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Tamm review

Contemporary forest restoration: A review emphasizing function

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ABSTRACT

The forest restoration challenge (globally 2 billion ha) and the prospect of changing climate with increasing frequency of extreme events argues for approaching restoration from a functional and landscape perspective. Because the practice of restoration utilizes many techniques common to silviculture, no clear line separates ordinary forestry practices from restoration. The distinction may be that extra-ordinary activities are required in the face of degraded, damaged, or destroyed ecosystems. Restoration is driven by the desire to increase sustainability of ecosystems and their services and restoration is likely to have multiple goals arising from the motivations of those involved. The process of setting restoration objectives translates vague goals into feasible, measurable targets and ultimately actions on the ground. Our objective for this review is to synthesize the science underpinning contemporary approaches to forest restoration practice. We focus on methods and present them within a coherent terminology of four restoration strategies: rehabilitation, reconstruction, reclamation, and replacement. While not a consensus terminology, these terms have a logical foundation. Rehabilitation restores desired species composition, structure, or processes to a degraded ecosystem. Reconstruction restores native plant communities on land recently in other resource uses, such as agriculture. Reclamation restores severely degraded land generally devoid of vegetation, often the result of resource extraction, such as mining. Replacement of species (or their locally-adapted genotypes) with new species (or new genotypes) is a response to climate change. Restoration methods are presented as available tools; because adding vegetation is an effective restoration technique, the discussion of methods begins with a description of available plant materials. We then discuss altering composition under different initial overstory conditions, including deployment methods depending upon whether or not an overstory is present, how much of the landscape will be restored, and the complexity of the planting design. We present some major approaches for altering structure in degraded forest stands, and describe approaches for restoration of two key ecosystem processes, fire and flooding. Although we consider stand-level designs, what we describe is mostly scalable to the landscape-level. No restoration project is undertaken in a social vacuum; even stand-level restoration occurs within a system of governance that regulates relationships among key agents. Gathering information and understanding the social dimensions of a restoration project is as necessary as understanding the biophysical dimensions. Social considerations can trump biophysical factors.

Contents

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1. Introduction

Worldwide, an estimated 2 billion ha of forests are degraded (Minnemayer et al., 2011) with roughly half in tropical countries (ITTO, 2002). Lack of consensus on the definition of "degraded" stymies efforts to inventory these forests (FAO, 2010). Nevertheless, several international efforts are directed toward restoring degraded ecosystems and have set goals, such as restoring 15% of degraded ecosystems (CBD, 2010) or 150 million ha of deforested and degraded forests (WRI, 2012) by 2020. In addition to anthropogenic alterations of global ecosystems (Foley et al., 2005; Kareiva et al., 2007; Ellis et al., 2013), the anticipated effects of global climate change suggest the future need for restoration will be even greater (Steffen et al., 2007; Zalasiewicz et al., 2010).

Restoration is driven by societal values that are often in conflict (Lackey, 2001) and motivated by vague goals (Clewell and Aronson, 2006) that generally fall within the concept of sustainability, for instance: repairing ecosystem functions or other desired attributes (Ciccarese et al., 2012), enhancing or enlarging specific ecosystems and habitat for species of concern (Thorpe and Stanley, 2011), or enhancing ecosystem capital, such as biodiversity (Seabrook et al., 2011). Although sociopolitical processes set goals that may be strategic, more often goals are pragmatic (Burton and Macdonald, 2011; Hallett et al., 2013; Burton, 2014) determined by those with the power to decide that restoration will occur and willing to pay for it. Because of this human component, attempts to formulate a universal definition of restoration or its various aspects continue to generate discussion and elude consensus (Stanturf, 2005; Hobbs et al., 2011).

The process of setting restoration objectives, conditioned by the scale, social context, and level of restoration desired, translates vague goals into feasible, measurable targets and ultimately actions on the ground. Given the large areas in need of restorative treatments, landscape-level approaches that emphasize functional ecosystems may be more effective than traditional approaches focusing on historical composition and structure of small areas, such as forest stands (Lamb et al., 2012; Oliver, 2014). A defining feature of functional restoration is its focus on sustainability of multi-scale ecosystem processes, including hydrologic cycles, ecosystem productivity, food web interactions, rather than particular compositions and structures. The focus prevalent in many restoration programs has been (and often still is) on restoring stands to some previous, putatively "natural" state (Burton and Macdonald, 2011; Stanturf et al., 2014). A functional perspective, as a primary objective of restoration, becomes more urgent and logical given unprecedented rates of change in global drivers of ecosystems, including climate change and changing land use. Given these changes, a focus on historic compositions and structures becomes less achievable because the characteristics deemed desirable now may become unsustainable in the not too distant future. A focus on restoring function avoids this pitfall and is still directly related to achieving stakeholder goals of ecosystem sustainability, economic efficiency, and social wellbeing, as derived from functioning landscapes.

In most landscapes, broadening the scope of a restoration beyond the site or stand will require integration of the restoration activity with other land uses, beyond that usually included in restoration planning (Stanturf et al., 2012a,b). Further, restoration will have to accommodate the diverse management objectives of multiple owners, and explicitly incorporate human livelihood needs (Lamb et al., 2012; Maginnis et al., 2012; Sayer et al., 2013). Achieving the ultimate restoration goal may require meeting subordinate, incremental objectives through sound ecological principles, applied dynamically with flexibility to meet the scope and limitations of each unique project (Pastorok et al., 1997; Ehrenfeld, 2000; Joyce et al., 2009). Where restoration will occur, how much will be restored, and what methods will be used to achieve it are choices that must be made (Clement and Junqueira, 2010; Wilson et al., 2011; Pullar and Lamb, 2012). Our goal is to synthesize the science underpinning contemporary, international approaches to forest restoration, particularly from a functional perspective, with focus on methods presented within a coherent terminology of four restoration strategies: rehabilitation, reconstruction, reclamation, and replacement. Restoration methods are presented as available tools, including appropriate materials and methods for altering composition, structure, and processes. We conclude with a discussion of elements for successful restoration, including the social context, ways for prioritizing restoration treatments, and determining restoration success through monitoring and evaluation.

2. Objectives and strategies

Restoration objectives can be broadly classified into overarching strategies, such as *rehabilitation, reconstruction, reclamation,* and *replacement* (Stanturf and Madsen, 2002; Stanturf et al., 2014). While we make no claims that this terminology represents consensus or widespread usage, we suggest an underlying logic exists to these terms. Moving from rehabilitation to reconstruction to reclamation encounters increasing levels of degradation, dysfunction, and loss of productivity, services, and sustainability. The several objectives and associated strategies, methods, and initial operations are summarized with examples in Table 1. Because restoration employs many techniques common to silviculture, they often overlap without clear separation (Wagner et al., 2000; Sarr et al., 2004; Sarr and Puettmann, 2008). Certainly, the extra-ordinary activities required in the face of degraded, damaged, or destroyed ecosystems set restoration apart. For example, where forest cover has been removed to use land for other purposes, such as agriculture, this is deforestation (Stanturf, 2005; Putz and Redford, 2010) and can be restored through afforestation; this is distinctly different from reforestation, a normal forestry practice of establishing a new stand following harvest.

2.1. Rehabilitation

Rehabilitation applies to restoring desired species composition, structure, or processes to an existing, but degraded ecosystem. Land managers may have many rehabilitation options and methods (Table 1) depending on the subordinate objective(s). Pursuing these options alters the degraded ecosystem so that resulting natural processes will lead to the desired function (primary objective). Although a climax seral state is often the ultimate restoration goal and may be the declared state for discussing restoration goals (Stanturf et al., 2014), other seral states may be desired in functional restoration, particularly to support threatened or endangered species. In fact, Swanson et al. (2010) and Greenberg et al. (2011) argue that early seral communities are disproportionately lacking in some forest landscapes.

Two specific approaches to rehabilitation, conversion and transformation, share some characteristics, but conversion seems to apply to wholesale removal of an existing overstory and replacement with other species (Zerbe, 2002; Spiecker et al., 2004; Hansen and Spiecker, 2005). Windstorms, hurricanes, and other intense disturbances provide opportunities for conversions when otherwise it would be uneconomical or engender social opposition (Drouineau et al., 2000; Brunner et al., 2006; Harmer and Morgan, 2009). Transformation applies to a more extended process of partial removals and species replacement (Pommerening, 2006) but obviously the demarcation between these approaches is indistinct (Kenk and Guehne, 2001; Nyland, 2003). Often, the availability of markets for removals would determine whether to transform or convert.

Forests may be degraded by myriad processes and rehabilitation may be achieved using several operations to augment or remove species (Fig. 1) or to restore natural disturbance processes, especially fire (Fig. 2). Often a combination of methods will be needed to meet objectives, including altering structure by thinning, planting desired woody species to restore composition, and seeding native understory plants to enhance biodiversity as well as to serve as fine fuel to carry prescribed fires (Brockway et al., 2005; Walker and Silletti, 2006). For example, to meet the great interest in restoring *Pinus palustris* ecosystems in the southeastern USA, appropriate sites may require conversion from other pine species or rehabilitation of degraded stands. Proper diagnosis of initial conditions in terms of site, overstory and understory condition leads to an initial restoration prescription (Table 2).

2.2. Reconstruction

Reconstruction refers to restoring native plant communities on land recently in other resource uses, such as crop production or pasture. Active approaches could include ameliorating the soil to increase organic matter content, decreasing bulk density, or reducing the weed seedbank; outplanting seedlings; or direct seeding. Passive approaches rely on recolonization of open land by natural dispersal means, but success can be limited by proximity to appropriate source plants and composition of initial seral species (Benjamin et al., 2005). A combination of approaches may be useful as well—actively seeding or planting seedlings of keystone species at wide spacing and subsequently relying on passive dispersal to fill remaining niches with other desired species (e.g., Scowcroft and Yeh, 2013).

Reconstruction may appear to begin with a blank template but previous land use often leaves a legacy of degraded soil and competing vegetation (Arnalds et al., 1987; Friday et al., 1999; Stanturf et al., 2004). Nevertheless, reconstruction affords the opportunity to restore ecosystems that have simple or complex structures, comprised of an overstory with one or many species and an understory that develops from recolonization or planting and seeding (Lamb, 2011). Decisions on which methods to use will be framed by overall objectives, initial site conditions, and landscape context.

2.3. Reclamation

Reclamation applies to severely degraded land generally devoid of vegetation, often the result of belowground resource extraction, such as mining (Fig. 3) or work pads associated with oil and gas drilling. On such sites, more intensive management techniques are usually necessary to revegetate the site although natural recolonization can be effective (Prach and Pysek, 2001; Prach and Hobbs, 2008). The methods may include amelioration to improve soil physical, chemical, and biological status; seeding or outplanting seedlings; and providing regular irrigation and weed control to ensure early survival (Fields-Johnson et al., 2012; Evans et al., 2013; Zipper et al., 2013). Occasionally non-native species are used as nurse plants to encourage the ultimate occurrence and proliferation of native vegetation (Parrotta, 1992; Parrotta et al., 1997; Lamb et al., 2005). Reclamation may require multiple interventions to achieve subordinate objectives, with the ultimate desired function not achieved for decades.

2.4. Replacement

As climate changes, another strategy will involve replacement of species (or their locally-adapted genotypes) being displaced by climate change with new species (or new genotypes of that species) that have been historically absent from the site (see Williams and Dumroese, 2013). Classifying the "nativity" of this replacement species or germplasm is a vexing topic, as the current definition of nativity can be vague, dependent on situation, agency, professional status, and other criteria (Smith and Winslow, 2001). Just as restoration goals should be scientifically grounded, dynamic, flexible, project specific, and realistic, future working definitions of "native" may need to be similarly conditioned (Shackelford et al., 2013).

Table 1
Contemporary restoration objectives, strategies, and methods.

Objective	Present forest condition	Strategies	Methods	Initial operations	References
Repair function					
Hydrologic (watershed, riparian, coastal)	Deforested (agricultural land use, open land, abandoned agriculture)	Reconstruction	Native re-colonization	Re-establish hydrologic connectivity; physical processes	Friedman et al. (1995), Stanford et al. (1996), Roni et al. (2002), Klimas et al. (2009), Hughes et al. (2012) and Jarzemsky et al. (2013)
			Afforestation, whole area	Site preparation; plant or direct seed natives or non-natives	Stanturf et al. (1998, 2000), Allen et al. (2001), Lockhart et al. (2003), Löf et al. (2004), Gardiner and Oliver (2005), Groninger (2005), Jõgiste et al. (2005), Lee and Suh (2005), Weber (2005), Ren et al. (2007), Rey Benayas et al. (2008), Weber et al. (2008, 2011), Onaindia and Mitxelena (2009), Dey et al. (2010), Booth (2012), Harper et al. (2012) and Xi et al. (2012)
				Interplant; nurse crop; fast/slow growing natives or non-natives; inter-plant vegetables	Arnalds et al. (1987), Ashton et al. (1997), Gardiner et al. (2004), Aradóttir (2005), Lamb et al. (2005), McNamara et al. (2006), Nichols and Carpenter (2006), Blay et al. (2008), Stanturf et al. (2009), Blay (2012), Chazdon (2013) and Douterlungne and Thomas (2013)
				Plant mixtures of natives; framework species method	Ashton et al. (2001), Leopold et al. (2001), Blakesley et al. (2002), Elliott et al. (2003), de Souza and Batista (2004), Lockhart et al. (2006, 2008), Lamb (2011) and Corbin and Holl (2012)
			Afforestation, partial area	Nucleation, cluster	Schönenberger (2001), Manning et al. (2006), Zahawi (2008), Zahawi and Holl (2009), Holl et al. (2011), Corbin and Holl (2012), Díaz-Rodríguez et al. (2012) and Saha et al. (2012)
			Afforestation, linear planting	Site preparation; plant or direct seed natives or non-natives	Newmark (1993), Mann and Plummer (1995), Schultz et al. (1995), Parkyn et al. (2003), Kindlmann and Burel (2008), Mize et al. (2008) and Bentrup et al. (2012)
			Simple mixtures	Interplant; fast/slow growing; natives or non-natives	Pommerening and Murphy (2004) and Stanturf et al. (2009)
			Complex mixtures	Plant mixtures of natives or non-natives; planting group method, framework species method; rainforestation	Blakesley et al. (2002), Elliott et al. (2003, 2012), Göltenboth and Hutter (2004), Kamada (2005), Nave and Rodrigues (2007), Lockhart et al. (2008), Rodrigues et al. (2009, 2011) and Lamb (2011)
	Degraded forest (cleared or burned, lacking desired species)	Rehabilitation	Conversion	Clear fell and plant all desired species	Zerbe (2002), Thompson et al. (2003), Spiecker et al. (2004), Hansen and Spiecker (2005), Harmer et al. (2005, 2011)
				Enrichment planting; framework species method	Montagnini et al. (1997), Elliott et al. (2003, 2012)
				Assisted natural regeneration; farmer assisted natural regeneration	Hardwick et al. (1997), Friday et al. (1999), Otsamo (2000), Kobayashi (2004), van Noordwijk et al. (2008) and Haglund et al. (2011)
				Blowdown; with or without salvage logging; plant desired species	Drouineau et al. (2000), Spiecker et al. (2004), Hahn et al. (2005), Brunner et al. (2006), Harmer and Morgan (2009) and Morimoto et al. (2011)
				Agroforestry methods	Murgueitio et al. (2011), Friday et al. (1999), Schlönvoigt and Beer (2001), Khamzina et al. (2006), Sileshi et al. (2007), Blay et al. (2008), van Noordwijk et al. (2008), Tabuti et al. (2011), Blay (2012), Blinn et al. (2013), Roshetko et al. (2013) and Mbow et al. (2014)
			Transformation	Partial overstory removal; underplanting; natural regeneration	Malcolm et al. (2001), Nyland (2003), Kobayashi (2004), Hahn et al. (2005), Löf et al. (2005), Gardiner and Yeiser (2006), Paquette et al. (2006), Pommerening (2006), Madsen and Hahn (2008) and Schneider (2010)
			Reforestation (post-fire restoration)	Erosion control (re-seed native understory; mulching); with or without salvage logging; plant desired species	Beschta et al. (2004), Pausas et al. (2004), Raftoyannis and Spanos (2005), Wagenbrenner et al. (2006), Ahn et al. (2014) and Robichaud et al. (2013a, 2013b)
	Degraded forest (lacking desired structure)	Rehabilitation	Transformation	Partial overstory removal	Aubry et al. (1999), Kerr (1999), Kenk and Guehne (2001), Mason (2002), Nyland (2003), Pommerening and Murphy (2004), Pommerening (2006), Pastur et al. (2009), O'Hara et al. (2010), Baker and Read (2011), Lencinas et al. (2011), Gustafsson et al. (2012), Harmer et al. (2012) and Lindenmayer et al. (2012)
			Conversion	Clear fell with residuals; variable density thinning	Franklin et al. (1997), Sullivan et al. (2001), Vanha-Majamaa and Jalonen (2001), Carey (2003) and Gustafsson et al. (2010)
	Degraded forest (lacking desired fire disturbance)	Rehabilitation	Re-introduce fire	Fuel reduction by mechanical or chemical means; re-introduce prescribed fire; fire surrogates	Ryan (2002), Graham et al. (2004), Brockway et al. (2005), Kaufmann et al. (2005), Van Lear and Wurtz (2005), Varner et al. (2005), Walker and Silletti (2006), Schwilk et al. (2009), Jain and Graham (2010), Liu et al. (2012), Phillips et al. (2012), Ryan et al. (2013) and Weekley et al. (2013)

