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Evaluating the Success of Forest Restoration

by

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Abstract

Forest restoration projects are occurring throughout the world. Restoration projects can vary greatly depending on the type of forest and the type of stressors that have caused ecosystem degradation and the need for restoration. Because of this variability, and because objective criteria for determining the success of restoration projects are lacking, it is difficult to evaluate the overall success of forest restoration projects. Using ecological standards developed for river restoration as a model, a similar set of standards was applied to forest restoration projects. The standards put forward can be used to evaluate the success of ecosystem restoration universally through the use of site-specific indicators of ecological success. This analysis found that many but not all of the criteria are being used to evaluate forest restoration success. Furthermore, the ecological health of the restored ecosystem is not always prioritized, as socioeconomic values are occasionally favored. Thus, it is important for a set of evaluation criteria primarily related to ecological health to be readily accepted by forest restoration practitioners.

Introduction

Roughly 2 billion hectares of forest are degraded and in need of restoration globally (Stanturf, Palik, & Dumroese, 2014). To accommodate this, forest restoration projects are becoming more popular and are now being implemented across the world, contributing to a decline in the net rate of forest loss (Chazdon, 2008). Restoration projects vary in many ways, including spatial and temporal scales, approaches to implementation and project goals and outcomes. For instance, the reintroduction of forest fires is an effective restoration technique for some forests (Ahn et al., 2014; Penttilä, Junninen, Punntila, & Siitonen, 2013; Ryan, Knapp, & Varner, 2013), but other methods such as nucleation or plantation based recovery might be better suited for other types of degraded forests (Campos-Filho, Da Costa, De Sousa, & Junqueira, 2013; Holl, Zahawi, Cole, Ostertag, & Cordell, 2011; Kamali & Hashim, 2011; Löff, Bolte, Jacobs, & Jensen, 2014). Studies of forest restoration projects regarding the ecological impacts of controlled burns can last several decades (Penttilä et al., 2013), and restoration projects can span entire watersheds (Campos-Filho et al., 2013). The wide range of ecosystem properties, as well as the varied cause of ecosystem degradation call for restoration procedures that are adapted to each unique circumstance. Thus, evaluating "the success of a restoration work is very challenging due mainly to the lack of a generally accepted criteria for measuring the success." (Kamali & Hashim, 2011)

These difficulties are apparent in more specialized types of restoration, such as forest restoration. Forests vary in many ways, including in their structure, species composition, and abiotic conditions. For example, tropical rainforests are very dense, and feature multiple vertical strata, hundreds of tree species, and relatively stable temperatures; in contrast, high-latitude boreal forests have few species, with low canopy cover, short-stature trees, and extreme temperature differences throughout the year. Because of the variable nature of forests, a uniform approach to forest restoration is inappropriate. Forests must be evaluated on a regional or biome-specific basis for the types of stressors present and with respect to the desired outcome of the project before a restoration method is selected.

Determining the success of forest restoration is further complicated based on the time-scale in which forest restoration operates. As tree dominated ecosystems, it can take several years to several decades for mature trees to start performing ecosystem functions which are vital for the overall health of the biological community, such as regulating water quality (Campos-Filho et al., 2013), sequestering carbon (Chazdon, 2008; Ciccarese, Mattsson, & Pettenella, 2012; van Rooyen, van Rooyen, & Stoffberg, 2013), and impacts on biodiversity (Jones, Rickman, Vazquez, Sado, & Tate, 2005; Löff et al., 2014; Penttilä et al., 2013). Though these ecosystem services are a tangible benefit of successful restoration, debates still exist over how restoration success should be evaluated (Ahn et al., 2014; Zedler, 2007). Thus, an understanding of the ecosystem's trajectory towards the target condition should help with evaluation in the intervening years.

The extent of degraded forests across the globe illustrates the need for restoration projects, with major investments of time and resources being spent on reforestation efforts (Lamb, 2005; Lindenmayer et al., 2012; Stanturf et al., 2014). For instance, poorly implemented volunteer mangrove restoration efforts can cost thousands to millions of dollars (Kamali & Hashim, 2011). Studies of different restoration techniques can last up to several decades (Löff et al., 2014; Penttilä et al., 2013), with the potential to provide a great deal of insight into restoration practices, but the high level of investment over time could lead to wasted resources in the event of a failed restoration. Also, despite the abundance of restoration projects occurring throughout the world, "evaluation of the success of a restoration work is very challenging due mainly to the lack of a generally accepted criteria for measuring the success" (Kamali & Hashim, 2011). An effective

way of evaluating ecosystem restoration projects is necessary for determining the successful progression of forest restoration.

A conceptual framework for evaluating the success of river restoration projects was proposed by Palmer et al. (2005). Their proposed criteria were designed to evaluate the ecological condition of restored rivers. Specifically, the authors proposed that the success of river restoration projects should be evaluated through the use of a guiding image or an end goal, the improvement of the ecosystem, an increased resiliency, the absence of lasting harm, and a proper assessment of the pre- and post- project conditions (Palmer et al., 2005). It is worth noting that the review focused primarily on metrics associated with ecological success. Socioeconomic evaluations were still recognized for their importance, but ecological successes were given higher priority (Palmer et al., 2005).

Because these criteria are not limited to system-specific conditions, other ecosystems may also be analyzed using this method. Using these criteria as a model, the success of forest restoration projects was analyzed primarily with ecological standards in mind, with some discussion of socioeconomic importance. This review aims to highlight the ecological effectiveness of existing restoration methods, providing a synthesis on the elements common in ecologically successful designs while also acknowledging potential areas of concern. Several case studies were analyzed with respect to the standards proposed by Palmer et al. (2005) to provide a better understanding of how forest restoration is currently being evaluated.

Importance of planning and design

Many important factors that determine a restoration's outcome occur early in the restoration process, even before the project is initiated. Planning is a vital part of the restoration process, in terms of determining what the end result should look like and how the project will be assessed and evaluated (Palmer et al., 2005). Planning is an essential part of the restoration process, yet it is still occasionally overlooked or done poorly. Volunteer restoration projects sometimes adopt ad hoc approaches to restoration, ignoring the initial steps of designing a plan for the project (Kamali & Hashim, 2011). This can be a problem, as restoration projects should be done with an end condition in mind, thereby driving the restoration itself (Palmer et al., 2005). The end result of the restoration can also determine if the planning process was successful or not.

