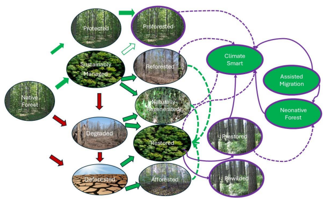

Emerging terms for reforestation forests

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Abstract

New terms have proliferated as international focus on forest condition surged because of the role forests play in climate change mitigation and adaptation. From umbrella concepts (e.g., forestation, nature-based solutions, and ecosystem restoration) to specific methods (e.g., forest landscape restoration, rewilding, and assisted migration), nuanced terms target different beginning conditions (non-forest, harvested, deforested, or degraded forest) and desired future conditions (forest cover, self-sustaining systems, ecological integrity). Human well-being may or may not be a relevant objective. Quality forest reproductive material is critical for the success of large-scale planting to meet current policy objectives and future needs as climate warming and increased intensity and frequency of extreme events add to reforestation backlogs embodied in the new terminology and attitudes toward forest management.

Keywords

Regeneration; Restoration; Proforestation; Prestoration; Rewilding; Climate-adapted; Nature-based solutions

Contents

1 Introduction

Forests continue to be extensively discussed in national and international policy forums because of their indispensable roles as a home for biodiversity (IPBES 2019; CBD 2021), providers of ecosystem services that contribute to sustainable development goals (Timko et al. 2018; Carr et al. 2021), and strategies for mitigating and adapting to climate change (Keenan 2015; Moomaw et al. 2020). Perhaps due to the ubiquity and importance of forests, and their place on the agenda of multiple international policy frameworks, new terms for managing forests have proliferated and older terms conflated. As terms become embedded at multiple sociopolitical levels in policies and programs, they take on legal and contractual meaning. Word meaning and usage are shaped by world views, value systems, and simply different ecological context and professional experience, for example, between researchers and practitioners (Rodriguez-Franco and Haan 2015; Gerwing 2023; Arts et al. 2024).

Science requires specialized terminology to communicate ideas and concepts, and scientific terms are usually regarded as more precise than everyday communication (Hirst 2003; Venhuizen et al. 2019; Soto et al. 2024). Nevertheless, meanings could change as new information and understanding develop. Meanings evolve over time and policies and popular understanding based on older scientific underpinning become obsolete and possibly maladaptive as data accumulate and paradigms change to accommodate new understanding. Forest ecosystems are dynamic, subject to periodic disturbances, and policies and values based on unchanging forests and their ecological attributes can be counter-productive, as can be seen in fire suppression policies (Kreider et al. 2024).

The dominance of English in scientific publishing ensures that the meaning of terms with different connotations (often with no direct translation) in other languages often will be unclear, introduce ambiguity, and hinder public engagement with diverse audiences while creating knowledge gaps. In the complex multicultural and multi-linguistic environment of forest science-policy forums, consensus concepts expressed in English might not be adequately expressed in other languages, philosophical frameworks, or cultures. Our objectives here are to (1) present a collection of current terms that are used ambiguously in discussions of forest transitions and climate mitigation and adaptation, (2) provide nuanced definitions of terms associated with forest transitions, specifically the regeneration phase of forest dynamics that includes reforestation and restoration, and (3) explore the relationships among the concepts underlying the terms. Undoubtedly, our selection of terms omits some terms that other authors would include; we do not claim our list is exhaustive. Our aim is to advance the understanding of this terminology among forestry professionals for clarity and to foster effective communication with multiple audiences. Adherence to a specific definition of a strategy or method is less important than mutual understanding of the expected outcomes.

2 Terms

Multiple definitions of forest condition can be distilled into three general states: (1) "native" forests, often under some form of protection or passive management, (2) forests actively managed for sustainability, or (3) degraded or deforested. The latter condition has been the focus of restoration efforts (Lamb et al. 2012; Stanturf et al. 2014b), a target that was extended to all ecosystems by the declaration of the United Nations Decade on Ecosystem Restoration 2021-2030 (United Nations Environment Agency, 2019 Resolution 73/284: United Nations Decade on Ecosystem Restoration Available online at: https://undocs.org/A/RES/73/284).

The starting point for understanding the nuances of the terms describing forest land use transitions is the native, intact forest (Figure 1). Although most reporting mechanisms use the FAO definition of a forest that sets minimum threshold for area (0.5 ha), percentage cover (10%), and tree height (5 m) (FAO 2018), it has been criticized for failing to sufficiently differentiate forest condition and quality, and unable to distinguish restoration and regeneration dynamics (Sasaki and Putz 2009; Putz and

Redford 2010; Chazdon et al. 2016; Sexton et al. 2016). Admittedly, the FAO definition is a minimum standard to qualify as forest and does not differentiate between different conditions or origins such as primary or secondary forest. Other forest conditions (e.g., naturally regenerated or planted, production or protected) are defined in general terms but specifics are up to the reporting countries.

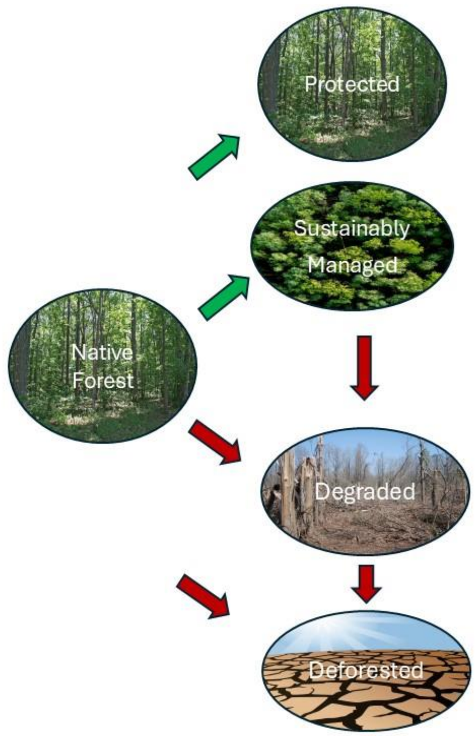

Figure 1. The possible management pathways for the intact native forest. Passive management (often called unmanaged forest) could be protected with human intervention excluded, subject to natural disturbances and stand dynamics. This also applies to forests too remote to be significantly impacted by humans. Active management can be done sustainably, providing a flow of ecosystem services. If unsustainably managed, i.e., exploited, the forest begins down the degradation pathway and possibly becomes deforested and converted to another land use.