(*continued on next page*)

Table 1 (*continued*)

Objective	Present forest condition	Strategies	Methods	Initial operations	References
	Deforested and disturbed site (mined land, polluted land)	Reclamation	Replacement	Stabilize site; plant natives or non-natives; fertilize	Martin et al. (1990), Hart et al. (1999), Parrotta and Knowles (2001), Lamb et al. (2005), Renou and Farrell (2005), Rochefort and Lode (2006), Koch (2007), Koch and Samsa (2007), Renou-Wilson et al. (2008), Kuznetsova et al. (2010), Prach et al. (2011), Fields-Johnson et al. (2012), Harper et al. (2012), Evans et al. (2013) and Zipper et al. (2013)
Coastal protection	Deforested (agricultural land use, open land, abandoned aquaculture)	Reconstruction	Native re-colonization (intertidal water, mangrove)	Re-establish hydrologic connectivity; do nothing	Field (1999), Kairo et al. (2001), Bosire et al. (2008) and Kamali and Hashim (2011)
		Reconstruction	Afforestation (coastal barrier, dune stabilization)	Site preparation; plant or direct seed natives or non-natives	Madsen et al. (2005) and Lithgow et al. (2013)
		Rehabilitation	Transformation	Enrichment planting	Conner et al. (2007)
				Blowdown; with or without salvage logging; plant desired species	Stanturf et al. (2007) and Conner et al. (2012)
	Deforested and disturbed site (mined land, polluted land)	Reclamation	Replacement	Stabilize site; plant seedlings of natives or non-natives; fertilize	Parrotta and Knowles (2001), Lewis (2005) and Renou and Farrell (2005)
Geologic protection	Deforested and disturbed site (avalanche track, landslide, lava flow)	Reclamation	Replacement	Stabilize site; plant seedlings of natives or non-natives	O'Loughlin (1984), Brang et al. (2001), Schönenberger (2001), Singh et al. (2001), Stokes (2006), Phillips et al. (2013) and Preti (2013)
Carbon sequestration	Deforested (agricultural land use, open land, abandoned agriculture)	Reconstruction	Afforestation	Site preparation; plant or direct seed natives, non-natives, or naturalized non-natives	Ciccarese et al. (2005), Blay (2012) and Ciccarese et al. (2012)
	Degraded forest (lacking desired species or stocking)	Rehabilitation	Conversion	Clear fell and plant all desired species	Blay et al. (2008), Putz and Nasi (2009), Blay (2012) and Pichancourt et al. (2014)
				Agroforestry	Schlönvoigt and Beer (2001), Oelbermann et al. (2004), Foroughbakhch et al. (2006), Sileshi et al. (2007), Blinn et al. (2013), Roshetko et al. (2013) and Mbow et al. (2014)
	Deforested, mined land, polluted land	Reclamation	Replacement	Stabilize site; plant seedlings of natives or non-natives; fertilize	Harper et al. (2012), Townsend et al. (2012) and van Rooyen et al. (2013)
Enhance diversity					
Species or landscape diversity	Agricultural land (could be open land, abandoned agriculture)	Reconstruction	Native re-colonization	Remove disturbance; fencing; leave alone	Hodge and Harmer (1996), Kerr et al. (1996), Balandier et al. (2005), Benjamin et al. (2005), Flinn and Vellend (2005), Shono et al. (2007), Griscom and Ashton (2011), Lamb (2011) and Scowcroft and Yeh (2013)
		Reconstruction	Afforestation	Site preparation; plant or direct seed natives or non-natives; enrichment planting	Brockerhoff et al. (2013, 2008), Orni (1969), El Houri Ahmed (1986), Schönenberger (2001), Gardiner and Oliver (2005), Kush et al. (2004), Maestre and Cortina (2004), Willoughby et al. (2004), Brockway et al. (2005), Groninger (2005), Jõgiste et al. (2005), Madsen et al. (2005), McCreary and Cañellas (2005), Weber (2005), Dey et al. (2010), Geldenhuys (2010), Griscom and Ashton (2011), Löf et al. (2012), Munro et al. (2012), Boothroyd-Roberts et al. (2013), Campos-Filho et al. (2013) and Tomaz et al. (2013)
				Interplant; fast/slow growing natives; taungya	Weersum (1982), Menzies (1988), Schlönvoigt and Beer (2001), Agyeman et al. (2003), Prévosto and Balandier (2007), Blay et al. (2008), Stanturf et al. (2009) and Blay (2012)
				Plant mixtures of natives	Leopold et al. (2001), Lamb and Gilmour (2003), Balandier et al. (2005), Kanowski et al. (2005), Rey Benayas et al. (2008), Rodrigues et al. (2009), Kanowski and Catterall (2010), Griscom and Ashton (2011), Lamb (2011) and Tomaz et al. (2013)
	Degraded forest (lacking desired species) or as second intervention	Rehabilitation	Conversion	Clear fell; plant all desired species	Williams et al. (2002), Zerbe (2002), Spiecker et al. (2004), Brockway et al. (2005), Hansen and Spiecker (2005) and Hu et al. (2012)
				Enrichment planting	Lamb and Gilmour (2003), Twedt (2006), Rodrigues et al. (2009) and Yamagawa et al. (2010)
				Assisted natural regeneration	Hardwick et al. (1997), Friday et al. (1999), Shono et al. (2007), Igarashi and Kiyono (2008), Osem et al. (2009) and Moreira et al. (2013)
				Blowdown; with or without salvage logging; plant desired species	Drouineau et al. (2000), Spiecker et al. (2004), Hansen and Spiecker (2005), Lilja et al. (2005), Stanturf et al. (2007), Harmer and Morgan (2009), Löf et al. (2012) and Saure et al. (2013)
			Transformation	Partial overstory removal; planting; natural regeneration	Weaver (1987), Ramos and Del Amo (1992), Adjers et al. (1995), Keenan et al. (1997), Montagnini et al. (1997), Ashton et al. (1998), Peña-Claros et al. (2002), Carey (2003),

					Thompson et al. (2003), Harmer et al. (2005, 2011), Lamb et al. (2005), Löf et al. (2005), Nagaike et al. (2005), Gardiner and Yeiser (2006), McNamara et al. (2006), Paquette et al. (2006), Vanha-Majamaa et al. (2007), Madsen and Hahn (2008), Martínez Pastur et al. (2011), Booth (2012), Cogliastro and Paquette (2012), Dey et al. (2012), Fischer and Fischer (2012), Keefe et al. (2012), Parrott et al. (2012) and Lhotka and Loewenstein (2013)
	Degraded forest (lacking desired structure) or as second intervention	Rehabilitation	Transformation	Partial overstory removal	Moore et al. (1999), Buongiorno (2001), Kelty et al. (2003), Leak (2003), Baumhauer et al. (2005), Humphrey (2005), Loewenstein (2005), Coppini and Hermanin (2007), Fenton et al. (2009), O'Hara et al. (2010), Han et al. (2012) and Harmer et al. (2012)
			Conversion	Clear fell; with or without residuals; natural regeneration	Franklin et al. (1997), Aubry et al. (1999), Vanha-Majamaa and Jalonen (2001), Elmqvist et al. (2002), Harmer et al. (2005), O'Hara and Waring (2005), Pastur et al. (2009), Baker and Read (2011), Gustafsson et al. (2012) and Lindenmayer et al. (2012)
			Legacies	Deadwood retention or creation	Hooper and McAdie (1996), Graves et al. (2000), Grove and Meggs (2003), Lindhe and Lindelöw (2004), Hyvarinen et al. (2005), Lilja et al. (2005), Eriksson et al. (2006), Vanha-Majamaa et al. (2007), Laarmann et al. (2009) and Laarmann et al. (2013)
			Retention methods	Harvest	Franklin et al. (1997), Aubry et al. (1999), Zenner (2000), Sullivan et al. (2001), Gibbons et al. (2010), Gustafsson et al. (2010) and Ribe et al. (2013)
				Thinning	Aubry et al. (1999), Kenk and Guehne (2001), Carey (2003), O'Hara and Waring (2005), Waring and O'Hara (2005), Pastur et al. (2009), O'Hara et al. (2010), Baker and Read (2011) and Gustafsson et al. (2012)
	Degraded forest (lacking desired fire disturbance)	Rehabilitation	Prescribed burning, fire surrogates	Fuel reduction by mechanical or chemical means; re-introduce prescribed fire; fire surrogates	Moore et al. (1999), Allen et al. (2002), Kuuluvainen (2002), Kuuluvainen et al. (2002), Ryan (2002), Brown et al. (2004), Graham et al. (2004), Brockway et al. (2005), Kaufmann et al. (2005), Lilja et al. (2005), Vanha-Majamaa et al. (2007), Brockway et al. (2009), Schwilk et al. (2009), Jain and Graham (2010), Liu et al. (2012), Phillips et al. (2012), Ryan et al. (2013) and Weekley et al. (2013)
	Degraded forest (invasive species)	Rehabilitation	Invasives removal	Remove invasive species (hand clearing, mechanical, chemical); enhance natives (by controlling light, planting, etc.)	Jones et al. (2005), D'Antonio and Chambers (2006), Shepperd et al. (2006) and Schelhas et al. (2012)
	Degraded forest (climate change)	Replacement	Assisted migration (managed relocation)	Expand range	McLachlan et al. (2007), Pedlar et al. (2012) and Williams and Dumroese (2013)
				Novel ecosystems	Hobbs et al. (2009) and Doley and Audet (2013)
	Deforested and disturbed site (mined land, polluted land)	Reclamation (passive)	Rehabilitation	Native recolonization	Prach and Pysek (2001), Prach and Hobbs (2008), Alday et al. (2011) and Prach et al. (2011)
	Deforested and disturbed site (mined land, polluted land)	Reclamation (active)	Replacement	Stabilize site; plant seedlings of natives or non-natives; fertilize	Renou-Wilson et al. (2008), Doley and Audet (2013) and Woziwoda and Kopeć (2014)
Enhance livelihoods					
Wood products, non-timber forest products, wildlife habitat	Agricultural land	Reconstruction	Afforestation	Site preparation; plant or direct seed natives, non-natives, or naturalized non-natives	Agyeman et al. (2003), Lamb et al. (2005), Præstholm et al. (2006), Blay et al. (2008), Lamb (2011), Lee and Park (2011), Blay (2012), Booth (2012) and Rosengren (2012)
	Degraded forest (lacking desired species)	Rehabilitation	Conversion	Clear fell; plant all desired species	Weiss (2004), Hansen and Spiecker (2005) and Khamzina et al. (2006)
				Clear fell with enrichment planting	Hahn et al. (2005) and Lee and Park (2011)
				Assisted natural regeneration	Haglund et al. (2011), Lee and Park (2011) and Blay (2012)
				Blowdown with or without salvage logging, plant desired species	Hahn et al. (2005) and Hansen and Spiecker (2005)
		Rehabilitation	Transformation	Partial overstory removal and supplemental planting	Hanewinkel (2001), Hahn et al. (2005), Madsen and Hahn, 2008) and Geldenhuys (2010)
	Degraded forest (lacking desired structure)	Rehabilitation	Transformation	Partial overstory removals	Buongiorno (2001), Mason (2002) and Humphrey (2005)
	Deforested, mined land, polluted land	Reclamation	Replacement	Stabilize site; plant seedlings of natives or non-natives; fertilize	Lamb, 1998), Lamb et al. (2005), Morrison et al. (2005), Lamb, 2011) and Blay, 2012)

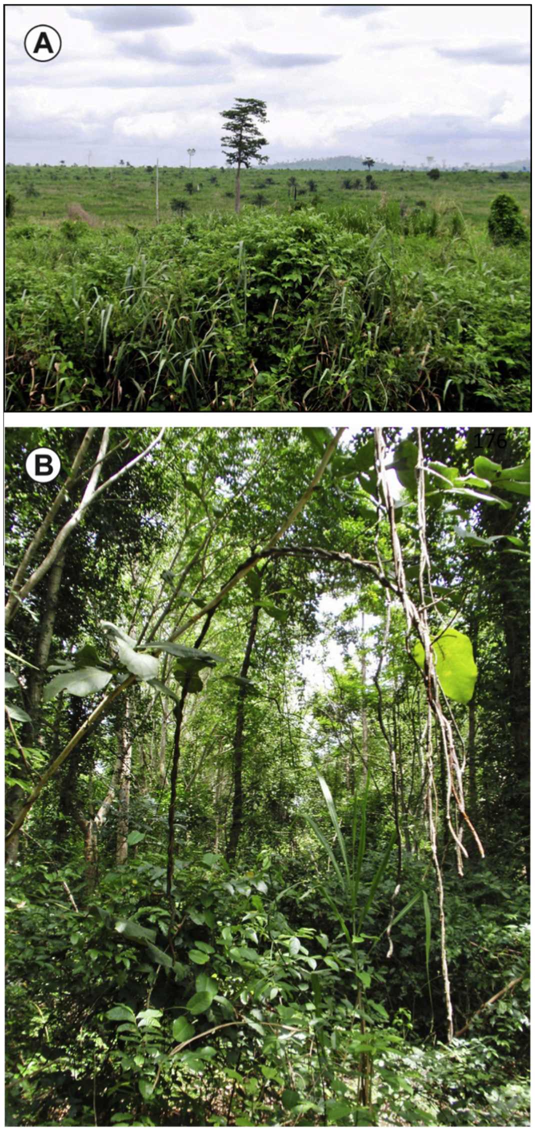

Fig. 1. In the dry tropical forest zone of Ghana, a combination of extractive logging without adequate regeneration, fire, and invasion by *Chromolaena odorata* (L.) King & H. Rob. resulted in severely degraded forests that became the starting point for community-based restoration using modified taungya (A). Two years of intercropping food plants with seedlings of eight tree species including *Cedrela odorata* L. gave rise to forest-like conditions after 10 years (B). Photos by John A. Stanturf.

Despite a contentious debate about the appropriateness, cost, and effectiveness of assisted migration (also called managed relocation) as a tool for species replacement (McLachlan et al., 2007), particularly when the transfer distances are large (Williams and Dumroese, 2013), we believe that assisted migration is a tool that makes perfect sense (Fig. 4). Looming shifts in habitat envelopes for ''currently'' native species can perhaps be viewed as extreme degradation given the rapid rate of climate change and the human caused barriers to migration that species experience in the contemporary landscape (Kindlmann and Burel, 2008). As such, we argue that assisted migration is going to be an important tool to implement a restoration strategy and meet objectives in the face of climate change (e.g., Pedlar et al., 2012).

3. Methods

The restoration toolbox is filled with many techniques and tools (Table 1) that may be used to achieve more than one objective. Admittedly, the dominant restoration paradigm is phytocentric and should be broadened to include belowground processes (Callaham et al., 2008; Van Der Heijden et al., 2008; Jiang et al., 2010; Kardol and Wardle, 2010). Nevertheless, the *sine qua non* of forest restoration is vegetation recovery or manipulation; with increasing degradation or deviation from historic conditions other things become significant such as soil amelioration, hydrologic repair, or reintroducing fire in conjunction with vegetation management. Because adding vegetation is an effective restoration technique, the following discussion of methods begins with a description of the kinds of available material. This is followed by a discussion of altering composition under different starting conditions of stand structure, because the method used to deploy the material depends on initial conditions: whether or not an overstory is present, how much of the landscape will be restored, and the complexity of the planting design. We then talk about some of the major approaches for altering structure to achieve restoration goals in degraded forest stands. Lastly, we describe approaches for restoration of two key ecosystem processes, fire and flooding.

3.1. Available Material

The Target Plant Concept is a useful method for developing restoration materials (Rose and Hasse, 1995; Landis and Dumroese, 2006). This concept defines the appropriate plant material through a series of interrelated steps that focus on project objectives, potential stocktypes (the size and type of plant), appropriate genetics and sexual diversity, limiting factors on the site, the outplanting window, and the most efficient planting tool. Thus, a target plant is one that has been cultured to survive and grow on a specific outplanting site and plant quality is determined by outplanting performance. Experiments designed to test potential target plant stocktypes must be done with care to ensure valid comparisons (Pinto et al., 2011).

The overarching objective is to establish vigorous, site-adapted plants and what constitutes appropriate material is project specific; we will simply introduce some of the many options available. Choice of plant material is a function of what material is available, management objectives, seedling quality, ease of planting, and site conditions. Examples of appropriate material for specific objectives can be found for sites in Denmark in (Kjær et al., 2005), for *Populus* plantations globally (Stanturf and van Oosten, 2014) and for framework species planting in Thailand (Elliott et al., 2012). Commonly used plant materials are illustrated in Fig. 5. Often, the goal for restoration plantings is different from traditional reforestation and commercially available material may not be suitable (Schröder and Prasse, 2013). Rather than a genetically improved seedling with fast growth, good form, or desirable wood quality, plant material for restoration may need other qualities such as precocious flowering or an ability to sprout after fire. Although the Target Plant Concept should determine the type of plant materials to use, often the choice is determined by availability, by cost, or simply preference. For example, wildlings of *Dipterocarpus* species in Indonesia are collected from intact forests and transplanted for restoration to overcome heavy pressure from frugivores of seeds that occur unpredictably and store poorly (Priadjati et al., 2001; Kettle, 2010).

