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RE-NEW (OPINION) ARTICLE

"Active" and "passive" ecological restoration strategies in meta-analysis

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One of the means of creating a more robust methodology for ecological restoration involves reducing the gap between ecological theory and restoration practices. A common strategy to do so is using meta-analysis to understand key drivers of restoration outcomes. "Active" and "passive" is a dichotomy often used to separate restoration strategies in such meta-analyses. We investigate previously raised concerns about selection bias and subjective categorization of strategies. We promote a paired experimental design in future empirical research and propose the use of three categories of restoration strategy in lieu of "passive" and "active" to alleviate inconsistency in definitions and categorization.

Key words: active, ecological restoration, meta-analysis, passive, restoration strategies, selection bias, terminology

Conceptual Implications

- To most effectively translate advances in restoration ecology into ecological restoration practices, research must be consistent and clear in its use of terminology.
- While the terms "active" and "passive" as categories of restoration strategies have been widely adopted, we found definitions remain inconsistent and in application to be exposed to selection bias.
- To reduce the degree of inconsistency and future misinterpretation, we propose a three-category framework adapted from the *International Principles and Standards for the Practice of Ecological Restoration*.
- We advocate the use of paired experiments to adequately test hypotheses relating to restoration strategies in the future.

One of the key aims of ecological restoration is to protect and enhance biodiversity (Gann et al. 2019). Restoration ecology aims to inform and improve the practice of ecological restoration, bolstering methods with scientific rigor, and evidence-based practice. Part of increasing the rigor of restoration in ecology is in developing general predictions and broad theories that apply to restoration projects across ecosystems and the globe (Lindenmayer 2020). Doing so will be crucial in meeting many recently proposed large-scale restoration targets efficiently and effectively, particularly by enabling the initiation of restoration without necessarily requiring extensive details on all aspects of the environment to be restored. In response to the need to greater link restoration with ecological theory, there has been a flurry of meta-analyses in recent years (Crouzeilles et al. 2016, 2017; Meli et al. 2017; Jones et al. 2018; Shimamoto et al. 2018; Huang et al. 2019). Meta-analysis has the potential to uncover key factors that may determine restoration outcomes not apparent at the site level or from any single study, and better understanding these processes may have profound implications for future planning and monitoring of restoration projects. Meta-analyses in restoration ecology have helped to highlight some generalities on the success of restoration. For example, on average, restoration projects produce a net gain in measured outcomes (biodiversity, habitat structure, etc.; Crouzeilles et al. 2016, 2017; Meli et al. 2017; Jones et al. 2018; Shimamoto et al. 2018; Huang et al. 2019), and restoration success will increase where a site has a history of relatively low degradation (Crouzeilles et al. 2016). Prach and del Moral (2015) first highlighted the need to use such syntheses to better understand the effectiveness of different strategies across varied environments. In subsequent meta-analyses, somewhat counterintuitively, natural regeneration ("passive" restoration) has been shown to achieve better, or equal, restoration outcomes compared with "active" restoration (Table 1) in meta-analyses (Fig. 1A; Crouzeilles et al. 2017; Jones et al. 2018; Shimamoto et al. 2018; Huang et al. 2019).

We suggest that inconsistent terminology and biases in results present issues for current generalizations on restoration strategies and we explore these problems and identify possible solutions in this article. Notably, robust future meta-analysis will be paramount in furthering the understanding of the success of different restoration strategies across a range of habitats and environments.

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The probability that active restoration strategies are employed at a given site is highly dependent on the degree of environmental degradation (Reid et al. 2018; Prach et al. 2020). Active restoration techniques are costly and tend to be used only in the most degraded ecosystems where passive approaches would almost certainly fail (Fig. 1C; Gann et al. 2019; Prach et al. 2020). Reid et al. (2018) note an inherent flaw that describes why a conceptual shift is necessary: when comparing a tree plantation in a degraded pasture (active restoration) with regeneration in a 10-year-old secondary forest (passive restoration) they note that the plantation has the opportunity to fail to establish, but by its nature, as an included study site the secondary forest has already established (Fig. 1). Thus, comparing studies that employ active restoration with passive restoration is likely hopelessly confounded by variation in pre-restoration conditions making any sensible conclusion nearly impossible.

Studies that pair different restoration techniques in similarly disturbed or degraded habitats are required to effectively elucidate the effectiveness of different strategies (Fig. 1). Encouragingly, some primary studies have begun to emerge using this approach (Trujillo-Miranda et al. 2018; Staples et al. 2020). Reid et al. (2018) suggest that a rigorous future meta-analysis of restoration strategies should not incorporate studies where a passive approach has already "succeeded" to some degree before the study takes place (for instance, the example of the 10-year-old secondary forest). We suggest such an approach would be difficult to implement in practice, and the meta-analysis of paired experiments would be of greater utility and may serve to illuminate instances in which the different approaches are complementary. The use of a paired experimental design both in empirical research but also in meta-analysis is key to a robust investigation of the effectiveness of different restoration strategies. Such an approach would allow for greater investigation of relationships between specific environmental conditions and restoration strategy preference (e.g. Prach et al. 2020).