Different terms describe the primary, original, or virgin forest that has not been significantly disturbed or influenced by human activity (Deal 2018), including primeval or old-growth (Bradshaw 2015). While this usually connotes large trees, complex stand structure, and high biodiversity, the extent of human influence is variable but usually means a forest that has never been logged (Gibson et al. 2011; Sabatini et al. 2018). In Europe, however, a primary forest allows for traditional human disturbances such as patch felling for shifting cultivation, coppicing, burning and selective/partial logging, as well as natural disturbances (Sabatini et al. 2018).

Thus, “protection” is a legal condition; not all primary forests are protected, and not all protected forests are without significant human influence (Leverington et al. 2010; Bennett 2015; Jones et al. 2018). A classification of protected areas by IUCN has six categories and only one, Category VI (protected areas with sustainable use of natural resources), allows low-level, non-industrial use of natural resources (Dudley et al. 2010). Just to confuse the issue, protection forests can mean forests serving a protection function, for example from avalanches (Brang et al. 2006). Conservation forest is an alternative term for passively managed forests, opposite to production or actively managed forests.

Much attention has been given to the degradation/deforestation trajectory, a gradient to a degraded forest lacking the structure, function, species composition, or productivity normally associated with the native forest yet still considered a forest land use. Whether or not human activity has degraded a forest is the difference between the definitions of degradation by the Convention on Biological Diversity (CBD[1]) and FAO (FAO 2011). The CBD definition requires human intervention, but the FAO includes any changes that negatively affect the structure or function of the stand or site (e.g., a tsunami, snow avalanche, or landslide).

Although degradation reduces the capacity of a forest to supply products and/or services, the land remains in forest land use and could still meet the FAO minima for a forest. Whereas, deforestation occurs when the land is converted to non-forest land use after the forest cover is removed (Runyan and D'Odorico 2016; FAO 2018). Human activity, such as conversion to agriculture, pasture, water reservoirs, mining, roads, or urban areas, historically have been the causes of deforestation (Mather 1992; DeFries et al. 2010; Curtis et al. 2018). Deforestation also includes areas that have been so impacted that a forest cannot sustain a canopy cover above the 10% threshold for forest land. Deforestation specifically excludes areas harvested or logged areas expected to regenerate naturally or with the aid of silvicultural measures.

Deforestation is easily defined and readily observable, despite the fact that some sources (and remote sensing techniques) mistake regenerating forests for deforestation. Degradation, however, is more challenging to detect and susceptible to different interpretations based on different standards, particularly what constitutes an unacceptable effect on the structure or function of the stand or site. For example, management for timber production has simplified and fragmented many forests (Riitters et al. 2000; Kuuluvainen et al. 2012; Knott et al. 2019). Aggressive fire suppression has caused "mesophication," a shift from open, shade-intolerant, fire-tolerant forests to closed, shade-tolerant, fire-sensitive forests (Nowacki and Abrams 2008; Amatangelo et al. 2011; Spinu et al. 2020). Intense browsing by high ungulate populations has caused regeneration difficulty and led to shifts in composition (Vodde et al. 2013; Stokely et al. 2020; Reed et al. 2021). Selective harvesting of high value species, so-called high grading, has caused shifts in composition to lower-valued species (Nyland 1992; Bravo and Montero 2003; Curtze et al. 2022). All of these actions are consequences of intentional methods to secure profit, protect resources and lives, or provide for hunter satisfaction. Nevertheless, all could be considered forest degradation and deemed unsustainable.

The concept of sustainability, long a feature in some form of enlightened forest management (Adamowicz and Burton 2003), has evolved from a singular focus on sustained timber yield to the broader Sustainable Forest Management (SFM), defined as "a dynamic and evolving concept intended to maintain and enhance the economic, social and environmental value of all types of forests, for the benefit of present and future generations" (FAO 2018). In Europe, SFM should "contribute to enhancing biodiversity or to halting or preventing the degradation of ecosystems, deforestation and habitat loss" (Regulation (EU) 2020/852 of the European Parliament and of the Council of 18 June 2020). An essential feature of SFM is successfully re-establishing a

[1] Convention on Biological Diversity (CBD) https://www.cbd.int/forest/definitions.shtml

forest following harvesting by various silvicultural methods (Matthews, 1991), that is, by passive (natural regeneration) or active (planting or direct seeding) methods.

A distinction sometimes is made between a planted forest and a forest plantation, including FAO (2018). An extreme position is that plantations are non-forest (e.g., https://www.rainforest-rescue.org/petitions/772/plantations-are-not-forests). This position stresses the frequent use in plantations of non-native species, dense spacing, and abbreviated rotation length. Nevertheless, the FAO definition of forests includes plantations as an intensively managed planted forest, usually of one or two species, not necessarily non-native, of the same age, at regular spacing (FAO 2018). In terms of stand dynamics, a plantation is a forest held in the stand initiation stage (Oliver and Larson 1996) by frequent harvest and intensive management. Indeed, many have noted the catalytic effect that even non-native species plantations can have on native species regeneration or how abandoned plantations can develop into secondary forests (Parrotta et al. 1997; Brancalion et al. 2019).

Planted forests can be made up of indigenous or exotic species. Semi-natural, or modified natural forests are comprised of indigenous species, sometimes mixtures, of different age classes, planted at different densities (Chokkalingam and De Jong 2001; Bongers et al. 2015). Secondary forests regenerate largely through natural processes after significant disturbance of the original forest at a single point in time or over an extended period and display a major difference in forest structure and/or composition with respect to nearby primary forest on similar sites (Chokkalingam and De Jong 2001; Bongers et al. 2015).