Planting stock can be produced from any plant material that can propagate a species, including seeds, bulbs or rhizomes, cuttings, or seedlings (Hoag and Landis, 2001; Dumroese et al., 2012). Plant material can be rooted or non-rooted. Species that easily reproduce vegetatively, such as, for example, most of the species in the genera *Populus*, *Salix, Eryhtrina, and Gliricidia,* may be planted directly as non-rooted, dormant cuttings (15 cm to 1 m), sets or whips (1.5–6 m), or poles or stakes (6–8 m), produced usually from

Fig. 2. Early 20th century, old-growth *Pinus resinosa* forests in northern Minnesota, USA were characterized by a low density overstory, open understory, and pine regeneration in openings (A). Contemporary stands have higher stand densities and woody shrub encroachment because of the lack of surface fires (B). Photo A by unknown; photo B by Christel Kern.

Table 2
Decision matrix for restoring *Pinus palustris* (longleaf pine) ecosystems before re-introducing summer burning in the southeastern USA (adapted from Brockway et al. (2005)).

Degree of degradation	Stand condition	Landscape position		
		Xeric and sub-xeric sandhills	Flatwoods and wet lowlands	Montane and mesic uplands
		Initial restoration prescription		
Moderately	Longleaf pine overstory, woody understory	Reduce fuel loads, introduce summer burns	Reduce fuel loads, introduce summer burns	Reduce fuel loads, remove other pines in overstory, introduce summer burns
Very	Other trees now in overstory, native plant understory	Chop and burn broadleaves; remove other pine; plant longleaf pine; no or minimal site preparation	Reduce fuel loads, remove other pines, chop; reduce slash, no bedding; plant longleaf pine	Reduce fuel loads, Remove other pines in overstory, plant longleaf pine
Severely	Former longleaf pine site, other trees now in overstory, non-native plant understory	Remove other trees; chop and burn; plant longleaf pine; establish *Aristida stricta* (a native grass to facilitate re-introduction of fire) by direct seeding or, if a longleaf pine overstory is present, plant grass seedlings	Remove other trees; chop and burn; plant longleaf pine; plant or direct seed *Aristida stricta*	Remove other trees; chop and burn; plant longleaf pine plant or direct seed *Aristida stricta*

Fig. 3. Progression of reclamation on oil shale mined land in Estonia. Active mining site, where the overburden is being removed to expose the exploitable oil shale strata that generally is 5–35 m below the surface (A). Before leveling and shaping into a new landscape, piles of calcareous detritus dot the landscape (B). Since the 1960s, reclamation to woodlands, the previous landuse, has favored *Pinus sylvestris* L.; the stand shown is approximately 33 years-old (C). Specific information can be found in Laarmann et al. (in press). Photos by John A. Stanturf.

stump sprouts or as serial cuttings from branches or stems (Zahawi and Holl, 2009; Stanturf and van Oosten, 2014). Species or clones that do not root readily may be rooted and grown in nurseries from cuttings (barbatelles) or sets (stecklings). Bareroot seedlings, grown in nurseries for varying lengths of time, are grown in great quantities for commercial species, particularly conifers.

Container seedlings may be a cost-effective alternative to bareroot stock, especially when the planting season is to be extended or adverse sites are to be planted (Brissette et al., 1991; Luoranen et al., 2005, 2006) although even bareroot stock can be planted later or earlier than generally recommended if environmental conditions are suitable (e.g., Seifert et al., 2006). Container seedlings,

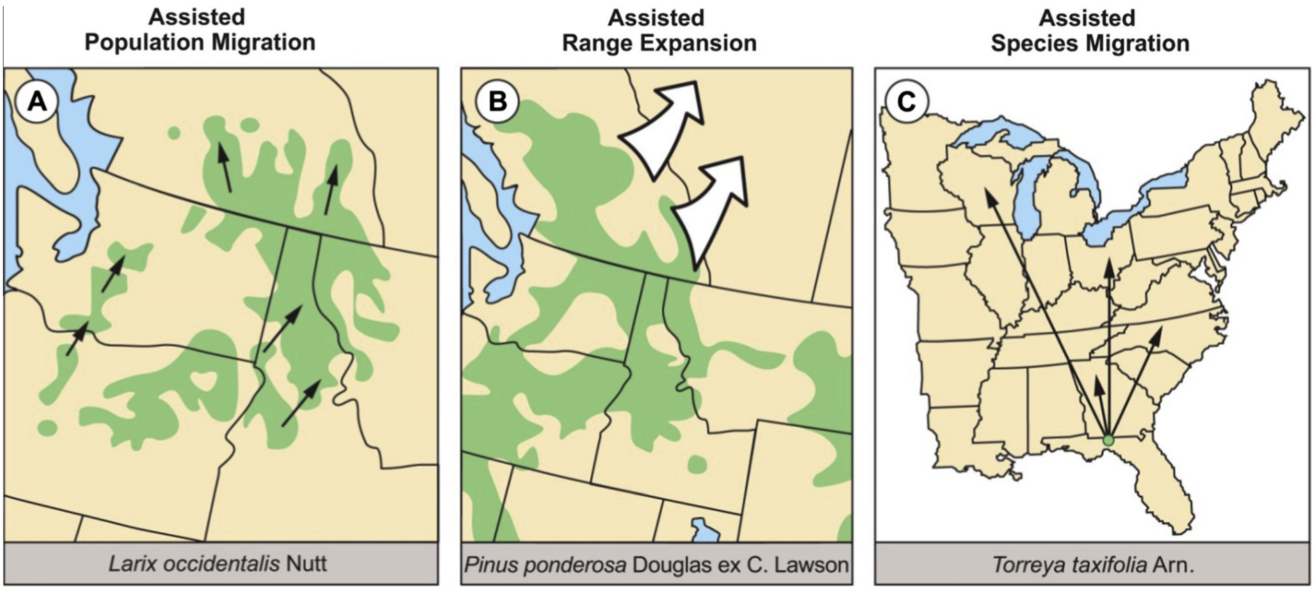

Fig. 4. Replacement using assisted migration (also called translocation or managed relocation) will be one method for adapting to climate change. Seed migration can occur as assisted population migration in which seed sources are moved climatically or geographically within their current ranges, even across seed transfer zones; e.g., moving *Larix occidentalis* Nutt. 200 km north within its current range in the United States and Canada (A). Seed sources can also be moved climatically or geographically from current ranges to suitable areas just outside the range to assist range expansion, such as moving seed sources of *Pinus ponderosa* Douglas ex C. Lawson into Alberta, Canada (B). For assisted species migration, species could be moved far outside current ranges to prevent extinction, such as planting the rare species *Torreya taxifolia* Arn. into states north of Florida (C). Modified from Williams and Dumroese (2014).

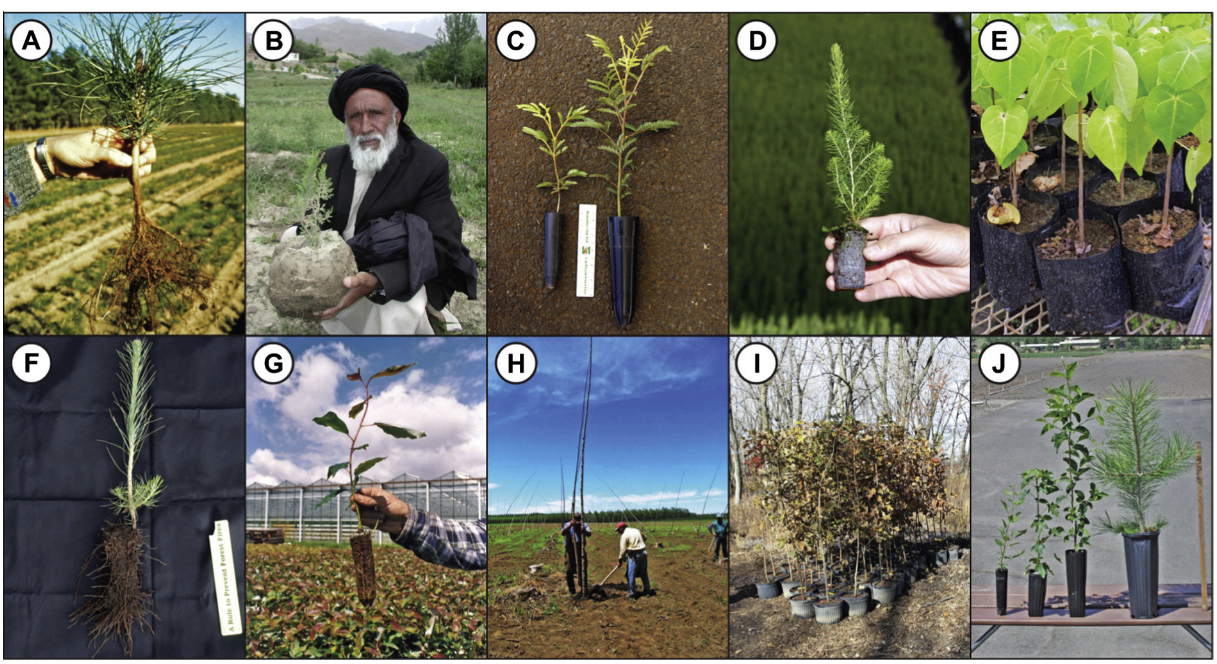

Fig. 5. A variety of planting stock can be produced. Plants can be regenerated from seeds; common seedling stocktypes include bareroot (A), balled-and-burlapped (B), hard-wall (C) and soft-wall (D) container seedlings, polybags (E), and combination container-bareroot seedlings that begin as container seedlings but are transplanted into bareroot fields for additional growth (F). Plants can be regenerated vegetatively; common stocktypes include rooted stem cuttings grown in containers (G) or large, non-rooted pole cuttings planted directly on site (H). Stocktypes can be various sizes depending on the restoration goal (I, J). Photo A, D, F, and J by Thomas D. Landis, B by Clark Fleege, C by R. Kasten Dumroese, E by Diane L. Haase, G by Cees van Oosten, H by John A. Stanturf, and I by Daniel C. Dey.

grown under varying degrees of environmental control and in many container types (Landis et al., 2010b) are produced to meet desired characteristics for outplanting under specified conditions (Brissette et al., 1991; Landis et al., 2010a). The optimum seedling size, whether bareroot or container, is that which yields acceptable results on the outplanting site. Although seedling quality is typically characterized by some morphological measure (Grossnickle, 2012), a seedling's physiological attributes are more important (Landis et al., 2010a).

The current paradigm for proper transfer of plant materials from site to site is that, in general, locally-adapted material is best (Gustafson et al., 2005; Johnson et al., 2010). In the western USA and Canada, where steep gradients in elevation and climate exist, the result is a plethora of species-dependent seed transfer guidelines intended to maintain genotypic adaptation to local climates (McKenney et al., 2007). In Europe, strict guidelines for seed sources and seedling quality result in high cost of material (Kjær et al., 2005) and the search for low-cost regeneration methods, such as direct seeding (Madsen et al., 2002; Madsen and Löf, 2005) and natural regeneration (Hahn et al., 2005). As the level of degradation increases, however, it may be advisable to replace locally-collected materials with those that are ecologically appropriate, selected for their enhanced ability to establish and persist on a degraded site without invasive tendencies or incompatibility with the existing plant community, and better suited than the local source for capturing the site (Jones, 2014). Collections must consider a plant's flowering system (dioecious vs. monecious) and mode of vegetative reproduction to ensure future reproduction on restored sites (Landis et al., 2003). In many tropical countries, insufficient knowledge of the collection, storage, germination and nursery cultivation requirements of native species has limited their availability for restoration, although this is improving (Butterfield, 1995; Blakesley et al., 2002; Hooper et al., 2002).

Restoration sites are likely to pose challenges uncommon to reforestation planting. For example, often competing vegetation will be more of a factor because site preparation is less intense and herbicides may be prohibited or unavailable (e.g., Stanturf et al., 2004). Soil conditions may be altered, with reduced fertility caused by erosion or wildfire. Mining sites often have extreme soil pH levels. Additionally, severe forest fires or surface mining can eliminate soil microorganisms such as mycorrhizal fungi and afforestation sites may not have suitable fungi (Kropp and Langlois, 1990; Bâ et al., 2010), especially if a non-native species is used. Thus, plants will require inoculation with the appropriate fungal symbiont before outplanting (Sousa et al., 2014). Even vigorous, site-adapted seedlings appropriately inoculated will struggle, however, if planted outside the outplanting window, the time period when environmental conditions (usually soil moisture and temperature) are most favorable for establishment.

The type of tool used to outplant nursery stock has ramifications for restoration programs. Easily planted materials have a lower establishment cost and are more likely to be properly outplanted than larger, more difficult to handle and plant, stocktypes. Thus, poorly supervised outplanting operations may impact survival (Allen et al., 2001; Preece et al., 2013). Direct seeding has proven to be a successful, low-cost alternative to growing and outplanting seedlings for some species (Engel and Parrotta, 2001; Camargo et al., 2002; Madsen and Löf, 2005; Dodd and Power, 2007; Doust et al., 2008; Cole et al., 2011), as long as it is done properly (Bullard et al., 1992; Stanturf et al., 1998; Willoughby et al., 2004; Ammer and Mosandl, 2007).

3.2. Altering composition

Altering species composition, often a key restoration objective, is achieved by adding and removing vegetation. Material can be added by passive restoration that depends upon natural dispersal and recolonization processes, active restoration using direct seeding or outplanting of desirable species, or some combination of the two (e.g., assisting natural regeneration from a seed bank or sprouting species on-site). In general, greater control of species composition is gained by active methods. After a method is chosen to alter composition, the species, their density, and spatial arrangement must be determined; this leads to appropriate cultural methods in the specific restoration context, such as site preparation, competition control, hand- versus machine-planting, etc. Many approaches and combinations of active and passive methods are being used to restore degraded ecosystems globally. Our way to systematically examine these is by grouping designs according to the degree of overstory present at the initiation of restoration (i.e., no, partial, or full overstory) and how much of the area is treated (all or partial). Initially we consider stand-level designs; these are mostly scalable to the landscape-level. Additional considerations may be necessary, however, in restoration designs for landscapes (Oliver et al., 2012; Wimberly et al., 2012; Oliver, 2014).

3.2.1. No overstory, entire area treated

The simplest design for restoration of composition comes within the context of single-species, single-cohort planting (Fig. 6). Often maligned as a monoculture plantation, this design may be implemented to enhance biodiversity (Brockerhoff et al., 2008) and non-uniform plantings can avoid the appearance of a plantation (e.g., Fig. 6b and c). Over time, these forests may develop a more natural look as they pass from the stem exclusion stage to the understory re-initiation stage (Oliver and Larson, 1996; Oliver and O'Hara, 2005). As gaps develop or are intentionally created, adding species may develop more complex structures (e.g., Twedt, 2006). On harsh sites, the initial stand may be comprised of non-native species replaced, as a forest floor develops and microclimate improves, with native species that regenerate in shade or in gaps from necessary, nearby seed sources (Nuttle and Haefner, 2005). This catalyzing effect of plantations has been noted in many environments (Parrotta et al., 1997; Lamb et al., 2005; Brockerhoff et al., 2008).

Variations on the single-species, single-cohort planting design include first sowing a cover crop, such as an annual grass, to reduce weed competition or inter-planting annual vegetable crops with tree seedlings. This type of agroforestry system, developed in Asia and known as taungya, has spread throughout the Tropics (Weersum, 1982; Schlönvoigt and Beer, 2001; Blay, 2012). In taungya, food crops may be grown for several years until the canopy begins to close and shade out vegetable production. One suggestion for restoring tropical forests on smallholder lands is to first establish the tree overstory and then underplant coffee or cocoa in the shade (Lamb et al., 2005). Another use for a plantation of a fast-growing species is to control competing vegetation when herbicides cannot be used due to regulation, non-availability, cost, or preference. The fast-growing species is planted at narrow spacing to quickly capture the site and shade competition, such as the competing fern *Pteridium caudatum* (L.) Maxon in Mexico (Chazdon, 2013; Douterlungne and Thomas, 2013); other species can be interplanted after overstory thinning or removal.

More complex designs involve adding mixtures of trees or trees and shrubs that may be temporary or permanent and may include single- or multiple-cohorts. Mixtures require more knowledge of the growth habits and interactions of the species involved (Oliver, 1980; Oliver et al., 1990). A temporary mixture in a single-cohort design usually involves planting two species, with one removed well before the other (Fig. 7). Although planting species with different shade-tolerance is preferable (Ashton et al., 2001) to prevent one species from disappearing, spacing can be adjusted to mitigate competition for light. Commonly termed a nurse-crop or interplanting (Chinnamani et al., 1965; Stanturf et al., 2000; Lamb et al., 2005), a faster growing species is planted first to provide both an early financial return (Forrester et al., 2006; Lamb, 2011) and favorable growing conditions for a slower growing, more valuable species. Temporary mixtures provide additional flexibility if the nurse-species can be coppiced; in the *Populus-Quercus* L. system used in the Lower Mississippi Alluvial Valley, USA coppicing the *Populus* (Fig. 7b) can guarantee at least one additional rotation of *Populus* before completely releasing the *Quercus* (Stanturf et al., 2009).