Once the restoration project is finished, the actual results can be compared with the hypothetical results, showing the strengths and weaknesses of the planning and design stages (Kamali & Hashim, 2011; Palmer et al., 2005).

When discussing the success of forest restoration, it is important to determine what indicators will be used to evaluate the outcomes of the project (Palmer et al., 2005). Indicators may take many forms depending on the characteristics of the ecosystem. In one study, the presence of wood-decaying fungi was used as an indicator of the successfulness of a forest fire regime (Penttilä et al., 2013). Studies that focus on planting and replanting may evaluate their results through indicators like seedling survival and size (Holl et al., 2011; Kamali & Hashim, 2011; Löf et al., 2014). The beneficial outputs, or ecosystem services, that forests provide also require their own sets of indicators (Yamagawa, Ito, & Nakao, 2010). Because of this, separate indicators must be used to evaluate the respective health of each specific forest (Yamagawa et al., 2010). In this case, site-specific indicators should be used to evaluate the broader standards. For example, every forest restoration project should be evaluated in terms of measurable ecological improvements (Palmer et al., 2005), but the indicator used to measure the improvement will vary depending on the specific conditions of each forest.

A case study of subalpine forests within China helps illustrate this point. These forests were exploited heavily in the latter half of the 20th century, and they have been the focus of extensive restoration projects ever since (Zhang, Gu, Liu, Liu, & Li, 2013). As a result, many different types of forests have replaced the traditional old growth forests of the region. These replacements include spruce plantation forests, spruce and birch mixed forests, natural birch forests, and fir and birch mixed forests (Zhang et al., 2013). The purpose of this study was to identify the differences in carbon sequestration rates between the different forest types to identify which ones held the greater sequestration capacity (Zhang et al., 2013). Thus, the effectiveness of carbon sequestration was used as a way of comparing and indicating the overall success of different restoration methods, in this case what forest type was most effective through plantation-based restoration. This study reinforces the point that indicators are useful on a case-by-case basis, but contribute to the effectiveness of using universal standards to evaluate restoration success.

Importance of methods

The use of proper techniques is important in many aspects. The cost of a study is a primary concern for stakeholders who want to maximize effectiveness and minimize spending (Ahn et al., 2014; Campos-Filho et al., 2013; Holl et al., 2011). Though this is important, the ecological success of the restoration should be given priority (Palmer et al., 2005). The restoration method used in a particular study varies depending on the nature of the ecosystem being restored. Controlled fires are an effective treatment in some areas where historic fires were common (Ahn et al., 2014; Penttilä et al., 2013; Ryan et al., 2013), but they can be potentially damaging in areas with sensitive root structures (Jones et al., 2005). Thus, it is important to understand the specific characteristics of the ecosystem before initiating the restoration project.

Prescribed burns

Fire regimes and prescribed burns are a restoration technique that is beneficial to the restoration of landscapes that have historically depended on fire (Ryan et al., 2013). Natural forest fires are an important ecological process that maintains species diversity through disturbances that create heterogeneity in landscapes through the resulting succession processes (Ahn et al., 2014; Ryan et al., 2013). Scientific analysis of fire management continues to grow, providing evidence that decades of fire suppression policies have led to the degradation of many forest ecosystems, particularly in the western United States (Ryan et al., 2013). While ending fire suppression and introducing controlled burns to restore forests are supported by scientific studies, major barriers to this restoration method mainly come from sociopolitical concerns (Ryan et al., 2013). Specific constraints on the reintroduction of natural fire regimes include public hesitancy, concerns about risk associated with them, and a lack of proper funding (Ryan et al., 2013).

To better understand the nature of forest fires and the role of disturbance in relation with biodiversity, Penttilä et al. (2013) carried out a long-term study of the effects of prescribed burns on the recovery of polypore fungi on trees. This study was in part sparked by the overabundance of fire suppression techniques, which have indirectly impacted biodiversity and forest composition (Penttilä et al., 2013). Further, the study was done in response to the limited amount of studies associated with prescribed burns, with previous studies primarily documenting short-term responses to disturbance (Penttilä et al., 2013).

The study was initiated in 1989 with the burning of two plots, one that was managed and one that was semi-natural (Penttilä et al., 2013). The effects of the fire were measured through polypore, a group of fungi that grow on trees (Penttilä et al., 2013). Polypore fungi were enumerated the year before the fire, the year of the fire, and then 1, 2, 6, 13, and 22 years afterwards. The study showed that the short-term impacts of the fire were primarily destructive, as species diversity was much lower during these years. However, many positive outcomes were observed after the fire. Several rarer and more sensitive species were observed in the study areas after 5 years, including species that were not even present at the time of the burn (Penttilä et al., 2013). Thus, prescribed burns were shown to be an efficient way of creating habitat for several species, including rare and sensitive species, but the results of such may not be observable until after several decades (Penttilä et al., 2013).

It is important to understand that prescribed burning has limitations as a successful restoration technique. A study was done in the Sierra Nevada in California to observe different approaches to restoring aspen stands, which are in competition with conifers (Jones et al., 2005). The appearance of conifer trees within aspen stands is the result of human changes to the local environment, including heavy fire suppression techniques and grazing pressure (Jones et al., 2005). The reintroduction of fires through prescribed burns may help facilitate aspen growth (Jones et al., 2005). However, a fire regime was not the main restoration method used in this study. Aspen is a species that reproduces clonally through self regenerative methods, making it resilient to many natural disturbances like fires or avalanches (Jones et al., 2005). Aspen reproduction occurs in the root system, though, so it is important that it not be damaged in the restoration process (Jones et al., 2005). The use of prescribed burns in areas with excessive amounts of woody debris or other sources of fuel, that have accumulated through years of fire suppression, can damage aspen roots, making it an inappropriate method of restoration on its own in this ecosystem (Jones et al., 2005).