3 Terminology of forest regeneration

Forest scientists and practitioners have a well-developed vocabulary for describing methods for establishing new forest stands after harvest and other disturbances. *Forestation* is a generic word for establishing a forest by any means, whether or not an area previously was forested (Ford-Robertson 1971). *Forestation* includes the widely used terms describing establishment methods including *regeneration*, *reforestation*, and *forest restoration* (Figure 2). *Regeneration* occurs on previously forested land, by natural or artificial means (passive or active), usually with the same or similar forest type shortly after the previous forest was removed (Deal 2018). Confusingly, regeneration as a noun refers to saplings or seedlings in the newly developing stand. *Natural regeneration* relies on natural processes, depending on reproductive material existing on-site or dispersed to a site by various mechanisms (e.g., wind, water, animals). This could involve protection from herbivores by fencing or aided by soil preparation. *Reforestation* is the re-establishment of forests through artificial means, by planting and/or deliberate seeding on forest land, without any intervening period in another land use. *Reforestation* includes planting or seeding of temporarily understocked forest areas with existing forest cover, including coppice from trees that were originally planted or seeded. Some sources include natural regeneration as a method of reforestation (Deal 2018). *Reforestation* here, however, excludes *natural regeneration*, following *(*FAO 2018). Logically, therefore, natural regeneration results in a secondary forest and reforestation produces a semi-natural forest (longer rotation, extensive management) or a plantation (shorter rotation, intensively managed). Of course, the distinctions shorter/longer and extensive/intensive are imprecise and subject to local definitions.

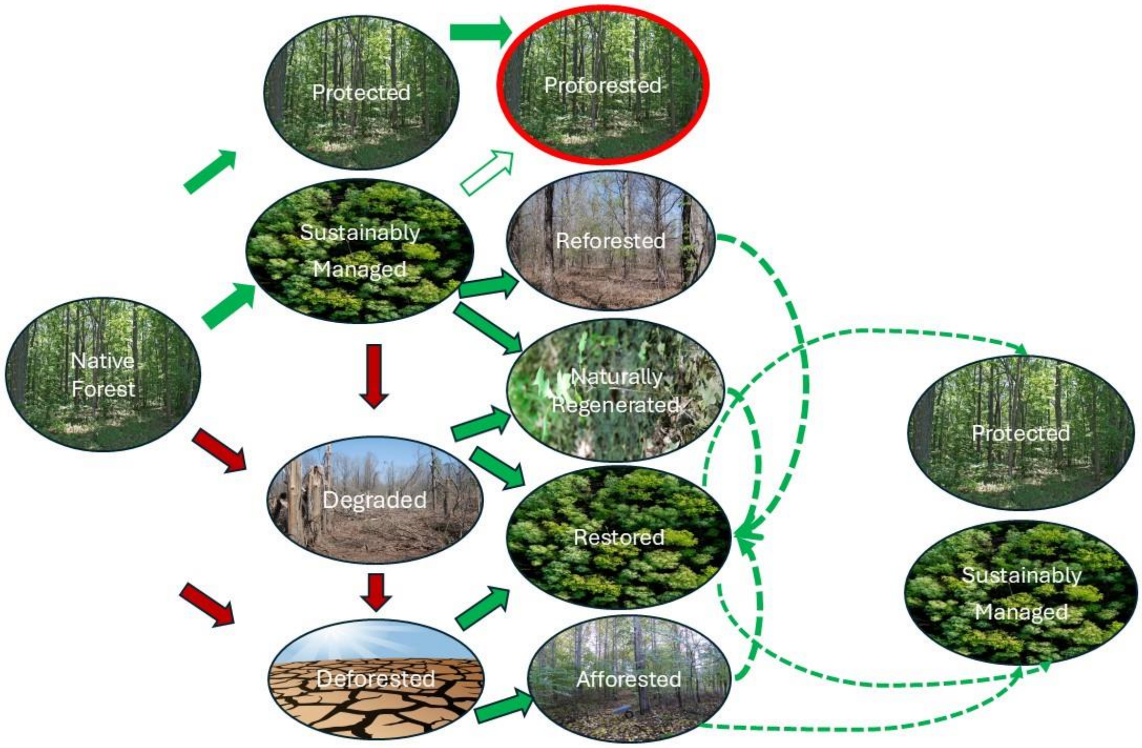

Figure 2. A harvested sustainably managed forest is regenerated quickly, either reforested (artificially by planting or direct seeding) or naturally regenerated. If the forest is maladapted to current or future climate, or management objectives change (e.g., from monoculture to mixed species), the forests can be restored with the resulting restored forest then managed passively (protected) or actively (sustainably). These potential pathways are indicated by dashed arrow. Degraded and deforested areas can also follow the restoration pathway. The degraded forest could also be abandoned and allowed to regenerate naturally. A deforested area could be restored by planting (i.e., afforested) or afforested for eventual sustainable management (e.g., an industrial plantation). An emergent term, proforestation, describes a form of passive management with the primary objective of carbon storage. Thos could apply to either the protected forest or to a sustainably managed forest with extended rotation.

Forestation also encompasses the transition from non-forest to forest, usually by *afforestation,* establishing a forest through planting and/or deliberate seeding on non-forest land (FAO 2018). There are at least 34 different definitions of *afforestation*, with only 14 that specify a change in both land cover and use (Lund 1999). Definitions also vary in the length of time an area has to have been non-forest, from a vague “within living memory” (FAO 2001) to a definite interval of five or more years. Further confusing the issue, the IPCC guidelines for greenhouse gas reporting (IPCC 2003) require a land use change for both *afforestation* and *reforestation*. Revegetation is the IPCC term that approximates the FAO *reforestation*.

