Conservation and Society AOP: 1-13, 2020

Review

A Review of Ecological Restoration Research in the Global South and North to Promote Knowledge Dialogue

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Abstract

To determine global trends in ecological restoration (ER) research, we conducted a geographically-explicit English-language literature review. We assessed a representative sample (n=603) of publications that use the ER concept (n=8,678). Only 19.2% (n=118) were explicit ER studies, and these were evaluated to determine geographic location, research framework, ER paradigm, journal disciplinary orientation, article type, disturbance factor studied, and ER-response measurements. The Global North produced 2x more studies than the South, and ecological research frameworks predominated overall. However, significantly more Southern studies operated under a postmodern paradigm (i.e., addressing ecosystem processes, functions and health) than in the North, where more studies sought to reconstitute pre-disturbance biotic assemblages (i.e., classical paradigm). Both regions published mostly in natural science journals, but significantly more in the North; in the South, there were significantly more publications in engineering journals. An incipient socio-ecological research framework was detected in the North (23.1%) and South (32.5%), but social science studies were only found in the North (11.5%). Plus, the North had significantly more conceptual publications. Opportunities exist in both regions to enhance a holistic ER perspective. Southern scientists and practitioners could pay attention to context-specific concepts and approaches. Understanding global and regional ER research trends can contribute to improving theoretical, practical and ethical outcomes.

Keywords: Ecosystem services, ecological restoration, environmental degradation, remediation, restoration ecology, socio-ecological systems

Access this article online	
Quick Response Code:	Website: www.conservationandsociety.org
	DOI: 10.4103/cs.cs_19_91

INTRODUCTION

Environmental problems, including ecological degradation, climate change, and biological invasions, have long been recognised as occurring from local to global scales (Vitousek et al. 1997; Hobbs et al. 2006), but it is becoming increasingly clear that managing these challenges depends on determining the human and natural drivers, consequences, and dynamics of what are ostensibly social-ecological systems (SES) (Carpenter et al. 2009; Díaz et al. 2015). SES-relevant knowledge itself must be understood as coming from multiple world-views that embody diverse values and have differential power and ability to express themselves (Karlsson 2002; Pascual et al. 2017; Diaz et al. 2018). SES knowledge, therefore, is required to implement effective and just sustainability policies and institutional frameworks, but has yet to be fully incorporated into decisions regarding environmental research or policy (Horan et al. 2011; Anderson et al. 2019). In this context, environmental management strategies, including ecological restoration (ER), climate change mitigation efforts (e.g., REDD+) or invasive species management, are simultaneously fields of scientific inquiry and communities of practice with their underlying processes of knowledge production, power equity and policy applications (Lawson et al. 2017).

In particular, ER is both an academic pursuit and management practice with increasing local and global importance for academics, policymakers and the general public (SER 2004; Suding 2011). Not only has ER research productivity increased during the last decade (Wortley et al. 2014), but it also has had ever-greater inclusion in environmental and conservation planning (Aronson and Alexander 2013; IPBES 2018). Since the 1990s, ER has gone from establishing basic conceptual foundations (Hobbs and Norton 1996) to becoming an increasingly predictive science (Brudvig et al. 2017). Furthermore, databases now make it possible to measure the effectiveness of restoration actions at achieving both ecological and socio-economic outcomes (Aronson et al. 2010; Wortley et al. 2014; Crouzeilles et al. 2016). Annually, billions of US dollars are invested in ER (BenDor et al. 2015), and numerous countries have taken on major commitments to restore millions of hectares of land as part of meeting global obligations to biodiversity loss, sustainability and climate change (e.g., *New York Declaration of Forests*, Bonn Challenge: http://www.bonnchallenge.org/commitments, UN Decade on Ecological Restoration 2021-2030: https://www.decadeonrestoration.org/, and the Convention for Biological Diversity's Aichi Biodiversity Targets -Target 15: https://www.cbd.int/sp/targets/rationale/target-15/).

Correspondingly, scholars have called for ER research and practice to become more holistic, incorporating multiple factors, such as: 1) ecological integrity, 2) sustainability, 3) an understanding of both past conditions and future scenarios, and 4) incorporating social relationships and/or benefits to people (Suding et al. 2015). Yet, in the Anthropocene, not only are there conflicts regarding equity in the access to nature and the distribution of its benefits (e.g., ecological distribution conflicts, Temper et al. 2018), but also the underlying, culture-based assumptions of nature (i.e., metaphysics) and approaches to its study (i.e., epistemology). Both the metaphysics and epistemologies of nature can be contested between academic disciplines, between science and other stakeholders, or even among scientists and stakeholders, which, in turn, can affect the consideration (or exclusion) of social values and restoration end points that are sought in ER (Martin 2017). In particular, disparities exist in scientific production and power among nations found in the Global South and North (Karlsson 2002; Amano et al. 2016), and among other things ecological science publications have been shown to be dominated by countries with a high Human Development Index—HDI (Livingston et al. 2016). These geographic differences in research productivity can be expressed in the quantity of scientific outputs (e.g., number of articles or books) and also in the type of scientific contributions to knowledge structure and hierarchy (i.e., whether the publication is about creating, evaluating, analysing, applying, understanding or replicating studies, Anderson et al. 2001). Consequently, it is imperative to incorporate new science policies, particularly in the Global South, where current structures foment and prioritise English-language publications in international journals, even though this approach may be detrimental to national and regional science systems or the solution of local socio-environmental problems (Bortolus 2012; Anderson et al. 2015a).

Arguably, the paradigms that have most influenced ER's historical development have been ecological concepts that are the product of the Global North, a term that encompasses countries with developed economies, high education levels and/or geopolitical influence over global resource governance (Fukuda-Parr 2004). For example, one highly-cited proposal to re-conceive nature in the Anthropocene that arose from the Global North is to recognise that today ecosystems are largely "novel," because modern biotic assemblages do not resemble those that historically were predominant in a particular biome (Hobbs et al. 2006). To date, however, this mostly natural-science concept has not fully recognised that concomitantly human societies are increasingly novel with new assemblages of values and perceptions of nature (Vertovec 2007; Buijs et al. 2008). Focusing research on novel social and ecological assemblages also can orient attention to cosmopolitan and urban SESs, which in turn should lead to ER efforts that are not only in natural or protected areas, but also in anthropogenic systems that can provide ecosystem services to cities, where diverse social actors may have different desired restoration outcomes (Standish et al. 2013). In this sense, truly taking responsibility for the human dimension of ER involves broadening ER's foundational concepts to include changing societies, heterogeneous stakeholders and the power relationships between them, diverse perceptions and expectations of and from the environment, and the production and application of knowledge for environmental management from local to global scales (e.g., REDD+; Mustalahti et al. 2012).

This re-conceptualisation of nature and human-nature relationships, however, challenges traditional endpoints for

environmental interventions and the typical Western separation of humans and nature (Anderson et al. 2015b). Instead of being purely ecologically-derived, these interventions must be, at least in part, socially-determined (Martin 2017). Tensions, therefore, would be expected to arise between the 'classical' paradigm of ER (*sensu* Higgs et al. 2014) and a 'postmodern' world-view (*sensu* Callicott 2010). While in the former, the focus of ER efforts is directed towards the mitigation of environmental degradation by returning an ecosystem to historical 'natural' conditions without explicitly considering humans and their activities (e.g., re-establish pre-disturbance, often pre-European, species assemblages, Box 1), the latter is more amenable to incorporating broader ecosystem functions and services. Ecosystem services, in turn, are valued based on socially-constructed relationships between humans and biodiversity (e.g., to restore riparian forests to ensure drinking water provision for cities, Box 2).