Despite a few limitations, the restoration of historic fire regimes is being considered as an essential part of forest recovery in many other ecosystems. Fire suppression methods have been used heavily in the 20th century, and their implementation resulted in alterations to forest composition, structure, and overall ecology (Korb, Fulé, & Stoddard, 2012). A study was done in the San Juan Mountains in Colorado to observe the effects that fire regimes had on the resulting

landscape. The study found that a combination of thinning and burning methods were effective at restoring the site to a desirable pre-settlement condition (Korb et al., 2012). Thus, controlled burns as a result of thinning and burning were advocated more so than traditional fire suppression techniques.

Similar studies have been done in other parts of the country, such as in Florida, where logging has become an increasingly common restoration technique (Weekley, Menges, Craddock, & Yahr, 2013). In Florida, logging is being advocated for as a way to manage forest ecosystems after historic fires have been suppressed (Weekley et al., 2013). However, the actual impacts of logging as a restoration technique are limited. The purpose of this study was to observe the impacts that logging and fire had on restoration, both alone and in conjunction, in response to the somewhat limited data (Weekley et al., 2013). Data was collected after 2 and 5 years. The results found that all of the studied methods of restoration (logging, burns, and the two together) were effective in meeting short-term forest restoration goals (Weekley et al., 2013). However, logging techniques did result in soil disturbances, which could arguably lead to the invasion of non-native species (Weekley et al., 2013). Thus, it was argued that burning alone should be the primary restoration technique to be used in the forest.

One of the overarching goals of many restoration projects is to return the forest to a natural or semi-natural state. This includes establishing historic levels of biodiversity. In Europe, common restoration goals include converting homogenized commercial forests from heavily managed to more natural conditions, and there are a number of restoration methods available to do this (Laarmann, Korjus, Sims, Kangur, & Stanturf, 2013). A study carried out in Estonia evaluated the successfulness of returning 30-60 year old homogenized forests to more favorable, natural conditions through three different restoration methods (Laarmann et al., 2013). Treatments primarily consisted of creating gaps. One treatment was to create gaps by removing over-story trees, the second treatment was to remove trees and add dead wood in their place, and the third was to use low intensity burns at the end of the summer season within a gap (Laarmann et al., 2013). Vegetation and insect diversity was used as an indicator for this study. The results found that the increased light in the system due to the gaps resulted in greater species diversity for both of these parameters (Laarmann et al., 2013). The results also show that species richness increased overall after the treatments were implemented, making all of these restoration methods

a successful way of restoring historic conditions (Laarmann et al., 2013). It is worth noting that the treatments in which prescribed burns were applied had the greatest amount of seedlings present after the survey (Laarmann et al., 2013).

It is important to understand the ecological conditions of a forest before issuing prescribed burns, as they can have considerable consequences. A study in Portugal evaluated the post-fire management conditions of forest plantations (Moreira et al., 2013). Fire regimes had been implemented in the forest to assist with natural regeneration, as fire was a historic disturbance in the ecosystem (Moreira et al., 2013). Unfortunately, these fire regimes can promote the invasion of non-native species to the forest (Moreira et al., 2013). Invasive species can impede the growth of native vegetation as well as contribute to greater, more destructive forest fires (Moreira et al., 2013). This study set out to describe post-fire conditions in pine and eucalypt stands in Portugal, specifically focusing on the impacts of invasive species. Plots in the forest were sampled over the course of five years (Moreira et al., 2013). The results found that post-fire stands facilitated the growth of invasive species while hindering the success of native trees, creating complications for the use of fire regimes (Moreira et al., 2013). The study illustrates the importance of understanding the trade-offs associated with a restoration technique, while also demonstrating possible barriers to forest restoration.

Plantations

Plantation based restoration is perhaps the most common restoration method implemented today (Holl et al., 2011). In Brazil, the most common restoration technique the development of plantations based on nursery-raised tree seedlings (Campos-Filho et al., 2013). However, this may be somewhat cost-prohibitive, and does not always result in high levels of biodiversity based on the availability of trees at nurseries (Campos-Filho et al., 2013). The effectiveness of planting seedlings was compared to a more efficient mechanized seeding technique in a study done in Brazil across 26 sites within the Xingu River Basin (Campos-Filho et al., 2013). The study showed that after five years both of the plantation techniques were effective in terms of minimizing costs and maximizing canopy cover (Campos-Filho et al., 2013). It was also noted that mechanized and direct seeding each worked better under a different set of circumstances. Specifically, direct-seeding methods are more effective in large-scale areas where mechanized

planting is ineffective, both economically and technically (Campos-Filho et al., 2013). Thus, the most effective approach to restoration was a combination of the two (Campos-Filho et al., 2013).

Despite the abundance of plantation based restoration projects, there is some ambiguity regarding their restoration potential (Saure, Vetaas, Odland, & Vandvik, 2013). Specifically, there are doubts as to whether or not ecological impacts associated with plantations such as changes in soil composition and biodiversity are reversible (Saure et al., 2013). To accommodate the need for more data on plantation-based restoration, a study was done in western Norway to compare the differences between native forests, conifer plantations, and restored forest sites on wind-felled plantations. The differences between these sites were quantified through measurements of species richness, species heterogeneity, and species composition. The plantations in this study included trees that were 40 to 60 years old, while the wind-felled plots were made up of replanted Norway spruce. The wind-felled forests were restored using passive restoration techniques such as allowing natural succession to occur with no human involvement (Saure et al., 2013). Data was collected using 5 by 5 meter plots. The species diversity of vascular plants was found to be higher in the wind-felled clearings than in either the native forests or the plantations. Furthermore, species composition within the wind-felled sites was similar to that of a natural forest, suggesting that the effects of a plantation on ecosystem structure may be reversible. The study also noted that bryophyte measurement was a more robust way to quantify community reestablishment compared to analysis of vascular plants (Saure et al., 2013). Bryophytes were chosen as indicators because they form a high proportion of understory vegetation and feature prominent roles in succession (Saure et al., 2013). The trends in beta diversity changes are similar for bryophytes and vascular plants but differ in alpha diversity, so bryophytes were favored to indicate the ecological success of the restoration (Saure et al., 2013).

