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Rewilding with the beaver in the iberian peninsula - Economic potential for river restoration

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A B S T R A C T

Nature restoration is essential to tackle the loss of biodiversity and to adapt and mitigate the effects of climate change. Recently the United Nations declared 2021 - 2030 the decade for the Restoration of Ecosystems, while the European Union 2030 Biodiversity Strategy includes restoration as a core pillar.

Rivers and streams are a key component of ecosystems, yet many are in poor ecological condition. The Portuguese Environmental Agency (APA) ran a program from 2018 to 2020 to restore degraded watercourses through bioengineering interventions. Yet these do not restore missing ecological processes, while additional funding would be required to expand their range. Thus long-term improvement is not assured.

Beavers used to inhabit the Iberian Peninsula and they have already been brought back to other areas, as a means to restore freshwater ecosystems. Beavers are ecosystem engineers, building dams, digging canals and cutting shrubs and trees. As a keystone species, beavers allow many others to thrive, delivering significant environmental and economic benefits.

In this work we select, among the actions listed in the APA river restoration guide, those that beavers might perform. We value these actions in monetary terms as avoided costs, taking into consideration price intervals and expected beaver colony activity.

We conclude that beavers have the potential to replicate many commonly-used river restoration actions, possibly saving millions of euros in interventions. Bringing back the beaver therefore seems a worthwhile endeavour, not only in Portugal but in the main river basins of the Iberian Peninsula. Furthermore, beavers could provide a boost to wildlife, increase landscape resilience to climate change and bring hope in the face of environmental challenges.

1. Introduction

The restoration of ecosystems is key to address biodiversity losses while mitigating greenhouse gas emissions and adapting to the effects of climate change [45]. In particular, freshwater ecosystems are among the most threatened habitats in Europe [36,44]. The European Environment Agency, in its latest overview, points out that "the conservation status of freshwater protected habitats and species is not changing, and remains predominantly unfavourable or bad." [26, pg.100] Several factors have contributed to this historical degradation, namely: hydromorphological alterations, such as dams [10,30], climate change [53] and invasive species [47].

In Portugal, the Agência Portuguesa do Ambiente (APA) financed a River Restoration Program from 2018 to 2020 [2] to tackle impaired river ecosystems and counter the effects of the huge 2017 forest fires. The program mainly supported bioengineering interventions to improve the conservation status of targeted river and streams. However, this approach to restoration does not address the root causes of degradation [9] nor does it rehabilitate natural processes, thus compromising its ability to achieve long-term goals [66].

In areas where the beaver is native, this herbivorous rodent is commonly used as a tool in river restoration programs [35,63]. Beavers have the ability to change their surroundings in ways that benefit many other species [14]. They are, therefore, considered both a keystone species and ecosystem engineers [15,43]. Their value to freshwater ecosystems has led to their reintroduction in several European locations [13,35,68]. Restoring beaver populations can be a valuable nature-based solution: their dams regulate water flows, minimizing the severity of droughts and flood events, reducing disaster risk and enabling climate change adaptation [27]. This paper aims to study from

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an economic and environmental perspective the extent to which beavers could be brought back to Portugal and Spain to replace human interventions in river restoration.

The analysis presented here is narrow in scope as it only looks at the monetary values associated with avoided river-restoration costs. It does not, therefore, encompass all the ecosystem services beavers are known to provide [72]. As discussed in Section 5, these benefits include: sediment storage [61], improved nutrient dynamics and habitat provision [17], increase in abundance and variety of wildlife [43], forest fire mitigation [29], greenhouse gas sequestration [72], regulation of water flows and improved water quality [40]. Additional benefits can be associated with new recreation opportunities, such as nature tourism [4]. Nevertheless, our analysis adds a novel perspective to the literature by providing a simple and easy method to assess at least part of the economic value of specific rewilding practices, such as species reintroduction programs.

Surprisingly, the economic analysis of rewilding both at micro (at designated sites) and macro (landscape) scales has not been significantly developed [69] when compared with ”classic” ecosystem management actions. Ecosystem restoration actions might take different forms, as discussed in the following section. Those that are financed through public funding often provide data on restoration costs of human interventions that can, and should, be used to consider the value of alternative approaches such as rewilding. In the specific case of river restoration, while some research has been carried out on beaver potential to improve habitats [17,67], and more generally on the economic value of beaver ecosystem services [72], no study has quantified the potential gain, in avoided costs, were beavers allowed to replace human river-restoration actions, including financial data from a real public policy in the analysis. Moreover, our case study considers the beavers' return to the Iberian Peninsula, a relevant area of species range expansion.

2. Background

There can be several approaches to nature conservation. In active management conservation, the focus tends to be on managing loss, by stopping the decline in abundance of certain species, and on preserving ecosystems in static states with well-defined conservation targets [59]. In this approach, when there is a missing process, human intervention often tries to replicate it [60]. Nonetheless, with climate change and rapid biodiversity loss, success is fleeting. More ambitious, proactive and flexible ways towards nature restoration must be sought [7,20].

Rewilding, understood as the passive management of ecological succession to restore natural ecosystem processes and reduce human control of landscapes, offers an alternative [34,59]. In Europe, the abandonment of former agricultural lands provides an opportunity to restore parts of the continent to a wilder, more biodiverse state with functional and dynamic ecosystems [59]. These have three important characteristics: complex trophic chains with herbivores, predators and scavengers, stochastic disturbances in the form of natural processes such as floods and natural fires and dispersal through wildlife corridors [60]. To develop ecosystems, historical baselines are fundamental yet should be used as guidelines rather than rigid templates [39]. Rewilding principles applied to river restoration can translate into dam removals [57], reintroduction of missing keystone species [37] or control and eradication of invasive ones [51].

Beavers are a keystone species [43] and can therefore play an important role in the restoration of freshwater habitats [49]. There are two species of beavers, the European (*Castor fiber*) and the American (*Castor canadensis*). Wetlands created by these rodents provide valuable habitat to many other animals: insects [65], amphibians [24], fishes [48], reptiles [43], birds [43], bats [55] and terrestrial and aquatic mammals [56].

Beaver habitat includes wetlands [40], deltas [75], estuaries [54], lakes [8], rivers [17] and even temporary streams [33]. Indeed, beavers are very adaptable creatures, who can even occupy urban [71] and agricultural areas [50]. These rodents are strictly vegetarian, feeding on vegetation in Spring and Summer and on tree bark in Autumn and Winter [17].

The European beaver *Castor fiber* is native to Portugal and Spain, as shown by fossil records [22,23], toponymic evidence [1] and Roman testimonies [25]. It became extinct in the Iberian Peninsula around the XVIIth century [1,22]. Recently, it was returned to Spain through an unofficial release in the Ebro River basin in 2003 [38], and it is now considered a protected species in the country [11].

No habitat suitability studies have been undertaken for the beaver in Portugal or Spain. Yet based on known past presence, habitat requirements [33], populations in similar climates [38] and foraged tree species [17], it is likely that suitable habitats exist [74], with the northern wetter areas potentially preferable to southern drier ones.

Regarding the legal framework, the Habitats Directive 92/43/EEC states that where species are absent from their historical range their translocation should be considered [28]. As the beaver is native to Portugal, its reintroduction can and should be given serious consideration. Moreover, Portugal was recently convicted of not complying adequately with the Directive, so a change in policies to protect habitats and endangered species is timely [21].

3. Data and method

The data for the current analysis came from the APA/FEUP Guide for the Restoration of Rivers and Streams in the Center of Portugal [3]. This Guide provides a list of restoration actions to use on degraded freshwater habitats and a unit-cost range for each one[1] Material actions are organized into six categories: river banks and beds, vegetation management, litter removal, planting of native species, hydraulic works and habitat heterogeneity. The guide also includes immaterial actions such as planning, monitoring and public participation. These were excluded from the analysis, as similar actions would presumably be necessary for beaver reintroduction.

A literature review of beaver ecosystem dynamics, for both European and American species [67,74], was undertaken to appraise the APA-listed material restoration actions. In particular, we sought to gauge which actions could be performed by beavers and what would be their expected magnitude. As a first step, APA-listed actions were classified into three categories (high, medium and low) according to the likelihood that beavers might perform them. The measures included in each category, and supporting sources, are described below.

The ”High likelihood” category includes actions for which the beaver is likely to deliver the same restoration outcome or mimic the restoration action. Specific evidence in the literature includes: creation of ponds, small wood or rock dams [17]; expansion in opportunities for wildlife such as shelter zones or feeding areas [43]; restoration of river and stream bank dynamics [62]; foraging activities which promote the spread of plant species [52]; and an increase in the diversity of micro habitats [49].

”Medium likelihood” gathers actions beavers can perform to some degree, yet where human intervention may still be necessary to achieve an equivalent restoration state. Even though beavers create opportunities for plant species to spread [52], in areas where the seed bank is depleted new tree planting (and protection) might still be necessary. Likewise, in places close to agricultural or urban areas, where banks are too debilitated, cribwalls or similar stabilization structures might yet be required. Beavers create new wetlands that store water and will work as retention basins [64]. However, this is not possible in all locations, since near towns or farms the subsequent flooding might be problematic. There might also be complications as beavers cut down tree and shrub

[1] Similar lists can be found in other manuals, such as the Soil Bioengineering Manual [70].

vegetation to their liking [17]. The control of *Myriophyllum aquaticum* was included in the medium category based on a paper describing how the American beaver's presence led to a 90% decrease in this plant species [58].

"Low likelihood" actions are those where active human intervention would still be required, namely in the control of invasive plant species [32]. Beaver effects on such species can be positive, by direct foraging or altered habitat characteristics [58]; or negative, because beaver dynamics can help invasive species if selective foraging leads beavers to focus on native species and avoid invasive ones, benefiting the latter [46]. Nonetheless, the literature around beaver effects on invasive vegetation is sparse.

From a total of forty-three (43) material restoration actions listed separately in the APA Guide [3], thirty-six (36) were identified as replicable by the beaver to some degree. Seven actions were excluded. These were related to the removal and construction of grey infrastructure as well as to the cleaning of litter in rivers.

The second step, for the remaining actions, was to build intervals for the expected physical magnitude of beaver interventions (see quantities in the Annex). The numbers describe the potential impact of a single beaver colony, consisting of one reproductive pair and kits from previous years, for one average beaver territory (a couple of kilometers of river length, [17]), during one year. These values are "guesstimates", albeit based on several studies [13,17,63]. We provide high and low quantity values, to account for uncertainty about the number of times an action will be performed by a beaver colony as well as for different site conditions.

Cost values were then calculated, for each action, by multiplying quantity values by their unit costs, taken from the APA Guide. Unit costs are in euros while action quantities are in natural numbers (units vary, see Annex). To accommodate for variation in both unit costs and physical outcomes, we computed four possible cost values for each action. Basically, we used the lower and higher values of the unit-cost range provided in the APA Guide combined with the limit values of our constructed quantity interval. This procedure yields, for each action, four possible values: Low Cost and Low Quantity (LC - LQ), High Cost and Low Quantity (HC - LQ), Low Cost and High Quantity (LC - HQ) and High Cost and High Quantity (HC - HQ).

As noted above, each avoided cost value pertains to a beaver colony in one year, even though beavers are bound to perform actions continuously over several years, as well as to reproduce and expand spatially over a catchment. This simplification facilitates comparison of the values with those of human interventions, which tend to be one-time only and circumscribed to well-delimited areas.

Finally, to assess the overall monetary values that could be saved in restoration costs if beavers were present, we grouped actions according to likelihood. Rarely will only one type of bioengineered action or beaver action be performed, since both human and animal interventions are multifaceted in any given site. Results are analysed in the following section.

4. Results

The key aim of this research was to understand the potential for beaver reintroduction to save on river restoration costs. (Table 4) shows five scenarios (rows) and cost-interval estimates (columns). In the Table, the "High" row aggregates only the costs of actions classified as "high likelihood" (listed in Table 1), for which beavers are expected to deliver a similar restoration outcome; the "Medium" row consists of the "medium likelihood" actions, which beavers can perform to some degree, yet where human intervention may be necessary (Table 2); "Low" considers only actions where beavers would be least successful so that active human intervention would probably be required (Table 3); the row "High+med" sums the first two types of actions; and finally, the row "All actions" aggregates all the values.

The potential cost savings from the use of beavers to perform river restoration can range from a few thousand euros to three million euros per beaver colony on a single territory, per year, depending on which types of actions beavers end up performing as well as on estimates of those actions' costs. The wide variability is associated with both variation in unit costs (from the APA Guide), mostly due to different site characteristics, and with the uncertainty regarding beaver performance in the Iberian context, for which little information exists.

The values in the first row describe the most easily achievable

Table 1
Actions that beavers are very likely to perform.

High Likelihood
Entrenched Wood
Fascine
Biorolo with Vegetation
Biorolo with no Vegetation
Branch Propagation
Bulbs
Rhizome
Sedges
Small wood wires - type 1
Small wood wires - type 2
Small rock wires
Heterogeneity in the river stream
Shelter zones
Feeding areas
Connectivity within the stream
Creation of small ponds
Creation of medium ponds

Table 2
Actions that beavers are likely to perform, perhaps imperfectly.

Medium Likelihood
Modeling Stream Banks
Live Gabion
Live Riprap
Cribwall
Cutting tree vegetation
Cutting down trees
Curb *Myriophyllum aquaticum*
Plants in lump
Bare roots plants
Seed Dispersal
Water Seed Dispersal
Creation of retention basins - type 1
Creation of retention basins - type 2

Table 3
Actions that beavers are less likely to perform

Low Likelihood
Curb *Acacia dealbata*
Curb *Ailanthus alissima*
Curb *Arundo donax*
Curb *Rubus spp*
Curb *Eichhornia crassipes*
Curb *Tradescantia fluminensis*

Table 4
Potential avoided costs of beaver-based restoration; values in €, for one average beaver colony and one year.

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

savings, since they only include actions that beavers are highly likely to replicate almost identically. As for the second row, it is important to note that one particularly expensive intervention accounts for the augmented cost values: the cribwall. Without it, the "High" and "Medium" scenarios would have around the same number of actions with similar price ranges.

Scenario "Low" has the smaller number of actions, as it only includes clearing invasive vegetation. Nonetheless, its highest estimated cost savings amount to nearly half a million euros. If beavers are indeed found to contribute to the eradication of at least some invasive species in watercourses, this will only strengthen the value of process-based restoration strategies, such as beaver action, to cope with invasive species at a landscape scale.

Naturally, these three first scenarios are not mutually exclusive. Consider Scenario 3 ("Low"). It would be strange indeed if beavers focused on eradicating invasive species perfectly (low likelihood action) while not building varied habitats or cutting vegetation, which are core beaver activities. Still, the exercise is useful to get an idea of the overall cost savings associated each action group.

Another important note is that in a river restoration intervention not all actions will be required. The selection will depend on the state of degradation of the site where the restoration actions are implemented. Moreover, for medium and low-likelihood actions, beavers are not expected to fully succeed at reproducing human interventions. Scenarios 4 (sum of High and Medium) and 5 (sum of all action types) illustrate what might be the maximum potential of beaver cost savings, although values should be interpreted with caution given the limitations stated above. Only in very particular cases could restoration cost savings actually be this high. On the other hand, the available unit-cost data is from 2013 and current estimates could turn out to be higher. Moreover, our estimates consider only one beaver territory and one-off values, for a better comparison with one-off river restoration interventions; nonetheless, the potential economic savings appear significant even without taking into account all the additional benefits beavers might bring over space and time.

To provide some context, the results can be compared with the values actually spent in APA's 2018–2020 river restoration program. The program had a total cost of 11.7 million euros, with a relatively low average cost per intervention. There were interventions in 57 locations with an impact on a total of 975 km of rivers and streams. Most interventions were between a dozen thousand euros to a couple of hundred thousand, yet there were some that were much more pricey, reaching values near a million euros. These higher values, however, were mostly due to walkways or other significant construction works [2].

Even though detailed studies are required to assess whether a given site is suitable for beavers [42], it is safe to assume that in many of the sites where APA supported an active management approach in 2018–2020, beavers could have been considered instead, with significant economic savings and much higher co-benefits, especially those related to biodiversity, water regulation and fire prevention. In particular, most interventions were small and often located in sites relatively close to each other, in rural areas [2], where a beaver population might have been able to perform equivalent work. Plus, the majority of interventions undertaken in the APA program were located North of the Tagus river [2], where the climate tends to be milder and wetter, providing better habitat for the beaver when compared with the hotter and drier South. Forest cover is also much more extensive in the North, leading to more outbreaks of forest fire; indeed, the 2018–2020 program was explicitly created to foster river restoration in areas that were recovering from the massive fires that burned through 500,000 ha of Portugal in 2017, leading to over 100 human deaths.

5. Discussion

In spite of beavers' potential benefits to river ecosystems, it is important to discuss the evidence of unwanted beaver impacts on human activities. Especially in agricultural or urban areas, conflicts with other users might arise, although a proactive approach might avoid most of them. Some fruitful measures are buffer areas around freshwater habitats [17], mitigation structures in areas with a high likelihood of conflict, namely close to small bridges or drainage pipes, and protection of valued tree specimens [13]. Renewed coexistence requires consultation and stakeholder involvement [5]. Moreover, the literature indicates that coexistence measures have low costs, demand little maintenance and are cheaper than population control or removal of beaver-made structures [12,41].

Human interventions to restore rivers and streams, such as those envisioned by APA and other environmental agencies, are controlled and have well-defined goals, whereas the beaver's impacts can be unpredictable and sometimes complicated to manage. Still, the beaver fills a void in the ecosystem, bringing balance to freshwater ecosystems and restoring a missing process [49]. Whereas human river restoration interventions would require extra resources and funds to scale up, beavers expand naturally until the population reaches capacity, restoring more kilometers of streams and rivers. Thus, using beavers in river restoration programs seems to be a sound investment. Beavers avoid many costly restoration actions and can have modest landscape-management costs if a proactive approach is taken from the start. Finally, translocation should not be a barrier: past experience with beavers shows that the species travels well and is thus relatively easy to reintroduce [6,13].

This study sought to determine if the beaver could be used as a cost-effective tool for river restoration in Portugal, for which some cost data was available, although conclusions extend to the rest of the Iberian Peninsula given the cross-border nature of its major river basins. As noted in the Introduction, the relatively limited focus does not take into account that, besides creating and restoring freshwater habitats on a local scale, a thriving beaver population can increase landscape resilience and bring additional benefits to people in the form of various ecosystem services.

Beaver wetlands increase the size of riparian forests and act as natural fire breaks, potentially mitigating the effects of forest fires [29]. Since water storage in the landscape is increased, extreme events such as droughts and floods are moderated [64]. Beaver dams are also known to filter sediments and nitrogen, improving water quality [61,64], while boosting biodiversity. Beavers create habitat conditions that benefit many additional species from invertebrates [65] to endangered wetland plants [52], providing nursing areas for declining fish species [17] and feeding and nesting zones for rare birds [43]. Beavers in the Iberian Peninsula could even become a prey species for the Iberian Wolf [31], and support extensive cattle raising [19]. There are also clear recreational benefits in the form of tourism opportunities such as wildlife spotting, hunting and fishing [4]. In fact, a recent meta-analysis points out that existing beaver populations in the Northern Hemisphere (around 11 million animals) are already delivering ecosystem services valued at several hundred millions of euros per year [72]. In that study, the heftiest overall monetary values were those belonging to habitat and biodiversity provision, greenhouse gas sequestration and non-consumptive recreation, whereas the highest per-hectare numbers included moderation of extreme events as well. Although our methodology is quite different, since we calculate avoided costs of river restoration based on national data rather than attempt to transfer ecosystem service values from the literature, both approaches highlight how beneficial beavers can be.

Further research is still needed to improve understanding of beaver impacts in Mediterranean-climate watersheds, analyse the impact of European beavers on relevant invasive species, specially *Acacia dealbata, Ailanthus alissima, Arundo donax, Eichhornia crassipes* and *Tradescantia fluminensis*, and assess their possible impact on endangered native species, for example plants and fishes listed, respectively, in the Portuguese Endangered Plants list [18] and Vertebrate Red list [16].

6. Illustration

To depict the likely impact of beavers on rivers and streams for a Iberian context, two series of images are included, illustrating the likely outcomes on a degraded stream of a bioengineered intervention versus beaver impact. The initial state, the first image of both series, shows a degraded stream, with an incised channel, invasive species and little forest cover [3], yet with enough habitat quality to support a beaver colony (beavers are adaptable creatures that can live in a wide range of habitats [33]). The difference between the first and the last image represents a 10-year timespan in both alternatives, portraying possible changes in the stream.

Fig. 1 represents the intervention carried out through the use of typical bioengineering techniques, such as those advocated by APA. The banks are smoothed, forest cover is promoted by means of newly-planted trees and branch propagation, while invasive plants are removed, in this case *Arundo donax* [3]. From the initial to the last stage, the area goes from low forest cover to a high-density cover with stabilized banks, yet the incision of the stream continues and the forest cover tends to be too dense with a monotonous habitat [73].

Fig. 2 shows the likely river restoration result if developed by beavers. It slowly but steadily stores sediments and reconnects the stream to its flood plain. Beavers forage on *Arundo donax*, eventually decreasing its abundance or removing it completely. A mosaic of habitat develops through time and slows the flow of water creating a wetland, which benefits a great diversity of wildlife [49].

Fig. 1 and Fig. 2 share a number of key features. The two interventions promote forest regeneration, improve the state of a degraded stream and remove invasive vegetation (represented by *Arundo donax*). Nevertheless, there are a number of important differences between a human restoration action and the beaver's. First, with beavers the stream is connected to its alluvial plain and is not incised: as dams are built with stones, mud and canes, this process slowly accumulates sediments and at last connects the stream to its floodplains [62]. Second, the creation of a mosaic of habitats leads to an increase in species richness and gains in ecosystem services that can hardly by replicated by human intervention [49]. Third, beavers restore a missing dynamic in the ecosystem. Whereas the bioengineered interventions need extra funds and resources to expand to new areas and may require regular maintenance, beavers expand restoration as suitable habitat is available, therefore are better suited to restore whole landscapes [35].

7. Conclusion

It is likely, in line with findings from other studies [13,35,63], that the use of beavers in future river restoration programs in Portugal and elsewhere in the Iberian Peninsula would be highly beneficial. This study has shown, through a simple cost assessment using available official data for a Portuguese region, that the potential for beavers to replicate river restoration actions is high, possibly saving many thousands and even millions of euros in the restoration of freshwater ecosystems. Coexistence costs are relatively low [12,41] and translocation expenses comparatively small [6].

Fig. 1. Bioengineered intervention.

Fig. 2. Beaver impact on a degraded stream.

The beaver's return would, additionally, provide a boost to biodiversity, benefiting many additional species through the creation of valuable habitat for many other species. Beaver presence would also create a landscape that not only sequesters carbon but is also more resilient to the effects of climate change, mitigating extreme meteorological events, such as droughts and floods, and lessening the gravity of forest fires. Taken together, all these findings provide a strong case for the reintroduction of the beaver in Portugal and Spain, especially in the main river basins.