Afforestation has acquired a negative connotation because historically it has meant single-species plantations, often of non-natives, for timber production or watershed protection (Dodet and Collet 2012). In tropical countries in particular, planting has been government sponsored on common lands without regard for traditional use by local communities (Kanowski 1997; Overbeek et al. 2012). In some places, *afforestation* of native grasslands has occurred or been proposed (Veldman et al. 2015; Veldman et al. 2017). Some local variants for *afforestation* are used, for example reafforestation to describe planting trees on farmland that was cleared of forest only within the last 20 years, or rainforestation, which essentially is afforestation using native rainforest species.

Forests can also develop “spontaneously” on non-forest land such as abandoned agriculture or pasture. Observations of such development has been called variously old field or secondary succession (Cramer et al. 2008), recolonization (Hodge and Harmer 1996; Bruun et al. 2010), or woody encroachment into other native vegetation (e.g., (García Criado et al. 2020; Langdon et al. 2020). As a process, this can be regarded as similar to natural regeneration.

Forest restoration uses many techniques common to silviculture (Stanturf et al. 2014a) and new terms have emerged, some as variations on traditional forestry terms. For example, assisted (or farmer assisted) natural regeneration involves humans protecting and preserving natural regeneration by removing barriers to their growth and survival, such as beating down competing vegetation, removing lianas, or protecting sprouts from domestic livestock. It may include some planting along with natural regeneration (FAO 2019; Kelly et al. 2021). Silviculture and *forest restoration* lack a clear separation (Wagner et al. 2000; Sarr et al. 2004). The distinction is that severely degraded, damaged, or destroyed forest ecosystems require extraordinary effort to recover functioning (Stanturf 2005; Putz and Redford 2010). Once restored, forests can be managed by sustainable silvicultural practices (Burton 2019) or simply protected, with appropriate adjustments for climate change and novel ecosystems (Lugo et al. 2020; Achim et al. 2021; Girona et al. 2023).

The terminology of restoration is extensive and remains confusing (Cairns Jr 1986; Aerts and Honnay 2011; Stanturf et al. 2014b; Mansourian 2018; Aronson et al. 2020). Early forms of restoration, such as passive secondary succession on abandoned farmland (Prach et al. 2007) or afforestation of heathlands (Madsen et al. 2015) were not called restoration. Ecological restoration, the process of assisting the recovery of an ecosystem that has been degraded, damaged, or destroyed (SERI 2004), grew out of practitioner efforts to re-establish historic conditions. The end-point goal initially was characterized by a reference stand, although this characterization evolved to recognize a range of historical conditions (Keane et al. 2009; Millar 2014). Recently, the end-point goal has again evolved to accommodate potential climate change (Harris et al. 2006; Pita et al. 2024). A broader concept, functional or trait-based forest restoration emphasized the restoration of abiotic and biotic processes in degraded ecosystems rather than “natural” or historical fidelity in composition and structure (Stanturf et al. 2014a; Stanturf et al. 2014b). In comparison to ecological restoration that focuses on the end point, functional restoration is more concerned with moving from degraded/deforested starting point to a more “natural” or resilient and functioning condition (Stanturf et al. 2014b).

Forest Landscape Restoration is an active process that “brings people together to identify, negotiate, and implement practices that restore an agreed optimal balance of the ecological, social, and economic benefits of forests and trees within a broader pattern of land uses” (Sabogal et al. 2015). *Forest Landscape Restoration* (FLR) differs from ecological restoration by operating at landscape scale and by emphasizing both regaining ecological functionality and enhancing human well-being (Stanturf and Mansourian 2020; Mansourian et al. 2021). *Forest Landscape Restoration* is intimately connected to the Bonn Challenge but other integrated landscape initiatives exist and include important co-benefits (Stanturf and Mansourian 2020; Stanturf et al. 2023). *Forest Landscape Restoration* explicitly engages diverse stakeholders in a participatory process. Notably, *Ecosystem Restoration* also has incorporated inclusive, participatory planning. The forest restoration literature seldom considers how the restored forest will be managed (Stanturf et al. 2017) except that the objective of ecological restoration, a self-sustaining forest, implicitly favors passive management (SERI 2004).

Proforestation is a new term (Figure 2, Table 1) for the practice of protecting existing natural forests to foster continuous growth, carbon accumulation, and structural complexity (Moomaw et al. 2019; Mackey et al. 2020). Proforestation has been advanced as a way to mitigate climate change by storing carbon in especially mature forests, and/or to address biodiversity decline (Moomaw et al. 2020; Law et al. 2022). *Proforestation* is also seen as a way to alter management of planted and naturally regenerated production forests to enhance carbon storage by lengthening rotation (Law et al. 2022) or extending harvest cycles and reducing cutting, primarily to increase carbon capture and storage (Moomaw et al. 2019; Mackey et al. 2020; Nunes et al. 2020). *Proforestation* aims to protect intact forests, significantly expanding reserved forest areas; if harvesting is to occur, the target is biological rather than economic maturity. *Proforestation* is appropriate for stable forest areas (Funk et al. 2019), i.e., those without not already significantly disturbed or at significant risk from storms, drought, wildfire, pests, or changing climate. Proforestation is primarily aimed at public lands (Moomaw et al. 2019) but could be attractive to private forest owners if they are compensated with carbon or biodiversity payments (Moomaw et al. 2019).

Another past-oriented term, *Rewilding*, emerged from academic literature in the 1980s from North American wilderness concepts (Carver et al. 2021). *Rewilding* originally defined a continental strategy to restore biodiversity through an interconnected network of reserves and re-introduction of apex carnivores and large herbivores, for example wolves and bison (Soulé and Noss 1998; Jørgensen 2015). Rewilding in European application includes non-native or domesticated proxies for extinct species to promote self-regulating biodiverse ecosystems (Corlett 2016; Jepson et al. 2018). Herbivores, rather than carnivores, are emphasized as the active restoration agent in Europe but spatial connectivity is emphasized in both Europe and North America. Variants of rewilding include reintroducing megafauna extirpated since the Late Pleistocene or releasing captive-bred animals to the wild, a form of assisted migration or species reintroduction (Novak et al. 2021). Passive rewilding overlaps with other passive restoration approaches that rely on natural regeneration to restore forest landscapes. *Rewilding* is distinguished from other forms of ecological restoration by the emphasis on establishing conditions for relinquishing direct human management, relying on autonomous biotic and abiotic agents and processes.