In tropical forests, the predominant restoration technique used is plantations made up of nursery-raised seedlings (Cole, Holl, Keene, & Zahawi, 2011). This method has many benefits, but it can also result in higher costs and require more work to achieve (Cole et al., 2011). Furthermore, nursery raised seedlings are often limited in terms of available species, and they tend to be more sensitive when transplanted (Cole et al., 2011). In response to these problems, Cole et al. (2011) initiated a study focusing on direct seeding as an alternative to nursery-raised trees as a forest restoration technique. The study was done in a tropical rain forest in Costa Rica

and tested five large-seeded primary-forest tree species as indicators (Cole et al., 2011). The trees were directly seeded into habitats, including abandoned pastures, young secondary forests, and mixed-species tree plantations (Cole et al., 2011). Factors including germination, growth rates, survivability, and biomass was analyzed over a 2 year period (Cole et al., 2011). The results show that seedlings generally lived longer and grew larger in plantations than the other two habitat types (Cole et al., 2011). The study also found that the costs of seeding were generally much lower than using nursery-raised trees (Cole et al., 2011). It is worth noting that this restoration technique does have its limitations, though, and should be used primarily in conjunction with other restoration techniques instead of serving as an alternative (Cole et al., 2011).

Seed planting alone is not always a guaranteed method of success. It is important to understand the physical and chemical characteristics of the ecosystem before initiating a restoration project. Mangrove restoration provides an excellent example of the need to understand the ecosystem context, as mangroves grow on shorelines and are influenced by abiotic conditions such as the wind or the waves (Kamali & Hashim, 2011). Mangrove forests provide many important ecological and socioeconomic functions, so their restoration is a primary concern to scientists and the public alike (Kamali & Hashim, 2011). Many volunteer-based restoration projects exist, but they consist primarily (if not exclusively) of planting seeds (Kamali & Hashim, 2011). To compare effects of passive approaches without any planting to the transplantation of seedlings, Kamali and Hashim (2011) implemented an experiment along the coast of Peninsular Malaysia. In this study, the main stressor to mangrove establishment was from oceanic waves. The study took place on a degraded shoreline where a fringing mangrove forest once stood. A breakwater was constructed to limit these interactions so that transplanted mangroves could mature without these stressors. Unfortunately, the transplanted seedlings did not survive, with most all of them dying within a year of the restoration. However, the presence of the breakwater allowed for sediment deposition which facilitated the growth of waterborne seedlings that were carried to the area roughly a year and a half after the initial transplantation (Kamali & Hashim, 2011). Thus, the original transplantation design was deemed unsuccessful as a result of poor sediment delivery at the time of implementation. It was hypothesized that the combination of limited physical stressors combined with the abundance of sediments may have facilitated the establishment of seedlings from plantation based restoration.

The seedling based plantation strategy is a common technique that has the potential to accelerate forest restoration, but its implementation is not always cost-effective (Holl et al., 2011). Several studies have instead advocated for the use of nucleation, or island based, restoration techniques (Corbin & Holl, 2012; Holl et al., 2011). Nucleation is intended to mimic the natural dispersal and growth of tree species by creating clusters of pioneer species which (Corbin & Holl, 2012; Holl et al., 2011). These clusters grow by dispersing their own trees as well as attracting birds, which carry seeds from other trees into the area (Corbin & Holl, 2012). It has been advocated as a restoration technique based on its facilitation of swift recovery of large areas of degraded forests in a cost-effective manner (Corbin & Holl, 2012; Holl et al., 2011).

Nucleation has specifically been proposed as an alternative to the more common methods of seedling-based plantation restoration, but there is a limited amount of data on the subject (Holl et al., 2011). To address this lack of data, a study was done in Costa Rica to compare the effectiveness of nucleation and plantation-based restoration methods (Holl et al., 2011). The growth of four tree species was observed in two different plots, each one utilizing plantation or nucleation methods (Holl et al., 2011). The effectiveness was measured through metrics like soil compaction, photosynthesis rates, and tree growth rates (Holl et al., 2011). The study showed that seedlings tended to grow more within plantations than in the nuclei, with possible explanations including more stressful abiotic conditions in islands and a greater abundance of N-fixers in plantations. In terms of cost-effectiveness, the nucleation based restoration was significantly cheaper. The study tested different sizes of islands, ranging from small to large. The impacts of low seedling survival were much more pronounced in the islands of smaller sizes, so larger sizes were ultimately favored for this method of restoration.

Nucleation is being proposed as an alternative to traditional restoration methods, but there are still some gaps in the data of the methods. For example, many nucleation based studies do not consider animal behavior as a part of the successfulness of the study, specifically animal foraging patterns (Morrison, Lindell, Holl, & Zahawi, 2010). A study was done in 2010 to observe the impacts that island size had on bird foraging patterns, as foraging success was thought to be impacted by patch size (Morrison et al., 2010). The study took place in southern Costa Rica across six restoration sites, where foraging observations were made for four species of tropical birds (Morrison et al., 2010). The results showed that birds tended to be more

aggressive in larger patches, and that they achieved greater foraging success with less effort (Morrison et al., 2010). In this case, nucleation did impact the birds' behavior. This study illustrates the need for more data on this emerging restoration technique.

Plantation based designs are also commonly used in afforestation, which is the introduction of a forest or a stand in an area where there was not historically a forest (Lockhart, Ezell, Hodges, & Clatterbuck, 2006). Afforestation studies in the southern United States can include the introduction of hardwood species on lands that were previously used for agriculture (Lockhart et al., 2006). These projects often include little to no site preparation before planting, and there is often only one species of tree incorporated in the restoration (Lockhart et al., 2006). This can be problematic, as seedlings do not always reach their desired survivability, and the use of single-species results in homogenized stands (Lockhart et al., 2006). A study done in Mississippi was done to see whether or not natural conditions could be met in artificial stands through the use of mixed plantations (Lockhart et al., 2006). Two species of trees, cherrybark oak and sweetgum, were planted in mixtures on a former agricultural site (Lockhart et al., 2006). The results of the study show a great amount of survivability of all the trees coupled with increased growth, two features which were not observed through the single-species plantation methods (Lockhart et al., 2006). This study illustrates the importance of diversity in creating healthy forest stands.