Given the scant literature on beavers in Mediterranean areas, many of the assumptions used in this work were based on dynamics witnessed in different climates. Therefore, stated beaver impacts are somewhat unpredictable. Furthermore, using beavers for the restoration of fresh water ecosystem requires a careful choice of locations; in areas that are too degraded, where the slope of the river is too steep or which are close to agricultural or urban areas, beaver introductions may not be feasible. In spite of these limitations, the study adds to the understanding of the beaver's potential to restore degraded waterways in a cost-effective way.

As well as strengthening the case for beaver reintroduction, the findings of this study have a number of general implications. First, restoring processes instead of mimicking particular characteristics of ecosystems might be a more cost-effective use of funds. The focus should be on coexistence through human-wildlife conflict mitigation. Future river and stream restoration programs ought to favor process-based approaches, in line with the latest trends in conservation literature [45,60]. Second, the translocation of species can partially be justified through economic arguments, comparing the costs from actively managing ecosystems with the gains to be had if a missing species is brought back instead. This type of analysis can be undertaken for other species, for instance comparing the use of wild herbivores to mechanical vegetation clearing: the Iberian Goat, Capra pyrenaica, and wild herds of horses or cows could prevent forest fires and maintain an open mosaic of habitats with potentially lower costs. Third, restoring ecosystems is key to safeguard biodiversity and cope with the challenges of climate change. Restoration brings hope that it is possible to recover ecosystems after centuries of decline and it also seems sound from an economic perspective.

8. Annex

Table 5
Cost and quantity intervals for unit interventions.

APA Intervention Name	€ / unit		quantity (units)	
	low	high	low	high
Branch Propagation	0.15	1.5	50	250
Bulbs	0.2	2	50	250
Rhizome	0.2	2	50	250
Sedges	0.25	2	50	250
Plants in lump	2	10	25	150
Bare roots plants	1.5	8	25	150
Seed Dispersal	1	2	250	750
Water Seed Dispersal	1.5	5	250	750
Small wood wires - type 1	150	300	3	15
Small wood wires - type 2	30	50	3	15
Small rock wires	50	100	3	15
River stream Heterogeneity	100	2500	1	
Shelter zones	15		15	30
Feeding areas	10	15	15	30

Table 6
Cost and quantity intervals for meter interventions.

APA Intervention Name	€ / meter		quantity (meters)	
	low	high	low	high
Fascine	20	40	150	750
Biorolo with Vegetation	45	75	150	750
Biorolo with no Vegetation	25	45	150	750
Cutting Tree Vegetation	5	7.5	150	750
Cutting down trees	5	7.5	150	750

Table 7
Cost and quantity intervals for m2 interventions.

APA Intervention Name	€ / m^2		quantity (m^2)	
	low	high	low	high
Cribwall	90	125	1000	10,000
Entrenched Wood	20	35	1000	10,000
Acacia dealbata	5	10	1000	10,000
Ailanthus alissima	5	10	1000	10,000
Arundo donax	5	10	1000	10,000
Rubus spp	5	7.5	1000	10,000
Eichhornia crassipes	2	5	1000	10,000
Myriophyllum aquaticum	2	5	1000	10,000
Tradescantia fluminensis	2	5	1000	10,000
Connectivity within the stream	10	30	5000	15,000
Creation of small ponds	20	40	20	60
Creation of medium ponds	40	60	60	120

Table 8
Cost and quantity intervals for m3 interventions.

APA Intervention Name	€ / m^3		quantity (m^3)	
	low	high	low	high
Modeling Stream Banks	5	12.5	250	1 500
Live Gabion	70	100	250	1 500
Live Riprap	35	70	250	1 500
Creation of retention basins - type 1	5	12.5	500	1 000
Creation of retention basins - type 2	5	12.5	500	1 000

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

The data is publicly available and the remaining used values can be found in annex.

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