Permanent mixtures are usually more desirable for meeting biodiversity and structural complexity objectives, but require greater knowledge of silvical characteristics and interactions with site. Simple mixtures, two or more species planted in single-species rows or blocks (Fig. 8), require less knowledge although

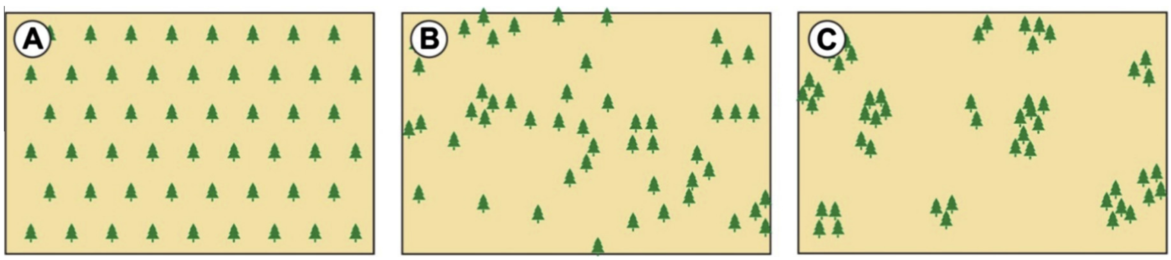

Fig. 6. Single species, single cohort plantings are the simplest to implement and manage. Depending on restoration objectives, plantings can have uniform spacing between rows and between trees within rows (A), random spacing to avoid the appearance of a monoculture plantation (B), or a clumped random spacing that provides additional space for other species to developed from dispersed seeds (C).

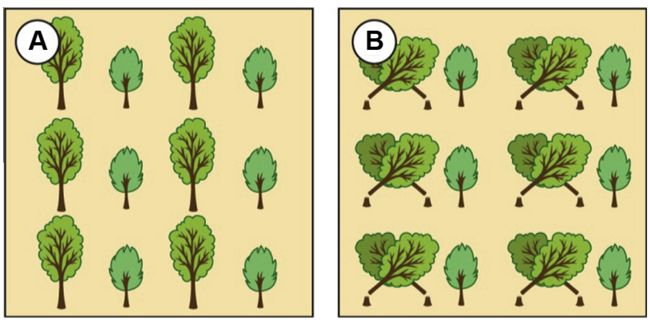

Fig. 7. Temporary mixture, single cohort plantings involve a fast growing nurse crop and a slower growing species (A). Depending upon the species used and their requirements for weed control, the slower growing species may be planted at the same time as the faster growing species or within a few years. Sometimes the slower growing species is planted between every other row of the faster grower; the faster growing species may then be removed by directional felling without damage to the slower grower (B). If the faster growing species regenerates by coppice, multiple harvests may be available before the slower growing species fully occupies the site.

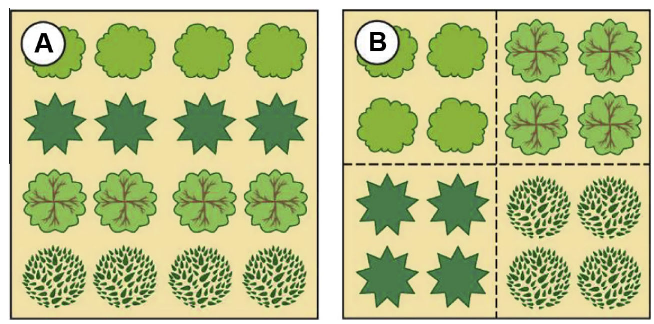

Fig. 8. Simple mixture, multiple species, single cohort plantings can either be achieved by planting two or more species in alternating rows (A) or with the species separated into single species blocks (B) of various shapes.

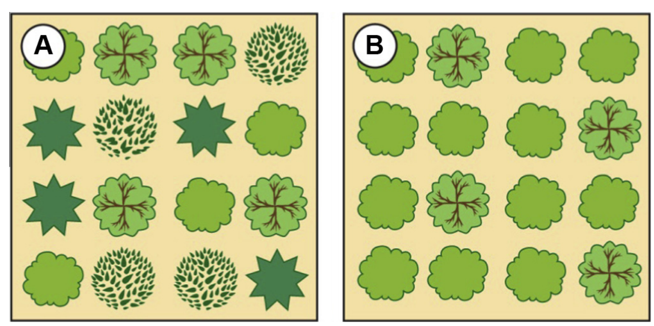

Fig. 9. Intimate mixture, multiple species, single cohort plantings may be random or designed and use knowledge of growth habit, shade tolerance, and other characteristics of the species to be successful. In a random planting, multiple species are outplanted or direct seeded in a random mixture (A). Examples include high diversity plantings and Framework Species plantings, as well as many other possible mixtures. In a designed planting, two or more species are planted together (B), with specific combinations based upon growth characteristics, usually with a specific desired objective such as stem form and value of a crop tree or maintenance of an endangered species.

matching species to site is always important. The resulting mosaic will grow to resemble a mixed species stand with clumped distribution. Planting multiple species in alternate single or multiple rows provides a more complex design with greater potential for inter-species competition and the species chosen may be based on successional status, as is done in the planting groups method used in Brazil (Nave and Rodrigues, 2007; Rodrigues et al., 2009). On sites with distinct gradients, for example soil drainage or inundation regime, these simple mixtures provide a design whereby species are selected by site adaptations. For example, in afforestation plantings in the Mississippi River floodplain in the southern USA, slight topographic differences are expressed as significantly different inundation regimes. More flood-tolerant species are planted on lower, more flood-prone portions of the landscape (Stanturf et al., 1998; Gardiner and Oliver, 2005).

Intimate mixtures, where several species are in close proximity, provide maximum diversity in both species composition and eventual structural complexity (Lamb, 2011). Two useful approaches, random (Fig. 9a) or designed mixtures (Fig. 9b), require knowledge of successional pathway, shade and moisture tolerances, growth rate and growth habit, self-thinning and self-pruning, and other silvical characteristics (Guldin and Lorimer, 1985; Oliver and Larson, 1996; Ashton et al., 2001). Designed mixtures take into account the spatial arrangement of species and may be based on observations of natural stands (Lockhart et al., 2006) that provide workable guidelines for self-assembly rules (Temperton, 2004; Lockhart et al., 2008).

Techniques to establish random mixtures include high diversity plantings where a mixture of seeds of as many species as possible are scattered (Lamb et al., 2012), effective when little silvical knowledge is available and seeds are readily available (Rodrigues et al., 2009); sowing site-adapted species of different successional status (Miyawaki, 1998); and the Framework Species approach developed in tropical Australia (Goosem and Tucker, 1995), applied in Southeast Asia (Hardwick et al., 1997; Blakesley et al., 2002; Elliott et al., 2003), and similar to "rainforestation farming" (Göltenboth and Hutter, 2004) in the Philippines. The Framework Species method utilizes local knowledge of species characteristics and plants 20–30 keystone species on a site (Elliott et al., 2012). The rationale for this method is that on deforested sites, planting keystone species will ameliorate site conditions and facilitate recolonization by other species. Framework species must be native (non-domesticated), have high survival and grow well on deforested sites, produce dense, broad crowns to quickly capture the site and control competing vegetation, produce fleshy fruits or nectar-rich flowers to attract seed-dispersing animals thereby increasing species diversity (Elliott et al., 2003, 2012).

Restoration following major, natural disturbances often must address further site degradation that may be caused by logging resulting from attempts to salvage financial value from damaged timber (Lupold, 1996; Prestemon et al., 2006), despite its controversial nature (Karr et al., 2004; Lindenmayer and Noss, 2006; Schmiegelow et al., 2006). Nevertheless, major disturbances provide opportunity to convert large areas lacking a canopy that otherwise would not have been harvested because of low economic return (Hahn et al., 2005; Brunner et al., 2006; Morimoto et al., 2011).

3.2.2. No overstory, partial area treated

In some situations it is neither feasible nor desirable to plant an entire area. Limited financial resources, for example, may preclude planting a large area and the need arises for designs that make the most effective use of natural re-colonization from existing stands. The most dispersed design is scattered trees on the landscape, or very low density planting in a stand (Fig. 10a). Even fewer trees have been used in restoring pastures using non-rooted hardwood cuttings of easy-to-root species, commonly called stakes or poles (Zahawi, 2008; Zahawi and Holl, 2009; Holl et al., 2011), recognizing that these scattered trees in natural woodlands and savannas are keystone structures (Manning et al., 2006). Nucleation (Corbin and Holl, 2012) has been proposed for predominantly farmed landscapes; establishing small wooded islets creates seed sources ready to disperse in areas undergoing transition from agriculture (Fig. 10b). Similarly, farmer assisted natural regeneration (van Noordwijk et al., 2008; Haglund et al., 2011) creates small patches of trees when individuals farming small parcels allow natural regeneration on a portion of their land. Because total farm size is often less than 5 ha, the wooded portion is probably too small to be classified as a forest stand under prevailing definitions. Nevertheless, in addition to providing fuelwood, construction material, and possibly fodder, this woody patch could provide seeds for colonizing the surrounding area if farming were to be abandoned. A dispersed design was attempted in early implementation of the Wetlands Reserve Program, a government-funded program, in the southern USA (Stanturf et al., 2000, 2001), where an objective was to enhance wildlife habitat by outplanting hard mast species. Large-seeded *Quercus* species are not readily dispersed so they were outplanted on wide spacing and light-seeded species were expected to fill-in and create closed-canopy stands (Fig. 6a). This approach was successful only where intact natural stands were nearby (Fig. 10a), generally within 100 m (Stanturf et al., 2001, 2009; Nuttle and Haefner, 2005).

Cluster afforestation (Schönenberger, 2001; Díaz-Rodríguez et al., 2012; Saha et al., 2012) is similar to nucleation in that plantings are scattered on the landscape (Fig. 10d). The distinction is that clusters are small stands, as opposed to a few trees. Clusters may be comprised of simple or complex plantings. Corridors between intact forest stands for wildlife dispersal (Newmark, 1993; Mann and Plummer, 1995; Kindlmann and Burel, 2008) or riparian buffer strips along waterways to reduce farm runoff (Schultz et al., 1995; Mize et al., 2008; Bentrup et al., 2012) are examples of linear clusters (Fig. 11a and b). Clusters may provide seeds that can be dispersed longer distances and passively expand if surrounding land uses allow (e.g., Balandier et al., 2005). This is evident in the northeastern USA where native forests were extensively cleared for agriculture but small farm woodlots were maintained to serve farmers' needs. When farmland was abandoned during the 1920s and 1930s, these woodlots were the nucleus for the secondary forests that developed (e.g., Raup, 1966; Moore and Witham, 1996; Flinn et al., 2005).

3.2.3. Partial/complete overstory, partial treatment

Rehabilitation of forest stands with intact partial or complete overstory may require some site preparation, control of competing vegetation, and/or enhancement of light conditions by removal or reduction of overstory or midstory plants (Wagner and Lundqvist, 2005). Appropriate methods depend upon light conditions and the light requirements of the species to be restored. Natural regeneration may provide sufficient plants of desirable species or assisted regeneration may be necessary. Some stands may be sufficiently opened by previous thinning or other disturbances to plant or

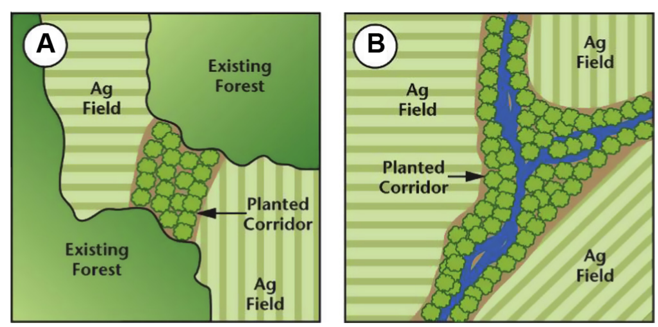

Fig. 11. Corridor plantings connect existing forested patches, often with the goal of facilitating movement of wildlife (A). Riparian buffer plantings within an agricultural matrix (B) may also facilitate wildlife movement, but they serve the additional role of mitigating chemical and erosion impacts on surface water. Any planting design shown in Figs. 4–7 may be used for these types of plantings.

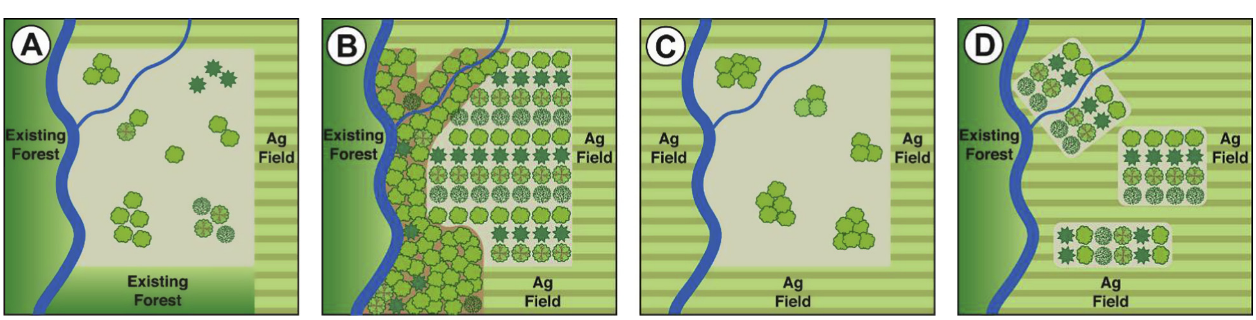

Fig. 10. At the landscape level, several planting designs are options. Dispersed plantings (A) involve planting scattered individual or clumps of a few trees near existing forests; these species are usually difficult to regenerate, such as heavy-seeded species with limited dispersal capability. The existing forests provide a seed source for species that are wind or water dispersed. Similar to dispersed plantings, combined plantings (B) rely on natural regeneration in areas adjacent to existing upland or riparian forests and within an effective seed dispersal distance, whereas a planted design is used elsewhere. Nucleation plantings (C) involve planting dispersed single or small clumps of trees (single or multiple species) within an agricultural matrix to provide a seed source to promote colonization into areas transitioning away from agriculture. Cluster afforestation (D) is similar to nucleation except that clusters are small plantations rather than one or a few trees.

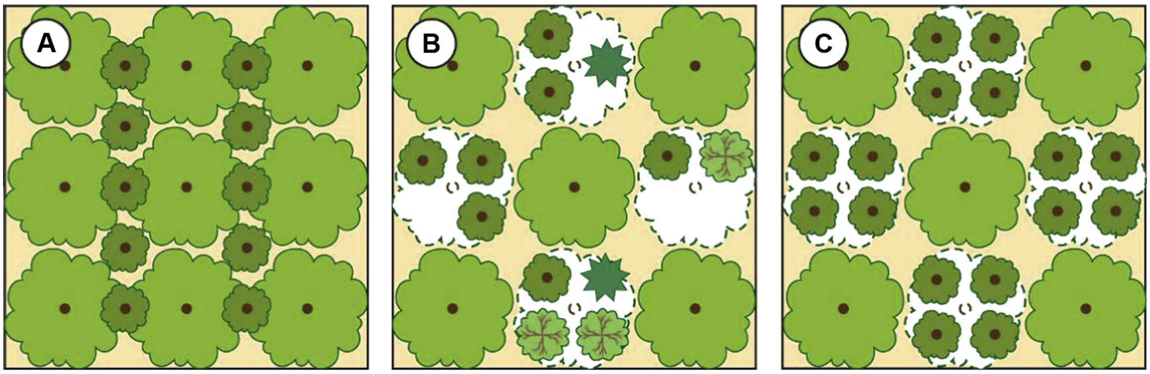

Fig. 12. The design for underplanting species into an existing forest is contingent on whether the overstory is partial or intact. Depending upon the crown transparency of the overstory trees and the shade tolerance of the desired species to be underplanted, no reduction of the overstory may be needed (A), although some site preparation may be required. If additional light is required by the desired understory species, gaps (outlined crowns) may be created by thinning to be filled by natural (B) or artificial (C) regeneration. For natural regeneration, advance regeneration already present will be released and may be aided by controlling competing vegetation (assisted natural regeneration).

sow mid to low shade-tolerant species without further overstory reduction (Fig. 12a). At one end of the light spectrum are dense stands, such as *Picea abies* (L.) Karst plantations in Europe; at the other end of the light spectrum are degraded forests where the understory has been captured by graminoids and herbaceous species (D'Antonio and Vitousek, 1992; Blay, 2012). Maintaining a continuous canopy is an important consideration in many countries, as in the transformation of the dense *P. abies* stands that must be thinned before even shade tolerant *Fagus sylvatica* L. can be underplanted (Hahn et al., 2005; Löf et al., 2005). Once light conditions have been adjusted, underplanting with seedlings or direct seeding is possible, usually with some form of soil preparation, such as scarification or strip plowing.