So far, the discussion has centered on the regeneration phase without explicitly considering how climate change will affect the future forest. Incorporating climate change into forest management can be for mitigation, adaptation, or both. Mitigation seeks to reduce greenhouse gas (GHG) emissions or to sequester and store carbon. Adaptation helps reduce vulnerability to the current or expected impacts of climate change. In practice, mitigation and adaptation are intertwined; adaptation is necessary to secure the benefits of mitigation and adaptation methods often have mitigation effects (D'Amato et al. 2011; Locatelli et al. 2011). Different forms of passive management (protection, *proforestation*) essentially ignore climate adaptation or rely on speciation and species migration without human intervention. Similarly, sustainable forest management moves along with business as usual or at most, incremental adaptation (Millar et al. 2007; Stanturf 2015). With the specter of a quite different climate and uncertain effects on forest ecosystems, new terms and concepts have emerged (Figure 3, Table 1).

Table 1. Traditional and emerging terminology describing goals and methods for regeneration, reforestation, and restoration of forests. The starting point describes the conditions where the term applies. Explicit ecological and social (livelihoods) objectives and climate focus are indicated, although particular applications may include an ecological or social objective or climate change mitigation or adaptation focus. (n/a indicates no explicit objectives or focus).

Starting Point	Term	Definition	Ecological objective	Social objective	Climate focus
Non-forest, harvested, degraded, and/or deforested	Forestation	The establishment of forest, naturally or artificially, on an area, whether previously carrying forest or not.	Forest cover	Ecosystem services	n/a
Non-forest	Afforestation	The direct human-induced conversion of land that has not been forest for a period of at least 50 years to forest through planting, seeding and/or the human-induced promotion of natural seed sources, where the conversion has taken place after 31 December 1989.	Forest cover	Ecosystem services	n/a
Harvested or degraded	Reforestation	The re-establishment of forests through artificial means, by planting and/or deliberate seeding on forest land, without any intervening period in another land use.	Forest cover	Ecosystem services	n/a
Harvested, degraded, and/or deforested	Natural Regeneration	The establishment of a plant or plant age class from natural seeding, sprouting, suckering, or layering. Assisted or farmer assisted natural regeneration are restoration methods where local people intervene to help trees and native vegetation by eliminating barriers and threats to their growth. It may include some supplemental planting.	Forest cover	Ecosystem services	n/a
Non forest, harvested, degraded, and/or deforested	Rewilding	A form of ecological restoration that relies on autonomous biotic and abiotic agents and processes to restore natural conditions. Rewilding may involve creation of an interconnected network of reserves (core areas and corridors) and the reintroduction of missing keystone species (including non-native proxies for extinct species), such as apex carnivores or large herbivores.	Self-sustaining ecosystem	Ecosystem services	n/a
Intact, harvested, or degraded	Proforestation	The practice of protecting existing natural forests to foster continuous growth, carbon accumulation, and structural complexity.	Self-sustaining forest	Ecosystem services	Mitigation
Degraded and/or deforested	Prestoration	Utilizing species in restoration efforts for which a site represents suitable habitat now and into the future.	Self-sustaining forest	Human livelihood	Adaptation
Non forest, degraded and/or deforested	Ecological restoration	The process of assisting the recovery of an ecosystem that has been degraded, damaged, or destroyed.	Self-sustaining forest	Ecosystem services	n/a

Non forest, degraded and/or deforested	Forest landscape restoration	An active process that brings people together to identify, negotiate, and implement practices that restore an agreed optimal balance of the ecological, social, and economic benefits of forests and trees within a broader pattern of land uses.	Ecological integrity	Human livelihood	n/a
Non forest, degraded and/or deforested	Ecosystem restoration	A process of reversing the degradation of ecosystems, such as landscapes, lakes, and oceans to regain their ecological functionality; in other words, to improve the productivity and capacity of ecosystems to meet the needs of society.	Self-sustaining forest	Human livelihood	n/a
Intact, harvested, degraded, deforested, and/or maladapted	Nature Based Solutions	Actions to protect, sustainably manage and restore natural or modified ecosystems that address societal challenges effectively and adaptively, simultaneously providing human well-being and biodiversity benefits.	Self-sustaining forest	Ecosystem services	n/a
Intact, harvested, degraded, deforested, and/or maladapted	Nature Based Climate Solutions	A variant form of Nature-based Solutions that allows for adapting an ecosystem beyond its current/historical condition.	Ecological integrity	Ecosystem services	Mitigation and/or Adaptation
Intact, Intact, harvested, degraded, deforested, and/or maladapted	Climate Smart, Climate Adapted Forestry	A targeted approach or strategy to increase the climate benefits from forests and the forest sector, in a way that creates synergies with other needs related to forests. The approach builds on three pillars: reducing and/or removing greenhouse gas emissions to mitigate climate change, adapting forest management to build resilient forests, and active forest management aiming to sustainably increase productivity and provide all benefits that forests can provide.	Ecological integrity	Ecosystem services	Mitigation and/or Adaptation
Intact, harvested, degraded, deforested, and/or maladapted	Assisted Migration	Assisted migration moves seeds or other forest reproductive material from one bioclimatic zone to another, to preserve economic goods, sustain ecosystem services, or avoid species extinction.	Ecological integrity	n/a	Adaptation

Prestoration is an emergent term with a future-orientation. *Prestoration* is defined as utilizing species in restoration efforts for which a site represents suitable habitat now and into the future (Butterfield et al. 2017; Svensson et al. 2023). This could be favoring species currently in low abundance or of secondary importance in current forest stands but expected to be highly adapted to future conditions, for example *Acer rubrum* in northern hardwood forests in the eastern United States (Stanturf et al. 2014a). *Prestoration* also seeks to restore ecosystem structure and function in a changing climate (Butterfield et al. 2017) by introducing one or several species into a degraded habitat. *Prestoration* in that sense is similar to *Assisted Migration* (AM), although AM is more concerned with conservation of the species being translocated (Williams and Dumroese 2013; Stanturf et al. 2024b) and *Prestoration* with adapting a stand to altered climate.

