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Review

Restoration, Reintroduction, and Rewilding in a Changing World

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The increasing abandonment of marginal land creates new opportunities for restoration, reintroduction, and rewilding, but what do these terms mean in a rapidly and irreversibly changing world? The 're' prefix means 'back', but it is becoming clear that the traditional use of past ecosystems as targets and criteria for success must be replaced by an orientation towards an uncertain future. Current opinions in restoration and reintroduction biology range from a defense of traditional definitions, with some modifications, to acceptance of more radical responses, including assisted migration, taxon substitution, de-extinction, and genetic modification. Rewilding attempts to minimize sustained intervention, but this hands-off approach is also threatened by rapid environmental change.

Restoration, Reintroduction, and Rewilding

The abandonment of marginal agricultural land in response to economic development [1] creates new opportunities for restoration, reintroduction, and rewilding, but what do these terms actually mean in a changing world? The prefix 're', meaning back or again in English, can be attached to almost any verb and appears in many terms used for active interventions in conservation biology. These include: reconnect, recover, recreate, reforest, rehabilitate, reinforce, reintroduce, remediate, repair, restock, restore, revegetate, and rewild. Most of these have obvious meanings, although some, such as rewild, are newly coined whereas others, such as restore, were imported into English with the prefix already in place. Thus ecological restoration is returning an ecosystem back to the way it was, reintroduction is returning a species back to where it used to live, and rewilding is returning a managed area back to the wild. These terms came into common use during the nostalgic phase of conservation biology, when the initial, preservationist phase was running out of pristine areas to protect and the main task facing conservationists was seen as returning degraded ecosystems to their previous state, or as close to this as possible [2,3].

Inherent in the use of the 're' prefix, however, is the question 'back to when?' and this has become increasingly difficult to answer. The idea that the environment is changing unidirectionally, rapidly, and irreversibly is not new, but it is only in the past decade that it has become widely accepted, and its consequences widely understood, in conservation biology [4,5]. In statistical terms, most environmental parameters of relevance to the distribution and abundance of organisms are now clearly non-stationary [4]. Natural systems at all levels have an inherent degree of resilience, but there are thresholds of environmental change – generally unknown in advance – beyond which system changes can become irreversible [6]. The impacts of anthropogenic climate change are largely responsible for this shift in viewpoint, but irreversible environmental changes also arise from other human impacts, including land-use legacies such

Trends

Abandonment of agricultural land provides an opportunity for creating new ecosystems, but the traditional use of past ecosystems as targets is likely to be inappropriate in a time of rapid environmental change.

There is no agreement among conservationists about how to replace the historically based reference frame, with opinions ranging from minor modification to the acceptance of increasingly radical alternatives including moving species outside their current native ranges, using non-native taxon substitutions to maintain key functions, and the acceptance of novel ecosystems that are different from any past analogs.

New technologies will facilitate the genetic modification of threatened species and make the 'de-extinction' of at least some species possible, providing new, controversial options for conservationists.

Future debates seem likely to increasingly focus on the degree of human intervention that is desirable as 'wildness' is seen as an increasingly important attribute. Rewilding attempts to minimize sustained intervention, but this approach is also threatened by rapid environmental change.

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as soil erosion, nutrient enrichment, population and species extinctions, and invasive alien species – all markers of the proposed new geological epoch, the **Anthropocene** (see Glossary) [4]. If we cannot go back, the traditional use of present and past ecosystems as targets and criteria for success in ecological interventions must be replaced by an orientation not just towards the future, but towards an uncertain future. Nostalgia is no longer an option, but what should replace it?

A Taxonomy of Terms

Three clusters of related terms are widely used in the recent (2010–2015) conservation literature (Table 1). One group fits under the umbrella of restoration in the broad sense of 'assisting the recovery of an ecosystem that has been degraded, damaged, or destroyed' [7] and includes restoration in the strict sense of restoring species composition, structure, and function to an approximation of a historical reference system, as well as the less ambitious targets of reforestation, revegetation, rehabilitation, and reclamation and the more human-focused approach of ecological engineering. A second group of terms fits under the IUCN's definition of conservation translocation, which is the movement and release of organisms for conservation reasons, including reintroduction and reinforcement, where the organisms are released within their indigenous range, as well as conservation introductions outside this range, to avoid extinction (assisted colonization) or to restore ecological function (ecological replacement or **taxon substitution**) [8]. Assisted migration, the most widely used term for overcoming dispersal limitations in species that will be harmed by climate change, is best understood as a subcategory of assisted colonization [9]. Two additional terms are not used in the IUCN guidelines: assisted

Table 1. A Taxonomy of the Major Terms Mentioned in this Review with a Brief Explanation of Their Recent Usage

Umbrella Term	Term	Key Element in Usage	Refs
Restoration	Restoration (in a strict sense)	Restoring original composition and function	[60]
	Functional restoration	Prioritizing function over species composition	[25]
	Reforestation	Restoring forest cover	[21]
	Revegetation	Restoring vegetation cover	[21]
	Rehabilitation	Returning highly degraded sites to usefulness	[60]
	Reclamation	Returning highly degraded sites to usefulness	[60]
	Ecological engineering	Creating sustainable ecosystems with both human and ecological value	[60]
Conservation Translocation	Reintroduction	Release within previous native range	[8]
	Reinforcement	Release into an existing population	[8]
	Assisted gene flow	Release within native range to assist adaptation	[61]
	Pleistocene reintroduction	Release within the Pleistocene range	[55]
	Conservation introduction	Release outside the native range	[8]
	Assisted colonization	To avoid extinction	[8]
	Assisted migration	To keep up with climate change	[9]
	Ecological replacement	To restore an ecological function	[8]
	Restocking	Mostly of harvested wild populations	[62]
Rewilding	Trophic rewilding	Introductions to restore top-down trophic interactions	[12]
	Pleistocene rewilding	Restoring to a pre-human Pleistocene baseline	[55]
	Ecological rewilding	Allowing natural processes to regain dominance	[13]
	Passive rewilding	Little or no human interference	[12]

Glossary

Anthropocene: a proposed geological epoch following the Holocene that began when human activities started to have a major impact on the global environment. Various starting dates have been suggested, with around 1800 or 1950 having the most support currently.

De-extinction: the process of bringing a species – or something closely resembling it – back from extinction. Advances in genetics and reproductive technology make it likely that this will be possible for some species within the next few years.

***Ex situ* conservation:** literally 'off-site conservation' that is, protecting an endangered plant or animal species outside its natural habitat, in zoos, botanical gardens, seed banks, or gene banks.

Taxon substitution: the replacement of an extinct species by a functionally similar substitute to restore ecological processes. The substitute may or may not be closely related to the extinct species.

Virtual fences: the reliance on techniques other than physical barriers to modify animal behavior at boundaries. Examples include sensory deterrents, biological barriers, training collars, and real-time tracking systems.