Restoration with multiple-cohort designs may begin as simple plantings with a new cohort underplanted or direct-seeded beneath the established canopy (Fig. 12b,c); this often directly follows thinning (Paquette et al., 2006; Twedt, 2006; Cogliastro and Paquette, 2012) although thinning may be conducted later to release the seedlings (Baumhauer et al., 2005). Thinning must be conducted carefully to favor desirable seedlings and avoid rampant weed growth. It should be noted that at times the impediment is a dense midstory, rather than the overstory, and this must be reduced to provide sufficient light (Lorimer et al., 1994; Dey et al., 2012; Parrott et al., 2012). Paquette et al. (2006), in their review of underplanting studies across a variety of forest types, found that only a moderate thinning to a dense or intermediate density was needed for increased survival of underplanted trees, but the effects were temporary; thus, multiple interventions may be needed to maintain an adequate light environment for successful seedling establishment, perhaps until desired trees achieve crown closure. These thinning interventions may be in concert with other treatments. For example, when underplanting light-demanding *Quercus* species, Dey et al. (2012) recommend reducing stand density through manipulation of the mid- and overstory in one or more stages accompanied by control of woody and herbaceous competition and herbivory.

In degraded stands with dense groundcover or understory, desirable species may be in the overstory and producing seeds but new seedlings cannot establish because of competing vegetation. Where this competition cannot be controlled by herbicides because of regulations, cost, or non-availability, assisted natural regeneration (ANR) is a labor-intensive method that mechanically controls the competition around desirable seedlings by cutting or matting down the competitors (Hardwick et al., 1997; Friday et al., 1999; Shono et al., 2007). Treatment must be applied multiple times, often during several growing seasons; thus, ANR is limited to small restoration areas, often with local community involvement that provides the necessary labor, or where resources are less limited.

Creating gaps in the overstory is another way to assist regeneration of desirable species that are established by outplanting or direct-seeding in stands with an existing overstory. On one hand, just as thinning intensity is a balance between adequate light for desirable species versus too much light that promotes undesirable competing vegetation, gaps must be sufficiently large to provide the proper light environment (Fig. 12c). This is especially true for shade-intolerant, light-demanding species (Grubb, 1977; Malcolm et al., 2001). On the other hand, even without the concern of competing vegetation, large gaps may expose seedlings to harsh conditions of high temperatures, inadequate soil moisture, high atmospheric evaporative demand, or lack of shelter from frost (Lundmark and Hällgren, 1987; Dey et al., 2012).

3.3. Altering structure

For many forest types, simplification of structure relative to historic reference conditions is an unanticipated (or sometimes intended) outcome of management that may have spanned decades (Palik et al., 2002). This is manifest in simplified age structure, reduced spatial heterogeneity of structural characteristics, and a depletion of decadent and dead trees. Globally, interest in managing forests for greater structural heterogeneity in ways that emulate the structural outcomes of natural disturbance and stand development processes is increasing (Attiwill, 1994; Larson and Churchill, 2012). Managing forest stands to restore structural heterogeneity is, in fact, an important goal for ecological management (Franklin et al., 2007). Some of the primary ways structural heterogeneity is accomplished is through approaches that increase age class diversity in single-cohort stands, through innovative uses of thinning to increase spatial heterogeneity of structure, and through deliberate creation of decadence and retention of deadwood.

3.3.1. Restoring age diversity

Stands with age diversity generally are more species rich than stands with less diverse structure (Thompson, 2012). Similarly, at the landscape level a diversity of stand structures promotes the greatest diversity of species (O'Hara, 1998; Oliver et al., 2012). In particular, early seral stands are underrepresented in many managed forested landscapes (Swanson et al., 2010; Greenberg et al., 2011). Transforming simple to complex structures (age-simplified to age-complex) requires time and multiple entries into stands (Nyland, 2003; Pommerening, 2006). Even so, many forest

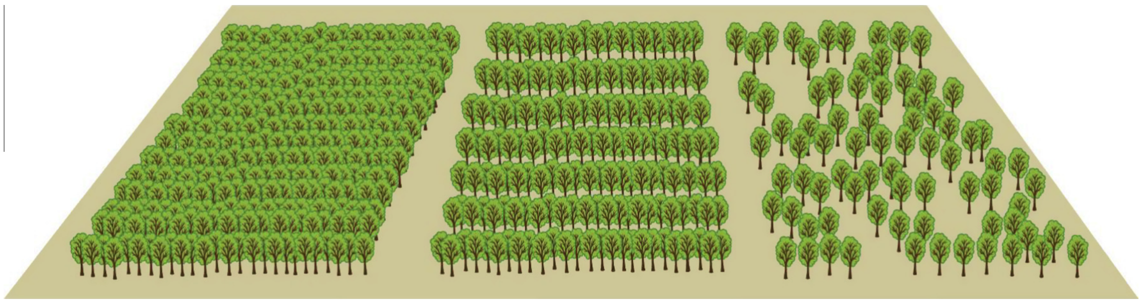

Fig. 13. Established stands can be thinned to a standard or alternatively to a variable density to create greater structural heterogeneity. The non-thinned stand (left) can be thinned by sequentially removing every other tree or row to yield a constant, or standard density (center), or treated with variable density thinning (VDT), often called the "skips and gaps" approach (right) that leaves non-thinned areas (skips) surrounded by heavily thinned areas (gaps) along a gradient from low to high density.

owners and managers are increasingly interested in managing for more complex age structures (Nyland, 2003), motivated by societal concerns about even-aged management using clearfelling; approaches that leave continuous cover at some level are preferred and lend themselves to development of uneven-aged stands (Pommerening and Murphy, 2004). While the social goals that drive such transformations may be valid, doing so should only be construed as structural restoration if the forest type in question was actually characterized historically by more complex structure.

Fortunately, a strong ecological basis for transformation to some form of complex (uneven)-age structure exists in many forest types, based on the recognition that natural disturbance dynamics often result in complex age structures compared to managed counterparts. In fact, retention of live trees at harvest has evolved as a key approach for restoring more age-complex forest stands (Elmqvist et al., 2002; Gustafsson et al., 2012; Lindenmayer et al., 2012). Retention management approaches reflect the fact that post-natural disturbance stands often display more complex age structure than is typical after traditional even-aged management approaches. While common, complex structure is not universal; woodlands and savannas are more open communities, possibly with irregular multi-aged structure of the overstory trees where fire burned more frequently (e.g., Guyette et al., 2012; Hanberry et al., 2014).

Prevelance of complex structure is easily conceptualized in forests that are characterized by gap or patch-based, less-than-stand replacing disturbances. By definition, these forests have near continuous canopy cover in the stand matrix. Trees regenerate in gaps of various sizes, establishing a new cohort within the older forest matrix. Forests characterized by gap-based disturbance regimes may consist of several distinct cohorts, resulting in spatially heterogeneous age and canopy structure across the stand (e.g., Frelich and Lorimer, 1991). Silvicultural approaches based on gap- and patch dynamics have been developed to transform stands with simple even-aged structure to more complex multi-cohort structure (e.g., Kenk and Guehne, 2001; Leak, 2003; Loewenstein, 2005). Some of the challenges of doing this, as summarized by Nyland (2003), include (i) a shift in composition to more shade tolerant tree species, (ii) a need to change the harvesting methods and equipment used, (iii) a change in habitat characteristics for some species, and (iv) the long amount of time required (many decades to centuries) to make the transition.

Retention of live trees at harvest is also ecologically justified in forests characterized by stand replacing or heavy-partial disturbance regimes. The post-disturbance stand provides the context for new regeneration and continuity of ecological functions dependent on mature trees in the developing stand (Franklin et al., 2000). Live tree legacies in post-disturbance stands result in more complex age structure than that found in managed even-aged stands, including largely single-cohort forests containing scattered older individuals (Zenner, 2000; Franklin et al., 2002; Schmiegelow et al., 2006), as well as age structures best described as two-cohort (Wallenius et al., 2002; Fraver and Palik, 2012). Transformation of even-aged stands to two-cohort structure, or single-cohort with reserves (i.e., residual trees), as part of a structural restoration program, is relatively straightforward and can be achieved faster when compared to restoration of more complex multi-cohort stands. In fact, this approach for restoration of complex age structure is widely practiced in the context of variable retention harvesting regimes (Gustafsson et al., 2012).

3.3.2. Restoring structural heterogeneity

Thinning treatments in established stands are generally modeled on natural decline and mortality of trees that occurs during stand development; natural thinning augmented by small-scale disturbances contribute to spatial heterogeneity of stand structure (Franklin et al., 2002). Standard thinning is intended to anticipate natural competition-induced mortality by removing suppressed trees before they die from resource limitations (thinning from below) or by removing dominant trees and thus allow subdominant and suppressed trees to increase in growth (thinning from above). Traditionally, standard thinning in plantations is implemented in a way that deliberately creates an evenly distributed population of crop trees, all having similar access to light, water, and soil nutrients, often times through use of row thinning. In naturally regenerated stands, thinning also focuses on reducing competition on crop trees but spatial distribution is less uniform.

In contrast, passively managed stands undergoing competitive thinning and non-competitive mortality often display some spatial variation in tree densities, growth rates, and tree sizes. It is this kind of variation in structure that restorationists may desire to create in simplified stands and to do so in a way that accelerates the development of structural heterogeneity that otherwise may take decades to develop passively. From a restoration perspective, the goal of this type of thinning is to create structural heterogeneity throughout the stand, rather than to concentrate growth on selected trees and create spatially uniform stands, as in a traditional forest management approach.

Structural heterogeneity can be developed using an approach known as variable density thinning or VDT (Aubry et al., 1999; Vanha-Majamaa and Jalonen, 2001; Pastur et al., 2009; O'Hara et al., 2010; Baker and Read, 2011; Lencinas et al., 2011; Ribe et al., 2013) (Fig. 13). Prescriptions for VDT have been formulated and implemented in a variety of ways, but one popular and easily conceptualized approach is known as "skips and gaps" thinning. With this approach, VDT prescriptions provide for unthinned areas (referred to as "skips") and heavily thinned patches ("gaps"), along with intermediate levels of thinning and residual density throughout the bulk of the stand matrix (Lindenmayer and Franklin, 2002). The result is greater spatial variability in stand densities and, consequently, greater structural complexity and heterogeneity of structure than occurs with standard thinning. Ecological benefits of VDT include development of large trees in the thinned matrix, opportunities for release or new establishment of woody and herbaceous species in gaps, protection of unique structures or species in skips, and in general, the creation of spatially variable microclimatic and habitat conditions. Moreover, the natural structural heterogeneity that develops after many decades of stand development, through accumulation of the effects of both competitive and non-competitive mortality, can be achieved fairly rapidly, thus accelerating the restoration process (O'Hara et al., 2010).

3.3.3. Restoring deadwood structures

Large woody debris is an important habitat element that can be abundant in passively managed stands, but is often depleted in managed stands (Harmon et al., 1986; Grove and Meggs, 2003). The depletion reflects the relatively short rotation or cutting cycle lengths of managed stands, compared to the natural life spans of trees, such that significant amounts of large deadwood does not have time to develop. Additionally, dead trees may not be left as biological legacies (*sensu* Franklin et al., 2000) in harvested stands. Moreover, living but decadent trees in the process of decline, decay, and eventual mortality, are abundant in natural forests, but managed against in traditional commercial forestry (e.g., Fridman and Walheim, 2000; Kruys et al., 2013). In fact, traditional thinning is often used to improve and standardize tree quality and form, such that poor quality trees (e.g., those with cavities, large branches, or decay pockets) may be preferentially removed (Graves et al., 2000).

Given the importance of dead and dying trees in forest ecosystems as habitat for many other organisms (Harmon et al., 1986; Jonsson et al., 2005), a restoration program might include active techniques, beyond time, to add these structural elements into managed stands. One such approach is the inclusion of dead and dying trees in retention harvesting prescriptions. Conceptually, variable retention harvesting is meant to consider and include more than just large live trees, but also other structural elements that are retained in the harvested stand as legacies, including standing and downed deadwood (Franklin et al., 1997; Grove and Meggs, 2003). A restoration program might include actions such as deliberate killing of living trees, or injuring them to induce decline, with the goal of creating cavity trees and dead wood in its various forms in established stands (Laarmann et al., 2009; Vanha-Majamaa et al., 2007; Gibbons et al., 2010). Alternatively, artificial cavities have been successfully created for some endangered species (Hooper and McAdie, 1996; Lindenmayer et al., 2009). Leaving high stumps after harvest benefits saproxylic beetles by providing breeding habitat (e.g., Lindhe and Lindelöw, 2004).

3.3.4. Restoring complex structure at multiple scales

Restoring structural heterogeneity at multiple scales often is a component of habitat restoration for birds and other animals. Complex vegetation structures can be especially important for conservation of some top predators, but a diversity of structures may be needed to fulfill the habitat requirements of their prey. For example, the Amur tiger (*Panthera tigris altaica*) population in northeast China remains at low levels despite effective bans on hunting and poaching and a shortage of open structures suitable for their prey is one factor (Han et al., 2012). As previously noted, early successional structures also are in short supply and their scarcity threatens some species (Litvaitis, 2001; Swanson et al., 2010; Greenberg et al., 2011). A landscape of managed forest stands of similar structure (and possibly age) can be transformed using variable retention harvesting (Fig. 14). The amount of retained stems (or basal area) can be varied, as well as the spatial arrangement of retention stems, either aggregated or dispersed (e.g., Sullivan et al., 2001). Diversity and spatial arrangements of microhabitats can influence successful dispersal by animals into restored sites and considerable time may be needed for some components to develop (Vesk et al., 2008). For example, Christie et al. (2013) found that placing small woody debris piles near intact Jarrah forest in southwestern Australia facilitated colonization of restored mined sites by Napolean's skink (*Egernia napoleonis*).

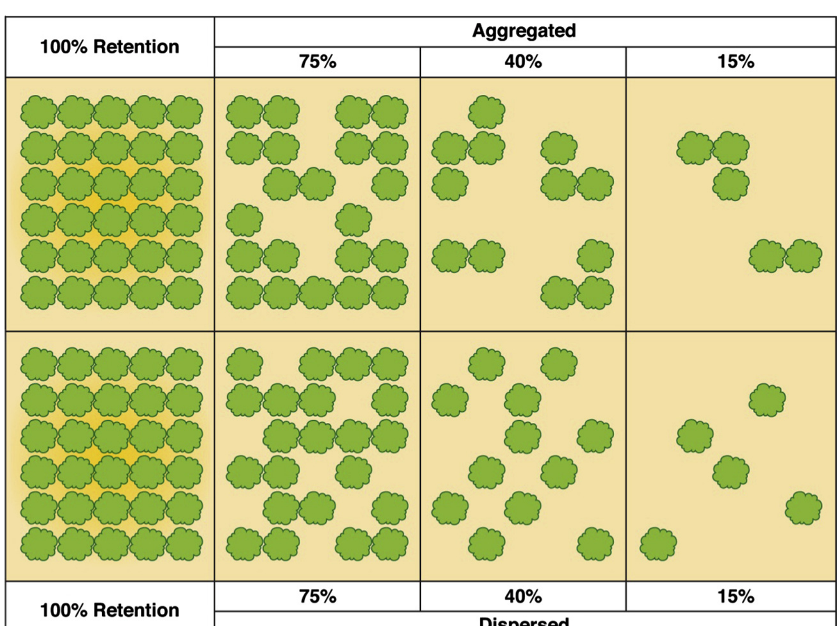

Fig. 14. Variable retention harvest designs create structural complexity and heterogeneity at the landscape level. Different densities of retained stems may be dispersed or aggregated within the stand and stands have different levels and patterns of retention across the landscape.

3.4. Legacies

Legacies from past land use or from previous stands may influence the restoration trajectory (Foster et al., 1998, 2003; Kettle et al., 2000). From the perspective of restoration objectives, such legacies may be beneficial or detrimental. As discussed earlier, deadwood in its various forms and conditions provides desirable function by providing habitat and other resources to a wide variety of species (Harmon et al., 1986). When it is missing in a managed stand, actions to restore it are needed. Conversely, when it is present in a managed stand, actions to maintain it as an important legacy are needed, particularly after regeneration harvesting (Boddy, 2001; Nordén et al., 2004). As Jonsson et al. (2005) pointed out, no single target volume of deadwood exists that meets the requirements of all species, so they recommended that a variety of deadwood be maintained because all types of deadwood probably have associated species. Desirable amounts of deadwood may be ascertained from old forest stands that have been conservatively managed or protected (e.g., Fridman and Walheim, 2000). Quality of deadwood is primarily determined by size and stage of decay (Jonsson et al., 2005); in managed forests, deadwood size is skewed toward smaller diameters (Fridman and Walheim, 2000; Jonsson et al., 2005; Brumelis et al., 2011), therefore often the challenge in restoration is to create larger diameter deadwood.

Undesirable legacies in forests are numerous (Foster et al., 2003) and often so ingrained in the landscape that their influence on forest development is taken for granted. These include eroded or infertile soil, depauperate species composition from exploitive harvesting (Allen et al., 2001) or high herbivore pressure (Nuttle et al., 2013), altered drainage (Yaalon and Yaron, 1966; Gardiner and Oliver, 2005; Hughes et al., 2012), or hardwood species encroachment due to lack of fire, for example, in eastern North American forests (Abrams, 1992; Nowacki and Abrams, 2008). Even residual high soil fertility and pH from agricultural use, conditions that favor non-native invasive plants, can be an undesirable legacy (Allison and Ausden, 2004; Weiler et al., 2013).

