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# Evaluating the evolution of forest restoration research in a changing world: a "big literature" review

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**Abstract** In a rapidly changing world, characterized by novel ecological scenarios and fluctuating socioeconomic and ecological demands, ecological restoration practices must constantly adapt to emerging issues and circumstances. Restoration ecology, the scientific discipline that informs ecological restoration, must therefore evolve and expand its focus to address this need. To describe and evaluate the evolution of research pertaining to the ecological restoration of forests within the field of forestry, we performed a review of all 29,766 abstracts published over the last 35 years (1980–2014) in 15 leading forestry journals using automated content analysis, a machine learning-based tool for automated review of large volumes of literature ("big literature"). We found not only a 50-fold increase in the prominence of restoration ecology in forestry literature from 2000 to 2013, but also an evolution in the focus of forest restoration research. This evolution is likely in response to emerging topics and issues affecting forest restoration, such as exotic species, altered disturbance regimes, degraded tropical forests, and ecosystem services. Our results also revealed a pattern of "cyclic development," in which research in the 1990s was focused on constructing theoretical frameworks, in the 2000s research appeared to be concentrated on restoration practices and programs, while in the 2010s research revisited established theoretical frameworks, possibly indicating a conceptual expansion. Our study highlighted gaps in research on important topics and emerging challenges, such as global climate change, genetic considerations, landscape-level factors, and restoring degraded systems, thus pointing the way for new and necessary research directions.

**Keywords** Automated content analysis (ACA) · Big literature · Biodiversity · Cyclic development · Degraded · Literature review

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## Introduction

Forests worldwide have been subjected to a widespread range of human-induced challenges. Outbreaks of pests and diseases, chronic low-level pollution, conversions to other land uses, changes in land cover and/or disturbance regimes, among others have led to various levels of forest ecosystem degradation (Stanturf and Madsen 2010). Consequently, degraded forests display reduced productivity and functionality, as well as reduced delivery of ecosystem services (Fearnside 2005; Foley et al. 2007; Lamb et al. 2005; Wenhua 2004).

While human influences are at the root of most forest degradation, humans have simultaneous, yet indirectly, been able to stimulate the recovery of some degraded forests via shifting socioeconomic practices and perspectives. Within the last 200 years, major events worldwide, such as wars, plagues, population movement and fluctuations, along with a shift in energy sources from biomass to fossil fuels in developed nations, have led to agricultural abandonment and subsequent reversion to forests (Stanturf and Madsen 2010). In the early to mid-twentieth century, the threat of timber scarcity and stability of forest-dependent human systems in the United States bolstered interest in the recovery of productivity in degraded areas (MacCleery 2008; Stanturf and Madsen 2010; Wiersum 1995). At the same time, the growing environmental awareness and emerging non-timber forest values (e.g., biodiversity, climate regulation, recreation) of the 1960s, highlighted the importance of maintaining the multiple and dynamic aspects that shape forests (MacCleery 2008; Wiersum 1995).

However, once an ecosystem has passed a certain threshold of degradation, its self-recovery becomes increasingly challenged (Lamb et al. 2005), raising the need for active intervention in returning the system to its former state of functionality (DellaSala et al. 2003). One of the major approaches to achieve this goal is ecological restoration—the deliberate anthropogenic initiation or acceleration of the recovery of an ecosystem's health, integrity and sustainability (SER 2004). Successful forest restorations are an interdisciplinary endeavor that address ecological, economic, and social needs, while emphasizing the enhancement of ecological integrity through the recovery of natural processes and ecosystem resiliency (DellaSala et al. 2003). Although both fiscally and logistically demanding, forest restoration has revealed numerous benefits extending well beyond that of timber production, including enhancing biodiversity (Caravaca et al. 2003; Dosskey et al. 2012; Parrotta and Knowles 1999), aiding in the recovery of fish and wildlife populations (Dalgleish and Swihart 2012; Kalies et al. 2010), a return of hindered natural disturbance regimes (Fulé et al. 2012), and the recovery of ecosystem services (Benayas et al. 2009).

