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MAIN FACTORS INFLUENCING ECOSYSTEM RESTORATION OUTCOMES: A GLOBAL QUALITATIVE META-ANALYSIS

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Summary

Ecosystem restoration (ER) has been proven useful to help reversing ecosystem degradation caused by human activities and its consequent loss of biodiversity. However, its current efficiency is limited, and it is not meeting the initial expectations. In order to know what is defining this limited performance, the main goal of this study is to know the main elements hampering and improving the outcomes of ER. For this purpose, we performed a global qualitative meta-analysis of 131 reviews on ER in all types of ecosystems. From the reviews, we extracted 579 qualitative variables subsequently categorized into 25 factors to which a weight value was assigned. These factors cover different aspects like policy, economy, society, practice and science. We concluded that the choice of restoration techniques, the performance assessment and evaluation, and the temporal scale of the restoration project were the factors with highest influence on ER results. We also highlighted the need of deeper scientific research on more complex ecological attributes as a crucial element to tackle several factors. With these results, we provide guidelines to improve the performance of current ER from a local (practice) to a global (international strategies) scales.

Key words: barriers, limitations, boosters, review, success

Resumen

La restauración de ecosistemas (RE) se ha probado útil para ayudar a revertir la degradación de ecosistemas causada por la actividad humana y su consecuente pérdida de biodiversidad. Sin embargo, su actual eficiencia es limitada y no está cumpliendo con las expectativas iniciales. Para saber qué define estas limitaciones, el principal objetivo de este estudio es conocer los principales elementos que están obstaculizando y mejorando los resultados de la RE. Con este propósito, llevamos a cabo un meta-análisis cualitativo global de 131 revisiones sobre la RE en todo tipo de ecosistemas. De las revisiones, extrajimos 579 variables cualitativas posteriormente categorizadas en 25 factores a los cuales se les asignó un peso. Estos factores cubren diferentes aspectos de la RE como la política, la economía, la sociedad, la práctica y la ciencia. Concluimos que la elección de las técnicas de restauración, la evaluación de la actuación y la escala temporal del proyecto de restauración fueron los factores con la mayor influencia en los resultados de la RE. También reseñamos la necesidad de profundizar en el estudio de atributos ecológicos más complejos como elemento crucial para abordar diferentes factores. Con estos resultados, proveemos una guía para mejorar la actuación de la RE desde la escala local (práctica) hasta la global (estrategias internacionales).

Palabras clave: barreras, limitaciones, potenciadores, revisión, éxito

Introduction

Ecosystem degradation is globally increasing as represented by the loss of forest cover in the tropics (Hansen et al., 2013), the reduction of wetlands functionality (Zedler and Kercher, 2005) or the bleaching of coral reefs (Heron et al., 2016). This trend has involved a constant loss of biodiversity and its related functions and services (Butchart et al., 2010; Cardinale et al., 2012) threatening over thirty thousand species in 2020 (IUCN, 2020). Land degradation also influences food and water security, affects human health by increasing the burden of infectious diseases or the contamination of drinking water, increase poverty, worsen human inequality and can impair human security, particularly in places where degradation leads to involuntary migration or exacerbates the risk of violent conflict (IPBES, 2018). When implemented effectively and sustainably, ecosystem restoration (ER) has the potential of reverting these trends (Gann et al., 2019). Several studies have shown the benefits of restoration from ecological (Rey Benayas et al., 2009) and economic perspectives (de Groot et al., 2013). For these reasons, restoration has become a global practice used in many countries with different socioeconomic and ecological backgrounds (Bullock et al., 2011). Billions of dollars are spent annually restoring ecosystems and also developing restoration methods, technology and knowledge capacity (Menz et al., 2013; Matesanz et al., 2019). Several international programs where restoration plays a pivotal role have emerged in the last years like the Aichi Bidioviersity Targets 2020, the United Nations Collaborative Programme on Reducing Emissions from Deforestation and forest Degradation goal, the EU Biodiversity Strategy 2020 (European Commission, 2011) or the New York Declaration on Forests (Climate Focus, 2016). In addition, the decade 2021-2030 has been declared by the United Nations as the UN Decade of ER (UN environment programme, 2019).

The momentum of restoration is on the rise and with it, the expectations of stakeholders and policy makers. However, multiple evaluations show a limited performance of restoration, which may question the feasibility to address those global challenges. A meta-analysis of 621 wetland sites showed that even after a century, biogeochemical functioning and biological structure remained lower (23% and 26% respectively) than the reference site (Moreno-Mateos et al., 2012). More than the half of 644 stream restoration projects failed at improving functionality or biodiversity attributes regardless of the way these were measured (Pamer et al., 2014). Moreover, 89 studies analyzing the recovery of lakes and coastal areas affected by eutrophication demonstrated that it took decades to barely achieve 30% of the pre-disturbance condition (McCrackin et al., 2017). These results are consistent with a broader scope meta-analysis of 400 studies worldwide, where the recovery of ecosystems was found to be rarely completed (Jones et al. 2018). Finally, even if restoration is considered achieved, restored ecosystems are consistently less diverse and functional than undisturbed ecosystems (Moreno-Mateos et al., 2017), potentially taking hundreds to thousands of years to reach the completeness of recovery (Curran et al., 2014). Several international strategies have recently failed to achieve proposed outcomes. The Aichi Biodiversity Targets failed in several of its goals due to their improvable approach to measure progress and outcomes and the no obligation to communicate their proposals and actions from signing countries (Nature, press release 2020). The UE Biodiversity Strategy for 2020 has also failed in its goal of restoring 15% of European degraded ecosystems (EUROPARC federation, 2019). Lastly, the new EU Biodiversity Target 2030 has been criticized by its spatial incoherence and the poorly described goal of planting 3 billion trees (Gómez-González et al., 2020; Selva et al., 2020).

The high expectation put on ER, its lack of success and the ongoing release of new programs make more important than ever to gather evidence about which are the specific factors that are fostering or hampering the success of restoration. This will help constructing a more efficient and resolute ER approach and avoiding misguided but well-intentioned environmental policies. Several authors have provided evidence of specific factors influencing restoration outcomes. For example, the effects of invasive species (Fox and Cundill, 2018) , the consideration of genetics knowledge (Aavik and Helm, 2018), the integration of society (Fox and Cundill, 2018), the governance as a way to engage stakeholders (Sapkota et al., 2018), the availability of resources to fund a long-term monitoring, the lack of communication of restoration results (Nilsson et al., 2016), the consideration of spatial and temporal scale and the relation between goals setting and success assessing approach (Ockendon et al., 2018). Other authors have focused on ER of specific ecosystem types like forests (Mansourian and Vallauri, 2014; Andersen et al., 2017), rivers (González et al., 2015), drylands (Costantini et al., 2016), coral reefs (Hein et al., 2017) or peatlands (Andersen et al., 2017). For example, in forests and peatlands, the private ownership of the land, the high economic cost of monitoring or the scarce knowledge of indigenous species ecology were found as hampering elements. On the other hand, the engagement of stakeholders, the goal setting according to their interests and the economical quantification of ER benefits were found as fostering factors (Mansourian and Vallauri, 2014; Andersen et al., 2017). In rivers, using reference states to measure success and broadening the assessment approach were highlighted as fostering factors (González et al., 2015). In drylands, the choice of plants or practices not suited to the site were reported as limitations, while the success assessment method and the deep knowledge of plants ecology were so as enhancers (Costantini et al., 2016). In coral reefs, the short-term monitoring was found to be hampering success (Hein et al., 2017).

However, a global evaluation of the main factors hampering or fostering the restoration at a global scale is missing. Thus, the goal of this study is finding and categorizing these factors. To address this goal, we will use meta-analytical techniques to semi-quantitatively evaluate published conventional reviews, systematic reviews and meta-analysis on the effectiveness of restoration in any kind of ecosystem.

Methodology.

Data collection

We included conventional reviews, systematic reviews, and meta-analyses published in the last 20 years with the aim of finding consistent, pre-curated, and large-scale evidence that supported detected restoration barriers and boosters. We performed the search in Web of Science on 01-03-2019 using the following parameters : Topic: "ecosystem* and (review or meta-analysis)", Title: "restor*", Years: custom range: 1999-2019, Database: Science Citation Index – Expanded, Social Science Citation Index, and Emerging Science Citation Index. Our initial search resulted in 339 hits. Papers were then selected based on the match between the titles and the aim of the study (285 reviews) and the match between the abstracts and the aim of the study (164 reviews). We then reviewed the whole text of the review and selected those with clear evidence supporting identifiable elements influencing the outcomes of ER leaving 131 reviews. From those 131, we extracted 579 qualitative variables classified as barriers or booster (Fig 1).

We defined barrier as a variable that limits the overall success of a restoration project. We defined booster as a variable that improves the performance of the overall restoration project. To ensure that the identified barriers and boosters were clearly supported in the selected studies, we rejected barriers and boosters preceded by the terms "could be", "may be", or "might be", we only accepted those preceded by terms like "it is" or "it has been" were accepted.