3.5. Landscape considerations

The restoration methods discussed so far have focused on actions generally taken at the stand level with some reference to adjacent land use, but restoring ecological processes that operate at landscape scale is a defining attribute of functional restoration. Processes that transfer energy and matter, such as hydrological flows, wildfire, hillslope processes, wind, and animal movements are the flows that shape structure and composition of landscape elements as well as their spatial patterning in a landscape mosaic (Turner, 1989). Spatial patterning of patches with similar composition is important too, as these are affected by natural and socioeconomic attributes related to land ownership, tenure, and use. Clearly the landscape mosaic and its component patches are defined in the context of the way it is approached and spatial modeling is one way to understand landscape level vegetation dynamics, disturbances, and management activities such as restoration (Shinneman et al., 2012; Wimberly et al., 2012). Landscape classification should be more detailed than simply forest/non-forest (Lindenmayer et al., 2008), consider trade-offs among livelihoods and conservation options (Bradford and D'Amato, 2011; Boedhihartono and Sayer, 2012; Sayer et al., 2013), and identify suitable sites for intervention, prioritizing among sites for allocating scarce resources (Lamb et al., 2012), and for guiding the monitoring design and determining success (Ruiz-Jaén and Aide, 2005b; Bestelmeyer et al., 2006; Holl and Aide, 2011). Lindenmayer et al. (2008) and Sayer et al. (2013) provide guidance on factors to consider in the landscape approach.

The planting designs for treating an entire area can be simply spread over the entire landscape or different patches planted variously in simple and complex designs (Figs. 6–10). Similarly, the approaches to transformation and conversion, including underplanting (Fig. 12) and variable retention harvests (Figs. 13 and 15), can be applied in various configurations that would result in structural and compositional diversity. Cluster afforestation (Schönenberger, 2001; Díaz-Rodríguez et al., 2012) is a landscape design, and the planting scheme within a cluster can be varied. Buffer strips, wildlife corridors and other linear plantings (Fig. 11) can serve multiple purposes; again, the planting design within the linear strip can be varied by species and density (Bentrup et al., 2012). The design goal should be to create a diversity of vegetation types on the landscape (Lamb et al., 2012) and an important consideration, especially for restoring sites damaged by natural disasters, is to create asynchrony in terms of stand ages and developmental stages (Millar et al., 2007). Staggering outplanting or thinning across decades, perhaps, are ways to create temporal diversity. Another possibility is to accelerate or delay stand development through density manipulation or interplanting.

Hermann et al. (2013) provided an example of the approaches we have discussed. They used silvics of *Pinus palustris* and historical descriptions to restore a National Military Park in central Alabama, USA to the structure and composition of the forest that likely surrounded an 1814 battlefield. They were guided by the decision matrix shown in Table 2 and expanded it to the landscape by first diagnosing initial conditions including condition of existing stands, location of isolated trees, and soil characteristics. They used soils information and dispersal distances of *P. palustris* to identify patches where natural regeneration, including seeds from isolated trees, could augment outplanting. Options considered were outplanting, fuel reduction by prescribed burning, and removal of off-site broadleaved species.

The design of future landscapes involves many more considerations than planting design, including reconciling competing visions and goals, allocating scarce resources, and how to evaluate different designs. These issues are taken up later, but it is important to consider that to be successful, the goals and values of people living in or near the land to be restored should be considered as well as the programmatic goals of the organization funding the work. Elements of both top-down and bottom-up approaches will be useful in balancing competing visions and goals (Lamb, 2011; Boedhihartono and Sayer, 2012).

Fig. 15. *Quercus rubra* L. individuals persisting in the understory of a managed *Pinus resinosa* forest in northern Minnesota, USA. Photo by Christel Kern.

3.6. Restoring process

Ecological processes are physical, chemical, and biological actions or events linking organisms to their environment and involve transfers of material and energy through the landscape. Falk (2006) proposed a central emphasis on ecological functions and ecosystem processes as the foundation of restoration research and practice. He proposed replacing reference sites with reference dynamics, where underlying mechanisms of change are the primary factors. These mechanisms might be natural (Stringham et al., 2003) or anthropomorphic (Doren et al., 2009), which influences the way ecological processes are defined and used in different approaches to restoration. Herrick et al. (2006) provided an example from fire-adapted forest and savanna ecosystems where the fire regime depends on the composition, structure, and spatial arrangement of the vegetation, as well as ignition sources. A useful categorization defines four primary processes: the hydrologic cycle, biogeochemical cycles, energetics (energy capture and the carbon cycle), and disturbances. These processes affect vegetation and animal population dynamics (Bestelmeyer et al., 2006; Turner, 2010), including gene flows (Banks et al., 2013). Attempts to directly restore ecological processes have concentrated on fire and hydroperiod; indirect attempts to restore disturbance processes invoke vegetation manipulations to achieve effects on structure and composition that are similar to the effects of the disturbance, for example windstorms or wildfire. We discuss two specific examples of Process Restoration, fire and inundation regime, in the following sections.

3.6.1. Restoring fire regime

Wildfire is a primary disturbance agent affecting the structure and composition of many forest ecosystems and fire is essential to ecosystem functioning where species have evolved to withstand burning and facilitate fire spread (Myers, 2006; Meyn et al., 2007). Such fire-dependent ecosystems include many coniferous boreal, temperate, and tropical forests; *Eucalyptus* forests; most vegetation types in Mediterranean climates; some *Quercus* dominated forests; grasslands, savannas, and marshes; and palm forests (Myers, 2006). Even so, such ecosystems are vulnerable to fire regimes altered by humans (e.g., Briant et al., 2010; Armenteras et al., 2013; Laurance et al., 2014).

Natural fire regimes have been altered in many fire-adapted forest types and restoring fire is an objective for ecological or safety reasons (Agee, 2002; Keeley et al., 2009; for additonal examples, see Table 1). Climate change that results in drier, warmer climates has the potential to increase fire occurrence and intensify fire behavior and thus may alter the distribution of fire- dependent, sensitive, and influenced ecosystems (Myers, 2006). Recently, persistent weather anomalies, such as prolonged warm and dry seasons or extended drought, have contributed to a phenomenon of very intense, destructive megafires (Williams, 2013; Liu et al., 2014) and the effects are amplified by former land management that focused on fire suppression, which reduced fire frequency but now contributes to increased fire intensity (Williams, 2013). Although megafires seem to be worst in dry forest types with slow decomposition and long-term fire exclusion (Williams, 2013), altered fire regimes also occur when wetter forests are fragmented, resulting in drier conditions at the edge that allow escaped (or intentionally set) agricultural fires to encroach and gradually reduce the area of wet tropical forests (Myers, 2006; Cochrane and Laurance, 2008). Similarly, invasion by grasses and herbs that enhance fire spread results in the fire-grass cycle that reduces forest cover (D'Antonio and Vitousek, 1992).

Fire regime, the long-term presence of fire in an ecosystem, is mainly characterized by fire frequency (or fire return interval) and fire severity and can be classified as understory, stand-replacement, or mixed (Brown and Smith, 2000). Understory-regime fires generally do not kill the dominant vegetation or substantially change its structure, whereas a stand-replacement fire does. Mixed-regime fires can either cause selective mortality in dominant vegetation or not depending on a species' susceptibility to fire. Re-introducing fire into systems that have a natural fire regime of frequent, low-intensity understory fires may be more feasible than restoring a natural stand-replacing fire regime, particularly in areas close to human populations. Because many landscapes have been fragmented by roads, agriculture, and habitation, truly restoring even a low-intensity understory fire regime across the landscape that burns with varying intensity and leaves behind a mosaic of conditions (e.g., Turner, 2010) would be difficult because most forests have too many roads and too much suppression activity to allow for truly natural fire regimes at the landscape-scale (Covington et al., 1997; Phillips et al., 2012).

Restoring fire regimes usually involves treatments to reduce fuels to levels where prescribed burning can be safely conducted (Brose et al., 1999; Fulé et al., 2001; Baker and Shinneman, 2004; McIver et al., 2012; McCaw and Lachlan, 2013). The objective is to increase fire resilience by reducing surface fuels, increasing height to live crown, decreasing crown density, and retaining large trees or introducing seedlings of resistant species (Brown et al., 2004). Collectively these measures reduce flame length and lower the risk of crown fires; the lower intensity fires that occur should produce the lowest carbon loss. On one hand, this may be accomplished solely with prescribed burning at ecologically appropriate intervals if fuel conditions allow. On the other hand, it may be necessary to reduce stem density, especially of small diameter stems in overly dense stands, through mechanical means, followed by re-introduction of fire. The resulting low intensity fire regime may depart from historic conditions, especially on non-production and conservation forests if required to maintain essential habitat or otherwise protect important values (Brown et al., 2004) and with regard to future climatic conditions (Fulé, 2008). In stands with large accumulations of fuels, the restoration process may require multiple interventions over several years; problems that develop over decades cannot usually be solved with a single treatment. For example, in pine forests in the southern USA (e.g., Fig. 16), fire exclusion and continued litterfall allowed the duff layer to accumulate to as much as three times the level under normal fire return intervals (McNab et al., 1978). An incorrect prescribed fire under these conditions will ignite the duff layer and cause excessive smoke and overstory mortality (Varner et al., 2005; O'Brien et al., 2010). Depending on site conditions, effective restoration treatments may include some combination of reducing dense understory or midstory stems by mechanical or chemical means, conducting multiple low-intensity prescribed burns for several seasons to reduce fine fuel accumulation, planting ecologically appropriate herbaceous and graminoid species, or converting the overstory to more fire-adapted species (Mulligan et al., 2002; Hubbard et al., 2004).

3.6.2. Restoring hydroperiod

Wet forests in low-lying areas, river floodplains, and forests along coasts are important zones of energy and material exchange as they connect terrestrial and aquatic ecosystems (Witman et al., 2004; Nagy and Lockaby, 2012). These systems may be extensive or rare in the landscape, represent unique habitats locally and globally, with significant social and ecological values (Moberg and Ronnback, 2003; Alongi, 2008; Grossmann, 2012). They are generally heavily impacted by humans (Wohl, 2005; Miettinen et al., 2012) and especially in coastal areas, urbanized (Burbridge, 2012). Despite the highly altered nature of these areas, the interest in restoring wetland and coastal ecosystems is great as a way to mitigate damage from changing land use in upland areas of

Fig. 16. Different intervals of fire exclusion in 90-year-old *Pinus palustris* stands in Florida, USA dramatically affect build-up of fuels. Annual prescribed burning limits development of perennial understory vegetation (the foresters are approximately 1.5 m tall) (A). A four-year interval between prescribed burns allows an understory that is predominantly *Serenoa repens* W. Bartram, which persists from a lignotuber, as well as ericaceous shrubs (B). After 50 years of fire exclusion, the *S. repens* is taller than the foresters (circled). A wildfire in this stand would cause significant overstory mortality (C). Photos by Mac Callaham.

watersheds that cause downstream flooding (Bruijnzeel, 2004) and further challenges from sea-level rise, salt-water intrusion, and increased coastal storm and wave action under future climate (Gilman et al., 2008; Kaplan et al., 2010; Maschinski et al., 2011).

Restoring wet forests often requires a combination of hydrologic modification and revegetation, with due consideration for natural recolonization (Allen et al., 2001; Lewis, 2005). Restoring hydrologic functioning must begin with an objective examination of what is possible, in particular the extent to which hydroperiod can be truly restored. Fully restoring hydrological functioning goes beyond re-wetting but full restoration may be impractical because of cost, incompatibility with current land uses, or conflict with private property rights, especially in large riverine systems with extensive levees and flood control structures (Stanford et al., 1996; Lockaby and Stanturf, 2002; Hughes et al., 2012). Nevertheless, increased interest in "soft-engineering" approaches to water management (Day et al., 2003; Borsje et al., 2011), combined with predictions of coastal vulnerability to sea-level rise may change perceptions of feasibility (Danielsen et al., 2005; Zhang et al., 2012).

Restoring hydrologic functioning of rivers goes beyond forest restoration and may involve removing dams and breaching levees before restoring vegetation (Stanford et al., 1996; Schneider, 2010; Hughes et al., 2012). Inundation regime remains critical for matching species to site; for example, mangrove forests globally are inundated $\leqslant$30% of the time by tidal waters, which may require modifying the slope of the restoration site to the appropriate height above mean seal level (Lewis, 2005). If hydroperiod has not been altered, or can be easily restored, site factors are critical to determining restoration success. Many planting failures can be traced to outplanting species unadapted to the existing inundation regime (Stanturf et al., 1998, 2001; Lewis, 2005). Even though fully restoring a natural inundation regime may be infeasible, attempts to create site diversity have focused on modifying local topography and inundation effects (Hunter et al., 2008; Simmons et al., 2012; Jarzemsky et al., 2013), or using novel outplanting techniques that ensure riparian plants have access to the water table during the establishment phase (e.g., Dreesen and Fenchel, 2010).

4. Elements of success

Restoration paradigms differ in terms of their desired endpoints, in effect how each defines success (Stanturf et al., 2014). Ecological restoration seeks a return to a pre-disturbance state (SERI, 2004); forest landscape restoration defines success as a functioning landscape that meets livelihoods needs of local communities and provides ecosystem services (Lamb et al., 2012). Functional restoration looks to the future with incremental adaptations to altered climate and other conditions driving global change (Choi, 2007; Stanturf et al., 2014). Intervention ecology goes further and seeks transformative adaptation to future conditions (Hobbs et al., 2011; Kates et al., 2012). The key difference among these views is whether to look to the past or the future to define success (Clement and Junqueira, 2010). Reconciling these views is a foray into the realm of social preference (Daniels et al., 2012; Emborg et al., 2012) and beyond the scope of this review. Once preferences are expressed, however, they will be translated into goals and objectives that can be implemented. We conclude by describing some of the elements of a successful forest restoration program.

4.1. Define expectations and endpoints for the restored system

4.1.1. Expectations

Well-defined expectations have long been recognized as an essential element of a restoration project (Hobbs and Norton, 1996; Hallett et al., 2013) and lack of well-defined expectations has been a leading cause of failure (Kapos et al., 2008; Dey and Schweitzer, 2014). Expectations may be implicit rather than explicit; one common implicit expectation has been termed the "foster" (Munro et al., 2009) or "Field of Dreams" paradigm (Palmer et al., 1997) that attempts to create the necessary biophysical conditions such that a desired system will spontaneously develop. In wet forests, this often means restoring hydroperiod or at least matching expectations to the existing site hydrology (Stanturf et al., 2001;

Gardiner and Oliver, 2005; Lewis, 2005). Alternatively, another implicit expectation comes from the initial floristics successional model. This paradigm assumes that all desired species must be reintroduced; this may be true especially of understory and ground cover species (Munro et al., 2009). Explicit criteria are necessary, however, not only for monitoring and evaluation (critical to assessing whether efforts have been successful) but also for effectively communicating to stakeholders. The current emphasis on evidence-based conservation by donor agencies (Pullin et al., 2004; Sutherland et al., 2004; Ferraro and Pattanayak, 2006) and performance monitoring by governments (Peppin et al., 2010) also demands well-defined expectations (Crow, 2014).

Expectation is a prediction of the post-restoration state and the mechanism for change from the baseline condition (Toth and Anderson, 1998). Another way to look at expectation is that it defines not only the endpoint but also the mechanism of system change from the beginning to the endpoint (Burton, 2014; Dey and Schweitzer, 2014; Stanturf et al., 2014). Endpoints develop from goals, which express social values; expectations must reflect social values because multiple states are possible for any part of the landscape (Burton, 2014). Goals of ecosystem health (Crow, 2014), ecological integrity (SERI, 2004; Tierney et al., 2009), naturalness (Brumelis et al., 2011; Winter, 2012), or conservation (Lindenmayer and Franklin, 2002) lead to their own set of expectations. No single paradigm fits all conditions or social contexts but expectations should be realistic in terms of project scope, goals, and available resources (Ehrenfeld, 2000). To further complicate matters, expectations can change over time as social preferences and policies change, as land use changes as a result of population shifts from rural to urban areas, or from the effects of altered climate.

Expectations must express the mechanism for change, as well as the desired endpoint (Toth and Anderson, 1998). Different approaches include theory of change (Mascia et al., 2014), state-transition models (Rumpff et al., 2011), and conceptual ecological models (Doren et al., 2009) nevertheless all describe some causal mechanism for change that purports to link restoration interventions to changes in the ecosystem. Progress must be measured by reference to explicit criteria based on strong inference that establishes the causal connection between intervention and change in baseline condition (Stringham et al., 2003; Suding et al., 2004; Rumpff et al., 2011). Ecosystem components, however, differ in their temporal trajectories; some change faster than others. For example, Stanturf et al. (2001) discussed different ways to assess restoration success in afforestation to reconstruct riverine broadleaves and described time to crown closure as one way to compare treatments (relatively fast change) versus accumulation of soil carbon (slow to change) in former agricultural sites. Parsing expectations into indicators of different components of the restored ecosystem allows consideration of intermediate states as well as progress toward the endpoint; restoration takes time and intermediate conditions must be considered for evaluating success (Paine et al., 1998; Oliver and O'Hara, 2005; Swanson et al., 2010).