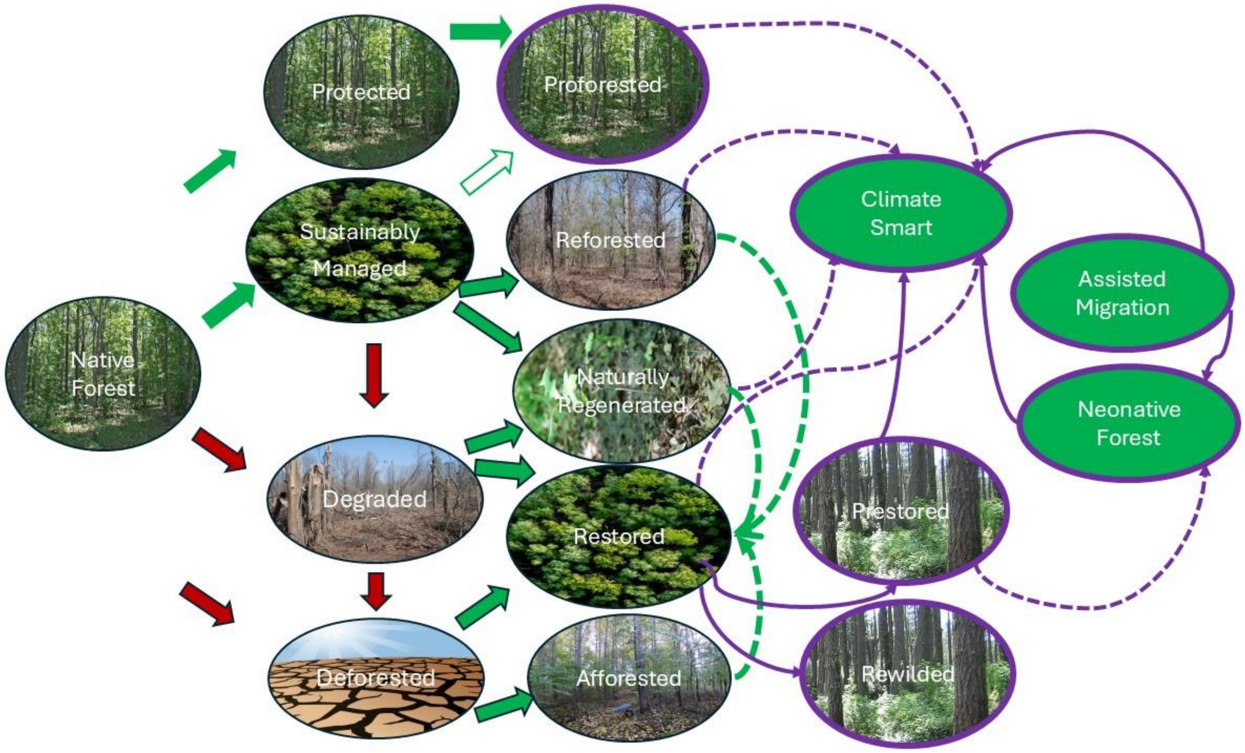

Figure 3. New terminology has emerged to describe pathways focused on climate change mitigation and adaptation, indicated by purple arrows (dashed for speculative pathways). The conditions of protected or sustainably managed shown in Figure 2 are not shown here for simplicity but they now follow the pathway to climate smart (or adapted) forests. A new term, rewilding, has been introduced as a form of restoration as essentially a form of passive management. Specific conditions for climate adaptation are determined locally. Proforestation would seem to be climate smart but although extending the rotation mitigates climate change, it also increases exposure to wildfire, insects and diseases, and windstorms and may not be adaptive. Managed forests, including commercial plantations, can be climate smart, depending on local conditions (i.e., the rate and direction of climate change and the management actions implemented). Assisted migration can be introduced to climate adapted species or provenances of native species; neonative forests can emerge spontaneously from movement of species or release of non-native or subordinate native species or intentionally by human intervention.

Assisted Migration is an incremental, anticipatory, or transformational adaptation method (Stanturf et al. 2024b) that facilitates natural range expansion in response to climate change (Aitken and Bemmels 2016; Sang et al. 2021). *Assisted Migration* can occur over three target migration distances by moving species or provenances: (1) within their current range, assisted population migration; (2) from the current range to suitable areas adjacent to the current range, assisted range expansion; or (3) far outside its current range, assisted species migration (Pedlar et al. 2012; Williams and Dumroese 2013; Stanturf et al. 2024b). The objectives for *Assisted Migration* include preserving economic goods, sustaining ecosystem services, or avoiding species extinction. Experience with invasive species has demonstrated that introductions risk ill-effects, advising caution with *Assisted Migration* (Pedlar et al. 2012; Breed et al. 2013; Breed et al. 2018), but arguably, climate warming already has adversely affected many forest ecosystems and not acting may be riskier than acting (Palik et al. 2022; Xu and Prescott 2024).

Over a long time, species assemblages change because of local extinctions, natural immigration, and evolution (speciation). Climate change is concerning because the rate of change outstrips the rate of species migration (Aitken et al. 2008). *Neonative Forests* are new assemblages of species that arise because of species range expansion in response to human-induced environmental change (Lugo et al. 2020; Essl et al. 2021). Forest types, defined by their dominant vegetation (Deal 2018), are not static. *Neonative Forests* describe novel assemblages that arise spontaneously as native species migrate under changing climate, at the leading or trailing edge of species distributions. Another pathway to *Neonative Forests* could be the incorporation of established invasive on-native species with useful functional traits, instead of attempting their exclusion (Nyssen et al. 2024). *Neonative Forests* might also arise through *Assisted Migration* and the intentional intermixing of native and non-native tree species or provenances better adapted to future climate conditions (Bolte et al. 2009; Essl et al. 2021).