Given this background, we would hypothesize, then, that the adoption of a broader approach to ER would increase over time, as the integration of human dimensions has consolidated in the understanding and management of socio-environmental problems (Mace 2014; Anderson et al. 2015b). Nonetheless, some recent global ER initiatives have paradoxically reenforced a classical perspective of ER endpoints and goals, seeking 'native' and 'natural' assemblages (see Higgs et al. 2018's discussion on the Society for Restoration Ecology's international standards and the UN Convention to Combat Desertification's Land Degradation Neutrality Framework), and consequently, ER may not be following the same path observed in other ecological sciences, such as the broader field of ecology (Anderson et al. 2015b) or invasion biology (Vaz et al. 2017). Yet, there is clearly a productive debate in the ER literature surrounding novel ecosystems, ecosystem services and human well-being (Martin 2017) and strong efforts to promote a holistic and open ER science and practice (Suding et al. 2015; Higgs et al. 2018). In this context, and given Global South-North disparities previously mentioned for science production and knowledge dialogue (Anderson et al. 2015a; Amano et al. 2016; Livingston et al. 2016), it is also likely that we would find geographic differences not only in the number of publications, but in the conceptualisation and application of ER itself. For example, we would expect to find that the North is the net producer of ER concepts, which are then applied in the South (Latta and Wittmann 2012; Livingston et al. 2016). Previously, it has been shown that there are geographic biases in ER research productivity (Wortley et al. 2014), but we know less about potential geographic differences in how ER research is conceived and carried out. Therefore, greater clarity about the meaning and use of ER helps refine research globally and relates it to place-specific contexts, which is a challenge for conducting

Box 1
Ecological restoration of areas degraded by invasive beavers in Patagonia using a classical paradigm to define objectives and endpoints

Despite being one of the world's iconic, remote landscapes, Patagonia actually faces numerous drivers of ecological degradation, ranging from biological invasions and climate change to wildfires and overgrazing (Clewell 2015; Ballari et al. 2016; Peri et al. 2017). How, then, does ER address these problems? Generally, the Western social imaginary envisions Patagonia as virgin and untouched land (Moss 2008); conservation organisations also positioned it as one of the world's last 'wilderness'areas (Mittermeier et al. 2003). This imaginary, though, largely excludes humans, and subsequently the goal of ER becomes returning the species assemblage to its 'natural' (i.e., pre-European) condition. One exemplary case of the classical ER paradigm at work is the efforts currently underway to deal with invasive North American beavers *Castor canadensis*, introduced to Tierra del Fuego in the 1940s to enrich local fauna and create a fur industry (Anonymous 1946). By the early-1990s, attitudes of scientists and environmental managers towards this species had changed, coming to conceive of it as a biological invasion that required action. Simultaneously, other social actors (e.g., ranchers) agreed with the need to control or eradicate beavers (Santo et al. 2015), but broadly, the general public in southern Patagonia has not considered biological invasions to be a priority environmental issue, even though they recognise it as a problem (Zagarola et al. 2014). Nonetheless, natural scientists successfully positioned this topic in the political agenda, eventually becoming the subject of a binational agreement, signed between Argentina and Chile in 2008, to work towards the eradication of beavers and the restoration of degraded ecosystems in southern Patagonia. In this document, restoration is defined under the rubric of the classical paradigm of ER (*sensu* Higgs et al. 2014), whereby the goal is to restore 'natural' (pre-disturbance) vegetation communities, rather than focusing on other human-derived benefits that can be obtained from these ecosystems. To date, research to implement ER ideas in Tierra del Fuego has focused on basic ecological questions (Henn et al. 2014), but at the same time there is an increasing emphasis on other human dimensions (Santo et al. 2015, 2017; Anderson et al. 2017). Not only biological invasions, but also all drivers of ecological degradation require ER efforts involve humans directly or indirectly, which requires pushing the frontiers of ER towards a new socio-ecological understanding.

Box 2
Ecological restoration of watersheds to obtain human benefits in the US Southwest, using a postmodern paradigm to define goals and endpoints

The US Federal Government owns extensive forests in the southwestern portion of the country. The improper management of these forests, combined with climate change and development, has caused not only ecological degradation, but also increased environmental hazards to humans (Covington et al. 1997). Together, for instance, these threats jeopardise the sustainability of water supplies throughout the West (Mueller et al. 2013). In northern Arizona, forested watersheds surrounding the city of Flagstaff are at high-risk due to wildfires, but in turn, the condition of these forests also affects the city's drinking water. To confront these issues, various stakeholders established the Flagstaff Watershed Protection Project (FWPP) in 2010 (Miller et al. 2017). This coalition has promoted Payments for Watershed Services (PWS) projects as a type of socio-environmental system to seek alternative funding for watershed restoration projects that decrease the risk of fire and increase (or secure) the provision of water resources (Miller 2015). In this case, ER was conceived of as improving an ecosystem service (not a classical historical reference point) by redistributing resources (via taxes) for broader and long-term societal benefits. This case incorporates humans as both a contributor to the ecosystem (as a driver of disturbance or restoration) and as a beneficiary of it (as a recipient of ecosystem services). It also provides an example that can be applied in other socio-ecological systems, which could pose different obstacles and opportunities. Therefore, a socio-ecological approach to ER requires understanding the idiosyncrasies of local contexts (e.g., type of government, differences in the level of perception/valuation of ecosystem services, etc.), rather than only applying general theories developed based on idealized understandings of natural systems.

globally-excellent and also regionally-relevant science (Rau et al. 2017; Díaz et al. 2018). For example, global initiatives, such as REDD+ or strategies to achieve the UN's Sustainable Development Goals, frequently incorporate ER as a principal mechanism to achieve both social and ecological outcomes (IPBES 2018).

In this study, we evaluated ER research from the Global South (i.e., Africa, Latin America and the Caribbean, and most of Asia) and North (i.e., Europe, northern North America, Oceania, and a few countries in Asia) (Figure 1a). We conducted a literature review of academic ER publications in the English language to examine research patterns and trends, considering parameters related to the study's geography (country, region), concepts (research frameworks, paradigms, objectives), and implementation (methodological approach, habitat studied, drivers identified, outcomes measured). Given the power relationships involved in South-North environmental management (Biermann 2000) and the fact that ecology articles from Northern countries generally have higher rates of placement in top-tier journals and citation indices (Smith et al. 2014), we anticipated that ER in the South would be oriented towards testing the paradigms of human-nature relationships that are predominately developed in the North, including a preponderance of studies that take field data to test

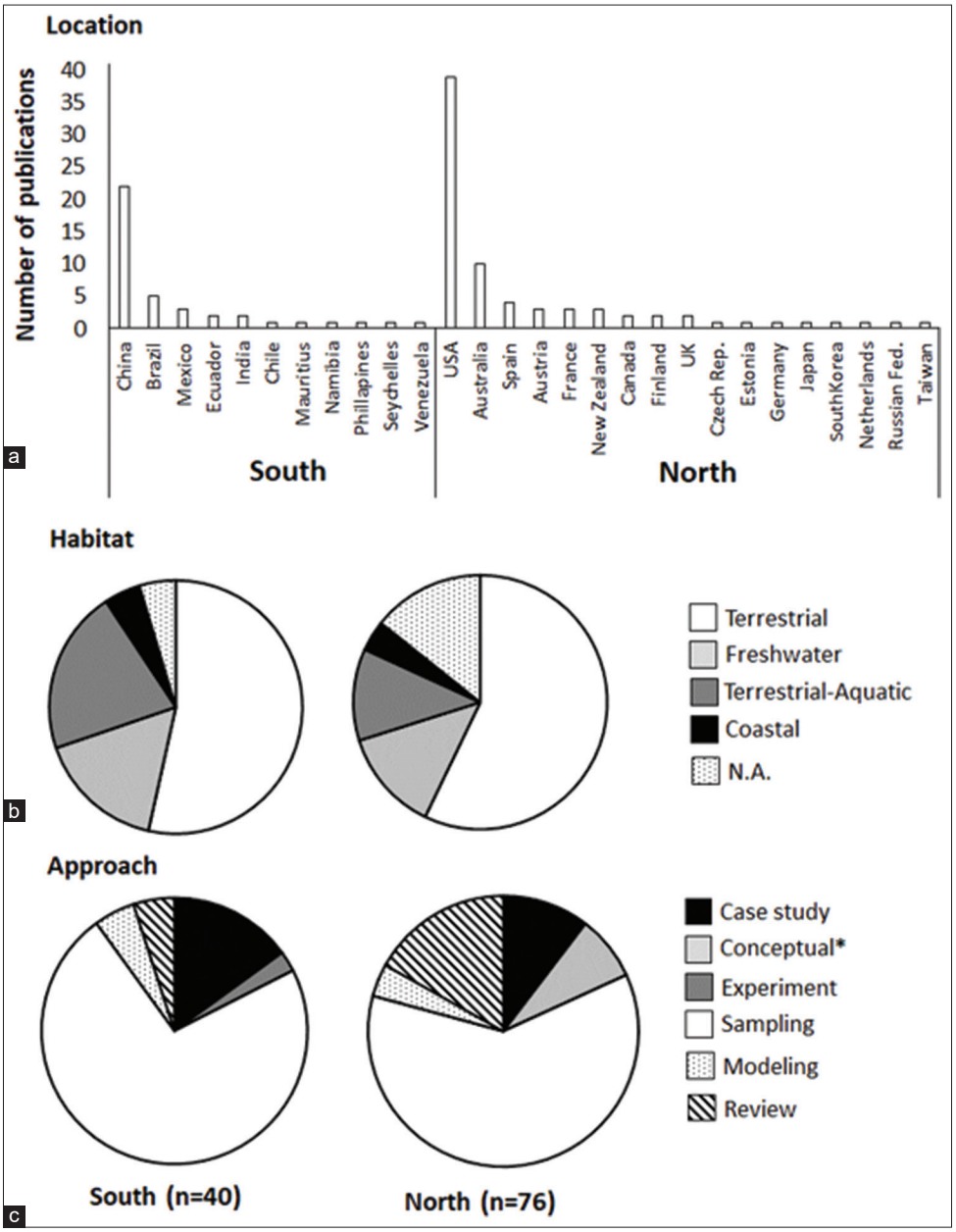

Figure 1

(a) Number of publications related to explicit studies of ecological restoration in countries from the Global South and North; (b) habitat types; and (c) methodological approaches of studies found in this literature review, compared as percentages of each category per region. Categories with an asterisk (*) have significant differences between the Global North and South with a χ^2 test ($p < 0.05$). See text for more statistical information

classical questions within an ecological framework, rather than developing conceptual frameworks that challenge dominant approaches.

METHODS

We combined elements of systematic and critical review methodologies (Grant and Booth 2009) both to evaluate quantitative trends in the academic research about ER in the Global South and North and to assess conceptual contributions to existing or emerging theory. Using the Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) approach (Moher et al. 2009, see Appendix S1), we sought to identify relevant English-language academic literature in the Web of Science (WoS) database from January 1900 to December 2016. While WoS does not fully incorporate regional or non-English journals (Holmgren and Schnitzer 2004), it was appropriate for this study to focus on global trends in how ER is conceived and studied due to the fact that non-English-speaking countries usually promote science policies to engage in this body of literature (e.g., Anderson et al. 2015a). Consequently such global databases now encompass the vast majority of published studies in the realm of conservation-related research (Amano et al. 2016) and therefore have become the dominant form of global knowledge circulation. To be as comprehensive as possible in finding publications aimed at reversing or ameliorating environmental degradation, we systematically searched for articles, reviews, proceedings papers and book chapters that had the following keywords: Topic = 'ecolog* restorat*' OR 'restorat* ecolog*' OR 'ecosyst* restorat*' OR 'environmental restorat*' OR 'environmental remediat*' OR 'ecosyst* remediat*'. The search discovered 8,678 publications. Then, we applied a sample size calculator (http://www.surveysystem.com/sscalc.htm) to determine the number of publications that would constitute a representative sub-sample of studies with a 95% confidence level with a <4% confidence interval. Subsequently, we conducted a random selection of 603 publications from the total database to analyse.

Publications were exported with citations and abstracts into EndNote. Finally, to determine eligibility for inclusion in this review, abstracts were assessed to determine whether the publication reported an explicit study of ER (Appendix S2). Other foci of research or use of the ER concept (i.e., restoration was used as the justification of the study; it was a basic ecological study whose results could be used in future ER; or physical or chemical experiments related to environmental remediation) were excluded.

These selection procedures produced 118 publications for inclusion in the analysis (19.2% of all ER studies meeting our criteria published in WoS). Each publication was assessed by the authors Sebastián A. Ballari (SAB), Christopher B. Anderson (CBA), and Catherine Roulier (CR), based on attributes related to the publication itself, geographic characteristics, conceptual considerations and operational parameters (Table 1). When authors coded differently, consensus was achieved for a final assessment of each publication. For some coding, if a single publication met two criteria (e.g., a study could pertain to two geographic regions), it was counted twice for that attribute. Assignment of articles to geographic region was based on the site where the study was conducted. Studies that were conceptual or reviews, and therefore did not take place in a specific place, were classified based on the first author's affiliation. While this classification does not account for the entirety of the spatially-explicit and network dynamics involved in academic publications, it is a common category used in global reviews (e.g., Wortley et al. 2014; Estévez et al. 2015; Amano et al. 2016; Vaz et al. 2017).

In this context, also, the terms Global South and Global North are used to refer to dialectical, metaphorical and geographical concepts that consider historical and current power relationships between countries (see de Sousa Santo 2006; Wallerstein 2011), whereby Northern countries have not only high economic, technological, and military strength, but also greater driving power over globalisation processes, unlike those of the South that accompany this process. For the purposes of our analysis, the Global South consisted of Africa, Asia (excluding Japan, Taiwan, Singapore, and South Korea) and Latin America and the Caribbean, while the Global North was comprised of northern North America (i.e., Canada, USA, and Greenland), Europe, and Oceania (i.e., Australia and New Zealand) and the Asian countries excluded from the Global South, as mentioned above. While China now arguably occupies an increasingly important position on the world stage, the North-South distinction encompasses both historical and contemporary aspects of power dynamics, which are not only based on economics or politics. Finally, results were compared quantitatively with descriptive statistics over time, by country and by region, and JMP14® software was used to conduct χ^2 analyses with a Likelihood ratio test to determine significant differences between the Global South and North.

RESULTS

Overall, countries from the Global North produced nearly twice as many ER publications as countries from the South (n=77 and n=41, respectively, Figure 1a). The USA and China had the greatest research activity, each accounting for about half of the publications for their respective regions–North and South. Next, we find Australia with 8.6% of the publications in the Global North. The remaining countries in both the South and North only contributed between 1% to 4% of all publications. There were no significant differences between regions regarding the types of habitats studied, and in both we see a clear emphasis towards studies conducted in terrestrial habitats (Figure 1b). For the methodological approach of these studies, we detected significantly more conceptual studies in the Global North than in the South ($\chi^2 = 5.34$; $d.f. = 1, 118$; $p = 0.02$), and field-sampling methods predominated in both regions (Figure 1c).

A total of 14 drivers of ecological degradation were detected, ranging from agricultural expansion and logging to mining and biological invasions (Table 2). A large proportion

Table 1
Attributes analysed in each empirical study of ecological restoration (n=118)

Assessment factors for each study	Categories
Publication attributes	
Publication timing	Year
Journal research category	Applied Natural Sciences (Agricultural Sciences, Fisheries, Forestry, Soil Sciences) Biological Sciences (Biology, Entomology, Ornithology, Plant Sciences, Water Resources, Zoology) Ecological and Environmental Sciences (Biodiversity conservation, Ecology, Environmental Sciences) Engineering and Technology (Architecture, Biotechnology, Civil Engineering, Environmental Engineering, Materials Engineering) Geography and Geosciences Multidisciplinary Sciences Social Sciences and Humanities (Anthropology, Philosophy, Social Sciences)
Study spatial parameters	
Location by country	Country name (s)
Location by Global South-North region[1]	Global South: Africa, Asia (except countries below) and Latin America & the Caribbean. Global North: Europe, Oceania (Australia, New Zealand), northern North America (USA, Canada, Greenland) and from Asia - Japan, Taiwan, Singapore and South Korea.
Study conceptual parameters	
Focus	Empirical study of ecological restoration
Framework	Ecological, Social, Socio-ecological
Paradigm	Classical[2], Postmodern[3]
Study operational parameters	
Methodology	Case study, Conceptual or theoretical reflection, Laboratory or field experiment, Field sampling, Modelling, Review
Environment type	Coastal, Freshwater, Terrestrial, Terrestrial-Aquatic
Degradation drivers	Agriculture, Biological invasions, Climate change, Erosion/densification, Eutrophication, Fire regime, Grazing, Habitat degradation/fragmentation, Hunting, Hydrology/geomorphology, Logging, Mining, Pollution, Urbanization/infrastructure
Restoration objective	Ecosystem functions, Ecosystem services, Healthy ecosystem, Species composition
Biological measurements	Biotic community, Ecosystem processes, Geomorphology, Landscape dynamics, Soil parameters, Species population, Water parameters
Social measurements	Human health, Public policy, Socio-economic variables

Reference: [1]de Sousa Santo (2006), Wallerstein (2011); [2]Higgs et al. (2014); [3]Callicott (2010)

Table 2
Drivers of degradation addressed in the ecological restoration studies published in the Global South and North, presented as percentage (%) of publications with each factor and the ranking of the factors (in descending order for the Global South)

Degradation drivers	Global South % (rank)	Global North % (rank)	d.f.	X^2	*P*
Erosion/desertification	**21.4 (1)**	**1.5 (8)**	**1, 118**	**9.34**	**0.002**
Habitat degradation/fragmentation	14.3 (2)	11.8 (5)	1, 118	0.77	0.34
Hydrology/geomorphology	11.9 (3)	11.8 (5)	1, 118	0.08	0.78
Unidentified	11.9 (3)	23.5 (1)	1, 118	2.18	0.14
Agriculture	9.5 (4)	14.7 (3)	1, 118	0.30	0.59
Biological invasions	9.5 (4)	19.1 (2)	1, 118	0.85	0.36
Urbanization/infrastructure	7.1 (5)	8.8 (6)	1, 118	0.01	0.91
Fire regime	4.8 (6)	14.7 (3)	1, 118	0.97	0.33
Grazing	4.8 (6)	11.8 (5)	1, 118	2.90	0.09
Hunting	**4.8 (6)**	**0.0 (9)**	**1, 118**	**4.26**	**0.04**
Mining	4.8 (6)	13.2 (4)	1, 118	1.66	0.20
Pollution	4.8 (6)	2.9 (7)	1, 118	1.35	0.25
Climate change	2.4 (7)	0.0 (9)	1, 118	2.12	0.15
Eutrophication	2.4 (7)	1.5 (8)	1, 118	0.19	0.66
Logging	0.0 (8)	2.9 (7)	1, 118	1.74	0.19

Significant differences were detected with a χ^2 test ($P<0.05$ shown in bold)

of studies in both the South and the North did not identify a specific driver that was causing the ecological degradation (11.9% and 23.5%, respectively). In the Global South, the most-studied driver was erosion/desertification (21.4%), which, together with hunting (4.8%), was studied significantly more than in the Global North (Table 2). Habitat degradation/fragmentation (14.3%) and altered hydrologic regime/geomorphology of fluvial systems (both 11.9%) were second and third in the ranking of drivers in the South. Meanwhile, in the Global North, biological invasions was the most studied

driver (19.1%), followed by agriculture and altered fire regime (both 14.7%).

In the Global North, the majority of studies (65%) were published in natural science journals with a systems focus (e.g., ecology and environmental sciences) or traditional organismic disciplines (e.g., ornithology or zoology), which was significantly more than in the South ($\chi^2 = 6.06$; *d.f.* = 1, 118; $p = 0.01$). Meanwhile, in the South natural science was also the highest category, but by a plurality (39%). Plus, with 19.5% of all studies in the South, engineering and technology journals were significantly more represented in the Global South than the North ($\chi^2 = 7.13$; *d.f.* = 1, 118; $p = 0.01$, Figure 2a). In contrast, while social science and humanities periodicals only accounted for 5.2% of publications in the North, this value was 0% for the South. Similarly, the research framework used by the studies in both regions was dominated by those that are purely ecological (Figure 2b). South and North also had between one-third and one-quarter of their production based on socio-ecological studies (32.5% and 23.1%, respectively). The only significant difference in this regard was for studies with a social framework, which, with 11.5% was significantly greater than 0% in the South ($\chi^2 = 7.20$; *d.f.* = 1, 118; $p = 0.01$, Figure 2b).

Finally, we see an exponential increase in ER studies since the 1990s ($y = 1.0797e^{0.4062x}$; $R^2 = 0.97$, Figure 3a), a trend which was true for both classical and postmodern paradigms ($y = 0.5326e^{0.3869x}$; $R^2 = 0.82$ and $y = 1.0366e^{0.3275x}$; $R^2 = 0.96$, respectively). A marked increase in the overall numbers of ER studies began in the 2010s. These data also show an early incorporation of the postmodern paradigm, but when we apply a regional analysis, we see that the Global North has maintained a more classical conceptual model of ER, compared to the Global South, and this result was statistically significant (N>S for classical paradigm: $\chi^2 = 3.90$; *d.f.* = 1, 118; $p = 0.05$; S>N for postmodern paradigm: $\chi^2 = 5.55$; *d.f.* = 1, 118; $p = 0.02$, Figure 3b). This finding coincides with a greater emphasis on studies that seek to restore species assemblages, which was significantly greater in the North than the South ($\chi^2 = 5.6$; *d.f.* = 1, 118; $p = 0.02$). Meanwhile, in the South there was a greater emphasis on ecosystem processes, and a focus on

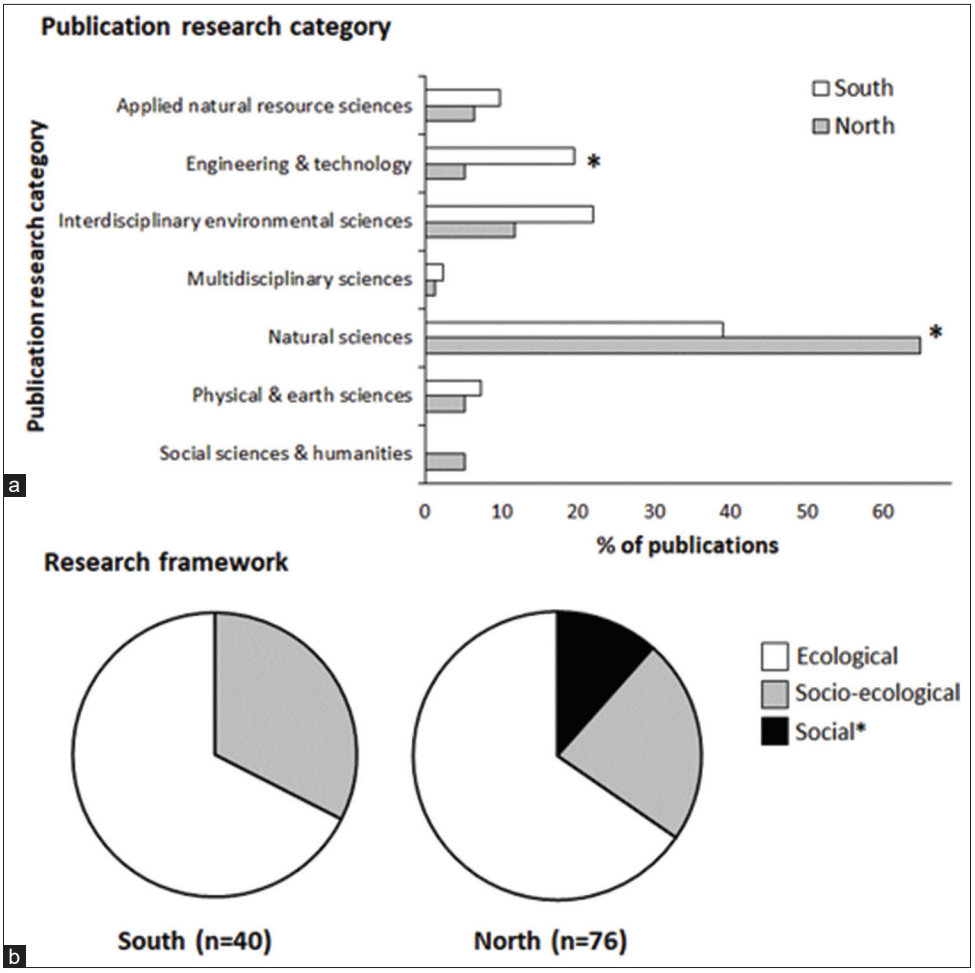

Figure 2

(a) Number of publications organised by the research category of the publishing journals from the Global South and North; (b) The percentage of publications from the Global South and North in terms of the research framework used in the studies classified in ecological, socio-ecological and social. Categories with an asterisk (*) have significant differences between the Global North and South, based on a χ^2 test ($p < 0.05$). See text for more statistical information

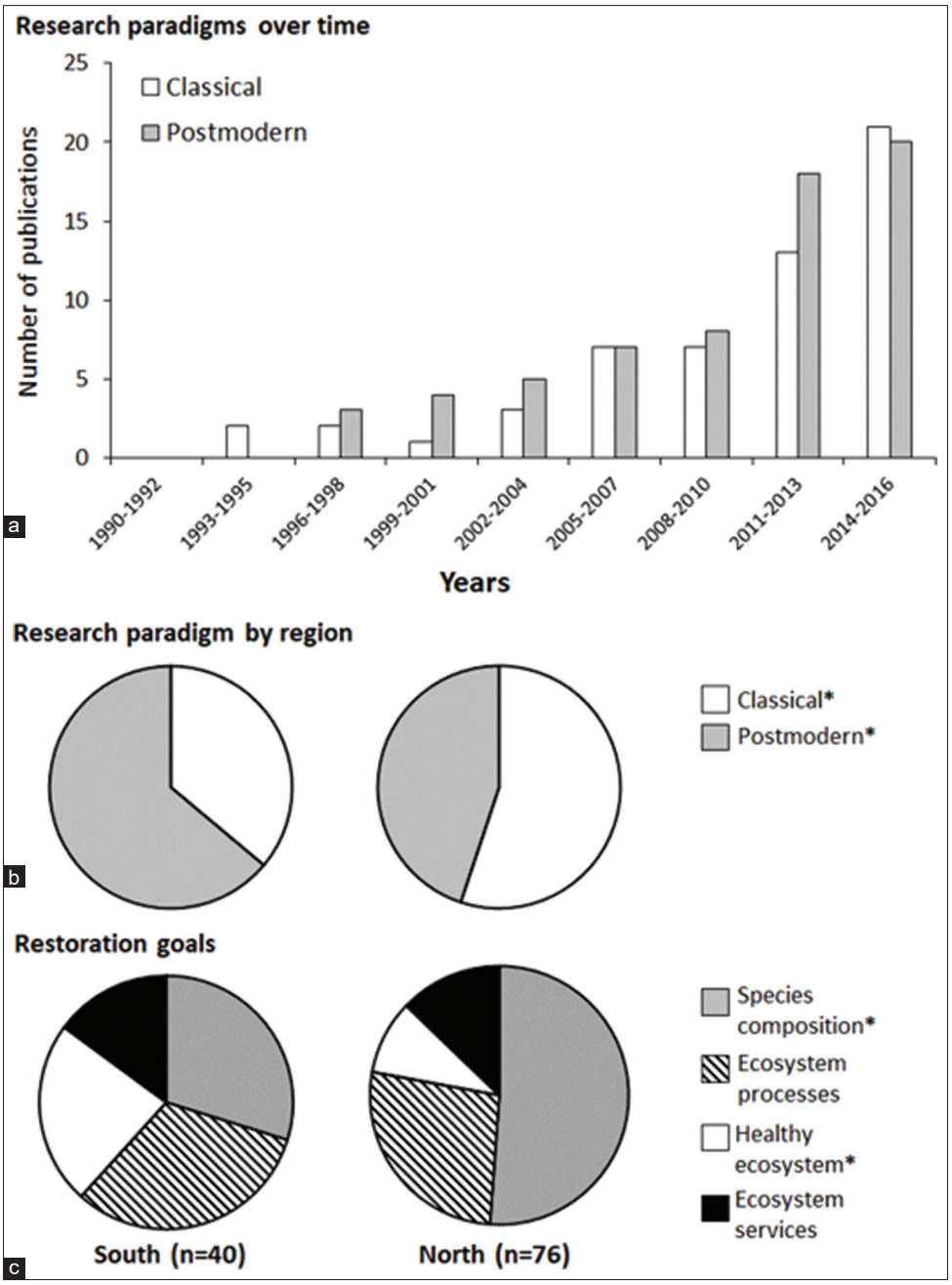

Figure 3

(a) Trend in the number of academic publications since the 1990s for research using classical or postmodern paradigms of ecological restoration; (b) Overall proportion of ecological restoration studies per research paradigm and region; and (c) Proportion of ecological restoration studies classified according the goal of the restoration effort. Categories with an asterisk (*) have significant differences between the Global North and South, based on a χ^2 test ($p < 0.05$). See text for more statistical information

ecosystem health was significantly greater than in the North ($\chi^2 = 6.42$; *d.f.* = 1, 118; $p = 0.01$; Figure 3c). In both regions, however, these studies are largely ecological, and the focus on ecosystem services or other human dimensions of ER is much less than the ecological perspective. Consequently, the focal variables studied are mostly based on natural elements of the environment, with studies of soil and water parameters being significantly greater in the Global South than the North (Table 3).

DISCUSSION

How we think about nature affects how we manage it

In the Anthropocene, there will be an increasing need to identify the new technical knowledge required to effectively restore the Earth's degraded ecosystems, given unprecedented rates and scales of environmental change (Cooke et al. 2018). In addition, it will be equally important to think broadly about

Table 3

Types of human and natural variables measured in ecological restoration studies from the Global South and North. Data are presented as the percentage of studies from each region that quantified specific human and natural outcomes, presented as percentage (%) of publications with each factor and the ranking of the factors (in descending order for the Global South)

Types of measurements	Global South % (rank)	Global North % (rank)	d.f.	X^2	*p*
Natural dimensions					
Biotic community	38.1 (1)	47.4 (1)	1, 118	0.22	0.64
Water parameters	**23.8 (2)**	**3.8 (4)**	**1, 118**	**10.79**	**0.001**
Soil parameters	**16.7 (3)**	**5.1 (3)**	**1, 118**	**4.13**	**0.04**
Species population	16.7 (3)	16.7 (2)	1, 118	0.27	0.60
Ecosystem processes	2.4 (4)	5.1 (3)	1, 118	0.56	0.45
Geomorphology	0.0 (5)	2.6 (5)	1, 118	1.74	0.19
Landscape dynamics	0.0 (5)	2.6 (5)	1, 118	1.74	0.19
Human dimensions					
Socio-economic	14.3 (1)	14.1 (1)	1, 118	0.05	0.82
Ecosystem services	2.4 (2)	0.0 (4)	1, 118	2.12	0.15
Health	2.4 (2)	2.6 (3)	1, 118	1.74	0.19
Policy	0.0 (3)	5.1 (2)	1, 118	3.52	0.06
Not applicable	19.0	11.5	1, 118	0.001	0.98

Significant differences were detected with a χ^2 test ($P<0.05$ shown in bold)

the knowledge(s) needed for ER, including social and cultural values and the diverse array of stakeholders that must be involve to ethically and legitimately decide what to restore and how (Martin 2017). In this context, it is clear that ER paradigms and theories can change over time or between groups. If the goal of ER today is to not only create supposedly natural biotic assemblages, but also just and sustainable societies (IPBES 2018), then we had hypothesised that scientists and practitioners would expand and deepen their understanding of ER as a SES over time. Plus, major international initiatives to apply ER, such as the UN's Decade of Ecosystem Restoration (2021-2030), are influenced heavily by countries in the Global South and are implementing a postmodern approach to ER, whereby ecological degradation is addressed not only to restore species assemblages, but also ensure human well-being aspects like food security and sustainable livelihoods. Nonetheless, in this review, we showed that globally, ER research continues to have a clear emphasis towards the ecological components of the system. At the same time, though, the body of literature on ER from both the Global South and North displays ample opportunities and conceptual space to more fully engage broader topics, including ecosystem services, human outcomes, and practical considerations.

Throughout the period studied, we found that the postmodern paradigm of restoration, proposed by Callicott (2010), was incorporated into ER studies at least two decades ago. However, the classical idea of ER, whereby endpoints are based on natural or historic species assemblages, has persisted and continues to predominate in the Global North, which was contrary to our expectations, but coincides with the warning posited by Higgs et al. (2018). This raises the question of what we are seeking to restore when we undertake an ER effort–or more broadly how do scientists and practitioners (and potentially other stakeholders) conceive an ideal world in which ecosystems conserve their integrity and biodiversity, and societies are sustainably coexisting with them. While an integrated or landscape perspective has been established conceptually in the ER literature (e.g., Suding et al. 2015; Martin 2017), and more broadly (Sayer et al. 2013), this idea clearly is not fully reflected in the way ER research is actually conducted at present. Similar findings have been reported in invasion biology, whereby invasion biologists working in Patagonia reported the need for social and policy research, but their studies were focused largely on quantifying invasive species' ecological impacts (Anderson and Valenzuela 2014), which is a trend found at regional (Pauchard et al. 2011) and global-levels, as well (Estévez et al. 2015; Kapitza et al. 2019). Therefore, today's challenge is how environmental scholars and management agencies institutionalise these holistic ideas and plural values in terms of their expression in actions (see Vatn 2005). Consequently, more consideration must be given to the practical, political and cultural aspects that are required to establish a paradigm (*sensu* Kuhn 1970), which encompasses a much wider socio-institutional context, including creating the textbooks, methods, scientific organisations, inter-agency collaborations, and training programmes that allow it to be applied in practice.

In fact, the biases towards natural science and classical concepts of ER found in our review are likely to be even greater than we show here, because our analysis considered explicit studies of ER. In fact, the concept of ER was evoked most frequently in the academic literature (81.8% of studies) to merely refer to a general idea of restoration in the context of purely ecological studies. For example, understanding rodent-plant interactions regarding seed foraging can ultimately be useful to managers in the context of re-vegetation efforts post-disturbance, and therefore is germane for ER, but such a basic ecology study does not explicitly engage or problematize the ER concept per se (Beard et al. 2013). Therefore, the broader conceptualisation of ER in the social imaginary of many scientists working on these topics could very well be even more classical and

ecological than our findings suggest for studies that were about explicit ER efforts.

Brain circulation versus knowledge dialogue

Some applied disciplines that seek to resolve environmental problems, such as conservation biology (Meine et al. 2010) and environmental justice scholarship (Reed and George 2011), have explicitly recognised the fact that they largely have been conceived of and developed in the Global North (particularly the USA), but portend to be relevant to the whole world. Taking responsibility for these historical legacies entails adopting measures to account for and attempt to control for such biases (see also Amano et al. 2016). Similar to results found in studies of biodiversity conservation (Wilson et al. 2016), in this review, we showed that, as expected, the North dominates the production of English-language research (nearly 2x more than the South), and two countries (the USA and China) dominate their respective regions. It remains to be seen how China's ascendency as a global power will affect historical North-South power dynamics in the realm of academia, and we also recognise the fluidity of some authors being from the South and being trained in the North, or vice versa. Clearly, research teams can be diverse and include scientists with diverse backgrounds. Nonetheless, using the geographic location of the study and/or the first author's affiliation as a proxy allowed us to demonstrate dominant trends that are relevant to the way ER is being conceived in the leading academic journals and debates (Anderson et al. 2015a, see also Wilson et al. 2016), while not discounting the increasingly hybrid nature of the novel social and ecological systems in which scientists themselves work. Yet, if we think of the global exchange of ideas in science, there are clearly some regions and some countries that are engaging more in these debates, due to the sheer volume and also their impact. For example, the North not only produces more research, but also publishes more conceptual and synthesis articles that are the most influential in creating and establishing the ideas with which subsequent studies are developed.

Furthermore, we recognise the role of language and publication norms in affecting these trends. There is likely an important body of ER literature in the Global South that is not published in English or is produced as part of grey literature, such as government reports, that are not incorporated into global databases. While these studies are not engaging the 'global brain circulation,' they can potentially be relevant for local problem-solving (Anderson et al. 2015a). In particular, the relative dearth in English-language social science research from the Global South could be a by-product that this particular body of scholarship is more frequently published in local languages (see Roulier et al. 2020).

Notwithstanding these studies, the English-language literature reviewed from both the Global South and North provides opportunities to delve deeper into the complexities of ER, but from different angles. The North had more social science research; however, it is focusing more on classical ecological endpoints of restoring species assemblages. Therefore, Northern scholars should become more aware that the social dimensions of their research not only should include not only humans as drivers or judges of ER, but also should encompass stakeholder participation in the definition of conservation ends points. Meanwhile in the South, an ecosystem perspective (e.g., processes or services) predominated, opening the possibility of including humans via the consideration of establishing restoration endpoints that preserve functions and services. However, this perspective can also be dangerous because it may reinforce a commodity-oriented view of the world (Higgs et al. 2014). Therefore, a careful consideration of the human dimension of ecosystems should include not only the instrumental uses, but also the intrinsic and relational values of nature embodied by diverse stakeholders (Chan et al. 2013, 2016).

Also, each region displayed some differences in the drivers of degradation that are being studied, indicating some regional-specificity in the environmental problems that are being prioritised. For example, in the North, research is oriented towards the problems of biological invasions, fire regimes, and agricultural expansion, while in the South, the most-studied issues are erosion/desertification and habitat degradation/fragmentation. These differences and similarities between global regions provide opportunities for future knowledge dialogue about the lessons learned from these contexts. Conservation and restoration efforts between the Global South and North can be complementary, when attention is given to observing and learning from particular approaches and ways of working in other parts of the world. Thus, for example, ecosystem services research from the North could be complementary to a more applied vision, focused on ecological processes in the South. In this way, paradigms and ideas of ER can stimulate thinking about restoration scenarios with multiple trajectories, to emphasise flexibility in setting objectives, to highlight the process over specific elements, and to define pragmatic goals that reflect human needs and livelihoods in relationship to healthy ecosystems (Higgs et al. 2014).

CONCLUSION

ER efforts have long considered the recuperation of historical ecosystems, but given the emergent and novel ecosystems inherent in the Anthropocene, it is also important to take into account issues like ecological goods and services, social expectations of nature by different stakeholders, and the equitable distribution of ecological costs and benefits (Jackson and Hobbs 2009; Paschke et al. 2019). Although at the global level, ER research uses both classical and postmodern paradigms, various lines of evidence show that humans are being integrated as an element in the equation of ER, but much more work is necessary to expand a truly SES approach to ER. Whether it be ER studies that are conducted with social or socio-ecological frameworks (Global North), or because ecosystem processes are the focus of restoration (Global South), conceptual space exists in both regions to enhance the study of the human dimension ER methods and endpoints in the

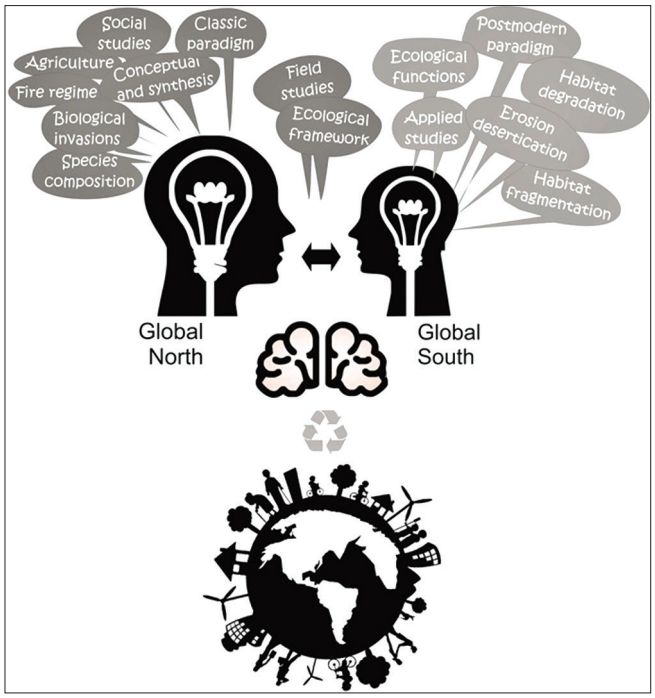

Figure 4
Graphic illustration summarizing the overall mentality of how the Global North and South conceive ecological restoration, based on an analysis of the academic literature found in Web of Science from 1900 to 2016

Anthropocene (Figure 4). This transformation, however, will be more effective, and perhaps more ethical, if ER researchers and practitioners explicitly recognise how their ideas or paradigms of science affect their actions, not only in academic literature, but also on geographically-specific places. In this context, it would be important for countries in the Global South to also conduct their own analyses of how ER is conceived in other languages and in policy documents. By putting into dialogue these local-global ideas and connecting them to the people, places, and cultures where they arise, we may also be able to conduct more effective, but also more just environmental research and management.

CONFLICTS OF INTEREST

The authors declare that they have no conflicts of interest.

ACKNOWLEDGEMENTS

This study was conducted with the support of NSF-CONICET International Cooperation Grant #RD5166/15 to CBA and EAN. CR was supported by a doctoral scholarship from CONICET-UNTDF. The authors thank the Grupo Socio-Eco, particularly M. Dicenta for conversations regarding the historical and conceptual context of the Global South-North typology.

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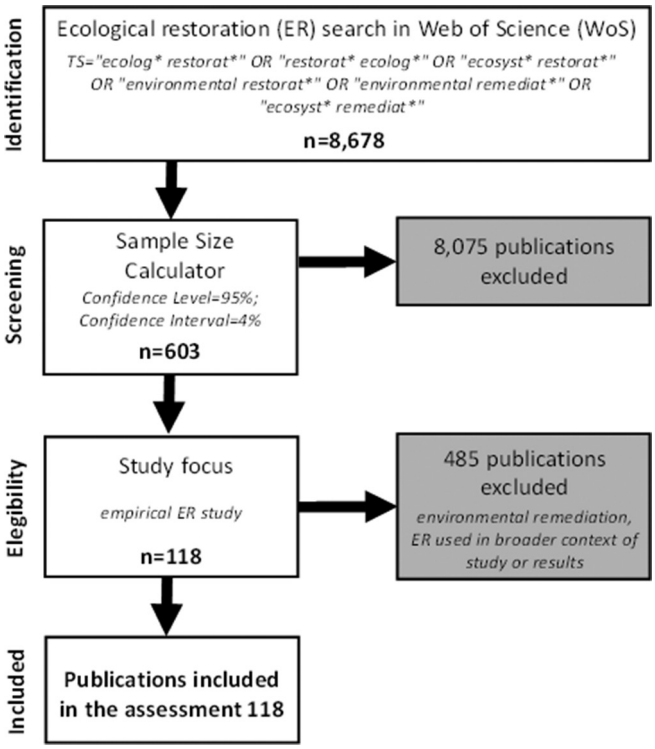
Received: 11-Jul-2019**; Revision:** 31-Dec-2019**; Accepted:** 07-Jan-2020**; Published:** 10-Jun-2020



Appendix S1

The PRISMA strategy was applied to conduct a systematic procedure for identifying, filtering and selecting publications to include in the review of ecological restoration.

APPENDIX S2

Publications found in a literature search in Web of Science from 1900-2016 using key words related to restoration ecology worldwide. Description of each publication classified as an article of ER ecological restoration (n = 118), including authors, region, paradigm, research framework and restoration goals. References: region* (south -S-; north -N-; general -G-); paradigm (classical -CL-; postmodern -PM-); research framework (ecological -E-, social -S-, socio-ecological -SE-); restoration goals (species composition -SC-, ecosystem processes -EP-, healthy ecosystem -HE-, ecosystem services -ES-). * North (North America, Europe and Oceania) and South (Africa, Asia and Latin America and the Caribbean). Below the entire reference of each publication.