4.1.2. Endpoints

The selection of end points for restoration based on historical or even contemporary reference conditions is increasingly recognized as difficult (Sprugel, 1991) if not futile, due to global change (Fulé, 2008; Ravenscroft et al., 2010; Hiers et al., 2012). The climatic conditions that resulted in the development of extant ecosystems, or reference conditions based on historical information, are increasingly becoming less relevant. Changing climate and the dynamic nature of species distributions and assemblages are well demonstrated (Davis, 1976; Millar, 2014), but until recently, these relationships were associated with millennial time frames. Current projections of anthropogenic climate change assume rates of change never seen historically (IPCC, 2007; Svenning and Skov, 2007). As such, the relevance of current ecosystem composition and structure and the reference conditions they represent will continually diminish in the future (Alig et al., 2004; Bolte et al., 2009; Davis et al., 2011). The challenges of continuing global change and impending climate variability render the goal of restoring to some past conditions even more unachievable (Harris et al., 2006). Recognition that restoration must take place within the context of rapid environmental change has begun to redefine restoration goals towards future adaptation rather than a return to historic conditions (Choi, 2007). This redefinition of restoration removes the underpinning of a presumed ecological imperative (Angermeier, 2000; Burton and Macdonald, 2011) and underscores the importance of clearly defined goals focused on functional ecosystems.

An overarching challenge, therefore, is determining how to pursue a contemporary restoration agenda while coping with great uncertainty regarding the specifics of future climatic conditions and their impacts on ecosystems. Management decisions at scales relevant to restoration need to consider how actions either enhance or detract from a forest's potential to adapt to changing climate (Stephens et al., 2010). An initial course of action is to still pursue endpoints that represent the best available understanding of the contemporary reference condition for the system in question (Fulé, 2008) but to do so in a way that facilitates adaptation to new climate conditions, by promoting resistance to extreme climate events or resilience in the face of these events. For example, density management to maintain forest stands at the low end of acceptable stocking is a potentially promising approach for alleviating moistures stress during drought events (Linder, 2000; D'Amato et al., 2013). The premise is that forests restored to low (but within the range of natural variability) density will be better able to maintain tree growth and vigor during a drought (resistance) or will have greater potential to recover growth and vigor rapidly after the event (resilience) (Kohler et al., 2010).

Another management approach for restoration in the face of climate change is to include actions that restore compositional, structural, and functional diversity to simplified stands, so as to provide flexibility and the potential to shift development in different directions as conditions warrant (Grubb, 1977; Díaz and Cabido, 2001). This is the diversified investment portfolio concept applied to forests; a greater range of investment options better ensures ability to adapt to changing conditions (Yemshanov et al., 2013). Increased temperatures, decreased precipitation, or extreme droughts will affect species and the age or size of their cohorts differently (Millar et al., 2007). Safe sites, or microrefugia, will persist because of spatial heterogeneity, particularly in complex terrains (Ashcroft and Gollan, 2013; De Frenne et al., 2013).

Restoring compositionally and functionally diverse ecosystems, based on an understanding of contemporary reference conditions, also is a starting point for maintaining response options that facilitate the transition of forests to future climate conditions (Millar et al., 2007; Millar, 2014). This approach better ensures that species will maintain their presence and respond favorably (adapt) to future climate and thus be in a position to increase in abundance (Bolte et al., 2009). As an example, in the northern forests of Minnesota and Maine USA, *Acer rubrum* L. has the potential to fit this model. This species occurs in many current forest ecosystems of these regions, but generally at low abundance (e.g., Seymour, 1992). Climate niche-models for the eastern USA predict increasing habitat suitability and importance under even the most extreme emissions scenarios (Iverson et al., 2008). Ensuring that *A. rubrum* and other species with adaptive potential are present in ecosystems where they occur naturally is an important adaptation strategy that can transition forests to future conditions. If these species are lacking, but should occur based on habitat suitability, then active management to reintroduce component species through seeding or outplanting may be needed, along with the cultural actions that ensure successful establishment and longevity.

4.2. Monitor and evaluate

Monitoring is almost always specified as an important aspect of restoration projects (e.g., Pastorok et al., 1997; Abella and Covington, 2004; Herrick et al., 2006) but monitoring deficiencies is a common problem (Wortley et al., 2013). One assessment revealed that only 18% of project managers indicated that monitoring was required; even so, monitoring was conducted on about 50% of the projects (Bash and Ryan, 2002). The considerable constraints on monitoring include unclear objectives, collecting data that serve financial accounting but not decision-making purposes, and effects of the project occurring outside project time frames (Kapos et al., 2008). Monitoring is often perceived as being too expensive to justify, although recent monitoring expenditures in the USA were a tiny fraction (0.1–5%) of the money spent nationally for ecological restoration projects and pale in comparison to the value of the resources being monitored (Lovett et al., 2007).

Monitoring can have several objectives and involve multiple steps. In restoration, implementation monitoring is short-term and evaluates how well management activities were conducted compared to the original design, whereas effectiveness monitoring seeks to determine if the treatments are yielding desired results (Hutto and Belote, 2013). Monitoring steps include goal setting, identifying what to monitor, establishing threshold points, developing a sampling design, collecting and analyzing data, evaluating results (Block et al., 2001; Bestelmeyer et al., 2006), and re-evaluating the process for future efforts. Verification of methodology and subsequent observed results is necessary to improve techniques and ensure that project goals are met. Lack of a holistic approach, emphasis on short-term and site-specific projects, disparate types of data collected, and neglect of proper, long-term monitoring limit the effectiveness of restoration efforts (Bash and Ryan, 2002; Reeve et al., 2006). Long-term monitoring is critical because projects deemed successful in the short-term may not sustain desired outcomes into the future and vice versa (Herrick et al., 2006; Matthews and Spyreas, 2010). This is particularly evident if species composition is the primary attribute monitored.

The most effective monitoring is embedded within an adaptive management framework that monitors for changes in the system, evaluates those changes against expectations, and determines if the change was caused by intervention (Anderson and Dugger, 1998; Stem et al., 2005; Doren et al., 2009), which requires a counter-factual, or no action control site that is similarly degraded as the restoration site (Ferraro, 2009).

Monitoring is conducted by periodically measuring indicators of ecosystem conditions. Indicators in forest restoration monitoring commonly focus on vegetation (Ruiz-Jaén and Aide, 2005a; Burton and Macdonald, 2011; Hallett et al., 2013). This is understandable as vegetation is fundamental and commonly is correlated with other functional attributes (Doren et al., 2009) and with suitable habitat for animals (e.g., Twedt and Portwood, 1997; McCoy and Mushinsky, 2002), but interactions among vegetation and fauna (e.g., pollinators, herbivores) are important and population dynamics should be properly monitored as well (Block et al., 2001). Selecting indicators to measure requires consideration of spatial and temporal characteristics. Spatial aspects can be arranged within a hierarchy of indicators, including the landscape, community (stand), and population (species) levels (Palik et al., 2000; Dey and Schweitzer, 2014). Generally, indicators related to community structure and composition are used in restoration projects and rarely are factors measured outside the project area such as attributes of the surrounding landscape (Ruiz-Jaén and Aide, 2005a). For example, Keddy and Drummond (1996) used criteria related to "original" forest structure and function and selected properties from existing relatively undisturbed forests. These included tree size, canopy composition, coarse woody debris, herbaceous layer, corticulous bryophytes, fungi, wildlife trees, forest area, birds, and large carnivores. To simplify evaluation, community-level indices can be constructed and compared to reference communities (Jaunatre et al., 2013). Monitoring at least two reference conditions and focusing on at least two variables within each of three ecosystem attributes (diversity, vegetation [e.g., cover, structure, biomass], ecological processes [e.g., nutrient pools and cycling, soil organic matter, mycorrhizae]) has been recommended (Ruiz-Jaén and Aide, 2005b) as a way to improve post-restoration strategies (Herrick et al., 2006).

Ecological process monitoring is seldom attempted, partly because most processes are difficult to monitor, may be slow to change, and the monitoring phase for restoration projects seldom lasts more than 5 years (Ruiz-Jaén and Aide, 2005a, 2005b). Short-term success, however, may not predict long-term sustainability (Herrick et al., 2006) and incorporating an understanding of ecosystem development patterns in the monitoring design may enable identifying deviation from objectives and the need for corrective intervention (Dey and Schweitzer, 2014). Spatial disaggregation of monitoring effort based on fundamental attributes, such as soil and site stability, hydrological functions, and biotic integrity, facilitates process monitoring (Palik et al., 2000; Herrick et al., 2006; Doren et al., 2009).

Selecting which indicators to monitor is daunting. The goal is to use the smallest set of indicators that can be simply and easily measured (Burton, 2014) to sufficiently monitor change, support science-based decision-making, and effectively communicate results to the public (Doren et al., 2009; Dey and Schweitzer, 2014). Criteria for choosing indicators can be found in Dey and Schweitzer (2014, Table 3) and Doren et al. (2009). Indicators may also span multiple scales, including specific landscape metrics (Lausch and Herzog, 2002; Sayer et al., 2007; Cushman et al., 2008), resources such as wildlife (Block et al., 2001; McCoy and Mushinsky, 2002), and social expectations (Hallett et al., 2013). Conversely, Stanturf et al. (2014) used sustainability attributes of forests to display indicators of degradation that could be reversed and used as indicators of restoration.

Indicators are what gets monitored and should be easy to measure, reliable, and have predictive as well as monitoring capability (Burton, 2014; Crow, 2014). Ground-based monitoring is time consuming, and therefore expensive, but resolution of species diversity and structure on a small scale is high, and this is the only method for examining most ecological processes. When resources are limited, focusing on indicator or keystone species may be a valid compromise (González et al., 2013; Mouquet et al., 2013). Remote sensing has advantages, especially as the size of the project area becomes larger, but a technique such as aerial photography is less robust in differentiating species (Shuman and Ambrose, 2003). Advances in the use of Light Detection and Ranging (LiDAR) when coupled with multi-spectral data, however, are providing land managers ways to discern species composition and structure in a variety of ecosystems (e.g., Hill and Thomson, 2005; Bork and Su, 2007; Holmgren et al., 2008), occurrence of invasive species (Asner et al., 2008), and suitability of vegetation as habitat for specific fauna (e.g., Bradbury et al., 2005). Availability of small unmanned aerial vehicles equipped with lightweight cameras offer additional low-cost methods for monitoring (Knoth et al., 2013).

Ultimately, long-term monitoring is required, particularly when reconstruction and reclamation are the strategies. The goal for monitoring is to assess progress toward achieving the overall functional restoration goal, and assists land managers in deciding what additional management activities, if any, are required. Thus, the trajectory of change is more important than static measurements in time. The 2- to 3-year cycle of research funding and declining agency budgets, however, usually produces at best sporadic monitoring. Citizen science approaches hold the promise of meeting some long-term monitoring needs (Goodchild, 2007; Tulloch et al., 2013; Daume et al., 2014). Community-based monitoring may be the only feasible approach in developing countries (Pratihast et al., 2013; Pritchard, 2013). Acknowledging the unpredictable nature of ecosystems (Doak et al., 2008; Oliver et al., 2012) suggests that successful restoration likely will require multiple interventions, whether planned or required in the face of unanticipated developments. Long-term monitoring provides the potential to respond with adaptive management (Hutto and Belote, 2013; Westgate et al., 2013) to meet these challenges.

4.3. Allocate resources

Key decisions to be made as part of a comprehensive restoration program are what resources can be mobilized and how best to allocate them (Holl and Aide, 2011). A critical question, to which an answer is seldom known, is this: How much does restoration cost? Although it is clear that costs for large-scale projects can be extremely high (for example, $13.4 billion for 20 years of restoration in the Everglades, USA), little credible information on average costs for restoration projects is available, and even then administrative costs may not be fully considered (Holl and Howarth, 2000; Rodrigues et al., 2011; Wu et al., 2011). Accounting for market and non-market benefits strengthens the rationale for restoration but projects seldom include all socioeconomic values and benefits (Aronson et al., 2010). Public funds are the most common financing for restoration, possibly with private-sector cost-sharing or in-kind services and volunteer labor (Holl and Howarth, 2000). Resources mobilized from public funds, however, usually have programmatic objectives that may constrain or skew how restoration is done. For example, publicly funded incentive programs usually have provisions for equal access by private landowners but this may not result in an optimal allocation in a landscape in terms of benefits derived (Mercer, 2005; Lamb, 2011). Funding may provide perverse incentives by underwriting expensive treatments when lower-cost alternatives are available or by favoring large companies and monocultures compared to owners with small land holdings (Ciccarese et al., 2012). Public programs are generally implemented such that all restoration expenses must be incurred within a short time (1 or 2 years) even though later intervention (e.g., weed control) may be needed to ensure success (e.g., Stanturf et al., 2004).

Efficient use of resources requires prioritizing where on the landscape to focus efforts. In simple terms this requires balancing the cost of activities against the expected benefits from the restored ecosystem. In practice it is difficult to fully estimate benefits and the balancing becomes less tractable if costs are borne by one group and most benefits accrue to others, or society at large (Mercer, 2005). On private land, economic return to the landowner is one way to prioritize and answer the question of where and how much to restore (Lamb et al., 2012; Wilson et al., 2012). Goldstein et al. (2008) looked specifically at how to pay for restoration on private land using return on investment. Mueller et al. (2013) used ex-post estimates of restoration values to assess willingness to pay by downstream water users (irrigators) for restoration of watershed services by upstream landowners. New funding sources from carbon mitigation and payments for other ecosystem services, added to financial returns from market goods such as timber, may augment or replace taxation-derived public funding for restoration (Pejchar and Press, 2006; Newton et al., 2012; Townsend et al., 2012).

Allocating, or prioritizing, resources can be done in many ways (Shinneman et al., 2010; Orsi et al., 2011; Wilson et al., 2011). Allocation methods include geospatial approaches ranging from relatively informal techniques to considerable, formal planning (Klimas et al., 2009; Pullar and Lamb, 2012; Wimberly et al., 2012). The idea behind any prioritization approach is to maximize benefits gained from use of limited resources. For example, Hyman and Leibowitz (2000) presented a linear modeling approach to prioritize wetland restoration based on an analysis that projects benefits for unit of effort. In contrast, Palik et al. (2000) used a fairly informal GIS approach that prioritized ecosystems for restoration based on combined rankings of degree of deviation from a reference condition (as an index of cost to restore) and rarity in the historical and contemporary landscapes. Pullar and Lamb (2012) present an approach that combines quantitative and qualitative metrics that describe benefits to various attributes of the landscape (e.g., biodiversity, watershed protection) and stakeholder assessments of different scenarios with a goal of consensus building for a particular scenario. The goal of any of these or similar methods is to direct scarce resources of an agency or organization in ways that optimize (most benefit for the dollar) the restoration outcome at a landscape scale.

4.4. Social context

No restoration project is undertaken in a social vacuum (Knight et al., 2010); even stand-level restoration occurs within a system of governance that regulates relationships among landowners, funding organization(s), implementer, and stakeholders. A global movement of broadening participation in natural resources decision-making has evolved towards sharing power and responsibility (Berkes, 2009). Forest Landscape Restoration is a co-management approach that developed in response to large-scale restoration and reforestation programs undertaken by public agencies that provided few local benefits, but generated much local ill will (Barr and Sayer, 2012; Boedhihartono and Sayer, 2012) because those whose livelihoods depended on the forest or other natural resources felt excluded from the management process (Ellis and Porter-Bolland, 2008; Colfer, 2011). Such exclusion leads only to conflict and resource degradation (e.g., García-Frapolli et al., 2009; Sayer et al., 2013) and its legacy of distrust and even animosity may persist (Oestreicher et al., 2009; Nysten-Haarala, 2013). Despite the movement toward more democratic, participatory forms of resource management, including restoration, the arrangements are diverse and reflect the governance structure, property rights and relations, and traditions of individual societies. Subsequently, no single arrangement has universal application and there are several potential obstacles to success as described below.

4.4.1. Complexities of tenure

Other aspects of social context that affect restoration include tenure and use rights (ownership versus use rights, *de jure* as opposed to *de facto*), participation by those affected (including Prior Informed Consent; Barr and Sayer, 2012), and the social capital available (including administrative capacity, technical knowledge, and available resources). In some societies, land ownership and use rights are well defined and enforced by the rule of law. In other instances, particularly in tropical countries, tenure relations are complex and corruption is endemic (Kolstad and Søreide, 2009). Today's complex ownership, tenure, and use rights may stem from historical development, for example a colonial past that has left a thin veneer of individual ownership over a traditional tenure system based on communal ownership (Lamb et al., 2005). Further complications arise when ownership of the forest, trees, or fruit from certain trees is separate from tenurial rights to the land for agriculture. Land tenure is generally understood as the mutually accepted terms and conditions under which land is held, used, and traded. It is important to note that land tenure is not a static system; it is a system and process that is continually evolving, influenced by the state of the economy, changing demographics, cultural interactions, political discourse, or a changing natural and physical environment (Murdiyarso et al., 2012). Land tenure can, however, have an impact on these factors, which is why it should be considered in conversations concerning forest restoration, socioeconomic development, and environmental change.