Climate-Smart, or Climate-Adapted Forestry, has the objective of increasing the climate benefits from forests and the forest sector, in a way that creates synergies with other needs related to forests. The approach builds on three pillars: reducing and/or removing greenhouse gas emissions to mitigate climate change, adapting forest management to build resilient forests, and active forest management aiming to sustainably increase productivity and provide all benefits that forests can provide (Bowditch et al. 2020; Verkerk et al. 2020; Santopuoli et al. 2021; Hallberg-Sramek et al. 2022; Shephard et al. 2022). Thus, *Climate-Smart Forestry (CSF)* is a form of *Sustainable Forest Management* with a future-orientation. Forest management practices consistent with CSF are specific to local context but may include reducing stand density to better cope with drought, promoting growth by thinning, and prescribed fire to manage fuel loads and reduce wildfire risk. Practices specific to the regeneration phase include site preparation to enhance survival and growth (e.g., bedding, mounding, ripping to improve soil conditions) or chemical treatments to control pests and competing vegetation. Planting diverse mixtures of species or provenances for genetic or trait diversity spreads the risk of extensive forest loss (Nabuurs et al. 2017; Nabuurs et al. 2018; Bowditch et al. 2020).

Climate-Smart Forestry must produce stands adapted to uncertain future conditions and at the same time, forests that are robust under the current climate. Novelty already is a multifaceted challenge (Radeloff et al. 2015; Lugo et al. 2020; Schittko et al. 2020) and the uncertain future could bring increased novelty in climate means and extremes as well as novel disturbance regimes (Williams and Jackson 2007; Mahony et al. 2017; Leverkus et al. 2021; Serrano et al. 2022).

Any method of *Forestation* (forest creation or regeneration) could be considered CSF if appropriately future-oriented (Figure 3). Certainly *Prestoration, Assisted Migration,* and *Neonative Forests* would qualify. Whether *Proforestation* is *CSF* would depend on projected changes in climate and disturbance regime in the area of a forest managed on extended rotation for mitigation benefits. A forest projected to have relatively stable climate, or in a climate refugium, could endure under those conditions (Frelich et al. 2020) but on the whole, *Proforestation* lacks a credible future orientation.

Zooming back out to the broader policy environment, *Nature-Based Solutions (NBS)* is an umbrella concept for employing natural systems to address interconnected challenges discussed in international climate and biodiversity policy fora such as the UN Framework Convention on Climate Change and the UN Convention on Biological

Diversity (Nesshöver et al. 2017; Seddon et al. 2021). It is a relatively recent term (MacKinnon et al., 2008; MacKinnon, 2009) and two different definitions for NBS have been proposed. The European Commission definition arose from urban development and environmental engineering (EuropeanCommission et al. 2015). It stresses the use of blue-green infrastructure (BGI), with a decidedly urban flavor (Depietri and McPhearson 2017; Andersson et al. 2019).

The definition proposed by the International Union for the Conservation of Nature (IUCN) is the most commonly used and is more focused on natural systems: "Actions to protect, sustainably manage and restore natural or modified ecosystems that address societal challenges effectively and adaptively, simultaneously providing human well-being and biodiversity benefits" (Cohen-Shacham et al. 2016). The *Nature-Based Solutions* concept was operationalized into eight principles and standards (Cohen-Shacham et al. 2019; IUCN 2020) that include *NBS* result in a net gain to biodiversity and ecosystem integration and NBS are economically viable. This definition seeks to avoid moving ecosystems further from their natural state distinction and seems to ignore the need to adapt to changing climate (Ellis et al. 2024). Notwithstanding the relative newness of *Nature-Based Solutions*, forest management (broadly 'forestry') has long been concerned with managing land using natural processes (Phillips 1931; Attiwill 1994; Perry 1998) and *SFM* could be considered a subset of *NBS* as long as relatively conservative measures are employed, i.e., incremental adaptations (*sensu* (Stanturf 2015) to changing climate.

Nature-Based Climate Solutions (NBCS) is a variation of *NBS* that allows, on the contrary, for adapting an ecosystem beyond its current/historical condition (Buma et al. 2024). Thus, *NBCS* would consider assisted migration of species in forestry (Pedlar et al. 2012; Dumroese et al. 2015; Stanturf et al. 2024b) an appropriate strategy while *NBS* probably would not (Ellis et al. 2024). *Climate-Smart Forestry,* therefore, is a subset of *Nature-Based Climate Solutions* even in its most transformational forms.

4 Discussion

A rapidly changing climate, expanding human population expecting higher living standards, and armed conflicts, the so-called polycrisis (Lawrence et al. 2024), ensure the future will be wildly divergent from the present. Despite the uncertainty, multiple efforts by many actors globally are underway, seeking to reverse deforestation and forest degradation, combat climate change, and conserve biodiversity. Forests are central in these efforts for obvious reasons (Carrasco et al. 2017; IPBES 2019; Pan et al. 2024) and massive tree planting schemes have been a response, including the Bonn Challenge to restore 350 million hectares to forests by 2030, and especially large-scale tree planting programs in many countries like the Great Green Walls across Africa and China. Central to efforts aimed at forest creation, renewal, and restoration is the critical regeneration or stand initiation phase (Grubb 1977; Oliver and Larson 1996). Some *forestation* efforts draw on the centuries of experience and research of forest scientists, others seek new paths. Some use the well-established forest science terminology for regeneration, but from new disciplines and non-foresters, new terms have emerged for how forests should be managed to meet the polycrisis.

Forestry professionals engaging in policy discussions or attempting to communicate with the public about forests and climate change face numerous challenges. Probably the most harrowing encounters are dialogues with audiences who equate forest management with logging and regeneration with deforestation. Attempting to counter such values-based views with scientific evidence probably will not succeed. In policy arenas where evidence-based positions carry more sway, expressing science concepts with precise terminology can appear to the non-scientist as using needlessly obtuse jargon. Further difficulty arises when scientific terms change meaning as knowledge expands and concepts evolve; policies and popular understanding based on older scientific understanding can become maladaptive. Communicating about forests to non-technical audiences with clarity may of necessity require simplification but, in the process, essential nuance and important local context can be lost. Translation of English terms for nature-based concepts into other languages may be difficult, and vice versa, leading to incomplete understanding.

To bring a semblance of order to the expanding population of terms about forests and their management, we began with the intact, native forest and the possible transitions to other conditions (passive management/protection, active/sustainable management, degradation, or deforestation/non forest (Figure 1). Different terms related to regenerating or creating a forest followed, under the umbrella term of forestation. Possible methods, depending on the starting point, included reforestation (artificial regeneration), natural regeneration, afforestation, or variations of restoration. Key differentials were whether they explicitly included a livelihood component or were future-oriented toward climate mitigation, adaptation, or both (Table 1).

Nature Based Solutions (NBS) and *Nature Based Climate Solutions* (NBCS) are over-arching terms that encompass activities that protect, sustainably manage, and restore natural or modified ecosystems. We placed forest management and forest restoration activities under the *NBS* umbrella, and along with *Climate Smart Forestry* and *Assisted Migration* under *NBCS*. The distinction between *NBS* and *NBCS* is how much novelty they tolerate, that is, how far from current forest composition and structure they allow (Radeloff et al. 2015).

Umbrella or visionary terms that express regeneration goals include *Forestation, Proforestation,* and *Prestoration* (Table 1). *Forestation* is a traditional forestry term for regeneration that refers to any condition without forest cover (Ford-Robertson 1971), whether following a harvest or a previously non-forest land use. The ecological target of *Forestation* is establishing forest cover; *Forestation* has no explicit social (livelihoods) or climate target. *Proforestation* emerged recently and may apply to any starting point, forested or not, but aimed primarily at intact forests, protecting or managing them on extended harvest cycles for climate mitigation (Moomaw et al. 2019). Conceivably *Proforestation* could be a restoration strategy for degraded forests. *Prestoration* has emerged as a restoration strategy that prioritizes adaptation to altered climate, favoring species adapted to current as well as future site conditions, focusing on degraded or deforested conditions (Butterfield et al. 2017).

These umbrella terms all are implemented by a gradient of the intensity of inputs or methods for controlling composition or structure (Chazdon et al. 2021; Stanturf et al. 2024a) that ranges from low/passive with no or minimal planting (*natural regeneration, rewilding*) or to high/active methods that include planting or direct seeding (*afforestation, reforestation, assisted migration*), as specified in Table 1. Low/passive methods such as *natural regeneration* and *rewilding* may exhibit low levels of control or inputs, but they can be quite costly if fencing is required to exclude herbivores out of regenerating areas (Löf et al. 2021; Pinchot et al. 2022; Brault et al. 2023) or if a rewilding site must be enclosed to keep herbivores inside (Root-Bernstein et al. 2018; Pedersen et al. 2019). Thus, low intensity methods are not necessarily low cost activities (Zahawi et al. 2014).

The long-term goal or desired future condition of the umbrella concepts and implementation methods might not be explicit. For example, the ecological goal of a self-sustaining forest (Table 1) implies little or no active management, possibly having protected status. The goal of a sustainably managed forest would be ecological integrity that may include or lack a climate focus on adaptation. While all terms state or imply the goal of providing ecosystems services, only one term, forest landscape restoration, specifically includes a social objective, a human livelihoods component.

In light of the rapidly evolving landscape of forest management, the terminology used to describe efforts in forest restoration, afforestation, and related interventions has grown increasingly complex and nuanced. The proliferation of terms reflects the growing recognition of forests' critical role in mitigating climate change, enhancing biodiversity, and providing ecosystem services. As this review has shown, these emerging terms are shaped by a range of factors, including the starting conditions of a given forested area, the desired ecological and social outcomes, and the degree of human intervention required.

Communication is difficult under the best circumstances and even among forest scientists the same terms often have a different meaning, or they are interpreted differently in their local application. Communicating forest science to a lay audience is likely to be even more challenging. Frequent changes in meaning of old and existing terms and new terms contribute to the confusion. Absent a global authority to discus, adopt, and implement terminology and how it is used, different groups will use different terms to describe the same forest conditions or practices, or conversely, they interpret and use the same terms in different, even contradictory, ways.

The conceptualization of forest management now spans a broad spectrum, from passive or low intensity methods like proforestation and rewilding, which emphasize minimal human interference, to active techniques such as assisted migration and afforestation, which involve deliberate human intervention to shape forest ecosystems. Notably, newer concepts such as prestoration and neonative forests underscore the importance of future-oriented strategies, addressing both the immediate and anticipated impacts of climate change on forest ecosystems. These approaches mark a significant shift in forest restoration practices by prioritizing the selection of species that will be resilient under future climate conditions.

Furthermore, the terminology associated with Nature-Based Solutions (NBS) and Nature-Based Climate Solutions (NBCS) illustrates how forest restoration is now viewed not only as an ecological challenge but also as a socio-political one, with direct implications for human livelihoods and climate policy. By fostering a clearer understanding of these terms among forest professionals and policymakers, this article seeks to advance both scientific clarity and practical collaboration across disciplines. Achieving successful forest restoration and management in the 21st century will require not only technical expertise but also a shared understanding of the language that defines our objectives and strategies.

As the field continues to evolve, it will be essential for forestry professionals, researchers, and policymakers to remain adaptable, ensuring that the terms and methods used in forest management reflect the latest scientific understanding while also accommodating the cultural and linguistic diversity that characterizes global forest policy discussions. This will enable more effective communication and collaboration in the critical task of restoring and managing the world's forests in an era of unprecedented environmental change.

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