Nurse Trees

Plantation based restoration also occurs through the use of nurse trees. A study done in Sweden showed the effectiveness of using nurse trees as part of a two-storied approach to plantation based restoration (Löf et al., 2014). In this study, nurse trees are defined as species of fast-growing, pioneer trees (Löf et al., 2014). The purpose of their implementation in this study was to facilitate the growth of desirable species, such as native broadleaved tree species (or target species) which tend to have late-succession characteristics and high regeneration costs (Löf et al., 2014). The nurse trees in this study were thought to mitigate the impacts of weeds on the growth of the target species, thus reducing the impacts of competition and facilitating restoration (Löf et al., 2014). Unfortunately, the data collected after 10 years did not support this hypothesis, as nurse trees had little to no impact on the growth of target species (Löf et al., 2014). One possibility is that nurse trees do have a positive correlation on the growth of target tree

species, but the results that restoration practitioners were expecting may not occur within the timeframes of this study (Löp et al., 2014). This study provides evidence for the use of mixed plantations as a way of achieving short-term boosts to forest productivity, which may be an efficient and cost-effective strategy to accelerate restoration projects (Löp et al., 2014).

Similar studies have occurred in other forest types, such as tropical forests. One study was done in Sri Lanka with the intention of using a species of pine trees as a nurse species, facilitating the growth of more sensitive, late-successional species (Ashton, Gamage, Gunatilleke, & Gunatilleke, 1997). Previous studies have demonstrated that seedlings tend not to fare well in cleared forests, making restoration difficult (Ashton et al., 1997). This study tested the growth of five tree species in conjunction with the removal of three to one rows of a pine tree species (Ashton et al., 1997). The study was done over a 2 year period in a pine tree plantation within southern Sri Lanka (Ashton et al., 1997). The results show that areas where canopy had been removed facilitated the most growth of the target tree species (Ashton et al., 1997). That is to say that the pine tree species worked well as a nurse tree, specifically when canopy cover is absent.

Implementation

Community Involvement

Community involvement is an important part of the implementation process. Ecological success should arguably take priority over measures of socioeconomic success, but in many instances these two methods of evaluation overlap. For example, people may rely on clean water, which is an ecosystem service of healthy forests. In this instance, the ecological health of the forest provides direct benefits to the people living in and around the area, providing an incentive for maintaining a healthy ecosystem.

This was the case in Brazil, where a campaign was initiated to combat deforestation along the Xingu River, a tributary to the Amazon. Deforestation in the area contributed to a decrease in water quality and flow, which in turn resulted in health problems for people who used the stream for drinking, fishing, or cleaning. The Y Ikatu Xingu campaign grew out of a concern for these conditions and involved stakeholders from the community and members from different fields of expertise, such as socioeconomic and environmental areas. The campaign was dedicated to sharing data about reforestation efforts, as well as assisting local landowners with

restoration projects. Since 2006, the campaign has assisted with restoring 2,400 ha of forests in Brazil. This study was limited to a few farms along the Amazon, but this sort of stakeholder interaction has the potential to bring about a great change in forest restoration by reducing costs and increasing manpower if implemented at much larger scales (Campos-Filho et al., 2013).

While useful in some instances, it is important to note that community involvement may not always result in ecological recovery. Ad hoc approaches to mangrove restoration initiated by public volunteers with no professional experience (Kamali & Hashim, 2011) may not be appropriate. The majority of mangrove restoration projects are initiated with poor understanding of the ecosystem and consist of basic planting/replanting methods that may not be tailored to the site-specific environmental conditions (Kamali & Hashim, 2011). The expected trajectory for the restoration is often not mentioned, resulting in a restoration project that is aimless (Kamali & Hashim, 2011). Further, these restoration projects are rarely monitored and documented, so no data or any sort of application comes from these approaches (Kamali & Hashim, 2011). Thus, these projects end up costing a great deal of time and money, without a successful project to show for the investment. Better scientific understanding is important for these sorts of restoration initiatives.

The use of simplified, direct vocabulary is also important when interacting between academic fields, such as interactions between ecologists and economists. The language associated with ecosystem restoration has evolved over time, as confusion used to exist surrounding words like "diversity," "importance," and "dominance" (Zedler, 2007). Ambiguity still exists in some discussions, so clarity is essential in discussing the results of a restoration project (Zedler, 2007). Without clear language, there is a real possibility for conflicting ideas regarding restoration practices. An example of this can be seen in South Korea's approach to ecosystem management strategies. Debates have arisen over the use of the terms "natural restoration" and "artificial restoration" (Ahn et al., 2014). In this case, these debates have influenced the restoration methods chosen by different organizations (Ahn et al., 2014). Debates like these have the potential to halt progress, taking the priority away from ecological success and putting it toward satisfying a political argument. Different organizations are making claims associated with the terms "natural restoration" and "artificial restoration" to influence restoration projects which will ultimately satisfy their own objectives, whether they be political or

ecological (Ahn et al., 2014). To avoid this confusion and delay, the vocabulary associated with ecosystem restoration should be as clear and concise as possible.

Cost-effectiveness

The ecological success of restoration should be prioritized in restoration projects. However, the cost-effectiveness of the restoration should be given some consideration as well. Finding a cost-effective set of restoration techniques may be useful in quickly facilitating forest restoration (Holl et al., 2011; Löff et al., 2014).

Some case studies have specifically evaluated the cost-effectiveness of alternative restoration techniques. For example, many studies were done to compare the cost-effectiveness of new restoration techniques to well established plantation methods. The two-storied nurse tree approach was designed to facilitate target tree growth through economic means (Löff et al., 2014). The results of this study showed that nurse trees had a marginal effect on the growth of target trees after 10 years, but they emphasized that the introduction of nurse trees in mixed plantations could be a viable option for swiftly and cheaply restoring forests (Löff et al., 2014). In this case, ecological success is not necessarily being compromised, but the cost-effective methods are definitely being given a higher priority. Though cost-effectiveness is a valuable factor that influences restoration, the restoration of ecosystem properties should be the focus of the project.

Island based restoration is another alternative to the traditional methods of plantation based restoration. This technique is not only more cost-effective, but it aims to mimic the natural progression of forest growth through seedling dispersal and clump based expansion (Holl et al., 2011). Studies that compare the effectiveness of island and plantation based restoration have found that island based restoration was in fact more cost-effective (Holl et al., 2011). However, more seedlings were damaged as a result of proximity to the island's edge which offered less protection to the elements or disturbances (Holl et al., 2011). Further, lower growth was observed in the islands than in the plantations (Holl et al., 2011). In this case, ecological success is being slightly compromised for the sake of a cost-effective restoration method. The restoration technique does show some potential, so further studies may reveal ways to encourage ecological success in tandem with its cost-effective nature. However, there are some studies that discuss potential gaps in the technique. One study noted that patches of smaller size were less likely to

provide enough food for bird species, which impeded the ecological integrity of the ecosystem (Morrison et al., 2010). There are still many things to learn about island based restoration, and future studies may reveal more about its strengths and weaknesses. Until then, it is important not to compromise the ecological integrity of the ecosystem for the potential economic benefits.

Results of the Case Studies

Many factors are important when evaluating the success of an ecosystem restoration project. These criteria can include the socioeconomic impacts of the restoration (such as the resulting value to local human communities and the cost-effectiveness of the efforts involved), but the ecological results are more significant for evaluating the success of the restoration (Palmer et al., 2005). Evaluating the ecological success of each project can be done through the use of standards. In this case, the standards used were proposed by Palmer et al.(2005) for river restoration projects, but they have relevance to forest restoration as well.

The first criterion for a successful restoration project is the existence of a guiding image or end result for the restoration. The guiding image is intended to drive the restoration towards a specific end goal. There are a few approaches to determining the guiding image for a project. When available, historical information such as maps or photographs can provide an idea of what historic, pre-disturbance conditions were like in the respective site. It is worth noting that climate change has, in many instances, altered the conditions of the local ecosystem, thereby rendering historical information irrelevant in many instances (Harris, Hobbs, Higgs, & Aronson, 2006). Reference sites are also important, as relatively similar yet undisturbed ecosystems may serve as an ideal or a model for how the restored site should ultimately look and function. The use of a guiding image primarily impacts the planning and design process of the restoration and evaluates the project itself rather than its ecological results (Palmer et al., 2005).

Despite the importance of this standard, many studies only briefly discuss the end goals of the project, if at all. Many studies tested different restoration techniques against one another, such as the studies proposing alternative methods to plantation based restoration (Corbin & Holl, 2012; Holl et al., 2011; Löff et al., 2014). Most of these studies were more experimental and were done to collect data on the differences between restoration methods. Of course, these studies were done with some idea of what the end result might look like. Nurse trees were planted in

conjunction with other trees with the guiding image being an ecologically healthy system as the result of two-storied planting techniques (Palmer et al., 2005). Similarly, nucleation was proposed as a viable strategy with the idea that island-based restoration would progress in a manner similar to natural forest (Holl et al., 2011). Concerning other techniques, studies involving fire regimes primarily introduced a controlled burn and gathered data on it in the following years (Penttilä et al., 2013). The purpose of this study was to make observations rather than develop a directed, guided plan for restoration (Penttilä et al., 2013). In some instances reference sites were used to help foster the idea of a guiding image (Saure et al., 2013), but for the most part discussion on the guiding images inspiring the projects was sparse.

Secondly, a successful restoration is evaluated on the improvement of the ecosystem itself. This sounds obvious, but it is an important factor in restoration nonetheless. Successful restoration projects must demonstrate measurable improvements in physiochemical and biological attributes (Palmer et al., 2005). It is important to note that these changes may take decades to materialize in forests, so an understanding of the ecosystem's trajectory and progress towards that goal is an appropriate alternative to the discussion of the overall success of the restoration (Palmer et al., 2005; Zedler, 2007). Thus, this standard deals with the progression and the quantifiable results of the restoration (Palmer et al., 2005).

When using this criterion, indicators for success need to be selected on a case by case basis (Palmer et al., 2005). The pre- and post- restoration conditions must be evaluated through the use of an indicator. Indicators will vary depending on the attributes of the specific forest. For example, a study describing the effectiveness of forest fires was evaluated through the use of polypores, or wood-decaying fungi, which were present in much higher numbers several years after a fire (Penttilä et al., 2013). Other studies used different metrics, such as the tree density (Campos-Filho et al., 2013), seedling survival (Corbin & Holl, 2012; Kamali & Hashim, 2011; Löf et al., 2014), and species diversity within the sites (Saure et al., 2013). Although most studies had a method of evaluating the restoration success, there were a few that noted less than optimal results (Holl et al., 2011; Kamali & Hashim, 2011; Löf et al., 2014).

The third standard is for the ecosystem to exhibit some degree of resiliency. Disturbances are a common threat to forests, with examples including fires and disease (Jones et al., 2005; Ryan et al., 2013). The purpose of this standard is to ensure that the restoration project sets out to

recreate a system that is able to withstand the lasting impacts of these types of disturbances (Palmer et al., 2005).

This standard is difficult to evaluate initially due to the time scale associated with it (Palmer et al., 2005). The goals associated with resiliency include little to no need for maintenance after the project is done (Palmer et al., 2005). However, the fulfillment of this criterion relies on the unforeseeable occurrences of disturbance within the site. Thus, restoration projects need to be designed in a way that resiliency is part of the end goal. A few studies did show some level of resiliency during their implementation. Controlled burns, though actually a form of disturbance, are being used to encourage natural resiliency (Jones et al., 2005; Penttilä et al., 2013; Ryan et al., 2013). Other studies noted that post-treatment conditions actually lead to less resiliency, creating problems with the restoration method of choice (Moreira et al., 2013).