Tentative and changing terms of tenure lead to uncertainty and short planning horizons. Short-term planning is less likely to entail large investments in productive assets or adoption of new technologies, as little opportunity is available for a tenant to capture benefits from long-term investments. The same is true for investments in tree planting and sustainable forestry. Thus, insecure tenure often leads to land degradation and is economically unsustainable in the long term (Robinson et al., in press). The implications for forest restoration are similar to those for sustainable forestry; seeing little potential benefit from a restored forest, a land owner may be indifferent or even hostile to a restoration project (Hansen et al., 2009; Damnyag et al., 2012). Recognizing these barriers to tree planting and private forest management in general, alternative benefit-sharing schemes, such as modified taungya, have been developed along with community participation in forest management and restoration (Agyeman et al., 2003; Blay et al., 2008; Schelhas et al., 2010).

4.4.2. Social capital and participatory management

Perhaps the greatest challenge to science-based functional restoration is the lack of social capital and supportive institutions to initiate and sustain restoration efforts. By social capital we mean the civic environment that shapes community structure and enables norms to develop that shape the quality and quantity of a society's social interactions (Adler and Kwon, 2002). Levels of social capital determine the adaptive capacity of institutions, groups, or communities within a nation and society as a whole (Folke et al., 2002; Smit and Wandel, 2006). In developing countries where many restoration opportunities lie, government institutions lack the resources, political will, and legitimacy (Wollenberg et al., 2006) to enforce natural resources regulations. Development assistance may provide short-term resources but without enhancing institutional capacity, donor projects are seldom sustainable once the donor leaves town.

A widespread institutional problem in natural resources is the chasm between research results and management implementation known as the ''knowing-doing gap'' (Pullin et al., 2004; Knight et al., 2008; Esler et al., 2010). This gap between researchers, land managers, and the public has long been recognized and attributed to differences in knowledge base and values. Traditional efforts at bridging these gaps have addressed structural and process barriers to exchange of information (Sarewitz and Pielke, 2007), whereas current efforts focus on closer physical and social proximity of knowledge producers and users and indeed, even blurring the role distinction through adoption of communities of practice, learning networks, and citizen science (Carey et al., 1999; Jakobsen et al., 2004; Sunderland et al., 2009; Hendriks et al., 2012; Sirigar et al., 2012). Lack of information, however, may not be the problem. Rather, opportunity costs may be too high for the landholder to undertake restoration, benefits may accrue to others or society at large but not to the landholder, or both. Fully understanding the distribution of costs and benefits of restoration is critical to achieving optimal landscape designs.

The benefits of participatory management have been advanced (Redpath et al., 2013; Young et al., 2013) as normative (strengthening democratic processes), substantive (additional knowledge and improved decision-making), and instrumental (improved legitimacy and trust with reduced intensity of conflicts). Berkes (2009) reviewed this topic and provided these key insights: institutions (government agency and local organizations) are not monolithic and have a multiplicity of interests; co-management is not a static formal structure of roles and responsibilities but rather a fluid problem-solving arrangement. Various methods are available to inform restoration project formulation and assess impacts on local communities (Chambers, 1994). One tool, participatory mapping, can be used to integrate social and biophysical perspectives by displaying spatially the location of resources, their condition, and how they are used (e.g., Boedhihartono and Sayer, 2012; Hewitt et al., 2014). Because co-management occurs within a social context, no single approach will yield universally positive results (Young et al., 2013). Therefore, gathering information and understanding the social dimensions of a restoration project is as necessary as understanding the biophysical dimensions (Charnley, 2006; Knight et al., 2008). As Crow (2014) concluded, social considerations can trump biophysical factors.

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References

Abella, S.R., Covington, W.W., 2004. Monitoring an Arizona ponderosa pine restoration: Sampling efficiency and multivariate analysis of understory vegetation. Restor. Ecol. 12, 359–367.
Abrams, M.D., 1992. Fire and the development of oak forests. BioScience 42, 346–353.
Adjers, G., Hadengganan, S., Kuusipalo, J., Nuryanto, K., Vesa, L., 1995. Enrichment planting of dipterocarps in logged-over secondary forests: effect of width, direction and maintenance method of planting line on selected Shorea species. Forest Ecol. Manag. 73, 259–270.
Adler, P.S., Kwon, S.-W., 2002. Social capital: prospects for a new concept. Academy Manag. Rev. 27, 17–40.
Agee, J.K., 2002. The fallacy of passive management: managing for firesafe forest reserves. Conserv. Mag. 3, 18–25.
Agyeman, V., Marfo, K., Kasanga, K., Danso, E., Asare, A., Yeboah, O., Agyeman, F., 2003. Revising the taungya plantation system: new revenue-sharing proposals from Ghana. Unasylva 54, 40–43.
Ahn, Y.S., Ryu, S.-R., Lim, J., Lee, C.H., Shin, J.H., Choi, W.I., Lee, B., Jeong, J.-H., An, K.W., Seo, J.I., 2014. Effects of forest fires on forest ecosystems in eastern coastal areas of Korea and an overview of restoration projects. Landscape Ecol. Eng. 10, 229–337.
Alday, J.G., Marrs, R.H., Martínez-Ruiz, C., 2011. Vegetation succession on reclaimed coal wastes in Spain: the influence of soil and environmental factors. Appl. Veg. Sci. 14, 84–94.
Alig, R.J., Adams, D., Joyce, L., Sohn-Gen, B., 2004. Climate change impacts and adaptation in forestry: responses by trees and markets. Choices 19, 1–7.
Allen, J.A., Keeland, B.D., Stanturf, J.A., Clewell, A.F., Kennedy Jr., H.E., 2001. A guide to bottomland hardwood restoration. USGS Biological Resources Division, Information and Technology Report 2000–0011, and USDA Forest Service, Southern Research Station, Gen. Tech. Rep. SRS-40, p. 142.
Allen, C.D., Savage, M., Falk, D.A., Suckling, K.F., Swetnam, T.W., Schulke, T., Stacey, P.B., Morgan, P., Hoffman, M., Klingel, J.T., 2002. Ecological restoration of southwestern ponderosa pine ecosystems: a broad perspective. Ecol. Appl. 12, 1418–1433.
Allison, M., Ausden, M., 2004. Successful use of topsoil removal and soil amelioration to create heathland vegetation. Biol. Conserv. 120, 221–228.
Alongi, D.M., 2008. Mangrove forests: resilience, protection from tsunamis, and responses to global climate change. Estuar. Coast. Shelf Sci. 76, 1–13.
Ammer, C., Mosandl, R., 2007. Which grow better under the canopy of Norway spruce—planted or sown seedlings of European beech? Forestry 80, 385–395.
Anderson, D.H., Dugger, B.D., 1998. A conceptual basis for evaluating restoration success. In: Transactions of the North American Wildlife and Natural Resources Conference, vol. 63, pp. 111–121.

Angermeier, P.L., 2000. The natural imperative for biological conservation. Conserv. Biol. 14, 373–381.
Aradóttir, A.L., 2005. Restoration of birch woodlands in Iceland. In: Stanturf, J.A., Madsen, P. (Eds.), Restoration of Boreal and Temperate Forests. CRC Press, Boca Raton, pp. 195–209.
Armenteras, D., González, T.M., Retana, J., 2013. Forest fragmentation and edge influence on fire occurrence and intensity under different management types in Amazon forests. Biol. Conserv. 159, 73–79.
Arnalds, O., Aradóttir, A.L., Thorsteinsson, I., 1987. The nature and restoration of denuded areas in Iceland. Arctic Alpine Res., 518–525.
Aronson, J., Blignaut, J.N., Milton, S.J., Le Maitre, D., Esler, K.J., Limouzin, A., Fontaine, C., De Wit, M.P., Prinsloo, P., Van Der Elst, L., 2010. Are socioeconomic benefits of restoration adequately quantified? A meta-analysis of recent papers (2000–2008) in Restoration Ecology and 12 other scientific journals. Restor. Ecol. 18, 143–154.
Ashcroft, M.B., Gollan, J.R., 2013. Moisture, thermal inertia, and the spatial distributions of near-surface soil and air temperatures: understanding factors that promote microrefugia. Agr. Forest Meteorol. 176, 77–89.
Ashton, P.M.S., Gamage, S., Gunatilleke, I.A.U.N., Gunatilleke, C.V.S., 1997. Restoration of a Sri Lankan rainforest: using Caribbean pine *Pinus caribaea* as a nurse for establishing late-successional tree species. J. Appl. Ecol., 915–925.
Ashton, P.M.S., Gamage, S., Gunatilleke, I.A.U.N., Gunatilleke, C.V.S., 1998. Using Caribbean pine to establish a mixed plantation: testing effects of pine canopy removal on plantings of rain forest tree species. Forest. Ecol. Manag. 106, 211–222.
Ashton, M.S., Gunatilleke, C.V.S., Singhakumara, B.M.P., Gunatilleke, I.A.U.N., 2001. Restoration pathways for rain forest in southwest Sri Lanka: a review of concepts and models. Forest. Ecol. Manag. 154, 409–430.
Asner, G.P., Knapp, D.E., Kennedy-Bowdoin, T., Jones, M.O., Martin, R.E., Boardman, J., Hughes, R.F., 2008. Invasive species detection in Hawaiian rainforests using airborne imaging spectroscopy and LiDAR. Remote Sens. Environ. 112, 1942–1955.
Attiwill, P.M., 1994. The disturbance of forest ecosystems: the ecological basis for conservative management. Forest. Ecol. Manag. 63, 247–300.
Aubry, K.B., Amaranthus, M.P., Halpern, C.B., White, J.D., Woodard, B.L., Peterson, C.E., Lagoudakis, C.A., Horton, A.J., 1999. Evaluating the effects of varying levels and patterns of green-tree retention: experimental design of the DEMO study. Northwest Sci. 73, 12–26.
Bâ, A.M., Diédhiou, A.G., Prin, Y., Galiana, A., Duponnois, R., 2010. Management of ectomycorrhizal symbionts associated to useful exotic tree species to improve reforestation performances in tropical Africa. Ann. For. Sci. 67, 301.
Baker, S.C., Read, S.M., 2011. Variable retention silviculture in Tasmania's wet forests: ecological rationale, adaptive management and synthesis of biodiversity benefits. Aust. Forest. 74, 218–232.
Baker, W.L., Shinneman, D.J., 2004. Fire and restoration of pinon-juniper woodlands in the western United States: a review. Forest. Ecol. Manag. 189, 1–21.
Balandier, P., Guitton, J.-L., Prévosto, B., 2005. Forest restoration in the French Massif Central mountains. In: Stanturf, J.A., Madsen, P. (Eds.), Restoration of Boreal and Temperate Forests. CRC Press, Boca Raton, pp. 355–369.
Banks, S.C., Cary, G.J., Smith, A.L., Davies, I.D., Driscoll, D.A., Gill, A.M., Lindenmayer, D.B., Peakall, R., 2013. How does ecological disturbance influence genetic diversity? Trends Ecol. Evol. 28, 670.
Barr, C.M., Sayer, J.A., 2012. The political economy of reforestation and forest restoration in Asia–Pacific: critical issues for REDD+. Biol. Conserv. 154, 9–19.
Bash, J.S., Ryan, C.M., 2002. Stream restoration and enhancement projects: is anyone monitoring? Environ. Manag. 29, 877–885.
Baumhauer, H., Madsen, P., Stanturf, J.A., 2005. Regeneration by direct seeding—a way to reduce costs of conversion. In: Stanturf, J.A., Madsen, P. (Eds.), Restoration of Boreal and Temperate Forests. CRC Press, Boca Raton, pp. 349–354.
Benjamin, K., Domon, G., Bouchard, A., 2005. Vegetation composition and succession of abandoned farmland: effects of ecological, historical and spatial factors. Landscape Ecol. 20, 627–647.
Bentrup, G., Dosskey, M., Wells, G., Schoeneberger, M., 2012. Connecting landscape fragments through riparian zones. In: Stanturf, J., Lamb, D., Madsen, P. (Eds.), Forest Landscape Restoration. Springer, Dordrecht, pp. 93–109.
Berkes, F., 2009. Evolution of co-management: role of knowledge generation, bridging organizations and social learning. J. Environ. Manag. 90, 1692–1702.
Beschta, R.L., Rhodes, J.J., Kauffman, J.B., Gresswell, R.E., Minshall, G.W., Karr, J.R., Perry, D.A., Hauer, F.R., Frissell, C.A., 2004. Postfire management on forested public lands of the western United States. Conserv. Biol. 18, 957–967.
Bestelmeyer, B., Trujillo, D., Tugel, A., Havstad, K., 2006. A multi-scale classification of vegetation dynamics in arid lands: what is the right scale for models, monitoring, and restoration? J. Arid Environ. 65, 296–318.
Blakesley, D., Hardwick, K., Elliott, S., 2002. Research needs for restoring tropical forests in Southeast Asia for wildlife conservation: framework species selection and seed propagation. New Forest. 24, 165–174.
Blay, D., 2012. Restoration of deforested and degraded areas in Africa. In: Stanturf, J., Madsen, P., Lamb, D. (Eds.), A Goal-Oriented Approach to Forest Landscape Restoration. Springer, Dordrecht, pp. 267–319.
Blay, D., Appiah, M., Damnyag, L., Dwomoh, F.K., Luukkanen, O., Pappinen, A., 2008. Involving local farmers in rehabilitation of degraded tropical forests: some lessons from Ghana. Environ. Develop. Sustain. 10, 503–518.
Blinn, C.E., Browder, J.O., Pedlowski, M.A., Wynne, R.H., 2013. Rebuilding the Brazilian rainforest: agroforestry strategies for secondary forest succession. Appl. Geogr. 43, 171–181.
Block, W.M., Franklin, A.B., Ward, J.P., Ganey, J.L., White, G.C., 2001. Design and implementation of monitoring studies to evaluate the success of ecological restoration on wildlife. Restor. Ecol. 9, 293–303.
Boddy, L., 2001. Fungal community ecology and wood decomposition processes in angiosperms: from standing tree to complete decay of coarse woody debris. Ecol. Bull. 49, 43–56.
Boedhihartono, A.K., Sayer, J., 2012. Forest landscape restoration: restoring what and for whom? In: Stanturf, J., Lamb, D., Madsen, P. (Eds.), Forest landscape restoration. Springer, Dordrecht, pp. 309–323.
Bolte, A., Ammer, C., Löf, M., Madsen, P., Nabuurs, G.J., Schall, P., Spathelf, P., Rock, J., 2009. Adaptive forest management in central Europe: climate change impacts, strategies and integrative concept. Scand. J. Forest Res. 24, 473–482.
Booth, T.H., 2012. Forest landscape restoration in Australia's Murray–Darling basin. In: Stanturf, J.A., Madsen, P., Lamb, D. (Eds.), A Goal-Oriented Approach to Forest Landscape Restoration. Springer, Dordrecht, pp. 355–371.
Boothroyd-Roberts, K., Gagnon, D., Truax, B., 2013. Can hybrid poplar plantations accelerate the restoration of forest understory attributes on abandoned fields? Forest. Ecol. Manag. 287, 77–89.
Bork, E.W., Su, J.G., 2007. Integrating LIDAR data and multispectral imagery for enhanced classification of rangeland vegetation: a meta analysis. Remote Sens. Environ. 111, 11–24.
Borsje, B.W., van Wesenbeeck, B.K., Dekker, F., Paalvast, P., Bouma, T.J., van Katwijk, M.M., de Vries, M.B., 2011. How ecological engineering can serve in coastal protection. Ecol. Eng. 37, 113–122.
Bosire, J.O., Dahdouh-Guebas, F., Walton, M., Crona, B., Lewis III, R.R., Field, C., Kairo, J.G., Koedam, N., 2008. Functionality of restored mangroves: a review. Aquat. Bot. 89, 251–259.
Bradbury, R.B., Hill, R.A., Mason, D.C., Hinsley, S.A., Wilson, J.D., Balzter, H., Anderson, G.Q., Whittingham, M.J., Davenport, I.J., Bellamy, P.E., 2005. Modelling relationships between birds and vegetation structure using airborne LiDAR data: a review with case studies from agricultural and woodland environments. Ibis 147, 443–452.
Bradford, J.B., D'Amato, A.W., 2011. Recognizing trade-offs in multi-objective land management. Front. Ecol. Environ. 10, 210–216.
Brang, P., Schönenberger, W., Ott, E., Gardner, B., 2001. Forests as protection from natural hazards. In: Evans, J. (Ed.), The Forests Handbook. Blackwell, London, pp. 53–81.
Briant, G., Gond, V., Laurance, S.G., 2010. Habitat fragmentation and the desiccation of forest canopies: a case study from eastern Amazonia. Biol. Conserv. 143, 2763–2769.
Brissette, J.C., Barnett, J.P., Landis, T.D., 1991. Container seedlings. In: Duryea, M., Dougherty, P. (Eds.), Forest Regeneration Manual. Kluwer, Dordrecht, pp. 117–141.
Brockerhoff, E.G., Jactel, H., