used, in the form of river restoration costs and ecosystem service assessments.

CHAPTER 3

# Methodology

The research question of this dissertation is: which approach makes more economic sense in the restoration of rivers and streams, an active management approach through human restoration actions or a passive management approach in the form of a beaver reintroduction? The APA program case study is an interesting example for several reasons. First, the availability of data, which in environmental analysis sometimes can be hard to come by; second, the increasing awareness of the need to develop more river and stream restoration programs; third, future plans to expand such programs to other areas and increase their funds. In-depth analysis of methodology will be presented in each of the following chapters.

Chapter 4 provides an analysis of the main facts about the beaver, historical distribution and suitability of its return to Portugal, as well as the legal framework of the species in the European Union and possible areas with suitable habitat. This is crucial, given that no previous study has explored the conditions beaver reintroduction in Portugal. Chapter 5 is the core of this dissertation, since it provides an economic analysis of the active vs passive restoration approaches, including an economic analysis of both. Chapter 6 offers insights into the likely landscape effects of a beaver population, scaling the impacts identified in the previous chapter, from a beaver family group to a beaver population. Although the large-scale effects can be hard to predict, it is relevant to provide an overview of the possibilities in the form of ecosystem services.

This work provides a simple cost-benefit analysis (CBA) of the two approaches. CBA dates back to the middle of the XIXth century, Jules Dupuit is credited as the father of the concept and later Alfred Marshall developed further the term [**Maneschi, 1996**] [**Robinson, 1990**]. A cost-benefit analysis (CBA) is "the process of comparing the costs involved in doing something to the advantage or profit that it may bring" [**Cambridge Dictionary, 2020**]. It can be used to guide public policy [**Boardman et al., 2017**] and is also a common tool to grasp the economic value of environmental projects [**Atkinson and Mourato, 2008**]. There are several steps in a cost-benefit analysis yet in this work a simpler approach was taken. First, the main goals in a river restoration project were identified, second, two alternative approaches were provided and third, both options were compared based on its direct and indirect benefits.

CHAPTER 4

# The case for the Beaver in Portugal

In this chapter the main points regarding a possible reintroduction are analysed, based on an adaptation of the IUCN Reintroduction Guidelines, which are one of the most well-known tools for assessing the translocation of wildlife, "designed to provide guidance on the justification, design and implementation of any conservation translocation" [**IUCN/SSC, 2013**]. We analyse qualitative data, in the form of literature research, to provide context for a reintroduction including: native Status with historical and fossil records for the beaver in the Iberia Peninsula; climate requirements for the specie based on existing populations in other areas of Europe and in North America. Possible benefits and conflicts with other species and beaver dynamics in the ecosystem. Social attitudes in countries in a similar situation with Portugal. Legal framework based on analysis of the Habitat Directive. and suggestions of suitable areas for the beaver are presented.

There are two species of beaver: the Eurasian beaver, also known as European beaver, *Castor fiber*, and the North American beaver *Castor canadensis*. In the remainder of this dissertation, the term "beaver" is used to refer to the Eurasian species [**Campbell-Palmer et al., 2016**]. Beavers are semi-aquatic animals and their habitat includes rivers, small streams, lakes and estuaries. They are one of the biggest rodent species, weighing between 13 and 35 kilos and measuring from head to tail 73 to 135 cm. They live in colonies with a reproductive male and female and reproduce once per year with litter size between 2 and 4. In the wild they can live up to 10 years. Beavers build lodges or bank burrows as a place to rest and raise their kits. They are known as ecosystem engineers because they shape the surrounding environment to suit their needs, by building dams to flood adjacent areas and constructing side channels to access food sources [**Campbell-Palmer et al., 2016**]. Where the habitat is suitable and new areas to expand are available, the population growth rate per year can be between 10% and 15% in the first 15 to 20 years [**Campbell-Palmer et al., 2016**].

This rodent is considered a keystone species, since it has a disproportionate impact on its ecosystem and plays a role no other animal is able to perform. Through ecological feedback loops, the beaver increases the complexity in the ecosystem benefiting a wide range of animals, from birds to mammals, fish and amphibians [**Janiszewski et al., 2014**]. The beaver also provides valuable ecosystem services, for example: its dams decrease the flow of sediment and nitrates, improve the quality of the water, minimize the effects of droughts and floods and also offer cultural benefits in the form of tourism opportunities [**Campbell-Palmer et al., 2016**].

### 4.1. Native status

The historical distribution of the beaver encompassed all of Europe and parts of Asia, from the Baltic to Southern Europe stretching across to the edges of Mongolia [**Halley et al., 2012**]. Yet, at the beginning of the XXth century, there were only around 1200 beavers in 8 relic populations [**Halley et al., 2012**]. This decrease in their range and number is due to overhunting for fur, meat and castoreum, a secretion produced by the animal, and also to habitat destruction [**Halley et al., 2012**]. Since its historical low the beaver population has been growing and recovering much of its former range, both through natural expansion from relic populations and through translocations [**Halley et al., 2012**] [**Halley et al., 2020**]. It is now present in thirty-three countries in Europe and Asia, and currently it is absent only from Portugal, the Southern Balkans and Turkey [**Halley et al., 2020**] [**IUCN, 2016**].

The endemic status of the beaver in the Iberian Peninsula, and in particular in Portugal, can be proven by fossil records as well as toponymy (names of places). Fossil remains show that the beaver was present on the main river basins of the Iberian Peninsula: the Ebro, Douro, Tagus, Guadalquivir and Jucar [**Cuenca-Bescós et al., 2017**]. Although there are no known fossil records near the Guadiana, Minho and Lima rivers, given the discharge levels, size of the rivers and vegetation types it is likely the beaver was present in these rivers as well. The majority of the fossil remains are from the Upper Pleistocene and Holocene geological ages, which means they are between 129 000 to 1 400 years old, attesting the recent presence of the beaver in the Iberian Peninsula [**Cuenca-Bescós et al., 2017**]. In Portugal, fossil remains were found in two sites, Caldeirão cave and Vila Nova de S.Pedro; both are from the Holocene [**Antunes, 1989**].

The other evidence of the presence of beavers in Portugal comes from the origin of names for places close to rivers and streams, some of which are linked to the ancient terms for beaver: *veiro*, *biber* and *castor* [**Antunes, 1989**]. Such names can be found in villages close to the rivers Minho, Lima, Cávado, Ave, Douro, Mondego and Tagus. It is, however, important to note that these villages are mainly distributed north of the Tagus river where the climate tends to be wetter [**Antunes, 1989**] [**Beck et al., 2018**]. The last known records point to the extinction of the beaver in Portugal around the XV century [**Antunes, 1989**].

A final point can be added. One of the most common questions in species reintroductions or translocations is: "is it possible to prove the species was present in this area?". Perhaps this could be changed to: "is it possible to prove that the specie was not present in this area?" [**Jiménez Pérez, 2018**].

### 4.2. Climate Requirements

If the beaver was present in Portugal in the past, are the conditions today appropriate for the beaver to return? Regarding the climate, although beavers are associated with humid northern climates, they are adaptable creatures that can live in a wide range of climate zones, from hot desert climates in the Arizona to subarctic climates in Scandinavia [**Halley et al., 2012**] [**Gibson and Olden, 2014**] [**Beck et al., 2018**]. Despite no habitat suitability study having been carried out for the Portuguese territory, this can be explored through the analysis of beaver populations in regions with similar climates [**IUCN/SSC, 2013**].

In Portugal, according to the Köppen-Geiger classification, the climates currently range from hot-summer Mediterranean (Csa) in the South to warm-summer Mediterranean (Csb) in the North, although climate change might limit the latter [**Beck et al., 2018**]. In similar climates, there are beaver populations in the following areas: i) southern France, in the delta of the Rhône River with a hot-summer mediterranean climate (Csa) [**Beck et al., 2018**] [**Halley et al., 2020**] [**Dubrulle and Catusse, 2012**]; ii) Spain, in the upper river Ebro, with a cold semi-arid climate [**Halley et al., 2020**]. Interestingly, the Spanish population, despite having originated in an unofficial release around 2003, has grown into a thriving and expanding population, leading the European Commission to declare, in 2018, that the beaver was a naturalized species in Spain and thus worthy of protection [**Indurain,** ]. Currently, there is no known beaver population in Warm-summer Mediterranean climates [**Halley et al., 2020**] [**Beck et al., 2018**], yet given their historical range and present climate distribution it is likely the beaver could establish population in regions with this type of climate.

The literature for beavers in arid and semi-arid environments is very short. Yet an analysis of the North American beaver offers clues. The North American beaver has recovered much of its historical distribution, while the European beaver has not. In particular, the North American beaver is present in semi-arid and arid regions in the United States, in the states of Arizona, Nevada, Utah and California [**Gibson and Olden, 2014**]. This may indicate that the European beaver can as well have the capacity to live in arid and semi-arid climates.

### 4.3. Foraged Species

Another important point is the foraging habits and plant composition in Portugal. The beaver is a strict herbivore; its diet includes a wide range of trees, shrubs and other plants. Table 4.1 shows tree and shrub species that could be available food sources for the beaver in Portugal [**ICNF, 2016**] [**Campbell-Palmer and Rosell, 2013**] [**Fustec and Cormier, 2007**].

| Common Portuguese Name | Common English Name | Scientific name |
|---|---|---|
| Amieiro | European Alder | *Alnus glutinosa* |
| Bidoeiro | Birch | *Betula pubescens* |
| Aveleira | Hazel | *Corylus avellana* |
| Freixo | Narrow Leaf Ash | *Fraxinus angustifolia* |
| Choupo branco | Aspen | *Populus alba* |
| Choupe negro | Aspen | *Populus nigra* |
| Salgueiro branco | Willow | *Salix alba* |
| Borrazeira preta | Willow | *Salix atrocinerea* |
| Salgueiro | Willow | *Salix neotricha* |
| Salgueiro branco | Willow | *Salix salviifolia* |
| Tramazeira | Rowan | *Sorbus aucuparia* |
| Ulmeiro | Elm | *Ulmus minor* |
| Ulmeiro | Elm | *Ulmus glaba* |

TABLE 4.1. Tree and shrubs species present in Portugal known to be foraged by beavers

### 4.4. Beaver impact on other species

A common concern in reintroduction programs [**IUCN/SSC, 2013**] is the potential for conflict between species present in a habitat and those to be reintroduced or translocated. Yet a wide range of studies points to the benefits several species get from beaver-made habitats [**IUCN/SSC, 2013**]. Animals such as the European otter (*Lutra lutra*) benefit from the increased availability of water in the landscape [**Campbell-Palmer et al., 2016**]. Several bird species benefit from beaver-made wetlands, such as the black stork (*Ciconia nigra*), kingfisher (*Alcedo atthis*), woodpeckers, and several species of ducks, among others which use these wetlands as nesting, feeding and resting sites [**Janiszewski et al., 2014**] [**Schwab, 2015**]. Regarding fish species, the Atlantic Salmon (*Salmo salar*), European Eel (*Anguilla anguilla*), Sea Lamprey (*Petromyzon marinus*), European River Lamprey (*Lampetra fluviatilis*) and Brown Trout (*Salmo trutta*) are also known to benefit from beaver-made ponds, which are used as nursing places [**Campbell-Palmer et al., 2016**]. Fish can overcome beaver dams in peak flow and deposit gravel on streams provide good habitat for spawning [**Brazier et al., 2020**]. Other species that might benefit are fish from the genera *Squalius*, *Barbus* and *Chondrostoma*; several amphibians such as frogs and newts [**Campbell-Palmer et al., 2016**]; pond turtles; last but not least, *Margaritifera margaritifera*, an endangered fresh water mussel [**Campbell-Palmer et al., 2016**]. The diversity of beaver-made habitats is also positive for several species of insects such as dragonflies. Yet in areas with species that have a high conservation value, a careful approach to beaver presence is advisable. Plus, beavers may also create suitable habitat for invasive species [**Pollock et al., 2015**] [**Campbell-Palmer et al., 2016**]. Figure 4.1 shows some of the benefits beaver engineered habitats can have for other species.


FIGURE 4.1. Illustrative drawing depicting beaver effects on other species. Image by Jeroen Helmer, ARK Nature

### 4.5. Social Attitudes

Social attitudes are a important part of any translocation program [**IUCN/SSC, 2013**]. Beavers have already been reintroduced to several countries, with local community support [**Halley et al., 2020**] [**Schwab, 2015**]. Although there is potential for conflict with humans, in general there are positive views in places where the beaver was reintroduced. An exhaustive study of a case in England, where the beaver was reintroduced in the river Otter, shows mainly positive views regarding beaver presence [**Brazier et al., 2020**]. For Portugal, there is a need to develop a social attitudes study to analyse this issue in detail, although significant problems are not anticipated given the experience in other countries.

### 4.6. Legal Framework

Another significant aspect of a translocation is the legal framework [**IUCN/SSC, 2013**]. It is worth analysing European Union legislation. According to the Council Directive 92/43/EEC on the Conservation of natural habitats and of wild fauna and flora, commonly known as Habitats Directive, several articles point to the need to consider the return of the beaver to Portuguese territory. It is important to consider that although the directive is from 1992, a recent fitness check showed that the directive is suitable and that one of the main problems is countries' implementation of the legal document [**European Commission, 2016**]. The following articles can be highlighted:

- Article 2, point 2: "Measures taken pursuant to this Directive shall be designed to maintain or restore, at favourable conservation status, natural habitats and species of wild fauna and flora of Community interest" [**European Commission, 1992**].
- Article 12, point 1: "Member States shall take the requisite measures to establish a system of strict protection for the animal species listed in Annex IV (a) in their natural range" [**European Commission, 1992**].
- Furthermore, according to the guidance document provided by the Commission to aide on its understanding, Article 12 point 17 states: "strict protection measures adopted under Article 12 should aim to fulfil the main objective of the Directive by contributing to the maintenance or restoration, at favourable conservation status, of Annex IV(a) species of Community interest, while taking into account economic, social and cultural requirements and regional and local characteristics" [**European Commission et al., 2007**].
- Article 22, line a) of the Directive requires Member States to "study the desirability of re-introducing species in Annex IV that are native to their territory where this might contribute to their conservation..." [**European Commission, 1992**].

The European beaver *Castor fiber* is present in annex II, IV(a) and V of the document [**European Commission, 1992**]. The beaver is a native specie to Portugal and as a consequence its reintroduction should be considered based on the Habitat Directive.

### 4.7. Past lack of interest in the beaver

The lack of studies or media interest in the beaver in Portugal may be related with shifting baseline syndrome (SBS), since humans tend to analyse nature with a baseline of decades, so it becomes hard to grasp the long decline in nature [**Pauly, 1995**] [**Papworth et al., 2009**]. An example of this phenomenon can be found in a recent comprehensive book about Portuguese rivers and streams, which describes the fauna and flora in several types of river streams, and even presents historical state descriptions, yet the beaver is conspicuously absent [**Feio and Ferreira, 2019**].

### 4.8. Possible areas with suitable habitat

In Portugal, all rivers and streams with a permanent flow of water, and even some with a temporary one, may be suitable for beavers [**Campbell-Palmer et al., 2016**] [**Gibson and Olden, 2014**]. Several areas show a high likelihood of suitable habitat for the beaver. Listed below are a few broad areas, although these are only suggestions which would still require a careful habitat suitability analysis and social attitudes.

- Existing Wetlands: there are several Ramsar sites, at least 5 of which have beaver-suitability potential. Those are: Paul do Boquilobo, Paul de Arzila, Paul do Taipal, Paul de Tornada and Paul de Madriz. Nonetheless, these wetlands are close to agricultural areas, which increases the potential for conflict.
- Several Rivers: Mainly north of the Tagus river, in the Northwest: Minho, Lima and Cávado; Portuguese tributaries of the Douro in areas with a small slope: Maçãs, Tua, Tuela, Sabor and Maçãs. Some Tagus tributaries: Nabão, Alviela. Portuguese western streams "Ribeiras do Oeste"; parts of the Guadiana and the high courses of the Sado.
- Mountain Ranges: in the Algarve, in streams close to Monchique Mountain like the Mira river. On the São Mamede Mountain range, on streams that lead to the Soraia river. In the Malcata in the rivers Côa, Ponsul and Ocreza. In Serra da Estrela, high courses of Zêzere and Mondego rivers and other streams.

Now that conditions for the beaver's return to Portugal are broadly assessed, the next chapter will explore the case for the beaver as a river restoration tool, to complement or substitute river restoration actions as a cost effective measure.

CHAPTER 5

# Case Study - APA River Restoration Program

## 5.1. Method

One approach that can be used to estimate the economic valuation of a river restoration program or intervention, as well as to compare various options, is a cost-benefit analysis [**Bergstrom and Loomis, 2017**]. In this chapter the costs and benefits of beaver reintroduction in Portugal, as a tool for river restoration, will be assessed in comparison with the values for the bio-engineering proposals contained in the APA River Restoration Program. Initially, the beaver potential for saving costs in bio-engineered river restoration actions are estimated. Then, expected beaver management costs are summarized and the reintroduction costs are discussed. To conclude, the findings are appraised in the context of a real river restoration program.

In the present study, the term "intervention" is the group of river restoration actions in a given site, while an "action" is one bio-engineered river restoration measure, for example planting a tree or clearing invasive vegetation.

It is important to begin by assessing whether some of the proposed actions in the APA 2013 river restoration guide could be complemented or substituted by reintroducing beavers to perform the same, or similar, river restoration actions. The analysis is based on documented ecosystem dynamics for both species of beaver, the European *C. fiber* and the North American *C. canadensis*, given that both species perform the same ecosystem role and have identical impacts in their environment [**Rosell et al., 2005**] [**Campbell-Palmer et al., 2016**] [**Gurnell et al., 2008**]. Nevertheless, there are some differences between the two species, since the North American beaver tends to have a stronger dam building capacity, bigger colony numbers and also a more numerous litter size [**Rosell et al., 2005**] [**Gurnell et al., 2008**]. In order to account for some degree of uncertainty in the actions that the beaver can replicate, those actions were divided into three categories: high degree, medium degree, and low degree of certainty. Plus, to account for variability in the number of times a restoration action is performed, which can vary from site to site, an interval of values was used based on likely restoration outcomes of a beaver colony, a reproductive pair and litters. The avoided costs were calculated by multiplying the price interval of each action by a value interval. This resulted in four scenarios based on the prices and quantities. These are: low cost - low quantity, low cost - high quantity, high cost - low quantity and high cost - high quantity.

As for the beaver management costs, although the full extent of future costs is impossible to foresee, it is possible to predict the costs of typical management measures. To select those measures a review of the known management measures was performed. Likewise, for the translocation costs a literature review of similar programs' costs and characteristics was undertaken. Together, these estimates provide a picture of the possible costs of using the beaver as a river restoration tool.

Lastly to provide context, the program undertaken by APA from 2018 to 2020 was analysed in the light of the findings. By using the APA 2013 river restoration guide as a proxy for the interventions performed in the 2018 - 2020 program, a good picture of the possible saved costs is attained. There is the chance that other actions performed by the program were not included in the guide, although the list provided in the APA guide is comprehensive and has a wide range of measures. In order too simplify the analysis labour costs were not included, nor costs related with monitoring actions which presumably could be similar for all programs. Note that some actions can be performed with no labour costs, as example if volunteers are available.

### 5.2. Data

The quantitative and qualitative data for the calculations come from two reports, both from APA. The first, "Guia de Orientação para a Intervenção em Linhas de Água", is an Orientation Guide for habitat restoration actions in rivers and streams, which provides a list of bio-engineering actions for river and streams and also provides price intervals for each action in the relevant units [**APA/FEUP, 2013**]. The information provided and the descriptions are similar to other documents depicting identical restoration actions [**Studer and Zeh, 2014**].

Regarding data for the beaver, the main goal was to choose measures that promote coexistence in a cost-efficient and long-lasting way. Therefore, culling and translocation of problematic animals were not considered in this study. The data comes from an extensive search in several sources: a store [**Flügel, 2020b**] [**Flügel, 2020a**], technical reports [**Pollock et al., 2015**] [**Brazier et al., 2020**] [**Valachovič, 2014**] and a book [**Campbell-Palmer et al., 2016**]. Past reintroduction and translocation programs were considered [**Brazier et al., 2020**] [**Bajomi, 2011**] to assess operation costs. Information about likely costs, time of the reintroduction program and characteristics of the projects, such as number of animals and release sites, were taken into account.

To have a comparison between the passive management and a active one, the analysis is compared with the "Relatório Síntese de Execução Final Intervenções de regularização fluvial", which details the overall results of the 2018 - 2020 program, location of the interventions, money invested per municipality and overall results of the program in kilometers and in the number of man-made river structures built [**APA, 2020**].

### 5.3. Beaver potential for river restoration

The interventions in the APA guide range from simple interventions, like habitat hides for fish and small animals, to complex ones, such as changing the path of a river stream. The costs also vary, from as low as some cents to a couple of thousand euros by action. The selection of actions that could be performed by beavers was based on ecosystem dynamics documented for the animal from a wide range of studies. These actions can be direct replacements or provide similar ecosystem dynamics, delivering similar results. This is evident when beavers replace small natural weirs by building dams or when beavers substitute the need for planting fruit trees by creating other opportunities for wildlife. Still, a limitation of the selected sources is that many refer to climates that are different from the Portuguese one, namely in regions with a continental rather than a Mediterranean climate. The latter has more intense drought periods and its effects on beavers are not well documented. Below an illustration of the restoration effects beavers have in rivers and streams [**Goldfarb, 2018**]. From the first image to the last the transformative effect beavers have on freshwater habitats is apparent.

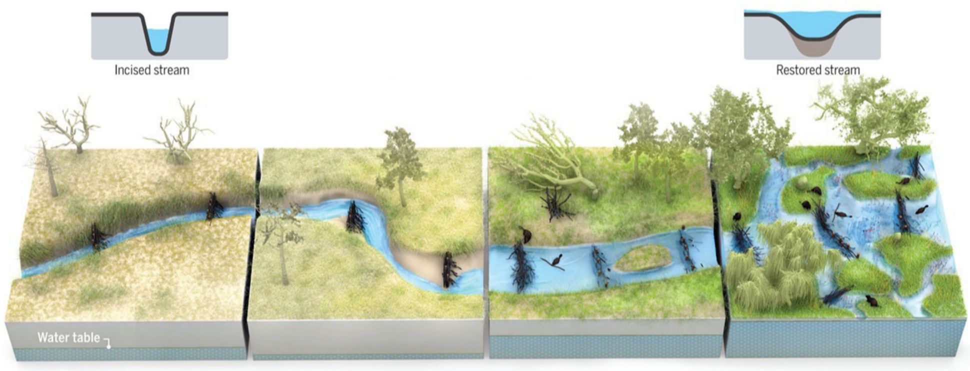


FIGURE 5.1. Beaver restoration effects on a stream. Image taken from [**Goldfarb, 2018**]

A list of the actions that have potential to be replicated by the beaver, and those which do not have such potential, is presented below. The actions are divided into high, medium and low degree of certainty, accounting for the different degrees of confidence about beaver replication. In the "High degree", actions that can be replicated almost identically by the beaver or deliver equivalent river restoration outcomes are listed. The "Medium degree" category contains actions that beavers can perform but would not deliver the same restoration goal without some level of human intervention. Finally, "low degree" shows the actions that would be difficult for the beaver to perform or those that have not been confirmed in the literature.

- High degree of probability
  - Maintenance of stream banks since beavers promote a dynamic of stream bank creation and destruction [**Pollock et al., 2015**] [**Gorczyca et al., 2018**] [**Campbell-Palmer et al., 2016**].
    * (actions 1.2.4, 1.2.5, 1.2.6a, 1.2.6b)
  - Spreading plants as beavers have been documented to forage on species of *Ranunculus* so would be likely to have the same effect for the species present in Portugal; it is well documented that beavers feed on reeds and rushes [**Campbell-Palmer et al., 2016**].
    * (actions: 4.1, 4.2, 4.3, 4.4)
  - Replication of small weirs because dam building is a well-known beaver activity [**Campbell-Palmer et al., 2016**] [**Pollock et al., 2014**] [**Schwab, 2015**].
    * (actions: 5.1.1, 5.1.2, 5.1.3)
  - Habitat heterogeneity, feeding opportunities and ponds adjacent to the river stream as beaver-made wetlands create several ponds and increase the variety of sub habitats in rivers and streams, thus creating foraging opportunities for several species [**Law et al., 2017**] [**Janiszewski et al., 2014**]. Action 6.2 is included as an action beavers can perform, yet given that no price interval is provided in the APA guide, this action is not part of the economic estimations.
    * (actions: 6.1, 6.2, 6.3, 6.4, 6.5, 6.6.1, 6.6.2)
- Medium degree of probability
  - Recovering incised streams and river bank stability as it is known that sediment retention by beaver dams averages 7.5 cm/year and can be as high as 40 centimeters [**Pollock et al., 2007**] [**Puttock et al., 2018**] [**Gorczyca et al., 2018**].
    * (actions: 1.1, 1.2.1, 1.2.2, 1.2.3)
  - Controlling vegetation, such as cutting trees is classified in the "medium" category because, although felling trees is a well documented beaver activity, in certain environments, such as urban and suburban areas, selective tree-cutting by humans may be a better approach [**Janiszewski et al., 2014**] [**Campbell-Palmer et al., 2016**].
    * (actions: 2.1, 2.1.3)
  - Controlling *Myriophyllum aquaticum*, beaver foraging behaviour reduces this invasive species by 90%, yet this did not result in a recolonization by native species, so some level of human intervention may be required to control the invasive plant [**Parker et al., 2007**].
    * (action: 2.3.2)

- Increasing River Tree Cover while beavers do not plant trees, they do create the conditions for natural regeneration of riparian plants and trees; this option may not be suitable where riparian forests are too degraded [**Campbell-Palmer et al., 2016**].
    * (actions 4.5, 4.6, 4.7.1, 4.7.2)
- Retention basis beavers help prevent floods by storing water in the landscape and reducing peak flow levels. Implementation in urban areas may be difficult, but in rural areas it may be a good option [**Brazier et al., 2020**] [**Campbell-Palmer et al., 2016**].
    * (action: 5.2.1, 5.2.2)

- Low degree of probability
  - Curb other invasive species, beavers are generalist feeders, with a diet that includes a wide range of plants, shrubs and trees [**Campbell-Palmer et al., 2016**]. Beavers can relate to invasive species in two ways: they may help control some species, as is the case of *Myriophyllum aquaticum* [**Parker et al., 2007**]; or they may create habitat that is suitable for them or even help spread them. Current knowledge is not yet sufficient, still given the generalist foraging behaviour of the beaver there is a chance that some invasive species would be eaten, thus helping with their control. Another way beavers can curb invasive vegetation is by increasing the native ecosystem's resilience.
    * (actions 2.1.1, 2.1.2, 2.2.1, 2.2.2, 2.3.1, 2.3.3)
- Actions that the beaver cannot perform
  - Maintaining or recovering human infrastructure such as walking trails or some buildings.
    * (actions: 1.3.1, 1.3.2, 1.4.1, 1.4.2, 1.4.3)
  - Removal of debris from a river stream, such as garbage.
    * (actions: 3.1, 3.2)

From a total of forty-three interventions, thirty-six were selected as having some potential for beaver replication. The majority, eighteen have a high degree of certainty, while twelve have medium, six have low and seven have none. In the annex is provided a list with the name of each action the beaver is able to perform by degree of certainty.

For the value interval in each action, the potential is based on a beaver colony of two adults and possibly some kits based on several studies [**Campbell-Palmer et al., 2016**] [**Pollock et al., 2015**] [**Schwab, 2015**] [**Brazier et al., 2020**]. Detailed information for each action value interval can be find on annex.

Table 5.1 shows an overview of the estimated cost scenarios. (LC - LQ) stands for Low cost - Low quantity, (HC - LQ) for Low cost - high quantity, (LC - HQ), High cost - low quantity and (HC - HQ) High cost - high quantity. These scenarios were calculated by multiplying the prince range with the value intervals. The values presented in the table are in euros. In annex the full table that was used for the calculations is present.

| | LC - LQ | HC - LQ | LC - HQ | HC - HQ |
|---|---|---|---|---|
| High Probability | 87,505 | 218,300 | 427,775 | 941,625 |
| Medium Probability | 126,712 | 192,575 | 1,104,900 | 1,617,950 |
| Low Probability | 24,000 | 47,500 | 240,000 | 475,000 |
| High and Medium | 214,217 | 410,875 | 1,532,675 | 2,559,575 |
| High, Medium and Low | 238,217 | 458,375 | 1,772,675 | 3,034,575 |

TABLE 5.1. Beaver potential to save river restoration costs - Scenarios estimations

The table shows a big difference between high and medium probability scenarios, which is due to the inclusion in "medium" of a particularly costly action, the cribwall. This is very pricey when compared with the others, since it alone accounts for around one million euros. Data from the table 1 show why the low scenario presents the smaller value of the three; in fact, there is a small number of actions in this category, which is mainly about cleaning invasive vegetation.

The results from the various scenarios show the potential for beavers to bring savings on river restoration costs. Yet it is important to highlight that this is a small scale analysis for only one beaver colony, and that on a given river restoration intervention not all the actions will normally be performed. The estimations are in line with findings from other studies [**Brazier et al., 2020**] [**Valachovič, 2014**] [**Pollock et al., 2015**]. These avoided costs must, of course, be compared to beaver management and reintroduction costs, which will be estimated in the following sections.

### 5.4. Beaver Management Costs

Although the presence of beavers is widely seen as positive from a nature conservation point of view, the species can create conflicts with humans. Due to their foraging behaviour, digging activities and dam building endeavors beavers can bring about various problems [**Valachovič, 2014**]. Among those there are: foraging on crops, since beavers are know to eat sugar beet, maize, wheat, corn among other grains, different vegetables and fruits from orchards [**Valachovič, 2014**]. These activities usually have a low economic impact, yet can increase when beavers learn to store food for winter [**Valachovič, 2014**]. They also forage species with a high economic value such as pine and oak [**Valachovič, 2014**] [**Campbell-Palmer et al., 2016**]. Other beaver activities, such as digging burrows, can impede the use of heavy machinery in farms [**Schwab,**

**2015**] [**Valachovič, 2014**]. Beavers can build dams in drainage pipes and sewage treatment plants [**Valachovič, 2014**]. Trees can fall on property infrastructure such as fences, power lines, buildings, roads, rails or cars [**Valachovič, 2014**]. They can increase maintenance costs in hydropower facilities, roads and train tracks [**Valachovič, 2014**]. Plus, beavers are also known to burrow in flood protection dikes close to rivers [**Schwab, 2015**] [**Valachovič, 2014**].

The management costs associated with beavers have tree phases. At reintroduction, if the habitat is suitable and beaver dams are not necessarily built, the conflicts are sporadic and management costs are low. In a second phase, as beaver population increases and expands, they occupy areas where the habitat is not ideal and build dams to improve it. Many potential conflicts arise and some can be costly at this stage. Finally, when there is no more suitable habitat for expansion and beaver population reaches capacity, management measures in place should avoid the majority of conflicts and new problems are either a result of a lack of maintenance or just occasional incidents [**Campbell-Palmer et al., 2016**]. Moreover, the majority of documented conflicts happen within 10 to 20 meters of a water body and beavers are unlikely to build dams in streams wider than 10 meters [**Campbell-Palmer et al., 2016**] [**Valachovič, 2014**] [**Schwab, 2015**]. Given this information it is possible to identify the areas where conflict is likely and where human wildlife management measures may be required.

There are two types of management approach. One takes the form of culling, removal of animals or removal of dams ; another focuses on creating the conditions for coexistence between humans and beavers. To prevent conflicts the ideal situation would be to create buffer areas close to rivers and streams [**Valachovič, 2014**] [**Campbell-Palmer et al., 2016**] [**Schwab, 2015**]. Yet, where management actions are required a pro-active approach, in the form of identifying likely areas of conflict and offering information campaigns, is a good strategy to minimize conflicts and promote coexistence [**Pollock et al., 2015**]. Moreover, actions such as culling or removal of animals tend to be costlier and deliver shorter-term benefits than coexistence measures [**Campbell-Palmer et al., 2016**] [**Pollock et al., 2015**] [**Hood et al., 2018a**]. For example, removing a beaver dam does not ensure beavers will not rebuild it on the same site; culling beavers from one location does not guarantee that a area will remain beaver free, since beavers can reappear from other areas. In contrast, a flow device or a road culvert prevents conflicts in the first place, lasts longer and tends to have low maintenance costs [**Hood et al., 2018b**] [**Boyles and Savitzky, 2009**].

In the following text a list of beaver management measures, followed by prices and value intervals, is presented, based on a extensive literature review. There are many ways to promote coexistence with the beaver, but these are the most commonly used measures.

- Tree protection, trees wrapped in metal fences to prevent beaver forage [**Campbell-Palmer et al., 2016**] [**Valachovič, 2014**].
  - (action 1.1)
- Sand Paint creates a texture on the tree bark that prevents beavers from foraging on treated trees and shrubs [**Valachovič, 2014**] [**Campbell-Palmer et al., 2016**] [**Pollock et al., 2015**].
  - (action 1.2)
- Flow devices, this are pipes passing through a beaver dam to control the water level in a beaver pond [**Pollock et al., 2015**] [**Schwab, 2015**].
  - (action 2.1)
- Road Culverts are built to protect bridges and drainage pipes, this prevents beavers from constructing dams on infrastructures [**Pollock et al., 2015**] [**Campbell-Palmer et al., 2016**].
  - (action 2.2)

To assess the costs of these management actions, various sources were tapped. For the actions to prevent forage, values are based on prices from "Flügel", a German store that specializes in preventing human/wildlife conflicts. These values were then used as a proxy to determine an interval of values, accounting for uncertainty in the price of implementing the measure. For the tree wrap, five to fifteen euros per tree based on [**Flügel, 2020a**], while for sand paint, three to six euros per tree [**Flügel, 2020b**]. For flow devices, to estimate a price interval several sources were analysed [**Brazier et al., 2020**] [**Pollock et al., 2015**] [**Campbell-Palmer et al., 2016**]. The report "The Beaver Restoration Guidebook" cites a study were average flow devices cost around 600 USD [**Pollock et al., 2015**]. The currrent study assumes a price interval from three hundred to one thousand euros for flow devices. Road culverts prevent beavers from blocking a culvert or drainage structure [**Pollock et al., 2015**] [**Campbell-Palmer et al., 2016**], and the price range to update drainage structures to be beaver prove can range from five hundred to one thousand and five hundred euros per structure.

It is important to note that the type of measure and quantity can vary significantly from on place to another. On the other hand, rarely will all management measures be used on the same site.

The cost estimates are shown in Table 5.2. The difference between Low cost - High quantity (LC - HQ) and High cost - Low quantity (HC - LQ) scenarios is due to big differences in the value interval of actions 1.1 and 1.2.

Other costs are not accounted for in the current estimates. For instance, several European Countries, such as Germany and the Czech Republic, provide state compensation payments for damages done by beavers in agriculture and forestry [**Campbell-Palmer et al., 2016**]. In the

| | LC - LQ | LC - HQ | HC - LQ | HC - HQ |
|---|---|---|---|---|
| Total | 975.00 | 4,450.00 | 3,900.00 | 17,900.00 |

Table 5.2. Beaver management costs - Scenarios estimations

state of Bavaria in Germany, there is a state fund dedicated to beaver conflicts. It grew from 250 000 euros in 2011 to a budget of around 700 000 euros in 2014 [**Bund Naturschutz in Bayern, 2020**]. Other measures that can be considered in beaver management include protecting river banks or canals [**Schwab, 2015**] and installing beaver-proof electric fences [**Valachovič, 2014**]. However, electric fences are not consensual, with some reports advising against them due to high costs, maintenance requirements and unsatisfactory results [**Pollock et al., 2015**].

### 5.5. Reintroduction costs

The return of the beaver can happen in two ways. The first option is to have a controlled trial, such as the one in South England in the river Otter [**Brazier et al., 2020**]. This trial happened in a fenced area within a controlled environment , where the effects of beaver presence on the environment where carefully monitored. The river Otter trial had no costs for the Government, as it was carried out by an environmental NGO in partnership with the university of Exeter; unfortunately, the full costs of the program were not released. The trial started with two beaver breeding pairs in 2015 and had a duration of 5 years [**Brazier et al., 2020**]. It studied in detail the biodiversity impacts associated with beaver presence as well as ecosystem services, such as flood prevention, social attitudes and the overall evolution and state of the population [**Brazier et al., 2020**].

An alternative is to release beavers directly in the wild, in a non fenced area. In Hungary, the reintroduction program released around 230 beavers in a period of 19 years, from 1996 to 2008, in 15 sites across the country [**Bajomi, 2011**]. The costs were financed by a private company and amounted to 325 000 euros. It was a fairly simple program, but the results were not published in any scientific publication and there is no information regarding education programs complementary to the animal release [**Bajomi, 2011**].

### 5.6. Results

The estimated saved costs in river restoration done by beavers ranged from a couple hundred thousand euros to between two and three million euros per beaver colony. Nevertheless, it is very unlikely that all river restoration actions were performed in every intervention, since small-scale ones tend to be used more often (clearing invasive vegetation, stabilizing banks or planting shrubs or trees). Plus, these findings may be somewhat limited given that translocation or reintroduction of animals is always dependent on a careful evaluation of a number of variables such as habitat suitability studies, local community attitudes, climate change models and disease risk among other factors [**IUCN/SSC, 2013**].

Beaver potential for conflict can be significant, so management measures are essential. Regarding the management costs, these can range from some hundreds of euros to tens of thousands. State compensation payments which may be several thousand euros or more were not accounted [**Bund Naturschutz in Bayern, 2020**]. Still, the literature shows that problems caused by the beaver can be minimized and in the majority of cases avoided, while the beaver-induced landscape effects can hardly be replicated through man-made actions in the ecosystem [**Brazier et al., 2020**] [**Pollock et al., 2015**]. Plus, the reintroduction or translocation costs are a one-time investment that yields returns in the medium and long term and the cost range, between one to three million euro, seems to be within river restoration program budgets.

APA's interventions are controlled and have clear expected goals. On the other hand, the beaver impacts come with a certain degree of uncertainty and management costs estimates may not be entirely accurate for the Portuguese case. Yet, the beaver does plug an existing gap in riverine ecosystems, providing balance and allowing a potential natural increase to restored rivers and streams as beavers expand to new areas. In contrast, most APA actions do not have potential to expand without further funds and interventions. Thus beavers seem to be good investments for river restoration, given that the potential to save on river restoration costs is high, management costs are relatively low and the reintroduction costs are within river restoration programs budgets.

### 5.7. Discussion

The APA 2018 - 2020 program spent 11.43 million euros in 57 separate interventions in the North and Center of Portugal, detailed image of the interventions and respective costs can be find in annex. The main goals of the program were: to guarantee water flow, to minimize the effects of erosion and to reduce the impact of flooding events. According to the overall data from the program the average price of a river and stream habitat restoration intervention is around 200 000 euros [**APA, 2020**]. The program achieved the following results: 591 km of rivers and streams received restoration actions, which benefited a total of 975 km of rivers and streams [**APA, 2020**]. Even though the detailed actions undertaken in each intervention are not public, it is safe to assume that those were guided by the APA 2013 River Restoration Guide [**APA/FEUP, 2013**].

The type of actions undertaken by APA in the 2018 - 2020 program are suitable in several situations, for instance: in urban or in sensitive agricultural areas that may require a more controlled intervention; to stabilize a water body in the months after a forest fire, to prevent erosion and clean the burned vegetation [**APA, 2017**]; or in areas where the habitat is not suitable or too degraded for beavers. In other situations, the beaver could well be considered.

Ideally interventions should begin in areas with a low human density and where agricultural activity is low. Yet even in urban and suburban areas there is suitable beaver habitat [**Swinnen et al., 2017**] [**Pollock et al., 2015**]. The beaver could be used to achieve the following restoration goals: recover incised streams; promote natural regeneration; create benefits for wildlife; or control invasive vegetation. It is important to note that the benefits for biodiversity and ecosystem services tend to be biggest in areas were the beaver can work without constraints [**Schwab, 2015**] [**Campbell-Palmer et al., 2016**], such as in protected areas or in low density zones with little to no agriculture.

Moreover, the impact of bio-engineered measures is localized and contained, while the beaver has the potential to expand in range if habitat is suitable and to develop further restoration actions. Furthermore, benefits for biodiversity increase in time with beaver presence while the bio-engineered actions require a certain degree of maintenance [**APA/FEUP, 2013**]. Beavers develop more complex habitat dynamics as the time passes, from one or two dams in the first and second year to a complex wetland after 5 to 10 years [**Law et al., 2017**] [**Pollock et al., 2015**] [**Campbell-Palmer et al., 2016**]. Plus, beavers can produce effects on the whole watershed or river basin [**Valachovič, 2014**].

Instead of promoting only local river restoration interventions, some funds could be used to bring back beavers, thus avoiding expenses in attempts to recreate natural processes that the beaver could undertake with fewer resources, more ecosystem services and biodiversity benefits [**Roni et al., 2008**] [**Beechie et al., 2010**] [**Law et al., 2017**]. The beaver could be complementary to some of the river restoration actions already performed by APA.

To conclude this chapter, we note that it is reasonable to assume, based on previous reintroduction programs, that a translocation would require a budget of between 500 thousand and 3 million euros in a period of 5 years. This would establish one to three population sites, with a beaver population of at least 30 animals each, plus pay for complementary education programs and monitoring of beaver impacts and population trends. For maximum positive impact, reintroduction could be done in key areas with the best expansion potential. With a population growth rate of 10% to 15% and average beaver impact on 6 kilometers of river bank [**Campbell-Palmer et al., 2016**] [**Gurnell et al., 2008**], a conservative estimate means that, after 5 years there would be around 150 beavers in at least 400 km of rivers and streams directly and indirectly influenced beavers, both directly by building dams, burrows and canals, and by foraging, and indirectly through impacts downstream of beaver site where water availability and its quality would increase. After 10 years there would be around 240 beavers in 600 km of waterways, possibly yielding savings of dozens of million euros in river restoration costs while fostering biodiversity and delivering valuable ecosystem services, as discussed in detail in the next chapter.

Management costs seem acceptable, especially if a proactive approach to conflicts is put in practice. Moreover, the costs for a reintroduction and management of the beaver could be completed with European Union funds such as the Life Program or shared between the central or local government and environmental NGOs.

CHAPTER 6

# Beaver Impacts in the Landscape

In previous chapters, beaver capacity to restore degraded habitats was discussed. This chapter analyses possible landscape effects from beaver activities. A small population of beavers will have a small impact, yet in a scale with a population of dozens or hundreds can have big effects in landscape resilience, especially in key locations such as mountain ranges or upstream of flood-prone villages and cities [**Campbell-Palmer et al., 2016**] [**Pollock et al., 2015**].

Although monetary quantification of such impacts is difficult, it is a valuable exercise to highlight the beaver's potential to deliver ecosystem services and help guide future policy decisions [**Vermaat et al., 2016**]. The following impacts will be considered: biodiversity gains, recreation in the form of tourism opportunities, regulation of water flows, improvements in water quality, water supplies and mitigation of wildfires. To quantify in monetary terms the potential for beavers to deliver ecosystem services a recent study was used. The work titled "Ecosystem services provided by beavers *Castor* spp.", quantifies beaver made ecosystem services in the North Hemisphere for both species of beaver. It provides estimations in monetary terms per hectare per year for 7 types of ecosystem services. It also provides estimations for the overall benefits beaver populations create, as example both species of beaver produce per year around 133 million dollars worth of "habitat and biodiversity provision" [**Thompson et al., 2020**].

| Ecosystem Service | Per Hectare Service Value | Coefficient | Per beaver colony |
|---|---|---|---|
| Biodiversity | 113.1 | 1 | 3393 |
| Recreation | 142 | 0.26 | 1108 |
| Regulation of Water Flows | 105.4 | 0.26 | 822 |
| Water Quality | 91.8 | 0.26 | 716 |
| Water Supply | 65.5 | 0.26 | 511 |

TABLE 6.1. Values used in the Ecosystem Service Estimations

Given that the study was performed in US dollars there was the need to convert the values to euros, the exchange ratio used was 1usd - 0.85euros [**Bloommberg, 2020**]. A beaver colony has on average a territory of around 30 hectares [**Campbell-Palmer et al., 2016**]. The values are per hectare and are annual. Regarding the coefficient, this accounts to human density close to beaver sites, there needs to be human populations close to beaver sites in order to value certain beaver made ecosystem services. Table 6.1, depicts the information used to estimate a monetary value for each ecosystem service. This are dam building beaver colonies, it is important to note that beavers do not always create wetlands. The scenarios were develop for the following numbers of beavers dam building colonies: 1, 75, 750 and 1500. Recreational Fish and Hunting was not included, which is mainly related with beaver hunting [**Thompson et al., 2020**] nor was GHG Storage Effects, given that the literature for the European beaver range is very limited [**Nummi et al., 2018**]. Forest Fires were included even though a economic valuation of such benefits is not provided. Lastly, a number of examples around Portugal, where beavers could potentially be used as a solution for local problems affecting rivers and streams, is discussed.

### 6.1. Biodiversity and Habitat Provision

Beaver can provide a helping hand in boosting biodiversity, as stated in chapter 4. This specie presence can benefit a wide range of species; mammals, birds, reptiles, amphibians, fresh water mussels and insects [**Campbell-Palmer et al., 2016**].

| nº of beaver colonies | 1 | 75 | 750 | 1500 |
|---|---|---|---|---|
| ES monetary value | 3 393 | 254 4475 | 2 544 750 | 5 089 500 |

Table 6.2. Monetary Valuation - Biodiversity and Habitat Provision

The monetary valuation of "Biodiversity and Habitat Provision" can potentially also account for the save in river restoration actions which was analysed in the previous chapter.

### 6.2. Recreational Benefits

An additional dimension of beaver benefits is tourism. The reintroduction of animals tends to happen in low density rural areas, to decrease the likelihood of conflicts. Thus, beavers create a good opportunity to develop nature tourism that benefits local communities. Nevertheless, beaver activities do not fit people's standard views of clean and organized landscapes. Wild landscapes do not look tidy, which may affect the type of tourist choosing to visit the area [**Valachovič, 2014**]. Besides direct tourism opportunities also produce other benefits such as inspiration and mental and physical well being.

| nº of beaver colonies | 1 | 75 | 750 | 1500 |
|---|---|---|---|---|
| ES monetary value | 1 108 | 83 100 | 831 000 | 1 662 000 |

Table 6.3. Monetary Valuation - Recreation

### 6.3. Regulation of Water Flows

Climate is going to change in Portugal as in the whole Iberian Peninsula, with more irregular precipitation patterns and more frequent drought periods predicted [**Beck et al., 2018**] [**IPCC,**

**2019**]. One beaver colony can create a wetland with a storage capacity of around 1000 m3 of water, although this value can vary from wet to dry season [**Puttock et al., 2017**]. Beaver wetlands increase the storage capacity and decrease water velocity, which normalizes peak flows and minimizes the effects of both droughts and floods. Yet it is important to note that the type of habitat, existence of building materials and channel characteristics affect the beaver's dam building capacity [**Puttock et al., 2017**]. Moreover, the people that benefit from the new water-regulation ecosystem services are not necessarily the same that bear the costs [**Brazier et al., 2020**]. Economic valuation of this ecosystem service is presented in following table.

| nº of beaver colonies | 1 | 75 | 750 | 1500 |
|---|---|---|---|---|
| ES monetary value | 822 | 61 650 | 616 500 | 1 233 000 |

Table 6.4. Monetary Valuation - Regulation of Water Flows

### 6.4. Water Quality

Nitrate and phosphate from agriculture and livestock origins are common pollutants in Portuguese water bodies [**APA, 2016**]. Together with sediments from soil erosion, these contaminants decrease water quality in rivers and streams [**Kristensen et al., 2018**]. Two beavers in a controlled site, in the South West of England, created 13 ponds; these wetlands stored around 100t of sediment, 16t of nitrogen and 1t of carbon [**Puttock et al., 2018**]. This effect also helps mitigate the loss of soil in intensively managed grasslands [**Puttock et al., 2018**]. Therefore a beaver population can have a big impact in filtrating pollutants and decreasing sediment suspension in freshwater habitats. Below monetary valuation of beaver effects on water quality.

| nº of beaver colonies | 1 | 75 | 750 | 1500 |
|---|---|---|---|---|
| ES monetary value | 716 | 53 700 | 537 000 | 1 074 000 |

Table 6.5. Monetary Valuation - Water Quality

### 6.5. Water Storage

According to several studies beaver engineered wetlands "increase groundwater storage capacity, water table level, and aquifer recharge" [**Thompson et al., 2020**]. A beaver population can have a big impact in the water retention capacity of a given area, as already stated a beaver engineered wetland can store around 1000 m3 of water [**Puttock et al., 2017**]. Next, a economic estimation of this ecosystem service.

| nº of beaver colonies | 1 | 75 | 750 | 1500 |
|---|---|---|---|---|
| ES monetary value | 511 | 38 325 | 383 250 | 766 500 |

Table 6.6. Monetary Valuation - Water Supply

### 6.6. Mitigation of Forest Fires

Portugal is very prone to forest fires, with thousands of hectares burned each year. One natural break for wildfires is provided by riparian areas, vegetation areas close to streams and rivers where a fresher environment usually occurs [**Fairfax and Whittle, 2020**]. The relationship between beavers and wildfires is not very developed in the literature. Yet, a recent study shows that beaver activities expand the size of riparian zones, providing shelter areas to wildlife and increasing the size of natural firebreaks [**Fairfax and Whittle, 2020**]. Unfortunately, an economic valuation of this beaver made ecosystem service is not quantified in the study [**Thompson et al., 2020**].

The ecosystem services at a landscape scale can potentially account for many million euros. The main contributor is "biodiversity and habitat provision" mainly because the coefficient is 1 not 0.26. Some of the APA bio engineered river restoration actions may yield some similar benefits but not on the scale the beaver can. This values can be important in future decisions regarding future payment for ecosystem services schemes [**Thompson et al., 2020**]. Still, by aggregating all the ecosystem services estimations there is the risk of double accounting [**Thompson et al., 2020**]. Plus, beaver benefits can differ greatly from site to site and are dependent on human proximity. Still this analysis provides a clear insight into the beaver potential to deliver ecosystem services. Table 6.7 provides the sum of all monetary values estimated for the selected beaver made ecosystem services.

| nº beaver colonies | 1 | 75 | 750 | 1500 |
|---|---|---|---|---|
| ES monetary value | 6 039 | 491 250 | 4 912 500 | 9 825 000 |

Table 6.7. Total Ecosystem Services Monetary Valuation

Based on beaver dynamics recorded in other areas, a few Portuguese locations could be suggested as beneficiaries of beaver reintroduction. Given flood prevention benefits, with beaver wetlands decreasing peak flow, the severity of flood events in vulnerable cities and villages could be reduced [**Brazier et al., 2020**]. The city of Chaves, in northern Portugal, could benefit from this solution [**APS, 2014**] [**MdC, 2015**]. In Southern Portugal droughts are a recurrent event that is becoming more common [**Beck et al., 2018**]. Monchique or Marvão Mountain Ranges, for example could benefit from the presence of beavers for water retention. The creation of fire breaks, in fire prone areas in the center of Portugal, from the Nabão to the Vouga and from the

Côa to the Ponsul, would be useful too. Beavers could also promote favorable spawning grounds for salmon in the Lima and Minho rivers or increase baseline storage in Southern streams to support small native fish species. Beaver dams could filter agricultural pollution in Alentejo streams such as the Soraia, and beavers could possibly help control invasive vegetation such as wild cane (*Arundo donax*) or common water hyacinth (*Eichhornia crassipes*).

These are only suggestions. The choice of reintroduction sites would be dependent on a careful, detailed habitat viability analysis and a study of potential human wildlife conflicts. Beaver are not a one-size fits all solution. Other actions such as dam removal, better treatment plants, improved agricultural practices and control of invasive species are still required to guarantee a good ecological condition of rivers and streams [**Beechie et al., 2010**]. Plus, human wildlife management is key for a harmonious coexistence between people and the beaver [**Pollock et al., 2015**] [**Schwab, 2015**] [**Campbell-Palmer et al., 2016**].

CHAPTER 7

# Conclusion

This study set out to investigate which approach could deliver bigger economic and environmental benefits: active management of ecosystems in the form of river restoration programs or passive management approach in the form of a beaver reintroduction. As part of the analysis, we studied whether the conditions for the beaver to return exist in Portugal and what the costs and benefits of this return might be, as well as the likely landscape scale effects of such a return, including an improved ecological status of freshwater habitats.

The conditions for the beaver to return to Portuguese territory are in place, in terms of habitat, climate and the legal framework. Beavers exist in harsher climates and many native species would benefit from its presence here. Another finding is that the beaver can be a cost-effective tool in river restoration interventions, even after management and reintroduction costs are considered. Plus, based on beaver impacts seen in other areas, there is a relevant potential to deliver ecosystem services such as flood alleviation, drought mitigation, wildfire protection, water quality improvement and increasing nature tourism, especially in rural areas. It is safe to state that a passive management intervention based on beaver reintroduction makes sense from a economic and ecologic perspective. It saves river restoration costs, delivers a wide range of ecosystem services and increases the conditions for biodiversity to thrive.

There are several limitations of this study: it is impossible to predict all damages and benefits beavers will create. A reintroduction requires a in-depth analysis, more detailed than the one presented in this work. Even after considering environmental factors and economic ones, political and local attitudes are always key to reintroduce a species, especially one that has been absent for such a long time. Moreover, the literature for beavers in Mediterranean climates is not very developed, which can compromise some of the predicted landscape effects. Yet despite its exploratory nature, this study offers some insights into the environmental and economic potential of beavers in river and stream restoration actions. It thus makes a strong case for the beaver to be reintroduced to Portugal.

Several questions still remain to be answered. A first step would be to identify areas with suitable habitat for the beaver in Portugal, along with an exploration of particular beaver dynamics in Mediterranean-type climates and on the impact of beaver-made wetlands on forest fires. Further research might explore other situations where a passive management approach based on rewilding could make sense. For example, the Iberian Ibex *Capra pyrenaica* could be reintroduced to mountain ranges around Portugal, saving costs in clearing vegetation and potentially helping prevent forest fires. Lastly, in economics to account for all the direct and indirect costs and benefits is a long and complex endeavour. Analysing the costs of managed conservation actions versus restoring ecosystem processes, and securing the funds to manage human/wildlife conflicts, creates a strong economic argument for the reintroduction of certain species, specially if they are keystone in the ecosystem.

The findings of this study also have a number of policy implications. First, the reintroduction of the beaver in Portugal should be considered seriously. Beavers are ecosystem engineers and they deliver a wide range of benefits: saving habitat restoration cost, creating conditions for wildlife to thrive and increasing climate resilience in the landscape. Second, it is strongly advisable to consider the beaver as a tool in future river restoration programs in Portugal, as already happens in other countries. Third, there is a need to consider passive management (rewilding) as a valid conservation strategy. The restoration of ecosystems can help both mitigate and adapt to the effects of climate change and tackle biodiversity losses. Once missing species are present again, humans do to need to compensate for a missing ecological role. The amount of saved costs in managing the ecosystem plus the benefits in ecosystem services tend to be bigger than the costs in the reintroduction plus the expenses in managing potential human/wildlife conflicts. In a time of planetary emergency it is important to change the narrative. Humans can destroy ecosystems, but we can also can help them recover.

# Bibliography


[Antunes, 1989] Antunes, M. T. (1989). Castor fiber na gruta do caldeirão existência, distribuição e extinção do castor em portugal.

[APA, 2016] APA (2016). Pressões quantitativas e qualitativas sobre os recursos hídricos. `https://rea.apambiente.pt/content/press%C3%B5es-quantitativas-e-qualitativas-sobre-os-recursos-h%C3%ADdricos?language=pt-pt`. Accessed: 2020-10-28.

[APA, 2017] APA (2017). Áreas de intervenção prioritárias para a proteção dos recursos hídricos.

[APA, 2020] APA (2020). Relatório síntese de execução final: Intervenções de regularização fluvial.

[APA/FEUP, 2013] APA/FEUP (2013). Guia de Orientação para a Intervenção nas Linhas de Água.

[APS, 2014] APS (2014). Cartas de inundação e risco em cenários de alterações climáticas. Technical report, Associação Portuguesa de Seguradores.

[Atkinson and Mourato, 2008] Atkinson, G. and Mourato, S. (2008). Environmental cost-benefit analysis. *Annual review of environment and resources*, 33:317–344.

[Bajomi, 2011] Bajomi, B. (2011). Reintroduction of the eurasian beaver (castor fiber) in hungary. *Danube Parks Network of Protected Areas, Directorate of Duna-Dráva National Park, Budapest, Hungary.*

[Beck et al., 2018] Beck, H. E., Zimmermann, N. E., McVicar, T. R., Vergopolan, N., Berg, A., and Wood, E. F. (2018). Present and future köppen-geiger climate classification maps at 1-km resolution. *Scientific data*, 5:180214.

[Beechie et al., 2010] Beechie, T. J., Sear, D. A., Olden, J. D., Pess, G. R., Buffington, J. M., Moir, H., Roni, P., and Pollock, M. M. (2010). Process-based principles for restoring river ecosystems. *BioScience*, 60(3):209–222.

[Bergstrom and Loomis, 2017] Bergstrom, J. C. and Loomis, J. B. (2017). Economic valuation of river restoration: An analysis of the valuation literature and its uses in decision-making. *Water Resources and Economics*, 17:9–19.

[Beschta and Ripple, 2019] Beschta, R. L. and Ripple, W. J. (2019). Can large carnivores change streams via a trophic cascade? *Ecohydrology*, 12(1):e2048.

[Bloommberg, 2020] Bloommberg (2020). USD-EUR X-RATE. `https://www.bloomberg.com/quote/USDEUR:CUR`. Accessed: 2020-10-28.

[Boardman et al., 2017] Boardman, A. E., Greenberg, D. H., Vining, A. R., and Weimer, D. L. (2017). *Cost-benefit analysis: concepts and practice*. Cambridge University Press.

[Bond, 1994] Bond, W. (1994). Keystone species. In *Biodiversity and ecosystem function*, pages 237–253. Springer.

[Boyles and Savitzky, 2009] Boyles, S. L. and Savitzky, B. A. (2009). 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.

[Brazier et al., 2020] Brazier, R. E., Elliot, M., Andison, E., Auster, R. E., Bridgewater, S., Burgess, P., Chant, J., Graham, H., Knott, E., Puttock, A. K., Sansum, P., and Vowles, A. (2020). River Otter Beaver Trial Science and Evidence Report. Technical report.

[Bund Naturschutz in Bayern, 2020] Bund Naturschutz in Bayern (2020). Konflitkte und biberschänden vermeiden: die biberberater des bund naturschutz. `https://www.bund-naturschutz.de/tiere-in-bayern/biber/biberschaeden.html`. Accessed: 2020-10-17.

[Cabral et al., 2005] Cabral, M. J., Almeida, J., Almeida, P. R., Dellinger, T., Ferrand de Almeida, N., Oliveira, M., Palmeirim, J., Queirós, A., Rogado, L., and Santos-Reis, M. (2005). Livro vermelho dos vertebrados de portugal.

[Cambridge Dictionary, 2020] Cambridge Dictionary (2020). Cost-benefit analysis. `https://dictionary.cambridge.org/us/dictionary/english/cost-benefit-analysis`. Accessed: in 2020-10-25.

[Campbell-Palmer et al., 2016] Campbell-Palmer, R., Gow, D., Schwab, G., Halley, D., Gurnell, J., Girling, S., Lisle, S., Campbell, R., Dickinson, H., Jones, S., et al. (2016). *The Eurasian beaver handbook: ecology and management of Castor fiber*. Pelagic Publishing Ltd.

[Campbell-Palmer and Rosell, 2013] Campbell-Palmer, R. and Rosell, F. (2013). *Captive management guidelines for Eurasian Beavers (Castor fiber)*. Royal Zoological Society of Scotland.

[Ceballos et al., 2020] Ceballos, G., Ehrlich, P. R., and Raven, P. H. (2020). Vertebrates on the brink as indicators of biological annihilation and the sixth mass extinction. *Proceedings of the National Academy of Sciences*.

[CJEU, ] CJEU. 5 September 2019, Commission v. Portugal, Case 290/18.

[Cohen-Shacham et al., 2016] Cohen-Shacham, E., Walters, G., Janzen, C., and Maginnis, S. (2016). Nature-based solutions to address global societal challenges. *IUCN: Gland, Switzerland*, 97.

[Credite Suisse et al., 2014] Credite Suisse, WWF, and McKinsey&Company (2014). Conservation Finance: Moving beyond donor funding toward an investor-driven approach. Technical report.

[Cuenca-Bescós et al., 2017] Cuenca-Bescós, G., Ardévol, J. R., Morcillo-Amo, Á., Galindo-Pellicena, M. Á., Santos, E., and Costa, R. M. (2017). Beavers (castoridae, rodentia, mammalia) from the quaternary sites of the sierra de atapuerca, in burgos, spain. *Quaternary International*, 433:263–277.

[Dubrulle and Catusse, 2012] Dubrulle, P.-M. and Catusse, M. (2012). Où en est la colonisation du castor en france. *Faune sauvage*, 297:24–35.

[Earle et al., 2016] Earle, J., Moran, C., and Ward-Perkins, Z. (2016). *Econocracy*. Manchester University Press.

[European Commission, 1992] European Commission (1992). Directive 92/43/EEC of the European Commission of 21 May 1992 on the conservation of natural habitats and of wild fauna and flora. *Official journal of the European communities*, 21(05).

[European Commission, 2000] European Commission (2000). Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy. *Official journal of the European communities*, 22(12).

[European Commission, 2016] European Commission (2016). Commission staff working document. fitness check of the eu nature legislation (birds and habitats directives) directive 2009/147/ec of the european parliament and of the council of 30 november 2009 on the conservation of wild birds and council directive 92/43/eec of 21 may 1992 on the conservation of natural habitats and of wild fauna and flora.

[European Commission, 2020] European Commission (2020). Communication from the commission to the european parliament, the council, the economic and social committee and the committee of the regions. *EU Biodiversity Strategy for 2030 Bringing nature back into our lives*, pages 1–23.

[European Commission et al., 2007] European Commission et al. (2007). Guidance document on the strict protection of animal species of community interest under the habitats directive 92/43/eec.

[Fairfax and Whittle, 2020] Fairfax, E. and Whittle, A. (2020). Smokey the beaver: beaver-dammed riparian corridors stay green during wildfire throughout the western usa. *Ecological Applications*, page e2225.

[Faivre et al., 2017] Faivre, N., Fritz, M., Freitas, T., de Boissezon, B., and Vandewoestijne, S. (2017). Nature-based solutions in the eu: Innovating with nature to address social, economic and environmental challenges. *Environmental research*, 159:509–518.

[Feio and Ferreira, 2019] Feio, M. J. and Ferreira, V. (2019). *Rios de Portugal: comunidades, processos e alterações*. Imprensa da Universidade de Coimbra/Coimbra University Press.

[Fischer et al., 2017] Fischer, L., Hasell, J., Proctor, J. C., Uwakwe, D., Perkins, Z. W., and Watson, C. (2017). *Rethinking economics: An introduction to pluralist economics*. Routledge.

[Flügel, 2020a] Flügel (2020a). Plant saver schälschutzmatte protect 180. `https://www.fluegel-gmbh.de/produkte/pflanzenschutz/schaelschutz/plant-saver-schaelschutzmatte-protect-180-f04.016`. Accessed: 2020-10-13.

[Flügel, 2020b] Flügel (2020b). WÖbra mechanischer langzeitschälschutz. `https://www.fluegel-gmbh.de/produkte/pflanzenschutz/schaelschutz/woebra-mechanischer-langzeitschaelschutz-f04.006`. Accessed: 2020-10-13.

[Fustec and Cormier, 2007] Fustec, J. and Cormier, J.-P. (2007). Utilisation of woody plants for lodge construction by european beaver (castor fiber) in the loire valley, france. *Mammalia*, 71(1-2):11–15.

[Gibson and Olden, 2014] Gibson, P. P. and Olden, J. D. (2014). Ecology, management, and conservation implications of north american beaver (castor canadensis) in dryland streams. *Aquatic Conservation: Marine and Freshwater Ecosystems*, 24(3):391–409.

[Gillson et al., 2011] Gillson, L., Ladle, R. J., and Araújo, M. B. (2011). Baselines, patterns and process. *Conservation biogeography. Oxford: Wiley-Blackwell. p*, pages 31–44.

[Goldfarb, 2018] Goldfarb, B. (2018). Beavers, rebooted.

[Gorczyca et al., 2018] Gorczyca, E., Krzemień, K., Sobucki, M., and Jarzyna, K. (2018). Can beaver impact promote river renaturalization? the example of the raba river, southern poland. *Science of the Total Environment*, 615:1048–1060.

[Gregr et al., 2020] Gregr, E. J., Christensen, V., Nichol, L., Martone, R. G., Markel, R. W., Watson, J. C., Harley, C. D., Pakhomov, E. A., Shurin, J. B., and Chan, K. M. (2020). Cascading social-ecological costs and benefits triggered by a recovering keystone predator. *Science*, 368(6496):1243–1247.

[Grizzetti et al., 2017] Grizzetti, B., Pistocchi, A., Liquete, C., Udias, A., Bouraoui, F., and Van De Bund, W. (2017). Human pressures and ecological status of european rivers. *Scientific reports*, 7(1):1–11.

[Gurnell et al., 2008] Gurnell, J., Gurnell, A., Demeritt, D., Lurz, P., Shirley, M., Rushton, S., Faulkes, C., Nobert, S., and Hare, E. (2008). The feasibility and acceptability of reintroducing the european beaver to england. *Natural England/People's Trust for Endangered Species, Sheffield, UK*.

[Halley et al., 2012] Halley, D., Rosell, F., Saveljev, A., et al. (2012). Population and distribution of eurasian beaver (castor fiber). *Baltic Forestry*, 18(1):168–175.

[Halley et al., 2020] Halley, D. J., Saveljev, A. P., and Rosell, F. (2020). Population and distribution of beavers castor fiber and castor canadensis in eurasia. *Mammal Review*.

[Hayward et al., 2019] Hayward, M. W., Scanlon, R. J., Callen, A., Howell, L. G., Klop-Toker, K. L., Di Blanco, Y., Balkenhol, N., Bugir, C. K., Campbell, L., Caravaggi, A., et al. (2019). Reintroducing rewilding to restoration–rejecting the search for novelty. *Biological conservation*, 233:255–259.

[Hering et al., 2010] Hering, D., Borja, A., Carstensen, J., Carvalho, L., Elliott, M., Feld, C. K., Heiskanen, A.-S., Johnson, R. K., Moe, J., Pont, D., et al. (2010). The european water framework directive at the age of 10:

a critical review of the achievements with recommendations for the future. *Science of the total Environment*, 408(19):4007–4019.

[Higgs et al., 2014] Higgs, E., Falk, D. A., Guerrini, A., Hall, M., Harris, J., and Hobbs, R. J. (2014). The changing role of history in restoration ecology. (November).

[Hood et al., 2018a] Hood, G. A., Manaloor, V., and Dzioba, B. (2018a). Mitigating infrastructure loss from beaver flooding: A cost–benefit analysis. *Human Dimensions of Wildlife*, 23(2):146–159.

[Hood et al., 2018b] Hood, G. A., Manaloor, V., and Dzioba, B. (2018b). Mitigating infrastructure loss from beaver flooding: A cost–benefit analysis. *Human Dimensions of Wildlife*, 23(2):146–159.

[ICNF, 2016] ICNF (2016). Espécies arbóreas indígenas em portugal continental. Technical report.

[Indurain, ] Indurain, F. Petition on the protection of the beaver in Spain, No 0352/2018, (2018).

[IPBES, 2019] IPBES (2019). Summary for policymakers of the global assessment report on biodiversity and ecosystem services of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services. 2019. Technical report.

[IPCC, 2019] IPCC (2019). Land: An IPCC Special Report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems. 2019. Technical report.

[IUCN, 2016] IUCN (2016). Eurasian beaver. `https://www.iucnredlist.org/species/4007/115067136`. Accessed: in 2020-10-25.

[IUCN/SSC, 2013] IUCN/SSC (2013). Guidelines for reintroductions and other conservation translocations. Version 1.0.

[Janiszewski et al., 2014] Janiszewski, P., Hanzal, V., and Misiukiewicz, W. (2014). The eurasian beaver (castor fiber) as a keystone species–a literature review. *Baltic forestry*, 20(2):277–286.

[Jiménez Pérez, 2018] Jiménez Pérez, I. (2018). Producción de naturaleza: parques, rewilding y desarrollo local. *Ciudad Autónoma de Buenos Aires: The Conservation Land Trust Argentina*.

[Jones et al., 2018] Jones, H. P., Jones, P. C., Barbier, E. B., Blackburn, R. C., Benayas, J. M. R., Holl, K. D., Mccrackin, M., Meli, P., Montoya, D., Mateos, D. M., and Jones, H. P. (2018). Restoration and repair of Earth ' s damaged ecosystems.

[Jørgensen, 2015] Jørgensen, D. (2015). Rethinking rewilding. *Geoforum*, 65:482–488.

[Keesstra et al., 2018] Keesstra, S., Nunes, J., Novara, A., Finger, D., Avelar, D., Kalantari, Z., and Cerdà, A. (2018). The superior effect of nature based solutions in land management for enhancing ecosystem services. *Science of the Total Environment*, 610:997–1009.

[Keller et al., 2011] Keller, R. P., Geist, J., Jeschke, J. M., and Kühn, I. (2011). Invasive species in europe: ecology, status, and policy. *Environmental Sciences Europe*, 23(1):23.

[Kristensen et al., 2018] Kristensen, P., Whalley, C., and Klančnik, K. (2018). *European waters: assessment of status and pressures 2018*. European Environment Agency.

[Law et al., 2017] Law, A., Gaywood, M. J., Jones, K. C., Ramsay, P., and Willby, N. J. (2017). Using ecosystem engineers as tools in habitat restoration and rewilding: beaver and wetlands. *Science of the Total Environment*, 605:1021–1030.

[Leemans and De Groot, 2003] Leemans, R. and De Groot, R. (2003). *Millennium Ecosystem Assessment: Ecosystems and human well-being: a framework for assessment*. Island press.

[Maneschi, 1996] Maneschi, A. (1996). Jules dupuit: A sesquicentennial tribute to the founder of benefit-cost analysis. *Journal of the History of Economic Thought*, 3(3):411–432.

[Markovic et al., 2017] Markovic, D., Carrizo, S. F., Kärcher, O., Walz, A., and David, J. N. (2017). Vulnerability of european freshwater catchments to climate change. *Global Change Biology*, 23(9):3567–3580.

[Martin et al., 2020] Martin, J.-L., Chamaillé-Jammes, S., and Waller, D. M. (2020). Deer, wolves, and people: costs, benefits and challenges of living together. *Biological Reviews*, 95(3):782–801.

[MdC, 2015] MdC (2015). Revisão do Plano Diretor Municipal de Chaves. Technical report.

[Moran et al., 2018] Moran, E. F., Lopez, M. C., Moore, N., Müller, N., and Hyndman, D. W. (2018). Sustainable hydropower in the 21st century. *Proceedings of the National Academy of Sciences*, 115(47):11891–11898.

[Myers et al., 2000] Myers, N., Mittermeier, R. A., Mittermeier, C. G., Da Fonseca, G. A., and Kent, J. (2000). Biodiversity hotspots for conservation priorities. *Nature*, 403(6772):853.

[Nesshöver et al., 2017] Nesshöver, C., Assmuth, T., Irvine, K. N., Rusch, G. M., Waylen, K. A., Delbaere, B., Haase, D., Jones-Walters, L., Keune, H., Kovacs, E., et al. (2017). The science, policy and practice of nature-based solutions: An interdisciplinary perspective. *Science of the Total Environment*, 579:1215–1227.

[Nummi et al., 2018] Nummi, P., Vehkaoja, M., Pumpanen, J., and Ojala, A. (2018). Beavers affect carbon biogeochemistry: both short-term and long-term processes are involved. *Mammal Review*, 48(4):298–311.

[Papworth et al., 2009] Papworth, S. K., Rist, J., Coad, L., and Milner-Gulland, E. J. (2009). Evidence for shifting baseline syndrome in conservation. *Conservation Letters*, 2(2):93–100.

[Parker et al., 2007] Parker, J. D., Caudill, C. C., and Hay, M. E. (2007). Beaver herbivory on aquatic plants. *Oecologia*, 151(4):616–625.

[Pauly, 1995] Pauly, D. (1995). Anecdotes and the shifting baseline syndrome of fisheries. *Trends in ecology & evolution*, 10(10):430.

[Pereira and Navarro, 2015] Pereira, H. M. and Navarro, L. M. (2015). *Rewilding european landscapes*. Springer Nature.

[Perino et al., 2019] Perino, A., Pereira, H. M., Navarro, L. M., Fernández, N., Bullock, J. M., Ceaușu, S., Cortés-Avizanda, A., van Klink, R., Kuemmerle, T., Lomba, A., et al. (2019). Rewilding complex ecosystems. *Science*, 364(6438).

[Pollock et al., 2007] Pollock, M. M., Beechie, T. J., and Jordan, C. E. (2007). Geomorphic changes upstream of beaver dams in bridge creek, an incised stream channel in the interior columbia river basin, eastern oregon. *Earth Surface Processes and Landforms*, 32(8):1174–1185.

[Pollock et al., 2014] Pollock, M. M., Beechie, T. J., Wheaton, J. M., Jordan, C. E., Bouwes, N., Weber, N., and Volk, C. (2014). Using beaver dams to restore incised stream ecosystems. *Bioscience*, 64(4):279–290.

[Pollock et al., 2015] Pollock, M. M., Lewallen, G., Woodruff, K., Jordan, C. E., and Castro, J. M. (2015). The Beaver Restoration Guidebook: Working with Beaver to Restore Streams, Wetlands, and Floodplains. Technical report, United States Fish and Wildlife Service, Portland, Oregon.

[Puttock et al., 2018] Puttock, A., Graham, H. A., Carless, D., and Brazier, R. E. (2018). Sediment and nutrient storage in a beaver engineered wetland. *Earth surface processes and landforms*, 43(11):2358–2370.

[Puttock et al., 2017] Puttock, A., Graham, H. A., Cunliffe, A. M., Elliott, M., and Brazier, R. E. (2017). Eurasian beaver activity increases water storage, attenuates flow and mitigates diffuse pollution from intensively-managed grasslands. *Science of the total environment*, 576:430–443.

[Raworth, 2017] Raworth, K. (2017). *Doughnut economics: seven ways to think like a 21st-century economist*. Chelsea Green Publishing.

[Ripple and Beschta, 2012] Ripple, W. J. and Beschta, R. L. (2012). Trophic cascades in yellowstone: the first 15 years after wolf reintroduction. *Biological Conservation*, 145(1):205–213.

[Robinson, 1990] Robinson, J. C. (1990). Philosophical origins of the social rate of discount in cost-benefit analysis. *The Milbank Quarterly*, pages 245–265.

[Rockström et al., 2009] Rockström, J., Steffen, W., Noone, K., Persson, Å., Chapin III, F. S., Lambin, E., Lenton, T. M., Scheffer, M., Folke, C., Schellnhuber, H. J., et al. (2009). Planetary boundaries: exploring the safe operating space for humanity. *Ecology and society*, 14(2).

[Roni et al., 2008] Roni, P., Hanson, K., and Beechie, T. (2008). Global review of the physical and biological effectiveness of stream habitat rehabilitation techniques. *North American Journal of Fisheries Management*, 28(3):856–890.

[Rosell et al., 2005] Rosell, F., Bozser, O., Collen, P., and Parker, H. (2005). Ecological impact of beavers castor fiber and castor canadensis and their ability to modify ecosystems. *Mammal review*, 35(3-4):248–276.

[Sandom et al., 2020] Sandom, C. J., Middleton, O., Lundgren, E., Rowan, J., Schowanek, S. D., Svenning, J.-C., and Faurby, S. (2020). Trophic rewilding presents regionally specific opportunities for mitigating climate change. *Philosophical Transactions of the Royal Society B*, 375(1794):20190125.

[Schwab, 2015] Schwab, G. (2015). *Biber in Bayern Biologie und Management*. Bayerisches Landesamt für Umwelt.

[Seddon et al., 2007] Seddon, P. J., Armstrong, D. P., and Maloney, R. F. (2007). Developing the science of reintroduction biology. *Conservation biology*, 21(2):303–312.

[Soule and Noss, 1998] Soule, M. and Noss, R. (1998). Rewilding and biodiversity: complementary goals for continental conservation. *Wild Earth*, 8:18–28.

[Stern et al., 2006] Stern, N. H., Peters, S., Bakhshi, V., Bowen, A., Cameron, C., Catovsky, S., Crane, D., Cruickshank, S., Dietz, S., Edmonson, N., et al. (2006). *Stern Review: The economics of climate change*, volume 30. Cambridge University Press Cambridge.

[Studer and Zeh, 2014] Studer, R. and Zeh, H. (2014). *Soil bioengineering: Construction type manual*. vdf Hochschulverlag AG.

[Swinnen et al., 2017] Swinnen, K. R., Strubbe, D., Matthysen, E., and Leirs, H. (2017). Reintroduced eurasian beavers (castor fiber): colonization and range expansion across human-dominated landscapes. *Biodiversity and Conservation*, 26(8):1863–1876.

[Terborgh and Estes, 2013] Terborgh, J. and Estes, J. A. (2013). *Trophic cascades: predators, prey, and the changing dynamics of nature*. Island press.

[Thompson et al., 2020] Thompson, S., Vehkaoja, M., Pellikka, J., and Nummi, P. (2020). Ecosystem services provided by beavers castor spp. *Mammal Review*.

[Thompson and Barton, 1994] Thompson, S. C. G. and Barton, M. A. (1994). Ecocentric and anthropocentric attitudes toward the environment. *Journal of environmental Psychology*, 14(2):149–157.

[United Nations, 2018] United Nations (2018). Resolution adopted by the General Assembly on 1 March 2019 – United Nations Decade on Ecosystem Restoration 2021–2030. Seventy-third session. A/73/L.76. `https://undocs.org/en/A/RES/73/284`. Accessed: in 2020-10-25.

[Valachovič, 2014] Valachovič, D. (2014). Manual of beaver management within the danube river basin. *Danube Parks*.

[Vermaat et al., 2016] Vermaat, J. E., Wagtendonk, A. J., Brouwer, R., Sheremet, O., Ansink, E., Brockhoff, T., Plug, M., Hellsten, S., Aroviita, J., Tylec, L., et al. (2016). Assessing the societal benefits of river restoration using the ecosystem services approach. *Hydrobiologia*, 769(1):121–135.

[Voulvoulis et al., 2017] Voulvoulis, N., Arpon, K. D., and Giakoumis, T. (2017). The eu water framework directive: From great expectations to problems with implementation. *Science of the Total Environment*, 575:358–366.

[WEF, 2020] WEF (2020). The Future Of Nature And Business. Technical report.

[Wiedmann et al., 2020] Wiedmann, T., Lenzen, M., Keyßer, L. T., and Steinberger, J. K. (2020). Scientists' warning on affluence. *Nature communications*, 11(1):1–10.

[Wilmers et al., 2003] Wilmers, C. C., Crabtree, R. L., Smith, D. W., Murphy, K. M., and Getz, W. M. (2003). Trophic facilitation by introduced top predators: grey wolf subsidies to scavengers in yellowstone national park. *Journal of Animal Ecology*, 72(6):909–916.

[WWF, 2020] WWF (2020). Global Futures: Modelling the global economic to support policy-making. Technical Report February.