For each review, we also collected the following data: author, year of publication, geographic range, time range, ecosystem type, review type (conventional review, systematic review, or meta-analysis), and number of individual studies reviewed. Time range refers to the time frame that the review covered, ranging from the publication year of the earliest individual study included in the review to the year of publication of the review itself. In the cases where the time range was explicitly included in the review, we used this information. If the review provided a time range (e. g., 1980's), we used 1985 as the reference year. 1.7% percent of the variables did not have a clear temporal range and we did not used them in further analyses where this factor was considered.

Geographic range was the area covered by the review or meta-analysis. We estimated this by adding the geographical areas covered by individual studies. We estimated the area of each study by collecting the area of the region, country, state, province or study area at the lowest scale possible. We used the range "global" if the review or meta-analysis stated it, if provided a world map with studies globally distributed, or if indistinctively assumed from the information provided. In reviews or meta-analysis reporting at global scales without a clear definition of the real area covered, we used the largest area provided by any of our studies (Cruzeilles *et al.* 2016, 54.870.139 km^2). This helped us prevent overestimations caused by using the area of all emerged land (~150,000,000 km^2). In reviews or meta-analysis including studies focused on large countries, that included Russia, Canada, USA, China, Brazil, and Australia, we only used those studies with a level of geographic resolution at the state or province level. Three percent of the variables did not have a clear geographic range and we did not used them in further analyses where this factor was considered. Finally, we identified nine ecosystem types, agroecosystems, arid zones, coastal dunes, grasslands, lakes, marine ecosystems, rivers, wetlands and forests. Twenty four percent of the variables included several ecosystem types and we did not used in the analysis on the effects of ecosystem type.

Data classification and weighting

We grouped the 579 extracted variables in 25 factors. Factors belong to four major topics. First, policy, economy and society, including barriers and boosters related to regulations, governance, legislation, economic situation, funding and societal participation. Second, science, including factors related to the generation of new knowledge and its integration in novel restoration techniques. Third, practice, including the implementation of restoration efforts based on existing knowledge. Four, environment, including environmental factors, like the interactions among organisms and between organisms and the environment.

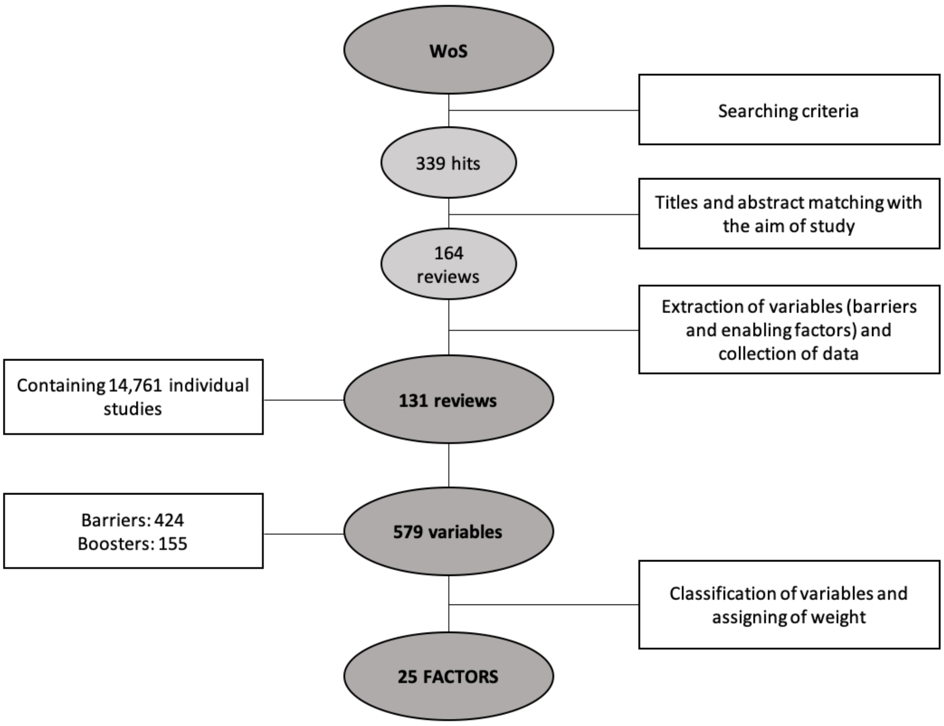

Figure 1. Mains steps taken on the review methodology: search un WoS under searching criteria, choice of studies based on titles and abstract match with purpose of review, extraction of variables and collection of data, categorization of variables and assigning of weight.

These factors can contain barriers and boosters variables, therefore, they are neutral elements that have an influence in the ER outcomes. The total intensity of this influence and the partial contribution of barriers and boosters were estimated through a weighting process. We used three weighting elements: the bibliographic weight (*Bw*), the temporal weight (*Tw*) and the geographic weight (*Tw*). These weights were assigned separately for the barriers and the boosters within each factor. The bibliographic weight (B_W) was estimated combining the number of variables a factor contained (N_V) and the number of individual studies included in the selected reviews where those variables were cited (N_s). This weighting factor assumes that the more times a factor (including one or more variables) is detected among reviews and the more studies within reviews detect it as a barrier or booster, the more widespread and relevant is its effect. To estimate the B_W, we used the formula,

$$B_W = V + S = \frac{N_{V\,barriers/boosters}}{N_{VT}} + \frac{N_{S\,barriers/boosters} \cdot (1 - F_O)}{N_{ST}}$$

where N_{VT} is the total amount of variables (579), N_{ST} is the total amount of individual studies analysed in the 131 reviews (14,761) and F_O is the overlap factor. To avoid duplicating studies repeated in different reviews, we estimated an overlapping factor based on existing overlapping studies among 10% of the reviews of the database that were randomly selected. The correction factor (F_O) was estimated as,

$$F_O = \frac{A - C}{A}$$

where *A* is the total amount of studies of all the selected reviews (1,142) and *C* is the count of all studies that do not overlap among papers (1,082). The resulting value was 5,25%.

We estimated the temporal weight (T_w) dividing the average time range of one of the factor categories ($T_{R,\ barriers}$ or $T_{R,\ boosters}$) by the average time range of the whole dataset ($T_{RT} = 25.32$ years). We estimated the geographic range (G_w) using the same approach ($G_{RT} = 19{,}860{,}998$ km^2).

$$T_W = \frac{T_{R_{barriers/booster}}}{T_{RT}} \qquad G_W = \frac{G_{R_{barriers/booster}}}{G_{RT}}$$

We then normalized each of the weighting elements to make them numerically comparable and thus operate with them using the formula:

$$X_W^* = \frac{X_W - X_{W\,min}}{X_{W\,max}}$$

Where X_W^* is the normalized weighting element, X_W is any of the three weighting elements for a category, and $X_{W\min}$ and $X_{W\max}$ are respectively the minimum and maximum value of the weighting element found within the 25 factors. The final weight (F_w) of each barrier or booster factor is

$$F_W = B_W/2 + T_W + G_W$$

where the B_W is divided by 2 to downscale its value given that two parameters (N_V and N_S) were added to estimate B_W as opposed to T_W and G_W that only had one element each. Since this weighing process was made separately for the barriers and boosters of each factor, by adding F_w of barriers and F_w of boosters we obtain the overall final weight of the factor (OF_w).

$$OF_W = F_{W,barriers} + F_{W,boosters}$$

Results

Eighty percent of the analyzed reviews were conventional reviews, 16% were meta-analyses, and 4% were systematic reviews. Overall, factors related to practice were the most cited ones (38% of variables), followed by environment (25%), policy, economy and society (19%) and science (18%) (Table 1). Similarly, the overall weighting elements were heaviest for practice ($OF_w = 1.47$) followed by environment ($OF_w = 0.86$), policy, economy and society ($OF_w = 0.79$) and science ($OF_w = 0.28$). The three weighting factors contributed similarly to the OF_w ($T_w = 33\%$; $G_w = 41\%$; $B_w = 26\%$) and presented a similar correlation with it (R^2 (T_w) = 0.59; R^2 (G_w) = 0.40; R^2 (B_w) = 0.58). The collected data for each factor is presented in table 2.

We found more barriers (73% of the data, 424 variables) than boosters (27% of the data, 155 variables) and the average barrier weight was higher than the average booster weight (0.82 and 0.71 respectively). Out of the 25 factors, six were only addressed as barriers in the selected reviews (methodological limitations, historical land-use, invasive species, geographic bias, scientific evidence behind the technique used and payment for ecosystem services). Restoration techniques was the factor with the highest influence on the restoration outcomes in general (highest OF_w value), and also the most influencing one at fostering its success (highest booster F_w value). On the other hand, performance assessment and evaluation was the second most influencing factor, and also the most influencing one at hampering the success of ER. Temporal scale and project planning and goal definition also were remarkably relevant in their overall influence on the ER outcomes. These four factors are related with the practice dimension of ER. The factors with the lowest overall weight were related with policy, economy and society (funding and payment for ecosystem services) and with science (i.e. scientific evidence behind the technique used and geographic bias). Funding was least influencing factor both ways at fostering or hampering restoration outcomes (fig. 2).

Table 1. Definition and classification of the factors affecting restoration performance according to the studies selected and examples of variables provided from the literature.

Factor	Description	Examples of variables
Policy, economy and society		
Socioeconomic knowledge	The existence of previous socioeconomic knowledge, like cost-benefit analyses or economic assessments	*Barrier*: Lack of economic considerations in the evaluation of coral restoration effectiveness (Hein et al., 2017). *Booster*: Attaching a monetary value to restored ecosystems helps to inform political and economic decisions (Mansourian and Vallauri, 2014)
Land-tenure rights	Issues related to land ownership and land-tenure rights	*Barrier*: Current land ownership in forest management discourages local farmers to make long-term investments (Xi et al., 2014). *Booster*: Clear and secure tenure rights was critical for forest landscape restoration success (Djenontin et al., 2018)
Economic costs of restoration	The economic cost derived from one or multiple restoration techniques or from the use of a specific resource	*Barrier*: Coral reef restoration high costs prevents its use in large areas (Yeemin et al., 2006). *Booster:* Using low-cost restoration methodologies improves the number, length, and success of restoration actions (Young et al., 2012)
Policies and governance	The effect of policies, regulations, international cooperation or governance	*Barrier:* Contrasting regulations and jurisdictions that overlap in a restoration site (Jiang et al., 2015). *Booster:* Clear legal environment promotes scaling-up of forest restoration (Melo et al., 2013)
Societal integration	The degree of stakeholder and local community involvement	*Barrier:* Local communities' opposition to restoration program (Romañach et al., 2018). *Booster:* Bottom-up participatory initiatives (Adams et al., 2016)
Funding	The existence of external economic sources funding restoration	*Barrier*: Lack of economic support from central, federal, state or department governments (Cao et al., 2011). *Booster:* Positive cycles of success-reputation-economic funding (Zamboni et al., 2017)
Payment for ecosystem services	The existence of economic compensation programs for local communities in exchange for restoration commitments	*Barrier 1*: Low payment to poor farmer communities who saw their labour land transformed by forest restoration programs cannot replace their previous incomes (Cao et al., 2011). *Barrier 2*: Exclusion of some social groups in payment for ecosystem services schemes (Bullock et al., 2011).

Factor	Description	Examples of variables
Science		
Geographic bias	The research bias towards specific regions	*Barrier 1*: Lack of research in tropical areas (Barral et al., 2015). *Barrier 2*: High-income countries where most restoration research happens are not the areas with highest restoration needs (Wortley et al., 2013)
Integration of existing scientific knowledge	The application of available scientific knowledge related to a technique	*Barrier*: Lack of consideration of top-down interactions in coastal habitat restoration (Zhang et al., 2018). *Booster*: Collaboration between invasive weed managers and restoration experts (Reid et al., 2009)
Knowledge on ecosystem structure and function	The existence of scientific knowledge about ecosystem structure processes, or dynamics	*Barrier*: Lack of biological and technical knowledge associated with seed germination biology (Kildisheva et al., 2016). *Booster:* Integration of paleoecology and evolutionary data (Barak et al., 2016)
Knowledge on genetics	The existence of knowledge about genetic diversity, population genetics, or gene flows	*Barrier:* Lack of awareness of the importance of genetics in restoration projects (Thomas et al., 2014). *Booster*: Considering connectivity and gene flow as factors to foster out-crossing of self-compatible species (Thomas et al., 2014)
Methodological limitations	Methodological issues in restoration research related to field surveys, experimental design, data analysis or consistency of published results	*Barrier 1:* Lack of rigorous study designs (Sánchez Meador et al., 2017). *Barrier 2*: Disturbance of the sampling plot by the crew, especially in calibration plots (Stapanian et al., 2016)
Scientific evidence behind the technique used	The existence of enough scientific evidence behind the restoration techniques and practices used	*Barrier 1:* Selection of herbicides, dosages and application have not been based on a previous scientific study (Smith-Ramírez et al., 2017) *Barrier 2:* scientific knowledge behind vegetation management is limited (Su and Shangguan, 2019)
Practice		
Restoration techniques	The choice of techniques used in restoration and the way they are used	*Barrier:* Incorporating exotic mycorrhizal fungi into a degraded site substantially changed indigenous mycorrhizal communities (Maltz and Treseder, 2015). *Booster*: Removing salt before tailings are reclaimed prevents limited water absorption by plants or mortality (Wang et al., 2018)
Performance assessment and evaluation	The use of available performance assessment tools (e.g. monitoring	*Barrier:* Use of low number of indicators for measuring recovery of ecological attributes (Gatica-Saavedra et al., 2017). *Booster:* Developing

Factor	Description	Examples of variables
	techniques, indicators) and evaluation criteria	reproducible approaches to identify the optimal spatial and temporal scales for monitoring specific indicators (Taddeo and Dronova, 2018)
Project planning and goal definition	The limitations and conflicts related to goal definition, project design, or action routes	*Barrier*: Hard selection of end points for restoration based on historical or even contemporary reference conditions (Stanturf et al., 2014). *Booster:* The use of multiple reference sites can overcome several of the difficulties of defining a reference standard for restoration (Matthews et al., 2009).
Instruments, technology and resources	The availability of a required technology or material (e.g., seeds, seedlings)	*Barrier:* Monexenic cultivation of arbuscular mycorrhizal fungi is technically demanding (Asmelash et al., 2016) . *Booster:* Technological advances like processing and quality assessments of wild collected seeds have been shown to be critical in establishing sufficient plants (Perring et al., 2015)
Temporal scale	The duration of factors like implementation, funding, or monitoring	*Barrier*: Short time for recovery prevented noticing a measurable effect on the benthic macroinvertebrate community (Feld et al., 2011). *Booster*: Long-term monitoring approach is critical when using species composition as a metric of restoration success (Taddeo and Dronova, 2018)
Accounting for environmental factors	Integration of local environmental factors and climate constraints during restoration	*Barrier*: Not integrating the effects and functioning of the disturbances and fluctuations caused by natural dynamics in the restoration planning reduce the understanding of the long-term structure and function of coastal wetlands (Simenstad et al., 2006). *Booste*r: Integration of natural environmental fluctuations and disturbance maintains habitat heterogeneity and favours biodiversity (Timpane-padgham et al., 2017)
	Environment	
Historical land-use	The existence of lagging impacts, including soil contaminants and impoverished seed banks	*Barrier 1*: The paucity of the soil seed bank of floodplains after decades of human occupation and limited dispersal of desirable species are seen as the main constraints for the recovery of the plant community in meadows (González et al., 2015) *Barrier 2*: Heavy metals are regularly present in mine tailings at sufficient concentrations to restrict the growth of plant unless considerable improvement is employed (Wang et al., 2018)

Factor	Description	Examples of variables
Ongoing degradation	The existence of current degrading activities, including agriculture, water flow regulation, or tourism	*Barrier*: Major improvements of the hydrological system are often not feasible, because of agricultural, residential or industrial interests in the area (Klimkowska et al., 2010) . *Booste*r: Original cause of degradation or extirpation enhance success in seabird restoration projects (Jones et al., 2012)
Invasive species	The presence of invasive species leading to reduced biodiversity and functionality	*Barrier 1*: Many invaders have resource-use and reproductive traits that allow them to utilize the limited resources more quickly than resident species (Hulvey et al., 2017). *Barrier 2*: Invasive N2-fixing woody species often produce copious amounts of seed that can persist in the seed bank for extended periods (Nsikan et al., 2018).
Intrinsic abiotic factors	The effect of abiotic elements on the recovery process	*Barrier*: Increased wave action and storms can cause fragment breakage and dislodgement as well as damage to the restoration of coral reef structures (Young et al., 2012). *Booster*: Flooding depth and frequency are critical factors in the survival of mangrove seedlings and mature trees (Bosire et al., 2008).
Intrinsic biotic factors	The effect of biotic elements on the recovery process	*Barrier*: The slow and incomplete recovery of plant assemblage is partly is caused by dispersal limitation, vulnerable early life history stages, or sensitivity of any life stage to altered conditions (Moreno-Mateos et al., 2012). *Booster*: Pre-existing vegetation can have large impacts on the success of species establishment in degraded systems (Gómez-Aparicio, 2009)
Spatial scale	The effects of the spatial scale on the recovery process (e. g., landscape processes, watershed processes)	*Barrier*: A main constrain is the divergence between scales of alteration and scales of restoration (Wohl et al., 2015). *Booster*: Considering the restoration of faunal communities, it is necessary to restore habitat diversity at the local and landscape scale, rather than just the rehabilitation of one particular vegetation type (Lamers et al., 2015)

Table 2. Values for each factor. N_V: Number of variables; N_S: number of individual studies; T_R: time range (years); G_R: geographic range (10^6 km^2); T_w: temporal weight; G_w: geographic weight; Bw: bibliographic weight; F_w: final weight for barriers or boosters; OF_w: overall final weight. The weighting factors are normalized.