Nonetheless, the "passive" versus "active" restoration strategy dichotomy remains in use in meta-analyses (Shimamoto et al. 2018; Huang et al. 2019). To achieve its primary goal of successful ecological restoration, research in restoration ecology must avoid casting terminology in a way that promotes confusion, and allows misinterpretation of restoration research. We found no clarity in the definitions of "passive" and "active" restoration by past meta-analysts (Table 1). Jones et al. (2019) highlight in response to a comment on their meta-analysis that it would be of great utility if restoration ecologists could agree on how to define the difference.

Future meta-analysts should find guidance from definitions in the *International Principles and Standards for the Practice of Ecological Restoration* (Gann et al. 2019) for many key definitions. Specifically, concerning restoration strategies, these principles define three broad categories: natural (or spontaneous) regeneration, assisted regeneration, and reconstruction (Table 2). It is proposed the categories in Table 2 be used in place of "passive" and "active."

Abandonment of the phrase "passive" in favor of "natural restoration" should provide further clarity. Additionally, where the

Table 1 Definitions of "passive" and "active" restoration in past meta-analyses.

Author	*Passive*	*Active*
Shimamoto et al. (2018)	Natural or assisted regeneration	Using individual trees to improve facilitation; Planting native species; Active restoration by planting exotic species, planting economically important species (*Pinus* spp., *Eucalyptus* spp., *Acacia* spp., and *Tectona* spp.) or native species and agricultural crops
Huang et al. (2019)	Protecting existing natural forests from excessive cutting; Fencing/grazing exclusion for grassland; Abandoning cropland	Planting tree (or grass) in the degraded cropland for soil and water protection; Restoring natural vegetation in ecologically sensitive areas; Vegetation restoration in mining areas; Artificial grassland establishment; Improving management measures (fertilizer, irrigation, forest thinning, transplanting, hallowing, reseeding, mixed-sowing, plowing)
Jones et al. (2018)	Recovery after disturbance with a combination of actions to end the disturbance	[Actions] to increase the rate and extent of recovery of damaged ecosystems after the disturbance ceased
Crouzeilles et al. (2016)	Forest re-growth following land abandonment or the cessation of disturbance pressure (e.g. exclusion of grazing)	Active management—manipulating disturbance regimes through the use of thinning and burning; Active planting—plantation of tree species to influence the successional trajectory of recovery
Crouzeilles et al. (2017)	Forest re-growth following land abandonment, selective logging, or assisted recovery of native tree species through human interventions, such as fencing, to control livestock from grazing, weed control, and fire protection	Manipulating disturbance regimes through the use of thinning and burning, the establishment of nursery-grown seedlings, direct seeding, or plantations of tree species
Meli et al. (2017)	Ending the prior anthropogenic land use type to allow the forest for natural or unassisted recovery	A range of human interventions in an effort to accelerate and influence the successional trajectory of recovery