Although ecological restorations have a long history, as exemplified by Aldo Leopold's re-creation of historic systems in the 1930 and other restoration efforts, about 35 years have passed since the emergence of restoration ecology as a scientific discipline (Galatowitsch 2012; van Andel and Aronson 2012). In this time, restoration ecology has been evolving, for instance, by shifting its focus from timber-based research to the regeneration of extremely degraded environments in the case of forest restorations (Oliet and Jacobs 2012). Similarly, the scope of forestry science has been expanding since the mid-twentieth century (Wiersum 1995), integrating the knowledge and perspectives of multiple new fields, including restoration ecology. Changing demands at the social (e.g., public concern for ecological sustainability), economic (e.g., cost-effectiveness of forest restoration and management) and ecological (e.g., emerging need to broaden the pool of species for restoration) level (DellaSala et al. 2003; Menz et al. 2013; Millar et al. 2007; Oliet and Jacobs 2012), along with emerging challenges presented by accelerated global change and increasingly unpredictable extreme climatic events (Harris et al. 2006; Hobbs and Cramer 2008; Jalili et al. 2010; Stanturf et al. 2014; Vitousek et al. 1997), require the simultaneous and reciprocate evolution of these scientific disciplines. The importance of reconsidering the theoretical and practical underpinnings of restoration through the prism of rapid environmental changes becomes increasingly evident as ecosystems are altered, novel ecosystems are formed, and the likelihood of returning to past states becomes increasingly unlikely (Hobbs and Cramer 2008).

For these reasons, the time is ideal to assess the evolution of restoration ecology within the field of forest science, and evaluate whether the discipline has adapted to these current and emerging issues/challenges in forest restoration. Here, we pursue this by synthesizing and reviewing the literature published over the past 35 years (1980–2014). We use automated content analysis (ACA), a novel and effective, machine learning-based tool for the automated review of literature. ACA is able to perform reviews comparable to the manual review process, but at substantially faster rates, allowing the unique opportunity to review mass amounts of literature or "big literature" (Grech et al. 2002; Penn-Edwards 2010; Smith and Humphreys 2006). We chose to use this technique since, unlike simple word counts, it determines if a given concept is present in a body of text through the detection of inter-related words known to reflect that concept. The use of concepts rather than single words further allows ACA to incorporate other semantic and linguistic complexities, such as synonyms and sentence construction (Roberts 2000).

The objectives of this review were: (1) to assess the importance of the concept of restoration ecology in forestry research, (2) to identify the major concepts associated with forest restoration, and (3) to explore the progression of these concepts over time. Ultimately, we intend to explore and describe the evolution of restoration ecology in forest science in order to assess if the discipline and practice of forest restoration has been progressing in a direction that responds to current social and ecological demands in a changing world.

**Table 1** The 15 forestry journals and the number of abstracts used from each in our analyses

| Journal title | No. of abstracts |
|---|---|
| Forest Ecology and Management | 10,364 |
| Applied Vegetation Science | 691 |
| European Journal of Forest Research | 824 |
| Forestry | 1166 |
| New Forests | 1165 |
| Annals of Forest Science | 1421 |
| Canadian Journal of Forest Research | 6450 |
| Journal of Forestry | 1907 |
| Silva Fennica | 1070 |
| Forests | 213 |
| Forest Science | 1842 |
| Scandinavian Journal of Forest Research | 1381 |
| International Forestry Review | 584 |
| Australian Forestry | 688 |

N = 29,766 published abstracts

These journals had both broadly defined scopes, helping to ensure limited bias in our results, and impact factors ranking within the top 30 forestry science journals for 2013

## Methods

### Literature retrieval

Because our study focused on ecological restoration solely in the context of forestry, we chose to analyze literature published in 15 forestry journals having both the highest impact factors (based on 2013 values) and the broadest self-defined scopes, as these journals are most likely to feature an unbiased representative sample (Table 1). Three specific criteria were used for journal selection: journals (1) were categorized under the forestry section of Thomson Reuters ISI Web of Science, (2) had one of the 30 highest impact factors in the forestry section, and (3) explicitly expressed a broadly scoped focus. With the exception of *Applied Vegetation Science*, all journals fulfilling these criteria exclusively focused on forest ecosystems. While *Applied Vegetation Science* publishes on systems other than forests, a preliminary analysis conducted both with and without this journal showed very similar results. Including journals other than the ones selected for this study would have introduced unwanted bias, as many other journals focus only on more targeted aspects of forest science (e.g. *Forest Pathology*, *Tree Physiology*). In June of 2014, we used the online database Scopus to obtain all abstracts published in these journals (N = 29,766), downloaded separately by decade, starting in 1980, and then analyzed the text in these abstracts using ACA as described below.

### Automated content analysis (ACA)

ACA is an innovative content analysis technique for the synthesis of large volumes of literature, in which a body of text is processed by text-parsing software and classified at a high resolution (i.e. text segments of 2–3 lines) into categories named *concepts* (Smith and Humphreys 2006). These concepts are groups of words that are highly correlated in the body of text and serve as predictive classifiers for a common theme or idea (Alexa and Zuell 2000; Krippendorff 2012; Smith and Humphreys 2006). Again, ACA differs from simple word counts, because it identifies the presence of concepts, rather than individual words. Not only is ACA able to identify predominant concepts and the associations among them, but is also able to measure the frequency of these concepts and the strength of their associations. We performed our ACA using Leximancer (Smith 2003).

To assess the importance of restoration over time, we first used ACA to identify the proportion of the literature analyzed for each decade classified under the concept of *restoration ecology* (ACA concepts are italicized to distinguish from ordinary words). The concept of *restoration ecology* was defined using the following terms as seeds (restoration, restorations, restore, restores, restoring). The ACA machine learning process uses these seeds to compile the group of highly related words in the literature, including synonyms and adjectives that constitutes a concept's thesaurus. The words in the thesaurus are considered to define the concept, and their presence in a given text segment are therefore used as evidence of the concept's presence in that text segment. Once a concept is detected in a text segment, the text segment is classified under said concept. For more information on Leximancer and the ACA process see Smith and Humphreys (2006). In addition, we implemented an iterative validation process in which the seeds used to identify the concept of *restoration ecology* were adjusted until 100 % of text segments selected in a random sample were correctly classified. Because <0.05 % of the literature analyzed for 1980–1989 contained the concept of *restoration ecology* (i.e. five text segments out of

11,566), we determined the amount insufficient to make meaningful inferences, and therefore eliminated this decade's literature from remaining analyses.

To determine the focus of restoration research in the forestry science literature and to assess the evolution of this focus, we identified the top 30 concepts having the strongest relationship with *restoration ecology* in each decade. These prominent concepts were obtained through a profiled ACA. In a profiled ACA, the system identifies concepts that are related to a concept of interest, in this case *restoration ecology*, by identifying concepts that co-occur frequently with the concept of interest (Smith and Humphreys 2006).

The prominent concepts identified through the profiled analysis were then ranked by the strength of their association to *restoration ecology* (i.e. the percentage of text segments that were classified under both the particular concept and *restoration ecology*). The percent change from one decade to the next in association strength and frequency (i.e. the number of text segments classified under that concept) of these concepts was calculated in order to assess temporal trends. In our study, we define a concept as experiencing an increase or decrease from the previous decade if its frequency or association strength exhibits a 10 % or greater change. Additionally, we produced a concept map from all surveyed abstracts. Concept maps are a visual depiction of the inter-relatedness found among predominant concepts determined to be present in the surveyed literature. These relationships are depicted by the spatial relation among the concepts in the map, with concepts having the strongest associations being linked to one another with a solid line. The purpose of our concept map was to compare the bodies of literature for each decade in the context of the entire body of literature, and to obtain a better understanding of the relationships among the top concepts associated to forest restoration, as well as their association to each decade.

## Results and discussion

### Restoration ecology in forestry research (objective 1)

We observed a steady, upward trajectory in the percentage of forestry literature associated with *restoration ecology* over the 35-year period of our investigation. The percentage of literature investigating forestry research increased over 12-fold from 1980 to 1989 (0.04 %) to the next decade (0.5 %). This percentage then increased further, reaching 2.02 % by 2010–2014 (i.e. 50 times the percentage for 1980–1989).

Although the actual percentage of the analyzed literature classified under the concept *restoration ecology* is small, when this percentage is considered in the broader context of forestry science, it is relatively much bigger. Forestry is a diverse discipline, integrating a wide variety of fields (e.g., silviculture, fire ecology, tree physiology, economics, to name a few) aimed at better understanding both the basic and applied aspects of forest ecosystems. A previous review of the forestry literature revealed that compared to other areas of study integrated into forestry, restoration ecology occupies a leading role as one of the top 15 most frequently studied fields (Nunez-Mir et al., unpublished data).

The growth of restoration ecology in forestry literature is a likely indication of increasing recognition and integration of this scientific discipline into the field of forestry. This trend is evident beyond forestry science, as demonstrated by a growing presence of restoration research in top-tier, wide-readership ecology journals (Brudvig 2011) and the steadily increasing percentage of publications in ecology comprised by restoration articles (Young et al. 2005). The expansion of restoration ecology in both forest science and general ecology is perhaps not surprising given the utility of restoration research to the broader understanding of ecological systems. After all, the practice of ecological restoration has been proposed as an "acid test" of ecological theory and as an ideal setting for hypothesis generation and testing (Bradshaw 1987). Furthermore, the highly manipulative nature of ecological restoration and large-scale experimentation more feasible in restoration sites (Palmer et al. 1997) both allow for unique insights and expanded possibilities for the practical testing of theory.

## Key concepts associated with forest restoration (objective 2)

Our analyses identified seven concepts that were consistently discussed in the context of forest restoration over time (Table 2). These concepts were found to be among the 30 most prominent concepts for all three decades, therefore representing unchanging key themes that are either highly connected to restoration ecology or that have been a considerable point of discussion. For instance, *degraded* was found to be the most prominent concept in the literature every decade, clearly illustrating the central focus of restoration ecology—returning or rehabilitating degraded systems to a historically more functional or more desirable state (Davis and Slobodkin 2004). Akin to the concept *degraded*, *biodiversity* and *conservation*, two other consistently discussed concepts, are inherently connected to restoration ecology. After all, the recovery of habitat loss and biodiversity has not only been one of the major goals of ecological restorations since its inception, but ecological restorations are increasingly regarded as a major conservation strategy to limit and reverse biodiversity loss (Bullock et al. 2011; Maron et al. 2012; Oliet and Jacobs 2012). In the same note, *success* [as in how to define and measure restoration success (Wortley et al. 2013)] and *prescribed burning* [a common restoration strategy (Pyke et al. 2010)] are also topics that have been continually explored in the literature.

## Progression of key concepts over time (objective 3)

Our results revealed that the focus of the restoration literature changes from decade to decade, evidencing the evolution of the field over time. For instance, we found that the frequency and association strength of most concepts changed over time, likely illustrating changes in the perceived importance of these concepts. Six different temporal trends in the frequency of concepts were detected (Table 3). The most common trend was decrease in frequency followed by an increase, indicating a current revisiting (i.e. since 2010) of

**Table 2** Prominent concepts that appeared in all decades investigated and their respective ranks relative to the top 30 concepts identified in each decade

| Concept | Rank | | |
|---|---|---|---|
| | 1990–1999 | 2000–2009 | 2010–2014 |
| Degraded | 1 | 1 | 1 |
| Biodiversity | 10 | 20 | 24 |
| Ecological | 12 | 14 | 6 |
| Success | 13 | 9 | 5 |
| Ecosystems | 15 | 18 | 15 |
| Conservation | 16 | 11 | 22 |
| Prescribed burning | 21 | 17 | 11 |

Rankings are based on the strength at which each concept is associated with the concept of *restoration ecology*

**Table 3** Temporal trends (1990s–early 2010s) in frequency of concepts found to be prominent in more than one decade; frequency was defined as the number of text segments classified under that concept

| Temporal trend | Concepts |
|---|---|
| Decrease followed by increase | Efforts, ecological, success, biodiversity, prescribed, landscapes, recovery, riparian |
| Steady increase | Woodlands, reforestation, native, grasslands, target |
| Increase followed by decrease | Strategy, burning, historical, seed bank |
| Steady decrease | Lands, abandoned, activities |
| No change followed by a decrease | Conservation, ponderosa |
| Decrease followed by no change | Degraded, ecosystems |

concepts frequently discussed in the 90s. Similarly, we found four different temporal trends with regards to association strength (Table 4). Unlike frequency trends, the majority of concepts displayed a steady increase in the strength of their association to restoration ecology over time, possibly suggesting that as the field of restoration ecology continues to grow within the field of forestry science, these concepts have become more strongly associated to restoration in the literature.

Furthermore, we found that not only are the frequencies and association strengths of concepts changing over time, but so are the prominent concepts themselves. For instance, a considerable proportion of the top concepts for each decade only appeared in that decade (15/30 concepts in the 1990s, 9/30 in the 2000s, and 10/30 in the early 2010s) (Table 5). This pattern not only highlights transitions in the focus of research, but also potentially describes the unique research focus of each decade. This separation among the prominent, yet unique, concepts of each decade was also observed in the concept map of the entire body of literature reviewed (Fig. 1). This concept map clearly separated distinct sets of concepts associated with specific decades (with the exception of *programs*, which linked to both the 1990s and the early 2010s).

Concept clusters in the concept map that were associated to a particular decade also allowed us to further describe the unique research focus of each decade (Fig. 1). Three such concept clusters occurred in the 2000s. The first cluster (*prescribed burning, mechanical,* and *Ponderosa*) appears to refer to the theme of effectiveness of prescribed

**Table 4** Temporal trends (1990s-early 2010s) in the strength of association with *restoration ecology* of concepts found to be prominent in more than one decade; association strength was defined as the percentage of text segments classified under both the given concept and *restoration ecology*

| Temporal trend | Concepts |
|---|---|
| Steady increase | Reforestation, native, ecological, success, target, grasslands, woodlands, prescribed, ecosystems, degraded, efforts |
| Increase followed by decrease | Conservation, burning, historical, ponderosa, bank, activities, abandoned, lands |
| Decrease followed by increase | Landscapes, recovery, riparian |
| Increase followed by no change | Strategy, biodiversity |

**Table 5** Concepts from the top 30 most prominent concepts that are unique to each surveyed decade

| 1990–1999 | | 2000–2009 | | 2010–2014 | |
|---|---|---|---|---|---|
| Concept | Rank | Concept | Rank | Concept | Rank |
| Dispersal | 3 | *Programs* | *6* | *Succession* | *7* |
| *Goals* | *4* | *Active* | *13* | *Successional* | *10* |
| *Ecology* | *6* | *Framework* | *21* | *Tropical* | *12* |
| *Large-scale* | *8* | *Enhance* | *22* | *Secondary* | *17* |
| Community | 11 | *Tool* | *23* | *Exotic* | *18* |
| Concept | 14 | *Suppression* | *25* | *Natural* | *19* |
| Managers | 19 | *Health* | *28* | *Regimes* | *20* |
| Disturbed | 20 | Dense | 29 | Diverse | 25 |
| Insect | 22 | Context | 30 | Planting | 27 |
| *Project* | *24* | | | Critical | 28 |
| *Designed* | *25* | | | | |
| *Social* | *26* | | | | |
| *Space* | *27* | | | | |
| *Knowledge* | *28* | | | | |
| *Practice* | *29* | | | | |

Concepts are ranked based on their frequency and association strength to *restoration ecology* relative to the top 30 most prominent concepts. Concepts that are italicized appear to be indicative of the stages of cyclical development (i.e. conceptualization in the 1990s, implementation in the 2000s, and expansion in the 2010s)

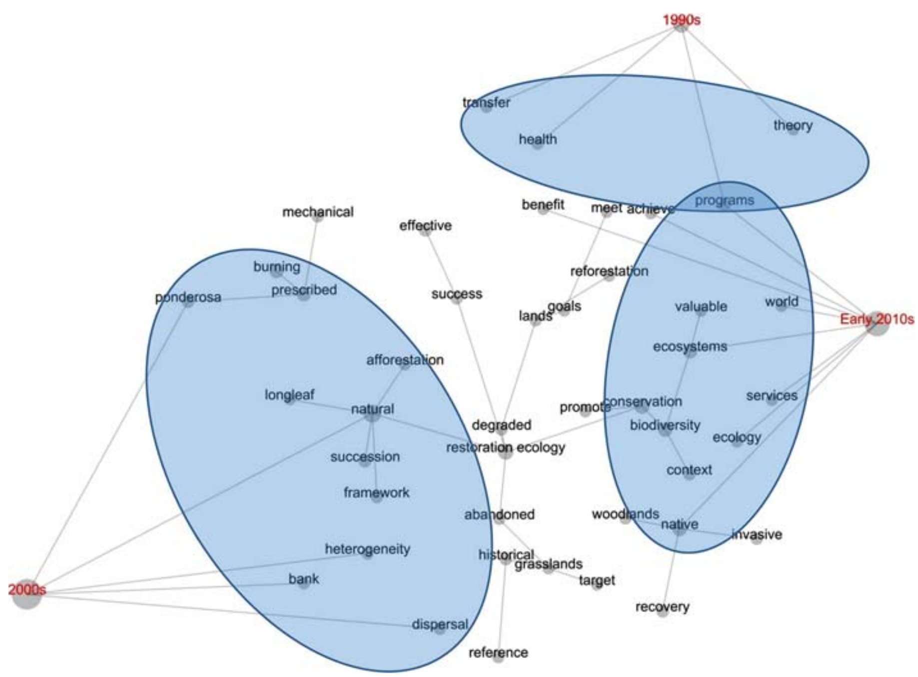


**Fig. 1** Concept map of the literature displaying the decades analyzed and the prominent concepts related to restoration ecology. The *position* of each individual concept or decade on the map represents its relationship to other concepts or decades mapped. *Dot size* indicates the number of text segments in a concept or decade. *Solid lines* indicate the strongest direct associations for each concept or decade. *Blue circles* highlight the concepts with strongest direct associations (i.e. connected by *solid lines*) to a decade. (Color figure online)

burning as a restoration tool, although specifically in the context of Ponderosa pine forests. The second cluster for the 2000s (*natural framework*, *afforestation, succession, success,* and *longleaf*) seems to represent numerous afforestation efforts and the restoration of longleaf pine in southeastern United States. The third cluster (*heterogeneity, seed bank,* and *dispersal*) could pertain to important sources of, and barriers to, seed recruitment and dispersal limitation.

A few clusters were also discernible for the early 2010s. These clusters seemed to show both an increased interest in key, fundamental concepts and conceptual expansion. The first cluster (*native*, *recovery*, *woodlands,* and *invasive*) likely refers to the rise of studies exploring the role of biological invasions in the dynamics of ecological restorations. The second cluster (*conservation*, *biodiversity* and *promote*) likely denotes the recognition of ecological restoration as a necessary activity in addressing and reversing biodiversity loss. The third cluster (*valuable* and *ecosystem services*) possibly refers to the rising interest in the enhancement of valuable ecosystem services through ecological restorations. Although no clusters were detected for the 90s, the concepts that were unique for this decade suggest research focused on the construction of theoretical frameworks.

## Evolution of forest restoration in response to current and emerging issues

Changing socioeconomic and ecological demands (Millar et al. 2007; Oliet and Jacobs 2012), partnered with accelerated global change (Harris et al. 2006; Hobbs and Cramer 2008; Jalili et al. 2010; Stanturf et al. 2014; Vitousek et al. 1997), have made the evolution of restoration ecology a necessary process. Indeed, the need for the constant development of new restoration practices and refinement of existing ones to meet these challenges is not exclusive to forest restorations. To illustrate, due to changing environmental and socioeconomic conditions, the theory and practice of ecological restorations will likely need to extend beyond the historical ranges of variability when considering desired restoration goals, thus bringing into question the usefulness of historical targets and reference conditions (Harris et al. 2006; Hobbs and Cramer 2008).

Our review of the forest restoration literature from recent decades has evidenced that restoration ecology is indeed not only rising in prominence, but also evolving and expanding in its focus to address emerging issues and challenges. For instance, a comparison of the clusters of prominent concepts forming in association to the literature from the 2000s and to the literature from the early 2010s (Fig. 1) highlight thematic differences between the research published in these two periods. The clusters of the 2000s make allusion to traditional restoration practices, particularly methods used for afforestation for timber-purposes. These findings coincide with trends previously recognized in the field of restoration ecology in general (i.e. beyond forests), in which basic and applied restoration research focuses mostly on established ecological principles and concepts (e.g. competition and physiological limits) (Young et al. 2005) and how they apply to the restoration of site-level conditions (Brudvig 2011). In contrast, the clusters of the early 2010s feature concepts that allude to emerging issues, such as the complex role of exotic species in restoration as both disturbers and facilitators of ecosystem functioning (Gaertner et al. 2012), and to emerging socioeconomic demands, such assigning value to forest ecosystems and functions through the more current, emerging framework of ecosystem services (Harris et al. 2006; Suding 2011).

## Cyclic development of forest restoration

This evolution of the discipline appears to follow a model of iterative and incremental growth, similar to the models of incremental development often described and used in fields such as software engineering (Larman and Basili 2003) and business (Gomory and Schmitt 1988). This pattern of growth of restoration ecology has been previously described as a "dynamic feedback loop" (van Andel and Aronson 2012). Here, we refer to this pattern as "cyclical development."

In cyclic development, a theoretical framework or scientific field (in our case restoration ecology) starts with the stage of conceptualization, in which the theoretical groundwork necessary for building the framework is laid, concepts are defined, and central hypotheses and guiding goals are identified. This stage is then followed by a period of implementation, in which the framework is applied and tested through active projects and experiments. The insights obtained from the implementation period lead to the last stage, expansion, in which the framework is refined and expanded to include new ideas, variables and perspectives not previously considered. The expanded version of the framework then re-enters the cycle. Through cyclic development, a theoretical framework or scientific field advances in an iterative, incremental manner based on both conceptual and applied feedback.

The literature analyzed provides evidence of cyclic development of restoration ecology in the context of forestry science. Our results suggest that the literature from the 90s reflects a period of conceptualization or definition of theoretical frameworks, the 2000s documents the ensuing implementation, while the early 2010s demonstrates a phase of expansion. First, a large proportion of the concepts found to be unique to each decade were indicative of individual stages of cyclical development (Table 5). More than 60 % of the concepts that were unique to the 90s seem to pertain to theory and the definition of objectives and goals (e.g., *goals, concept, knowledge*), more than 75 % of the concepts unique to the 2000s appeared to be referring to the implementation of active restoration projects and programs (e.g. *programs, tool, enhance*), and more than 70 % of the concepts unique to the early 2010s seem to address emerging perspectives, ideas, or variables in restoration (e.g., *tropical, exotic*).

Second, the concept map of the literature shows that the concepts from the early 2010s are considerably more associated (i.e. are close to each other in the map) with those from the 90s than the 2000s. This pattern suggests that the focus of the literature from the 90s resembles more closely that from the early 2010s.

Third, the temporal trends exhibited by a major proportion of concepts for both their frequency and their association strength is V-shaped, suggesting that the occurrence of these concepts were more similar for the 90s and early 2010s, than the 2000s (Tables 3 and 4). Therefore, the field seems to be revisiting these concepts. However, one must keep in mind that the stages of cyclic development are likely to be more fluid and not constrained to any one of the decades used to qualify time in our investigation. It is therefore more important to note the progression of change than to constrain it to any specific time period.

The cyclical development of the field further evidences the progressive evolution of forest restoration. It suggests that established principles and topics in the conceptualization phase (1990s) are not simply forgotten, but revisited and possibly reconsidered in the expansion phase (early 2010s) under fresh perspectives generated from new knowledge obtained from the implementation phase (2000s). For example, the concept biodiversity, which displayed a V-shape trend in the frequency with which it was discussed in the literature (i.e. decrease followed by increase), has been among the most commonly evaluated outcomes of restoration efforts (Ruiz-Jaen and Mitchell Aide 2005). In the past decades, restoration ecology has greatly focused on the effects of restoring site-level factors on biodiversity (Brudvig 2011). However, the considerable increase in the use of this concept in the literature in the most recent decade (early 2010s) might imply that the influence of other factors on biodiversity are now being explored further or are garnering more interest from researchers. Landscape-level factors (*landscapes* also displayed a V-shaped trend in both frequency and association strength) and factors related to historical contingency (Brudvig 2011; Menz et al. 2013; Stanturf et al. 2014) could be two such likely factors.

## Future directions

The concepts that were found to be prominent in the current decade (2010–2014) highlight the emerging ideas and perspectives in forest restoration, and therefore may offer some insight into the directions in which research in this field is expanding. Concepts such as *exotic* and *regimes* likely reflect the increasing focus of restoration research on the roles of invasive species and fire, as well as other disturbance regimes, have on restoration outcomes (Long 2009; Young et al. 2005). Another area that our findings suggest to be more frequently explored is the restoration of degraded tropical forests and the use of intensive planting to facilitate these efforts, as evidenced by the emergence of *tropical* and *planting* as prominent concepts in the last decade. Finally, the appearance of the concepts *succession* and *successional* suggest that, while these foundational ecological concepts have been historically important in restoration, their utility in the context of forest restorations are being revisited (Young et al. 2001) and various evolving models of succession are being tested (Young et al. 2005).

On the other hand, the absence in our results of other important concepts alluding to emerging topics and issues, such as global climate change, genetic considerations, metapopulation dynamics, ecosystem-based management, landscape-level factors, multi-scale ecosystem processes, socioeconomic considerations and extreme habitat vegetation restoration, indicates that these topics remain underexplored. These potentially important research gaps have been previously noted in the restoration ecology literature (Bell and Hobbs 2007; Ciccarese et al. 2012; DellaSala et al. 2003; Montoya et al. 2012; Padilla and Pugnaire 2006; Pausas et al. 2004; Prach and Pyšek 2001; Stanturf et al. 2014; Suding 2011; Young et al. 2005). The absence of these concepts suggests a need for further research addressing these and similar concepts within the context of forest restoration.

While many meaningful inferences have been made from our review, it is important to note that our study focused only on forestry journals. Forest restoration research is also published extensively in other journals, including journals specifically focusing on the field of restoration ecology itself (e.g. *Ecological Management and Restoration, Ecological Restoration, and Restoration Ecology*). Including papers from these restoration ecology journals in future reviews could potentially lead to new insights or help to further clarify the patterns revealed by this review. In addition, our investigation only analyzed text from article abstracts, and not from the entire research articles. While a study performed using entire research articles may provide a more complete understanding, we argue that abstracts should contain the most salient information from each reviewed article, and therefore expanding an investigation beyond article abstracts would not likely change our major conclusions.

## Concluding remarks

Our "big literature" review clearly shows that the study of restoration ecology within the context of forestry science is not only growing in importance, but is also expanding in focus to adapt to the new challenges and demands emerging in an increasingly changing world. Restoration ecology is a relatively young science, but has experienced great growth in the past decades in both the fields of forestry science and ecology as a whole. Additionally, our comparison of the literature from recent decades revealed shifts in the focus of research, suggesting an expansion of the field to explore established concepts and remaining issues from new perspectives, as well as undertake new concepts and emerging issues. Finally, our study revealed a cyclic pattern in the evolution of the field. An understanding of this cyclic development allows for the prioritization of research efforts. At this moment, restoration ecology in the context of forest science appears to be going through the stage of expansion, marking an ideal time for the exploration of new ideas, concepts and perspectives. As it continues to grow, the field of restoration ecology, both in general and in the specific context of forests, has the potential to provide unique contributions to the research, conservation, and management of forest ecosystems.

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