Appendix S2
Peer-reviewed publications database

N°	**Authors**	**Region**	**Paradigm**	**Research framework**	**Restoration goal**
1	Abella et al. 2015	N	CL	E	SC
2	Abensperg-Traun et al. 2004	N	CL	S	SC
3	Ager et al. 2016	N	PM	SE	EP; ES
4	Alario 1998	N	PM	S	HE
5	Albertson et al. 2011	N	PM	E	HE
6	Araujo et al. 2014	S	CL	E	SC
7	Aronson et al. 2016	G	PM	SE	ES
8	Bennett et al. 2013	N	CL	E	SC
9	Bradley and Bradley 1993	N	CL	E	SC
10	Brewer 2016	N	PM	E	EP
11	Brodman et al. 2006	N	CL	E	SC
12	Brudvig 2011	G	CL	SE	SC
13	Buizer et al. 2012	N	PM	S	SC; EP
14	Carreira et al. 2008	N	PM	E	EP
15	Chen et al. 2012a	S	PM	SE	EP; ES
16	Chen et al. 2012b	S	PM	E	HC
17	Chen et al. 2014	S	CL	E	SC
18	Chenot et al. 2014	N	CL	E	SC
19	Christian-Smith and Merenlender 2010	N	PM	SE	EP
20	Coen and Luckenbach 2000	N	PM	E	EP; ES
21	Corson and Campbell 2013	N	CL	E	SC
22	Critchley et al. 2013	N	CL	E	SC
23	Cui et al. 2009	S	CL/PM	E	SC; EP
24	Daessle et al. 2016	N; S	CL	E	SC
25	D' Antonio and Meyerson 2002	G	PM	E	EP
26	David 2013	N	CL	E	SC
27	David et al. 2016	N	CL	E	SC
28	Eremchenko et al. 2004	N	PM	E	EP
29	Everard 2016	S	PM	SE	HE
30	Fajardo et al. 2013	S	PM	E	HE
31	Feng et al. 2014	S	PM	E	HE
32	Feng et al. 2012	S	CL	E	SC
33	Fernandes et al. 2016	S	PM	E	HE
34	Gallego F. and Garcia N. 2007	N	CL	E	SC
35	Geerling et al. 2008	N	CL	E	SC
36	Giai and Boerner 2007	N	PM	E	EP
37	Gibbs et al. 2008	S	CL	E	SC
38	Goldsmith et al. 2007	N	CL	E	SC
39	Gould 2012	N	CL	E	SC
40	Griffiths et al. 2011	S	PM	E	EP
41	Gumiero et al. 2013	N	PM	SE	EP; ES
42	Gundale et al. 2006	N	CL	E	SC
43	Gunther and Assmann 2005	N	CL	E	SC

Contd...

Appendix S2
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N°	Authors	Region	Paradigm	Research framework	Restoration goal
44	Hagen 2007	N	PM	S	ES
45	He and Huo 2012	S	PM	SE	HE
46	Hein et al. 2010	G	PM	E	EP
47	Heslinga and Grese 2010	N	CL	E	SC
48	Higgs 2005	N	PM	SE	EP; ES
49	Hilario et al. 2011	S	PM	E	HE
50	Hodge and Adams 2016	N	NA	S	NA
51	Holl et al. 2003	G	PM	SE	EP
52	Hungate et al. 2007	N	PM	E	EP
53	Instone 2014	N	CL	S	SC
54	Ishii et al. 2016	S	CL	E	SC
55	Jaramillo et al. 2016	S	CL	E	SC
56	Jenkinson et al. 2006	N	PM	SE	HE
57	Jimenez et al. 2012	N	PM	E	HE
58	Kaiser-Bunbury et al. 2015	S	CL	E	SC
59	Katz 1996	G	CL	SE	SC
60	Katz et al. 2009	N	CL	E	SC
61	Kauffman et al. 1997	N	PM	E	HE
62	Kirkman et al. 2013	N	CL	E	SC
63	Klotzli and Grootjans 2001	N	CL	E	SC
64	Konlechner et al. 2015	N	CL	E	SC
65	Kuo et al. 2003	S	PM	SE	ES
66	Laughlin et al. 2006	N	CL	E	SC
67	Li et al. 2012	S	CL/PM	E	SC; EP
68	Liu et al. 2016	S	PM	SE	EP
69	Lomov et al. 2009	N	CL/PM	E	SC; EP
70	Longing et al. 2010	N	CL	E	SC
71	Martinez-Ruiz et al. 2007	N	CL	E	SC
72	McBride et al. 2010	N	PM	SE	EP
73	McCoy and Mushinsky 2002	N	CL	E	EP; ES
74	McDougall et al. 2016	N	CL	E	SC
75	Medellin-Azuara et al. 2007	S	PM	E	EP
76	Meli et al. 2014	G	CL/PM	SE	SC; ES
77	Miller 2006	N	CL	SE	SC
78	Mohandass et al. 2016	S	CL	E	SC
79	Muller et al. 1998	N	CL	SE	SC
80	Oudot-Canaff et al. 2013	N	CL	E	SC
81	Pang et al. 2016	S	PM	E	EP
82	Pensa et al. 2004	N	CL	E	SC
83	Pinjuv et al. 2000	N	PM	S	HE
84	Polizzi et al. 2015	N	PM	S	ES
85	Priest and Epstein 2011	N	CL	E	SC
86	Prober et al. 2014	N	PM	E	EP
87	Reynolds et al. 2012	N	PM	E	ES
88	Rinella et al. 2016	N	CL	E	SC
89	Romero-Mieres et al. 2014	S	CL	E	SC
90	Rose et al. 2015	N	CL/PM	SE	SC; EP
91	Sansevero et al. 2011	S	PM	E	EP; ES
92	Saunders and Norton 2001	N	PM	SE	HE
93	Shackelford et al. 2013	G	PM	SE	SC; EP; ES
94	Snyder and Hendrix 2008	G	PM	E	EP
95	Song et al. 2016	S	CL	SE	Sp. services
96	Speldewinde et al. 2015	G	PM	SE	HE
97	Sun et al. 2016	S	PM	SE	EP; ES
98	Tarvainen and Tolvanen 2016	N	PM	E	EP; ES

Contd...

Appendix S2
Contd...

N°	Authors	Region	Paradigm	Research framework	Restoration goal
99	Taylo and Bauman 2001	N	PM	SE	EP; ES
100	Tian et al. 2016	S	PM	E	EP
101	Towns 1994	N	CL	E	SC
102	Tropek et al. 2016	N	CL	E	SC
103	Volpato et al. 2013	S	CL	E	SC
104	Walters 1997	S	PM	SE	HE
105	Wang and Wang 2010	S	PM	E	HE
106	Wang et al. 2015	S	PM	E	HE
107	Wang et al. 2011	S	PM	SE	HE
108	Wang et al. 2004	S	PM	SE	HE
109	Wang et al. 2006	S	PM	E	ES
110	Wassenaar et al. 2013	S	PM	SE	EP; ES
111	Weekley et al. 2013	N	CL/PM	E	SC; EP
112	Xiao et al. 2016	S	PM	SE	EP
113	Yang et al. 2014	S	PM	E	EP
114	Yue et al. 2015	N; S	PM	E	HE
115	Zhao et al. 2012	S	PM	E	EP
116	Zhong et al. 2013	S	PM	SE	EP
117	Zhu et al. 2015	S	PM	E	EP
118	Zhu et al. 2016	S	CL	E	SC

Publications found in a literature search in Web of Science from 1900-2016 using key words related to restoration ecology worldwide. Description of each publication classified as an article of ER ecological restoration (n=118), including authors, region, paradigm, research framework and restoration goals. References: region* (south -S-; north -N-; general -G-); paradigm (classical -CL-; postmodern -PM-); research framework (ecological -E-, social -S-, socio-ecological -SE-); restoration goals (species composition -SC-, ecosystem processes -EP-, healthy ecosystem -HE-, ecosystem services -ES-). * North (North America, Europe and Oceania) and South (Africa, Asia and Latin America and the Caribbean). Below the entire reference of each publication.

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