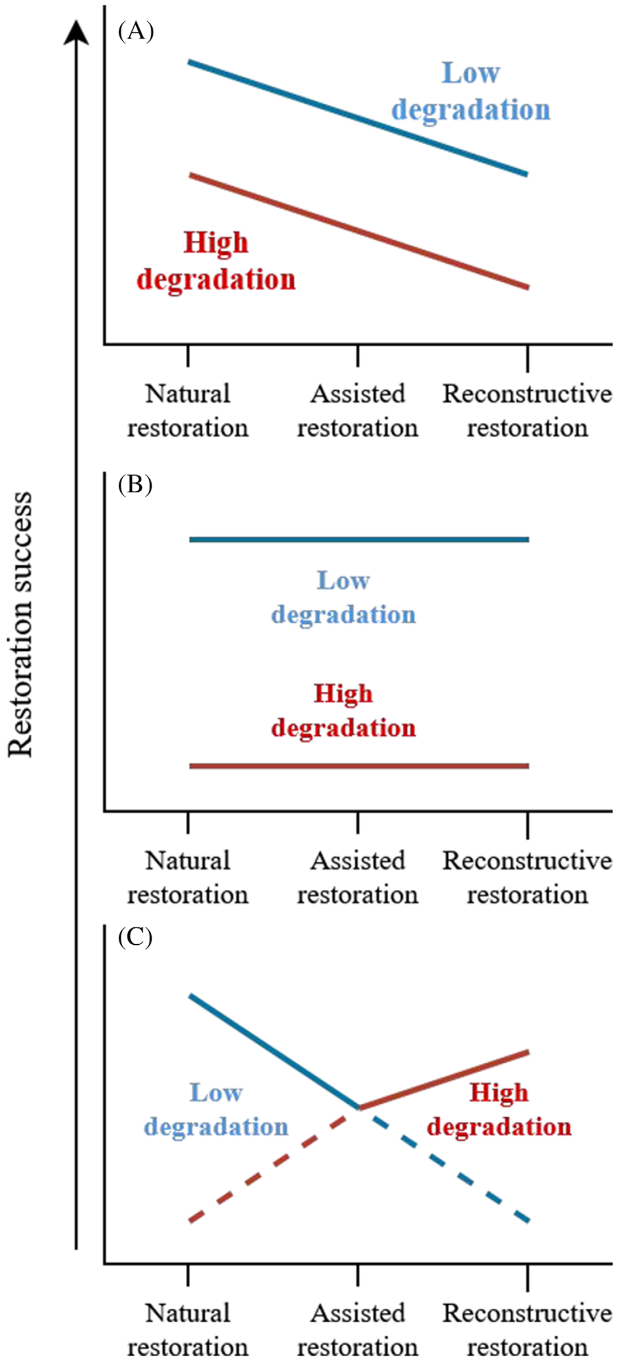

Figure 1 Potential scenarios of measured restoration success in response to different restoration strategies in two different contexts: habitats that have experienced low degradation, and those that have experienced high degradation. (A) depicts one relationship between strategies where the passive approaches (natural restoration) outperform active approaches (assisted/reconstructive restoration), as suggested by some recent meta-analysis. (B) represents an alternative scenario highlighted by some meta-analyses where passive and active approaches achieve comparable results, and differences in restoration success are due to the degree of ecological degradation prior to restoration. (C) is a hypothesized scenario that highlights an alternative interaction where conclusions (A) or (B) may be inadvertently drawn. Dashed lines represent a possible area of data deficiency, where study sites may not exist since they are not treated as candidates for those approaches in planning and implementation of restorations. This highlights a potential bias for meta-analysis where more complex approaches are reserved for more degraded conditions where success may be less consistent, which also likely represent a lower overall proportion of total global restoration sites. See Table 2 for a complete definition of the different restoration strategies.

Table 2 Restoration strategy categories proposed to replace "passive" and "active". Adapted from Gann et al. 2019, p 68–69.

	Restoration Strategy	*Context*
"Passive" restoration	Natural restoration	Ending degradation, e.g. Removal of contamination source, restriction of water flow, modifying inappropriate grazing, inappropriate fire regimes, cessation of logging, agricultural land retirement
"Active" restoration	Assisted restoration	A combination of the above strategy with abiotic and biotic interventions, e.g.: *Abiotic* Active remediation of substrate conditions (physical or chemical), habitat creation, reshaping watercourses, reintroduction of environmental water flows, applying artificial disturbance to promote seed germination *Biotic* Invasive species management, reintroduction of species, augmenting or reinforcing depleted populations of species
	Reconstructive restoration	A combination of the above strategies with the reintroduction of a major proportion of the desired biota. Possibly mimicking natural successional dynamics

target state remains one of economic interest rather than one of ecological integrity (e.g. production forestry, agricultural systems), drawing insights from such practices for ecological restoration may be of reduced utility. Such goals lie outside the definition of ecological restoration (Gann et al. 2019), and this practice may be better characterized as "natural rehabilitation."

We believe that "active" restoration should no longer be used in favor of the latter two categories in Table 2: assisted restoration and reconstructive restoration. Assisted restoration allows for some "middle-ground" strategies that have historically been treated as passive, for example, invasive species removal (Crouzeilles et al. 2017) or reintroduction of environmental water flows (Jones et al. 2018), which are very different approaches to examples of "natural restoration" strategies in Table 2. To alleviate further confusion, it is suggested here while maintaining the definitions of the terms from Gann et al. 2019, greater consistency may be achieved by using "restoration" in all three categories. In doing so natural (or spontaneous) regeneration becomes "natural restoration," assisted regeneration "assisted restoration," and reconstruction "reconstructive restoration" (Table 2).

Though providing clarity, these revised definitions will still be subject to the problem of comparing fundamentally different environments in comparing strategies without the use of paired sites or otherwise effectively controlling for confounding variables. By its nature, some details of the intervention required to effectively restore a site will be uniquely tied to site-level biotic, abiotic, logistical, and historical factors (Prach & del Moral 2015; Reid et al. 2018; Prach et al. 2020). Nonetheless, some generalities of ecological restoration have and can be made, and are of extreme practical utility.

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