The fourth standard is to ensure that no lasting harm is done through the restoration project. The goal of the restoration is to revitalize the ecological integrity of the target area. This may, in some instances, result in radical changes to the landscape or biological community. The purpose of this standard is to discourage these potentially harmful actions as much as possible. Similarly, restoration projects should be planned so that no harm is done to other ecosystems in the process (Palmer et al., 2005). This standard mainly applies to the planning and implementation of the restoration project.

The intention of this standard is that restoration projects improve the health of the target ecosystem without causing any harm, whether that be to the target system or a completely nearby ecosystem (Palmer et al., 2005). This point was discussed very little in the literature, as most studies were focused primarily on one site and did not have much potential to spill over into other areas. One study did discuss the lasting harm associated with prescribed burns and, as a result, opted for an entirely different restoration technique to avoid future damage (Jones et al., 2005). Other than that, there was little to no discussion of negative lasting impacts.

Finally, the fifth standard assesses the ecology of the restored ecosystem. Assessments should be done before the project is initiated and after its completion in order to properly evaluate the outcomes of the restoration. The pre-conditions are compared with the end results, providing insight into what the restoration process actually accomplished. Both the positives and

the negatives of the restoration projects must be assessed and discussed, as the results will influence the design of future restoration projects (Palmer et al., 2005).

This standard works in conjunction with the use of a guiding image; a restoration project can have clearly established goals without needing a fully developed image of what the final product should look like. As a result, most of the studies were assessed in some detail. Some studies discussed the failure to meet their goals. The results of the island-based restoration study did not fully meet the expectations in terms of seedling survival and growth (Holl et al., 2011). Similarly, the impacts that nurse trees had on two-storied plantation strategies were not as robust as was initially hypothesized (Löf et al., 2014). Other studies did show successful results from the environmental assessment. Fungi species were much more abundant in post-treatment plots where fire was introduced (Penttilä et al., 2013). Other studies showed that conifer removal strategies did have a positive impact on aspen restoration (Jones et al., 2005). Not every study was technically a success in regards to this criterion. Regardless, this standard was the most commonly used metric across the reviewed literature.

Aside from the ecological successes of a restoration project, there are socioeconomic ways of evaluating restoration. Community engagement is an important metric when dealing with ecosystem restoration that has a direct impact on people in the surrounding region (Campos-Filho et al., 2013). The urgent need for a healthy forest can drive stakeholders and other public volunteers to work towards an ecologically healthy system (Campos-Filho et al., 2013). The cost-effectiveness of a technique was another primary concern, specifically in cases in which a speedy recovery was necessary (Holl et al., 2011; Löf et al., 2014). While these standards are important, they should not overshadow the importance of ecologically healthy restoration design.

Discussion

Perhaps the most notable thing about this review is that many studies incorporated different standards for ecological success, but only one study included all of them (see Table 1. in the Appendix). Many of these studies include some form of discussion of their results through the framework presented by these criteria. This shows that there is an incentive to discuss the results of forest restoration in a concise, universal manner, but the lack of a widely accepted set of standards does not encourage the sort of discourse proposed by Palmer et al (2005). Further, it

has been stated that defining success is difficult (if not impossible) based on the lack of standards to which restoration projects should be held (Kamali & Hashim, 2011). The standards put forward by Palmer et al. (2005) are beneficial for discussing the ecological success of restoration without relying on site-specific indicators or criteria, making them a useful way for conveying data. It should also be noted that the same standards are being used to analyze forest restoration as river restoration. The nature of these criteria seem to avoid ecosystem specific conditions in their evaluation, but they may neglect some important aspects of the planning and design phases between the two restoration types.

The prioritization of cost-effectiveness over ecological success was also apparent in many cases. Restoration techniques were marketed as being natural alternatives to cost-prohibitive techniques, such as traditional plantation based restoration. However, many of the studies that used cost-effective techniques found marginal to negative impacts on the ecological integrity of restoration sites (Holl et al., 2011; Löf et al., 2014; Moreira et al., 2013). There is some appeal in maximizing cost-effectiveness in restoration, but only if the recovery of ecological attributes is not compromised. If the restoration project results in an ecosystem that is not ecologically healthy, then it may face problems in the future, such as poor resiliency continued degradation. Therefore, it is important to prioritize an ecosystem that is healthy enough to sustain itself rather than focus on a quick and cheap restoration which may require further maintenance in the future.

Utilizing clear terminology is essential when dealing with stakeholders from different fields. Confusion can arise from poorly worded goals and ambiguous terminology, which can lead to debates in some cases. These arguments have the potential to halt the progress of ecosystem restoration, as evidenced with some organizations in Korea (Ahn et al., 2014). The use of proper terminology should be implemented to avoid potentially confusing situations. Authors need to be clear in their writing as to whether they are making value judgments and what types of restoration techniques are being utilized (Ahn et al., 2014; Zedler, 2007).

Ultimately, the standards put forward by Palmer et al. (2005) can be beneficial when evaluating the success of forest restoration projects, though some changes may need to be made to make them more applicable to forest restoration. The criteria they presented are designed to be applicable to any restoration project, though the indicators of each criterion's success will surely

differ between sites. The use of clear language when discussing these criteria is essential for conveying each restoration project's success.

Conclusion

The existing literature on forest restoration is incorporating the discussion of ecological success, but the lack of unified standards means that not every study is using the same criteria to evaluate their results. A unified standard should be encouraged to promote more detailed discussions. Existing criteria exists for evaluating the success of other types of ecosystem restoration and can be adapted to fit the conditions necessary to evaluate forest projects. Proper indicators will vary on a site-by-site basis, but they should all work to evaluate a universal set of standards. Ecological success is not always given priority in forest restoration. Although socioeconomic metrics of evaluation are important, the ecological success of a restoration project should be the main goal. Finally, it is important to use clear vocabulary when discussing methods and success to avoid potential confusion. Results should be discussed objectively and with clarity so as to contribute to the future of forest restoration.

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Appendix : Data Table

Table 1. A summary of the case studies reviewed. The studies were defined by the forest type, restoration method, associated timescale, type of degradation and stressors present, the indicators of success, and whether or not the project was a success.

Study	Forest/Biome	Degradation/ Stressor	Method	Evaluation Criteria/Timescale	Success
Ashton et al. 1997	Tropical forest, Sri Lanka	Forest loss due to agricultural land	Examine the potential for late-successional trees through the use of a nurse species	Nurse trees ability to facilitate growth in target species 2 years	The nurse tree species was effective at facilitating the growth of sensitive, late-successional tree species
Campos-Filho et al. 2013	Riparian forest along the Amazon River, Brazil	Deforestation due to human consumption	Compare two methods of planting: direct seeding and mechanized seeding	Tree densities, restoration costs 5.5 years	Both methods were deemed important given the circumstances
Cole et al. 2011	Tropical forest, Costa Rica	Fragmentation	Compare seeding effectiveness in different restored forest types	Seedling germination, survival, growth, and biomass 2 years	Planting seedlings was deemed more cost-effective than planting nursery trees, but the method worked better as a complement to other restoration techniques
Holl et al. 2011	Tropical forest, Costa Rica	Former agricultural sites	Island based restoration versus traditional plantations	Species survival, height, canopy area 3 years	Island restoration had advantages and disadvantages in relation to traditional plantations
Jones et al. 2005	Aspen stands, California, US	Pressure from competing species	Mechanical removal of competitive species (Conifers)	Aspen density 2 and 4 years	Mechanical removal of conifers is an effective way of restoring aspen stands
Kamali and Hashim 2010	Mangrove forest, Peninsular Malaysia	Stress to seedlings from oceanic waves, erosion	Limit stressful abiotic interactions and allow for passive restoration	Seedling survivability 8 months	Initial results were unfavorable (all the transplanted trees died), but seedlings carried in from elsewhere were able to grow
Korb et al. 2012	Mixed conifer forest, Colorado, US	Fire suppression	Compare thin/burn, burn alone, and control treatments	Tree density, tree canopy cover, tree regeneration, similarity to historic conditions 6 years	Thin/burn methods were the most effective at returning the ecosystem to its historic conditions.

Study	Forest/Biome	Degradation/ Stressor	Method	Evaluation Criteria/Timescale	Success
Laarman et al. 2013	Conifer plantations, Estonia	Homogenized forest structure for commercial purposes	Thinning, burning, nurse logs	Biological diversity, insect diversity 3 years	Species richness and abundance increased in forest stands after the treatments were applied
Lockhart et al. 2006	Mixed plantations, Mississippi, US	Abandoned agricultural fields, homogenization	Afforestation in abandoned agricultural fields	Tree height and diameter 21 years	Trees had greater survivability, height, and diameter when planted in mixed-species plantations as opposed to single-species
Lof et al. 2014	Plantations, Sweden	Competition from other plant species	Use nurse trees to facilitate the growth of target tree species	Survival, growth 10 years	Nurse trees had little impact on target species growth in short time scales. Nurse trees may have positive impacts on speedy forest recovery.
Moreira et al. 2013	Plantation, Portugal	Pressure from invasive trees as a result of prescribed burns	Examine impacts of prescribed burns on native/exotic species interactions	Presence of invasive tree species 5 years	Post-fire management practices hindered the growth of native species but facilitated the growth of invasive species
Morrison et al. 2009	Tropical forest, Costa Rica	Forest loss due to agricultural land	Examine the effects that nucleation-based restoration has on bird foraging patterns	Bird foraging success, attack rates, arthropod density 1 year	The differences in patch-size did have an impact on animal behavior, which could have long term consequences
Penttilä et al. 2013	Boreal forest, Finland	Stagnation based on lack of fire-based disturbances	Implement a fire regime in two stands- a managed one and a semi-natural one	Polypore availability 23 years	Burning has a positive impact on the availability of threatened polypore species
Weekley et al. 2013	State Forest, Florida, US	Negative impacts of logging	Compare the impacts of logging and prescribed burns as restoration techniques	Improve habitat, increase biodiversity 2 and 5 years	Both methods were effective at achieving short term restoration goals, but burning was favored due to the negative impacts associated with logging

Table 2. A summary of the case studies reviewed in relation to the standards proposed by Palmer et al. (2005).

Study	Guiding Image	Improved Ecosystem	Increased Resiliency	No Lasting Harm	Ecological Assessment
Ashton et al. 1997	NA	Presence of late-successional trees	NA	NA	Post-assessment data available
Campos-Filho et al. 2013	NA	Early large-scale restoration completed	Some early maintenance was required	NA	Post-assessment data available
Cole et al. 2011	NA	Methods were found to work best in tandem with other methods	NA	NA	Post-assessment data available
Holl et al. 2011	NA	Some trade-offs associated with nucleation	NA	NA	Post-assessment data available
Jones et al. 2005	NA	Aspen stands were effectively restored	NA	Certain restoration techniques were avoided to ensure no lasting harm	Post-assessment data available
Kamali and Hashim 2010	NA	The study was not deemed successful	NA	NA	Post-assessment data available
Korb et al. 2012	Study was compared to reconstructed historic structure	Treatments resembled historic conditions of the site	Restoration made forests more resistant to fires	Forests were restored to resist future disturbances	Post-assessment data available
Laarman et al. 2013	A more natural state was desired	Restoration resulted in greater biodiversity	NA	NA	Post-assessment data available
Lockhart et al. 2006	NA	Trees grew larger in height and diameter	NA	NA	Post-assessment data available
Lof et al. 2014	NA	Methods were advocated for cost-effective means of restoration	NA	NA	Post-assessment data available

Study	Guiding Image	Improved Ecosystem	Increased Resiliency	No Lasting Harm	Ecological Assessment
Moreira et al. 2013	Study was compared to historic stands	Methods hindered native trees but facilitated invasive trees	Resiliency decreased	NA	Post-assessment data available
Morrison et al. 2009	NA	Patch size had positive and negative impacts on animal behavior	NA	NA	Post-assessment data available
Penttilä et al. 2013	NA	Controlled burns facilitated rare species growth	NA	Study showed positive results after 23 years	Post-assessment data available
Weekley et al. 2013	NA	Burning alone was identified as the best restoration practice	NA	Logging was identified as a harmful restoration practice	Post-assessment data available