APPENDIX A

# Annex

| APA Action Number | Probability | unit cost | | value interval | |
|---|---|---|---|---|---|
| 4.1 Branch Propagation | high | 0.15 | 1.5 | 50 | 250 |
| 4.2 Bulbs | high | 0.2 | 2 | 50 | 250 |
| 4.3 Rhizome | high | 0.2 | 2 | 50 | 250 |
| 4.4 Sedges | high | 0.25 | 2 | 50 | 250 |
| 4.5 Plants in lump | medium | 2 | 10 | 25 | 150 |
| 4.6 Bare roots plants | medium | 1.5 | 8 | 25 | 150 |
| 4.7.1 Seed Dispersal | medium | 1 | 2 | 250 | 750 |
| 4.7.2 Water Seed Dispersal | medium | 1.5 | 5 | 250 | 750 |
| 5.1.1 Small wood wires | high | 150 | 300 | 3 | 15 |
| 5.1.2 Small wood wires | high | 30 | 50 | 3 | 15 |
| 5.1.3 Small rock wires | high | 50 | 100 | 3 | 15 |
| 6.1 Increase River Heterogeneity | high | 100 | 2500 | 1 | |
| 6.3 Shelter zones | high | 15 | | 15 | 30 |
| 6.4 Feeding areas | high | 10 | 15 | 15 | 30 |

TABLE A.1. APA bio engineered actions - unit cost and beaver potential to replicate in value intervals

| APA Action Number | Probability | ml cost | | value interval | |
|---|---|---|---|---|---|
| 1.2.5 Fascine | high | 20 | 40 | 150 | 750 |
| 1.2.6a Biorolo with Vegetation | high | 45 | 75 | 150 | 750 |
| 1.2.6b Biorolo with no Vegetation | high | 25 | 45 | 150 | 750 |
| 2.1 Cutting Tree Vegetation | medium | 5 | 7.5 | 150 | 750 |
| 2.1.3 Cutting down trees | medium | 5 | 7.5 | 150 | 750 |

TABLE A.2. APA bio engineered actions - meter line (ml) cost and beaver potential to replicate in value intervals

| APA Action Number | Probability | m2 cost | | value interval | |
|---|---|---|---|---|---|
| 1.2.3 Cribwall | medium | 90 | 125 | 1000 | 10000 |
| 1.2.4 Entrenched Wood | high | 20 | 35 | 1000 | 10000 |
| 2.1.1 *Acacia dealbata* | low | 5 | 10 | 1000 | 10000 |
| 2.1.2 *Ailanthus alissima* | low | 5 | 10 | 1000 | 10000 |
| 2.2.1 *Arundo donax* | low | 5 | 10 | 1000 | 10000 |
| 2.2.2 *Rubus spp* | low | 5 | 7.5 | 1000 | 10000 |
| 2.3.1 *Eichhornia crassipes* | low | 2 | 5 | 1000 | 10000 |
| 2.3.2 *Myriophyllum aquaticum* | medium | 2 | 5 | 1000 | 10000 |
| 2.3.3 *Tradescantia fluminensis* | low | 2 | 5 | 1000 | 10000 |
| 6.5 Connectivity within the stream | high | 10 | 30 | 5000 | 15000 |
| 6.6.1 Creation of small ponds | high | 20 | 40 | 20 | 60 |
| 6.6.2 Creation of medium ponds | high | 40 | 60 | 60 | 120 |

Table A.3. APA bio engineered actions - squared meter (m2) cost and beaver potential to replicate in value intervals

| APA Action Number | Probability | m3 cost | | value interval | |
|---|---|---|---|---|---|
| 1.1 Modeling Stream Banks | medium | 5 | 12.5 | 250 | 1500 |
| 1.2.1 Alive Gabion | medium | 70 | 100 | 250 | 1500 |
| 1.2.2 Alive Riprap | medium | 35 | 70 | 250 | 1500 |
| 5.2.1 Creation of retention basis | medium | 5 | 12.5 | 500 | 1000 |
| 5.2.2 Creation of retention basis | medium | 5 | 12.5 | 500 | 1000 |

Table A.4. APA bio engineered actions - cubic meter (m3) cost and beaver potential to replicate in value intervals

| APA Action Number | LC - LQ | HC - LQ | LC - HQ | HC - HQ |
|---|---|---|---|---|
| 1.1 Modeling Stream Banks | 1250 | 3125 | 7500 | 18750 |
| 1.2.1 Alive Gabion | 17500 | 25000 | 105000 | 150000 |
| 1.2.2 Alive Riprap | 8750 | 17500 | 52500 | 105000 |
| 1.2.3 Cribwall | 90000 | 125000 | 900000 | 1250000 |
| 1.2.4 Entrenched Wood | 20000 | 35000 | 200000 | 350000 |
| 1.2.5 Fascine | 3000 | 6000 | 15000 | 30000 |
| 1.2.6a Biorolo with Vegetation | 6750 | 11250 | 33750 | 56250 |
| 1.2.6b Biorolo with no Vegetation | 3750 | 6750 | 18750 | 33750 |
| 2.1 Cutting Tree Vegetation | 750 | 1125 | 3750 | 5625 |
| 2.1.1 *Acacia dealbata* | 5000 | 10000 | 50000 | 100000 |
| 2.1.2 *Ailanthus alissima* | 5000 | 10000 | 50000 | 100000 |
| 2.1.3 Cutting down trees | 750 | 1125 | 3750 | 5625 |
| 2.2.1 *Arundo donax* | 5000 | 10000 | 50000 | 100000 |
| 2.2.2 *Rubus spp* | 5000 | 7500 | 50000 | 75000 |
| 2.3.1 *Eichhornia crassipes* | 2000 | 5000 | 20000 | 50000 |
| 2.3.2 *Myriophyllum aquaticum* | 2000 | 5000 | 20000 | 50000 |
| 2.3.3 *Tradescantia fluminensis* | 2000 | 5000 | 20000 | 50000 |
| 4.1 Branch Propagation | 7.5 | 75 | 37.5 | 375 |
| 4.2 Bulbs | 10 | 100 | 50 | 500 |
| 4.3 Rhizome | 10 | 100 | 50 | 500 |
| 4.4 Sedges | 12.5 | 100 | 62.5 | 500 |
| 4.5 Plants in lump | 50 | 250 | 300 | 1500 |
| 4.6 Bare roots plants | 37.5 | 200 | 225 | 1200 |
| 4.7.1 Seed Dispersal | 250 | 500 | 750 | 1500 |
| 4.7.2 Water Seed Dispersal | 375 | 1250 | 1125 | 3750 |
| 5.1.1 Small wood wires | 450 | 900 | 2250 | 4500 |
| 5.1.2 Small wood wires | 90 | 150 | 450 | 750 |
| 5.1.3 Small rock wires | 150 | 300 | 750 | 1500 |
| 5.2.1 Creation of retention basis | 2500 | 6250 | 5000 | 12500 |
| 5.2.2 Creation of retention basis | 2500 | 6250 | 5000 | 12500 |

TABLE A.5. Beaver potential to save river restoration actions - Part 1

| APA Action Number | LC - LQ | HC - LQ | LC - HQ | HC - HQ |
|---|---|---|---|---|
| 6.1 Increase River Heterogeneity | 100 | 2500 | 100 | 2500 |
| 6.3 Shelter zones | 225 | 450 | 225 | 450 |
| 6.4 Feeding areas | 150 | 225 | 300 | 450 |
| 6.5 Connectivity within the stream | 50000 | 150000 | 150000 | 450000 |
| 6.6.1 Creation of small ponds | 400 | 800 | 1200 | 2400 |
| 6.6.2 Creation of medium ponds | 2400 | 3600 | 4800 | 7200 |

TABLE A.6. Beaver potential to save river restoration actions - Part 2

| High Degree | Medium Degree | Small Degree |
|---|---|---|
| 1.2.4 Entrenched Wood | 1.1 Modeling Stream Banks | 2.1.1 *Acacia dealbata* |
| 1.2.5 Fascine | 1.2.1 Alive Gabion | 2.1.2 *Ailanthus alissima* |
| 1.2.6a Biorolo with Vegetation | 1.2.2 Alive Riprap | 2.2.1 *Arundo donax* |
| 1.2.6b Biorolo with no Vegetation | 1.2.3 Cribwall | 2.2.2 *Rubus spp.* |
| 4.1 Branch Propagation | 2.1 Cutting Tree Vegetation | 2.3.1 *Eichhornia crassipes* |
| 4.2 Bulbs | 2.1.3 Cutting down trees | 2.3.3 *Tradescantia fluminensis* |
| 4.3 Rhizome | 2.3.2 *Myriophyllum aquaticum* | |
| 4.4 Sedges | 4.5 Plants in lump | |
| 5.1.1 Small wood wires | 4.6 Bare roots plants | |
| 5.1.2 Small wood wires | 4.7.1 Seed Dispersal | |
| 5.1.3 Small rock wires | 4.7.2 Water Seed Dispersal | |
| 6.1 Increase River Heterogeneity | 5.2.1 Creation of retention basis | |
| 6.2 Creation of Current Zones | 5.2.2 Creation of retention basis | |
| 6.3 Shelter zones | | |
| 6.4 Feeding areas | | |
| 6.5 Connectivity within the stream | | |
| 6.6.1 Creation of small ponds | | |
| 6.6.2 Creation of medium ponds | | |

TABLE A.7. List of Bio-engineered River Restoration Actions the Beaver is able to perform by degree of certainty

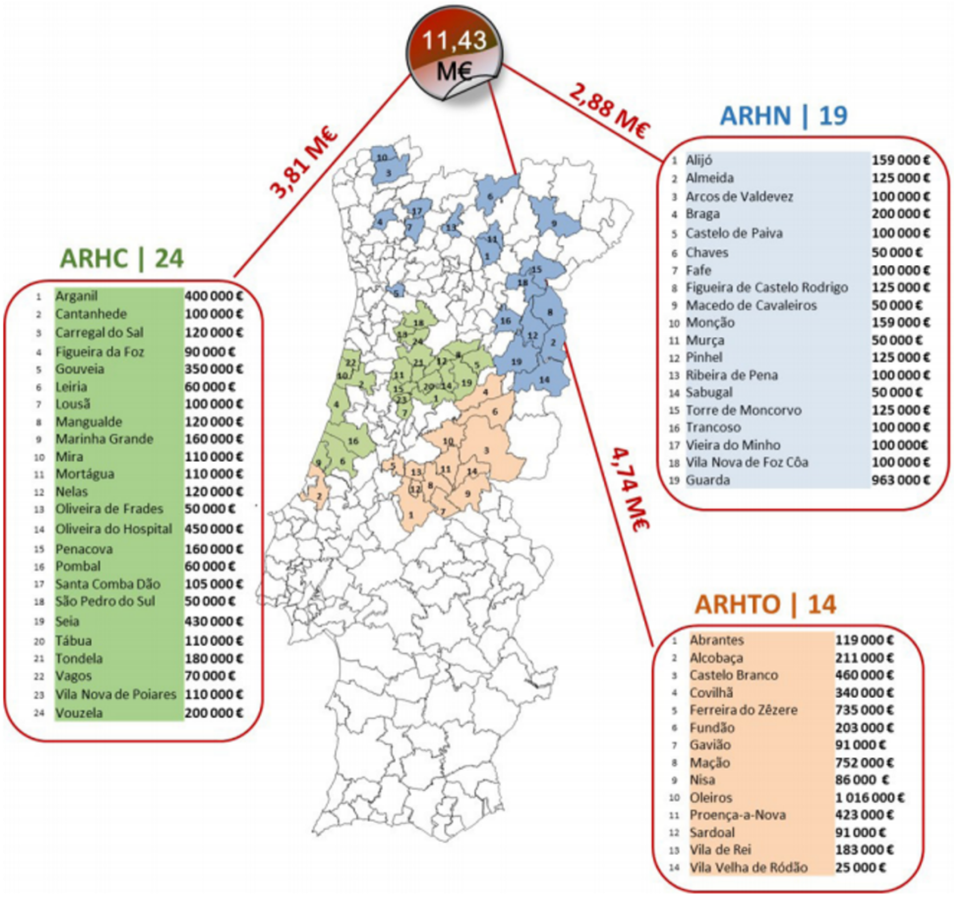


FIGURE A.1. Municipalities where APA Interventions were performed and respective cost. Image taken from [**APA, 2020**]