Factor	**Overall**	**Barriers**								**Boosters**								**Overall**
	N_V	N_V	N_S	T_R	G_R	T_w	G_w	B_w	F_w	N_V	N_S	T_R	G_R	T_w	G_w	B_w	F_w	OF_w
Socio-economic knowledge	8	7	2,439	20.1	31.6	0.124	0.639	0.239	1.002	1	45	10.00	12.5	0.000	0.247	0.001	0.248	1.250
Land-tenure rights	7	5	514	17.0	18.5	0.030	0.244	0.014	0.288	2	81	27.50	36.6	0.414	0.748	0.020	1.182	1.470
Economic costs of restoration	16	12	1,195	26.2	18.0	0.305	0.226	0.163	0.695	4	259	23.75	4.2	0.325	0.062	0.079	0.467	1.162
Policies and governance	25	18	3,164	20.8	15.2	0.145	0.144	0.437	0.726	7	783	15.00	7.1	0.118	0.202	0.217	0.538	1.264
Societal integration	38	18	1,275	25.8	33.2	0.295	0.685	0.239	1.219	20	752	18.50	14.9	0.201	0.252	0.366	0.820	2.038
Funding	9	8	476	21.9	10.4	0.176	0.000	0.043	0.220	1	39	10.00	2.8	0.000	0.060	0.000	0.060	0.279
Payment for ecosystem services	5	5	3,270	16.0	22.3	0.000	0.358	0.304	0.662	-	-	-	-	-	-	-	-	0.662
Geographic bias	7	7	995	23.3	32.1	0.220	0.653	0.087	0.960	-	-	-	-	-	-	-	-	0.960
Integration of existing scientific knowledge	16	13	1,094	25.7	20.6	0.290	0.306	0.164	0.760	3	188	18.33	3.1	0.197	0.000	0.053	0.250	1.010
Knowledge on ecosystem structure and function	38	27	1,913	26.0	17.8	0.301	0.222	0.406	0.929	11	540	28.09	9.7	0.428	0.237	0.217	0.882	1.811
Knowledge on genetic	14	7	437	25.0	26.0	0.270	0.469	0.028	0.767	7	510	25.71	27.1	0.372	0.461	0.164	0.996	1.764
Methodological limitations	23	23	1,513	33.3	24.6	0.520	0.426	0.319	1.265	-	-	-	-	-	-	-	-	1.265
Scientific evidence behind the technique used	9	9	992	23.8	23.1	0.233	0.382	0.109	0.724	-	-	-	-	-	-	-	-	0.724
Restoration techniques	67	25	1,184	27.0	12.4	0.329	0.059	0.307	0.695	42	2,548	29.90	21.6	0.471	0.552	0.980	2.003	2.698
Performance assessment and evaluation	57	45	4,751	25.4	22.5	0.282	0.364	0.904	1.550	12	955	21.33	20.7	0.268	0.414	0.311	0.993	2.543
Project planning and goal definition	33	27	2,924	25.2	21.1	0.275	0.320	0.512	1.107	6	938	23.33	21.7	0.316	0.462	0.236	1.014	2.121
Instruments, technology and resources	12	10	396	29.0	19.0	0.390	0.257	0.057	0.705	2	225	17.50	31.7	0.178	0.718	0.048	0.944	1.648
Temporal scale	34	27	2,589	25.1	19.3	0.275	0.266	0.477	1.017	7	567	29.50	24.7	0.462	0.566	0.175	1.202	2.219
Accounting for environmental factors	16	12	887	21.3	13.9	0.158	0.103	0.131	0.392	4	358	26.25	34.8	0.385	0.901	0.098	1.384	1.776
Historical land-use	19	19	1,966	30.3	25.9	0.430	0.467	0.322	1.220	-	-	-	-	-	-	-	-	1.220
Ongoing degradation	28	23	1,137	21.7	13.5	0.172	0.093	0.280	0.545	5	533	42.25	19.0	0.763	0.619	0.145	1.527	2.072
Invasive species	12	12	832	31.0	24.2	0.450	0.415	0.125	0.990	-	-	-	-	-	-	-	-	0.990
Intrinsic abiotic factors	22	14	381	22.8	14.2	0.204	0.112	0.100	0.416	8	758	26.25	17.9	0.385	0.534	0.224	1.143	1.559
Intrinsic biotic factors	43	37	2,065	24.9	19.1	0.267	0.260	0.533	1.060	6	426	24.17	11.2	0.335	0.238	0.135	0.709	1.769
Spatial scale	21	14	1,161	22.1	19.5	0.184	0.272	0.182	0.639	7	734	35.83	29.4	0.611	0.609	0.208	1.428	2.067
	579	**424**								**155**								

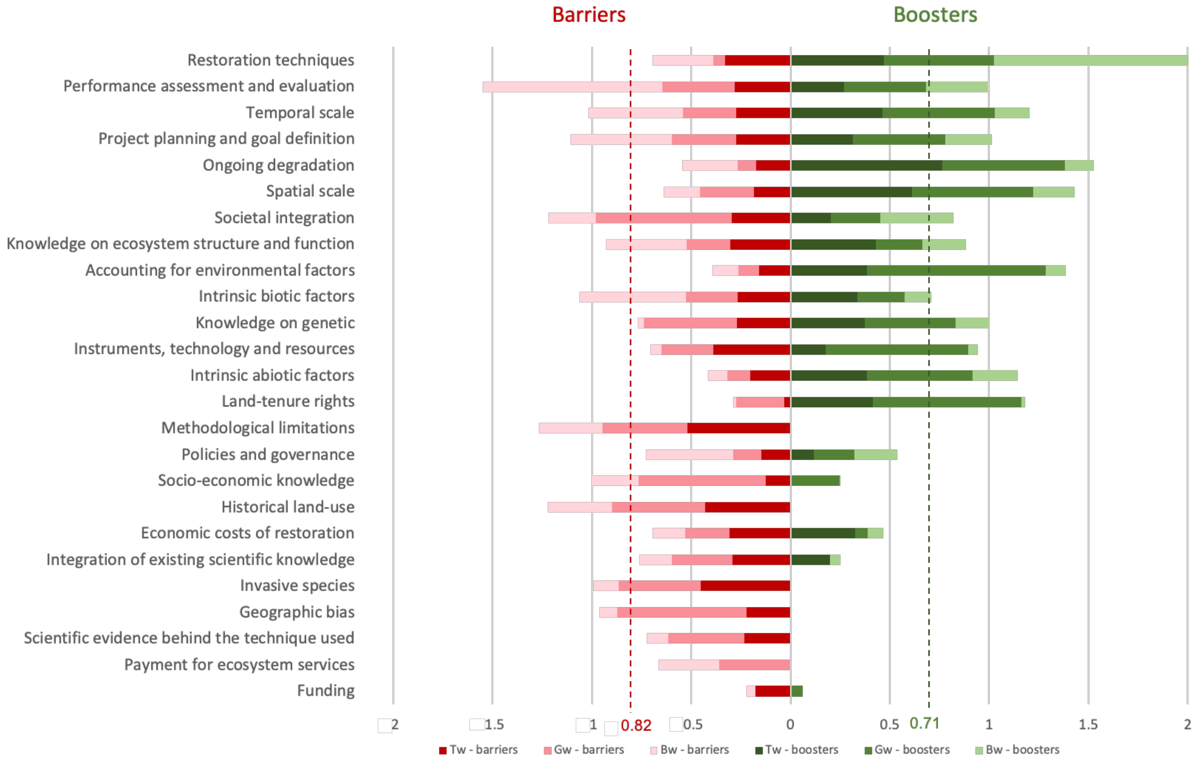

Figure 2. Weights of the factors. Factors ordered by the overall weight. The contribution of barriers (red) and boosters (green) is represented. Each group of variables is divided by the bibliographic weight (*BW*, pale color), geographic weight (*GW*, medium color) and temporal weight (*TW*, dark color). The average final weight value of barriers (red-dashed line) and boosters (green-dashed line) is shown.

We found nine ecosystem types (Fig. 3): forests (including forests, tropical forests, semi-natural forests, neotropical forests, and floodplain forests), wetlands (including freshwater wetlands, coastal wetlands, peatlands, mangroves, fen meadows and floodplains), rivers (including rivers, riparian vegetation, streams, estuaries, and watersheds), arid lands (including drylands, arid and semiarid zones), grasslands (including grasslands and steppe ecosystems), marine ecosystems (including coral reefs, seagrass and benthic areas), agroecosystems and coastal dunes. Some reviews included variables from several ecosystem types that could not be used in the ecosystem type analysis. Given the low number of variables found in many of the ecosystem types selected, we only used forests, wetlands and rivers.

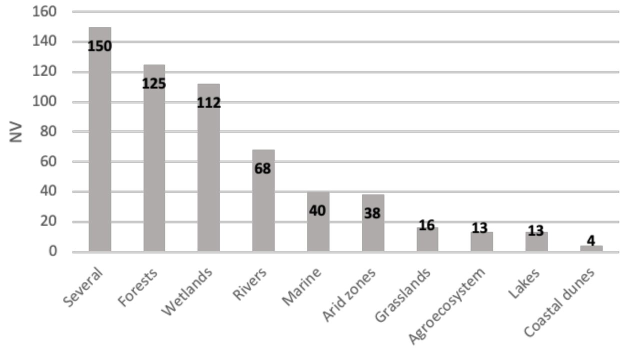

Figure 3. Ecosystem types found in the review and the number of variables contained within each one.

Within ecosystem types, we found differences in the factors that have influenced the most to each one. In forests, we found that restoration techniques was the most influencing factor, while methodological limitations and spatial scale were the most influencing ones at hampering and fostering ER outcomes respectively. In wetlands, performance assessment and evaluation was the most influencing factor on ER outcomes, intrinsic biotic factors was so at hampering them and restoration techniques at fostering them. Lastly, in river, policies and governances was the most influencing factor overall but also was so at fostering ER results, while temporal scale was the most influencing one at hampering them (fig. 4).

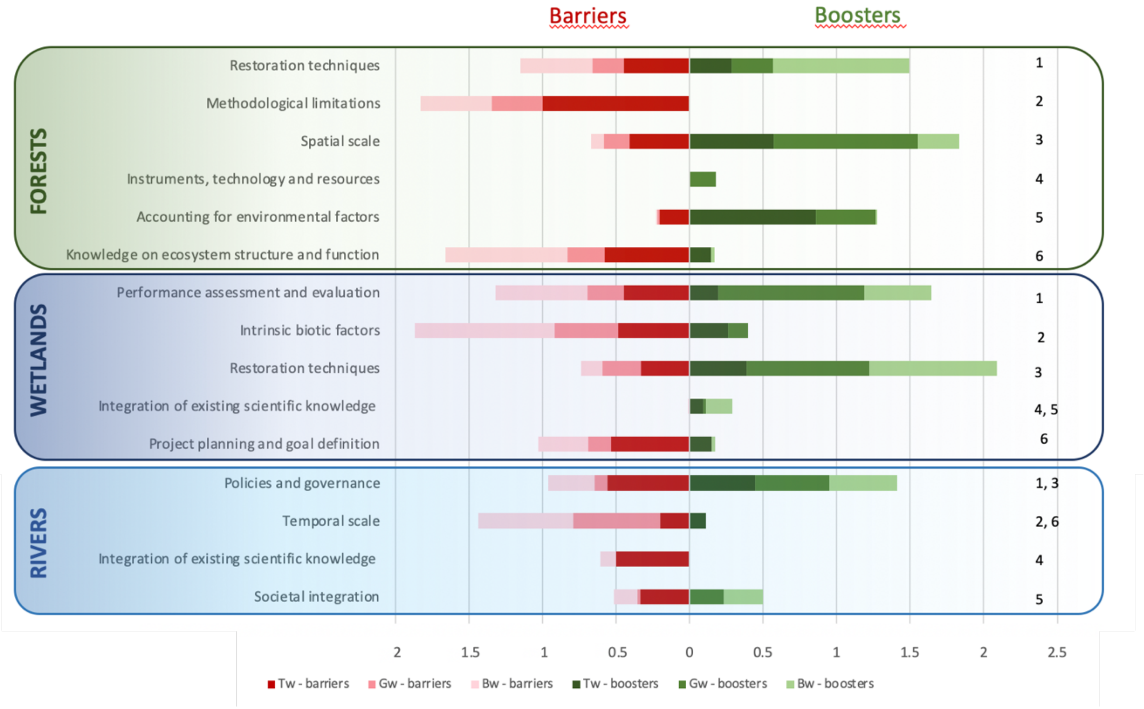

Figure 4. Main factors affecting restoration in forests, wetlands and rivers. Each box contains factors that are labeled (numbers 1-6, right-side). Label 1: Most influencing factor on ER outcomes (highest OF_w); label 2: Most influencing factor at hampering ER outcomes (highest barriers F_w); label 3: Most influencing factor at fostering ER outcomes (highest boosters F_w); label 4: Least influencing factor on ER outcomes (lowest OF_w); label 5: Least relevant factor at hampering ER outcomes (lowest barriers F_w); label 6: Least relevant factor at fostering ER outcomes (lowest boosters F_w).

Discussion

a) Hampering vs. fostering success

We have found a greater number of barriers in the literature and the average value of the overall final weight for barriers is higher than it is for boosters. This result reflects how ER is being hampered more frequently and more intensely than it is fostered under current restoration practice. This result is consistent with previous studies showing an incomplete or insufficient recovery of functional and structural attributes after restoration (Moreno-Mateos et al., 2012, 2017; Palmer et al., 2014; McCrackin et al., 2017) and help understanding the limited performance of recent international programmes like Aichi Biodiversity Targets 2020 (Nature, press release 2020) or the EU Biodiversity Targets 2020 (EUROPARC federation, 2019).

Regarding the importance of each factor, the solely fact of being present on our results make them relevant at a global scale. Our search has focused on papers that have already gathered evidence from multiple studies and thus, each factor contains variables strongly supported by the literature.

b) Applied science

The high relevance presented by the choice of restoration techniques is presumably related with the fact that ER is a field with direct applications and thus, the scientific research is mainly focus on the development of new, more efficient and versatile techniques to tackle different problematics. The fact that this factor has been detected as the most influencing one at fostering restoration outcomes might mean that the state of the art of ER is going in the good direction. This is in agreement with other studies that have found specific techniques as critical for the success of the restoration program. Some examples are the use of artificial bird perches for revegetation (Guidetti et al., 2016), the inoculation of native mycorrhizal fungi (Maltz and Treseder, 2015), the creation of hedgerows in agricultural lands (Barral et al., 2015), the removal of the topsoil in fen meadows (Klimkowska et al., 2010) or the stabilization of the coral reef substrate with electrolysis (Rinkevich, 2005). On the other hand, other studies have found that the application of general approaches like passive restoration can also be an effective tool (Ren et al., 2017; Shimamoto et al., 2018).

c) Evaluation of success and goal setting

The second most relevant factor influencing restoration outcomes was the performance assessment and evaluation, which also have resulted as the most influencing one at hampering its success. Conceptual approaches already highlighted measuring success and monitoring as crucial elements to improve restoration outcomes (Hobbs and Harris, 2001). Therefore, the lack of these elements or its inadequate application suppose a barrier to restoration. This is consistent with our results and other reviews, where either the lack of monitoring in restoration programmes (Mansourian and Vallauri, 2014; Palma and Laurance, 2015; Wohl et al., 2015) or the unproperly monitoring performance when applied (Aronson et al., 2010; Stanturf et al., 2014; Browne et al., 2018; Fernandes et al., 2018) were shown as hampering elements. A great number of reviews also report that the lack of standardized methods for evaluation, the wrong choice of indicators, and the ambiguous definition of success as frequent barriers (Koch M. and Richard, 2007; Chen et al., 2009; Jones and Kress, 2012; Stanturf et al., 2014; Zhao et al., 2015; Bechara et al., 2016). Success and monitoring criteria are dependent on the stablished goal, what has led many authors to contemplate the establishment of more realistic and dynamic goals in order to achieve success (Harris et al., 2006; Hobbs, 2007; Jones et al., 2018). Thus, we find a strong relation between monitoring and assessment and project planning and goal definition, which resulted the fourth most influencing one on ER outcomes in our analysis. These factors have played crucial roles on the failure of international programs like Aichi Biodiversity Targets or the EU Biodiversity Strategy for 2020 (Nature, 2020; EUROPARC, 2020).

d) Long-term requirements

Temporal scale is a factor that has been broadly addressed due to its relevance to understand the recovery of ecosystems (Curran et al., 2014; Moreno-Mateos et al., 2020). Most of the times, we do not know if the restored ecosystem has achieved the expected success because we lack a long-term monitoring required to evaluate complex ecological attributes and metrics as nutrient cycles, landscape attributes, populations dynamics, self-sustainability, or community composition (Maria and Aide, 2005; Crouzeilles et al., 2016; Yu et al., 2017). This lack of long-term monitoring is mainly due to the absence of long-term funding (Jones and Kress, 2012; Angelopoulos et al., 2017; Iftekhar et al., 2017; Sapkota et al., 2018). Therefore, long-term funding should be carefully considered by policy makers and stakeholders in order to incorporate a long-term commitment for restoration programs if we want to accomplish further success.

e) Ecosystem type insights

The high influence of restoration techniques in forests restoration can be related with the large number of studies focused on revegetation practices of forest ecosystems (Wang et al., 2013; Xi et al., 2014; Costantini et al., 2016; Guidetti et al., 2016; Aavik and Helm, 2018; Shimamoto et al., 2018). Some authors have found the excessive reliance on reforestation as a barrier when used as an isolated approach for recovery (Cao et al., 2011; Bechara et al., 2016). In some extreme cases and under bad planning (e.g. wrong species selection, excessive density, lack of meteorological data integration) reforestation can lead to the loss of soil moisture and increasing of aridity (Su and Shangguan, 2019). On the other hand, spatial scale variables detected are mainly contributing to the success of restoration, fact that mainly relies on the consideration of landscape ecological attributes in the restoration program. Big and continuous patches of forest cover surrounding a disturbed site can foster restoration success by enhancing litter accumulation and biodiversity and vegetation structure (Crouzeilles and Curran, 2016; Crouzeilles et al., 2016). We concur with de Souza et al. 2013, who stablished that once the restoration techniques overcome the constraints at local scale, one can address the landscape scale limitations (de Souza Leite et al., 2013). Methodological limitations might be hampering forest restoration mainly due to the limited reproducibility of experimental designs and their lack of accuracy (Sánchez Meador et al., 2017; Thomas & Gale, 2015). We think these factors should be carefully considered in to prevent the waste of well-intentioned but misguided actions and resources. Many of the current international programs aiming to restore ecosystems are focusing their efforts into forests restoration, some with the goal of planting billions of trees like the EU Biodiversity Targets 2030 (Climate Focus, 2016; European Commision, 2020).

In wetlands, success assessment and evaluation is the most influencing factor on success achievement according to our results, which are consistent with Browne et al., 2018, who found a lack of monitoring after implementing the restoration program in two thirds of 61 wetland studies as a major constraint. The way intrinsic biotic factors are hampering success may be mainly due to low dispersal ability and low seed production of target species (Lavoie et al., 2003; Klimkowska et al., 2010; Lamers et al., 2015). Restoration techniques was the factor fostering the most restoration of wetlands, which could indicate that current techniques to restore wetlands are properly chosen and applied. This is consistent with other studies where specific techniques like topsoil removal or rewetting favoured the projects (Klimkowska et al., 2010; Moreno-Mateos et al., 2012; Matthews et al., 2014; Lamers et al., 2015)

Lastly, in rivers, the most influencing factor was policies and governance. Stable national and regional policies are more relevant in river restoration since these ecosystems can cross multiple administrative units (from little private terrains to countries) with autonomy to differently manage a single watershed (Flávio et al., 2017; Hughes & Rood, 2003; Wohl et al., 2015). That is why political override caused by changes in government policies are reported by some studies as a reason of failure in restoration of rivers (Angelopoulos et al., 2017). Temporal scale has resulted the most influencing factor at hampering ER of rivers, what means that long-term monitoring, funding or project performance perse is mainly lacking or it is poorly accomplished. In rivers and streams, this is narrowly related to lagged effects of past land uses like continuous use of fertilizers, whose effects on river basin groundwaters can perdure during decades (Hamilton, 2012; González et al., 2015).

f) Deeper scientific research

We have seen that restoration techniques, the evaluation of success, goal establishment and temporal scale are some of the most influencing factors on the ER success. We think that behind these factors relies the understanding of complexity of ecosystems and therefore, the need of deeper scientific research. The good choice of a technique relies on the knowledge of the ecological attributes of the ecosystem to restore and the incorporation of this knowledge on the implementation of the technique, as well as the research on the effectiveness of the technique in question. Thereby we find a relation between restoration techniques factors with others like integration of existing scientific knowledge, knowledge on ecosystem structure and function, scientific evidence behind the technique used, intrinsic abiotic factors and intrinsic biotic factors. All of these rely in the last term on scientific knowledge. On the other hand, we would be able of stablishing more feasible goals if our previous knowledge of how ecosystems recover from human impacts were clearer and more complete, therefore being able of assessing success in a more consistent and reliable manner. In addition, the temporal scale factor relevance is also telling us that the amount of available information about the evolution and functioning over the long-term of an ecosystem will provide better understanding of its recovery. Thus, we think we should address the scientific research of ecosystems and their restoration from human impact as the main goal to accomplish further success. As few studies suggest, this research should tackle more complex attributes like species interactions, element that would drastically increase the resolution of our knowledge of how ecosystem assemble, conform a structure and develop certain functions (Moreno Mateos, 2019; Rodríguez-Uña et al., 2019; Moreno-Mateos et al., 2020).

g) Caveats and limitations of the study

Source of reviews: The major part of the analyzed reviews has been conventional reviews, which usually have non-canonical scientific structure (i.e. methods, discussion, conclusion) and usually have an unusual length, making the seeking and extraction of information a longer and more complex process (Szklo, 2006). On the contrary, Systematic Reviews and Meta-analysis make use of specific data extraction methods and analytical tools, conferring to their results a presumably higher significance than those extracted from a conventional review (Bown and Sutton, 2010). These facts might reflect the need of higher quality standards at performing a review about ER science.

One person reviewing. Since the extraction of information is not always clear and some variables are open to the interpretation of the reader, the results might be biased towards the main reviewer criteria.

Weighing criteria. The mathematical approach used as weighing criteria based on the available information, potentially missing relevant factors affection the importance of each variable. For this reason, the results should be carefully interpreted.

Conclusions and recommendations

The current ecosystem restoration approach is limited. We have already highlighted how some international commitments for the recovery and conservation of nature have failed along the last decade as a result of this limitation. Even though scientific knowledge is making progress in understanding the main elements that define this trend, application of scientific knowledge (through the deliberated implementation of new techniques or through new regulations and policies) usually takes many years to occur (Likens, 2010). However, we have being warned about the scarce amount of time we have to face the problems associated with global change like biodiversity losses or ecosystem degradation. This is why producing practical and global views are critically needed to guide possible solutions in the near future. Having under consideration the limitations of this qualitative meta-analysis, we consider that the list of 25 factors here presented offers a guide for policy makers, scientist and practitioners to improve the ecosystem restoration performance in the following years. Restoration techniques, performance assessment and evaluation, temporal scale and project planning and goal definition were the most influencing factors and so should be tackled. Nevertheless, each factor relies on papers that have already gathered evidence from multiple studies, and thus, all of them should be highly considered. In addition, we think that behind great part of the factors relies the need of performing deeper scientific research into more complex ecological attributes as species interactions. This could lead to better understanding about ecosystems and their recovery and therefore to the development of practical tools to tackle their degradation after human impacts. The declaration of the current decade by the United Nations as the UN Decade of Ecosystem Restoration might facilitate the incorporation of this conclusions within practical and political framework, what could help avoiding the failure of next international programs restoration goals like the EU Biodiversity Targets 2030.

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ANNEX

ANNEX I. Example of weighting process.

Here we present a demonstration of the factor weighting procedure through a hypothetical example that consist on 3 reviews (a), b) and c)), containing a total of 12 variables (7 barriers and 5 boosters) and allocated within 3 factors (i, ii, iii). Hypothetical data has been assigned to each review.

1) Graphical representation of weighting process

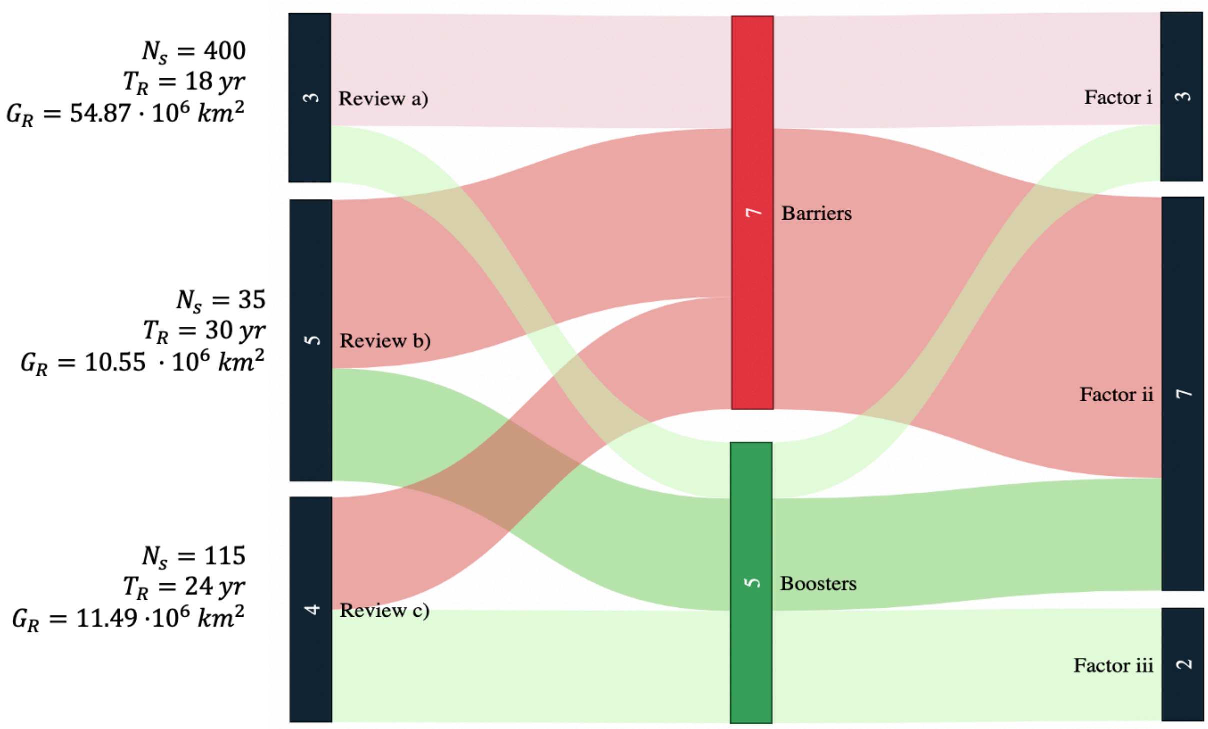

Figure 5. Sankey Diagram of weighting process. Data allocated in the left are hypothetical values given to each review (Ns: Number of reviewed studies; TR: Time range of the review; GR: geographical range of the review). Numbers allocated in the vertical bars represent the number of variables. 3 groups of vertical bars from left to right: number of variables found within each review; number of barriers and boosters; total number of variables assigned to each factor. The direction of the fluxes between bars represent the movement of this variables depending on: if the variables are barriers or boosters; what factor is related to. The color of the fluxes is greenish for boosters and reddish for barriers.

2) Factor weighting process. Here is represented the performed calculations to assign a weight to each factor. In the reddish box are the calculations for the barriers, and in the greenish box the calculations for the boosters.

   a. Factor i:

$N_V = 2 \mid N_S = 400 \mid T_R = 18\,years \mid G_R = 54.87 \cdot 10^6 km^2$

$$\boldsymbol{B_w = V + S} \quad \begin{cases} \boldsymbol{V} = \dfrac{2}{579} = 0{,}003 \\ \boldsymbol{S} = \dfrac{400 \cdot (1 - F_O)}{14{,}761} = 0{,}026 \end{cases}$$

$$\boldsymbol{T_W} = \frac{18\,years}{25.32\,years} = 0.711$$

$$\boldsymbol{G_W} = \frac{54.87 \cdot 10^6 km^2}{19.86 \cdot 10^6 km^2} = 2.76$$

$N_V = 1 \mid N_S = 400 \mid T_R = 18\,years \mid G_R = 54.87 \cdot 10^6 km^2$

$$\boldsymbol{B_w = V + S} \quad \begin{cases} \boldsymbol{V} = \dfrac{1}{579} = 0{,}001 \\ \boldsymbol{S} = \dfrac{400 \cdot (1 - F_O)}{14{,}761} = 0{,}026 \end{cases}$$

$$\boldsymbol{T_W} = \frac{18\,years}{25.32\,years} = 0.711$$

$$\boldsymbol{G_W} = \frac{54.87 \cdot 10^6 km^2}{19.86 \cdot 10^6 km^2} = 2.76$$

   b. Factor ii:

$N_V = 5 \mid N_S = 150 \mid T_R = 27.60\,years \mid G_R = 10.93 \cdot 10^6 km^2$

$$\boldsymbol{B_w = V + S} \quad \begin{cases} \boldsymbol{V} = \dfrac{5}{579} = 0.008 \\ \boldsymbol{S} = \dfrac{150 \cdot (1 - F_O)}{14{,}761} = 0{,}009 \end{cases}$$

$$\boldsymbol{T_W} = \frac{27.60\,years}{25.32\,years} = 1.0900$$

$$\boldsymbol{G_W} = \frac{10.93 \cdot 10^6 km^2}{19.86 \cdot 10^6 km^2} = 0.5503.$$

$N_V = 2 \mid N_S = 35 \mid T_R = 30\,years \mid G_R = 10.55 \cdot 10^6 km^2$

$$\boldsymbol{B_w = V + S} \quad \begin{cases} \boldsymbol{V} = \dfrac{2}{579} = 0.003 \\ \boldsymbol{S} = \dfrac{35 \cdot (1 - F_O)}{14{,}761} = 0{,}002 \end{cases}$$

$$\boldsymbol{T_W} = \frac{30\,years}{25.32\,years} = 1.185$$

$$\boldsymbol{G_W} = \frac{10.55 \cdot 10^6 km^2}{19.86 \cdot 10^6 km^2} = 0.531$$

   c. Factor iii:

$N_V = 0$

$N_V = 3 \mid N_S = 115 \mid T_R = 24\,years \mid G_R = 11.49 \cdot 10^6 km^2$

$$\boldsymbol{B_w = V + S} \quad \begin{cases} \boldsymbol{V} = \dfrac{2}{579} = 0.003 \\ \boldsymbol{S} = \dfrac{115 \cdot (1 - F_O)}{14{,}761} = 0.007 \end{cases}$$

$$\boldsymbol{T_W} = \frac{24\,years}{25.32\,years} = 0.948$$

$$\boldsymbol{G_W} = \frac{11.49 \cdot 10^6 km^2}{19.86 \cdot 10^6 km^2} = 0.578$$

3) Normalization:

- *Barriers:*

Table 1. Normalization data for barriers. T_w: temporal weight; G_w: geographic weight; V: first addend of bibliographic weight (B_W equation related to the number of variables (N_V); S: second addend of B_W equation related to the number of studies (N_S); Min.: minimum values; Max.: maximum values; T_w*: normalized T_w; G_w*: normalized G_w; B_W*: normalized B_W; F_w: final weight.

FACTOR	T_W	G_W	*V*	*S*	*V**	*S**	T_W*	G_W*	B_W*	F_W
Factor i	0.711	2.76	0.003	0.026	0	0.653	0	0.800	0.013	**0.814**
Factor ii	1.09	0.55	0.008	0.009	0.625	0	0.347	0	0.317	**0.665**
Factor iii	-	-	-	-	-	-	0	0	0	**0**
Min.	0.711	0.55	0.003	0.009						
Max.	1.09	2.76	0.008	0.026						

- *Boosters:*

Table 2. Normalization data for barriers. T_w: temporal weight; G_w: geographic weight; V: first addend of bibliographic weight (B_W equation related to the number of variables (N_V); S: second addend of B_W equation related to the number of studies (N_S); Min.: minimum values; Max.: maximum values; T_w*: normalized T_w; G_w*: normalized G_w; B_W*: normalized B_W; F_w: final weight.

FACTOR	T_W	G_W	*V*	*S*	*V**	*S**	T_W*	G_W*	B_W*	F_W
Factor i	0.711	2.76	0.001	0.026	0	0.923	0	0.807	0.013	**0.820**
Factor ii	1.185	0.531	0.003	0.002	0.667	0	0.4	0	0.334	**0.734**
Factor iii	0.948	0.578	0.003	0.007	0.667	0.192	0.2	0.017	0.429	**0.646**
Min.	0.711	0.531	0.001	0.002						
Max.	1.185	2.76	0.003	0.026						

Where:

$$X_W^* = \frac{X_W - X_{W\,min}}{X_{W\,max}}$$

and

$$F_W = B_W/2 + T_W + G_W$$

4) Final weight (Fw) estimation and overall final weight (OFw) estimation:

Table 3. Overal weight estimation for hypothetical factors. F_W: final weight; OF_W: overall final weight.

FACTOR	F_W barriers	F_W boosters	OF_W
Factor i	0.814	0.821	1.634
Factor ii	0.665	0.734	1.399
Factor iii	0.000	0.647	0.647

5) Graphical representation:

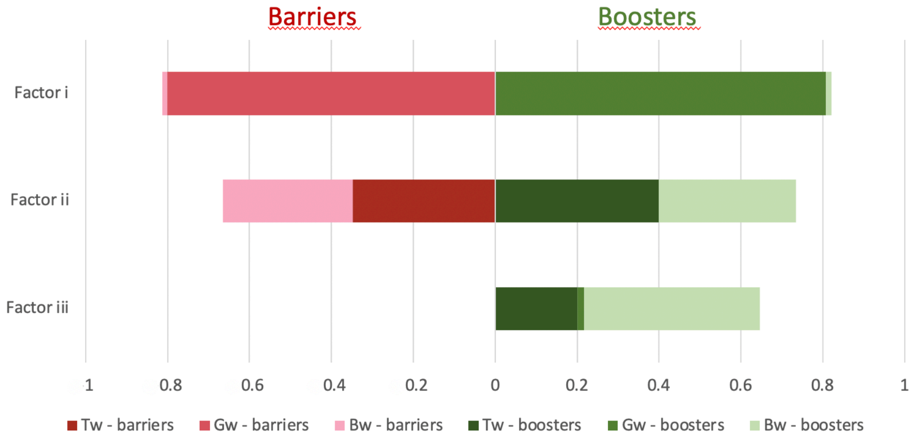

Figure 2. Weights of factors for hypothetical data. Factors ordered by the overall weight. The contribution of barriers (red) and boosters (green) is represented. Each group of variables is divided by the bibliographic weight (Bw, pale color), geographic weight (Gw, medium color) and temporal weight (Tw, dark color).

ANNEX II. List of 131 reviewed papers.

1. Aavik, T. & Helm, A. Restoration of plant species and genetic diversity depends on landscape-scale dispersal. *Restor. Ecol.* 26, S92–S102 (2018).
2. Adams, C., Rodrigues, S. T., Calmon, M. & Kumar, C. Impacts of large-scale forest restoration on socioeconomic status and local livelihoods: what we know and do not know. *Biotropica* 48, 731–744 (2016).
3. Andersen, R. *et al.* An overview of the progress and challenges of peatland restoration in Western Europe. *Restor. Ecol.* 25, 271–282 (2017).
4. Angelopoulos, N. V., Cowx, I. G. & Buijse, A. D. Integrated planning framework for successful river restoration projects: Upscaling lessons learnt from European case studies. *Environ. Sci. Policy* 76, 12–22 (2017).
5. Aronson, J. *et al.* Are Socioeconomic Benefits of Restoration Adequately Quantified? A Meta-analysis of Recent Papers (2000-2008) in Restoration Ecology and 12 Other Scientific Journals. *Restor. Ecol.* 18, 143–154 (2010).
6. Asmelash, F., Bekele, T. & Birhane, E. The potential role of arbuscular mycorrhizal fungi in the restoration of degraded lands. *Front. Microbiol.* 7, 1–15 (2016).
7. Baker, A. G. & Catterall, C. Managing fire-dependent vegetation in Byron Shire, Australia: Are we restoring the keystone ecological process of fire? *Ecol. Manag. Restor.* 17, 47–55 (2016).
8. Bakker, E. S., Van Donk, E. & Immers, A. K. Lake restoration by in-lake iron addition: a synopsis of iron impact on aquatic organisms and shallow lake ecosystems. *Aquat. Ecol.* 50, 121–135 (2016).
9. Barak, R. S. *et al.* Taking the long view: Integrating recorded, archeological, paleoecological, and evolutionary data into ecological restoration. *Int. J. Plant Sci.* 177, 90–102 (2016).
10. Bechara, F. C. *et al.* Neotropical rainforest restoration: comparing passive, plantation and nucleation approaches. *Biodivers. Conserv.* 25, 2021–2034 (2016).
11. Belder, D. J., Pierson, J. C., Ikin, K. & Lindenmayer, D. B. Beyond pattern to process: current themes and future directions for the conservation of woodland birds through restoration plantings. *Wildl. Res.* 45, 473 (2018).
12. Blignaut, J. *et al.* Establishing the links between economic development and the restoration of natural capital. *Curr. Opin. Environ. Sustain.* 5, 94–101 (2013).
13. Bosire, J. O. *et al.* Functionality of restored mangroves: A review. *Aquat. Bot.* 89, 251–259 (2008).
14. Browne, M., Fraser, G. & Snowball, J. Economic evaluation of wetland restoration: a systematic review of the literature. *Restor. Ecol.* 26, 1120–1126 (2018).

15. Bullock, J. M., Aronson, J., Newton, A. C., Pywell, R. F. & Rey-Benayas, J. M. Restoration of ecosystem services and biodiversity: conflicts and opportunities. *Trends Ecol. Evol.* 26, 541–9 (2011).
16. Burton, P. J. & Ellen Macdonald, S. The restorative imperative: Challenges, objectives and approaches to restoring naturalness in forests. *Silva Fenn.* 45, 843–863 (2011).
17. Cao, S. Impact of China's large-scale ecological restoration program on the environment and society in arid and semiarid areas of China: Achievements, problems, synthesis, and applications. *Crit. Rev. Environ. Sci. Technol.* 41, 317–335 (2011).
18. Cao, S. *et al.* Excessive reliance on afforestation in China's arid and semi-arid regions: Lessons in ecological restoration. *Earth-Science Rev.* 104, 240–245 (2011).
19. Chen, F., Yao, Q. & Tian, J. Review of Ecological Restoration Technology. *Eng. Rev.* 36, 115–121 (2016).
20. Chen, L., Wang, W., Zhang, Y. & Lin, G. Recent progresses in mangrove conservation, restoration and research in China. *J. Plant Ecol.* 2, 45–54 (2009).
21. Chimner, R. A., Cooper, D. J., Wurster, F. C. & Rochefort, L. An overview of peatland restoration in North America: where are we after 25 years? *Restor. Ecol.* 25, 283–292 (2017).
22. Cortina, J. *et al.* The restoration of vegetation cover in the semi-arid Iberian southeast. *J. Arid Environ.* 75, 1377–1384 (2011).
23. Costantini, E. A. C. *et al.* Soil indicators to assess the effectiveness of restoration strategies in dryland ecosystems. *Solid Earth* 7, 397–414 (2016).
24. Crouzeilles, R. & Curran, M. Which landscape size best predicts the influence of forest cover on restoration success? A global meta-analysis on the scale of effect. *J. Appl. Ecol.* 53, 440–448 (2016).
25. Crouzeilles, R. *et al.* A global meta-Analysis on the ecological drivers of forest restoration success. *Nat. Commun.* 7, (2016).
26. De Steven, D. & Gramling, J. M. Diverse characteristics of wetlands restored under the wetlands reserve program in the Southeastern United States. *Wetlands* 32, 593–604 (2012).
27. Djenontin, I. N. S., Foli, S. & Zulu, L. C. Revisiting the factors shaping outcomes for forest and landscape restoration in Sub-Saharan Africa: A way forward for policy, practice and research. *Sustainability (Switzerland)* 10, 906 (2018).
28. Elliott, M. *et al.* Ecoengineering with Ecohydrology: Successes and failures in estuarine restoration. *Estuar. Coast. Shelf Sci.* 176, 12–35 (2016).
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30. Feld, C. K. *et al. From Natural to Degraded Rivers and Back Again. A Test of Restoration Ecology Theory and Practice*. *Advances in Ecological Research* 44, (Elsevier Ltd., 2011).
31. Fernandes, K. *et al.* DNA metabarcoding—a new approach to fauna monitoring in mine site restoration. *Restor. Ecol.* 26, 1098–1107 (2018).
32. Flávio, H. M., Ferreira, P., Formigo, N. & Svendsen, J. C. Reconciling agriculture and stream restoration in Europe: A review relating to the EU Water Framework Directive. *Science of the Total Environment* 596–597, 378–395 (2017).
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34. France, R. L. From land to sea: Governance-management lessons from terrestrial restoration research useful for developing and expanding social-ecological marine restoration. *Ocean Coast. Manag.* 133, 64–71 (2016).
35. Gatica-Saavedra, P., Echeverría, C. & Nelson, C. R. Ecological indicators for assessing ecological success of forest restoration: a world review. *Restor. Ecol.* 25, 850–857 (2017).
36. Glenn, E. P., Nagler, P. L., Shafroth, P. B. & Jarchow, C. J. Effectiveness of environmental flows for riparian restoration in arid regions: A tale of four rivers. *Ecol. Eng.* 106, 695–703 (2017).
37. Gómez-Aparicio, L. The role of plant interactions in the restoration of degraded ecosystems: A meta-analysis across life-forms and ecosystems. *J. Ecol.* 97, 1202–1214 (2009).
38. González, E., Sher, A. A., Tabacchi, E., Masip, A. & Poulin, M. Restoration of riparian vegetation: A global review of implementation and evaluation approaches in the international, peer-reviewed literature. *J. Environ. Manage.* 158, 85–94 (2015).
39. Guidetti, B. Y., Amico, G. C., Dardanelli, S. & Rodriguez-Cabal, M. A. Artificial perches promote vegetation restoration. *Plant Ecol.* 217, 935–942 (2016).
40. Gulati, R. D. & Van Donk, E. Lakes in the Netherlands, their origin, eutrophication and restoration: State-of-the-art review. *Hydrobiologia* 478, 73–106 (2002).

41. Hamilton, S. K. Biogeochemical time lags may delay responses of streams to ecological restoration. *Freshw. Biol.* 57, 43–57 (2012).

42. Harzé, M. *et al.* Towards a population approach for evaluating grassland restoration—a systematic review. *Restor. Ecol.* 26, 227–234 (2018).

43. Hein, M. Y., Willis, B. L., Beeden, R. & Birtles, A. The need for broader ecological and socioeconomic tools to evaluate the effectiveness of coral restoration programs. *Restor. Ecol.* 25, 873–883 (2017).

44. Higgs, E. *et al.* The changing role of history in restoration ecology. *Front. Ecol. Environ.* 12, 499–506 (2014).

45. Hu, J., Lü, Y., Fu, B., Comber, A. J. & Harris, P. Quantifying the effect of ecological restoration on runoff and sediment yields: A meta-analysis for the Loess Plateau of China. *Prog. Phys. Geogr.* 41, 753–774 (2017).

46. Huang, C., Zhou, Z., Peng, C., Teng, M. & Wang, P. How is biodiversity changing in response to ecological restoration in terrestrial ecosystems? A meta-analysis in China. *Sci. Total Environ.* 650, 1–9 (2019).

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48. Hulvey, K. B. *et al.* Restoration islands: a tool for efficiently restoring dryland ecosystems? *Restor. Ecol.* 25, S124–S134 (2017).

49. Iftekhar, M. S., Polyakov, M., Ansell, D., Gibson, F. & Kay, G. M. How economics can further the success of ecological restoration. *Conserv. Biol.* 31, 261–268 (2017).

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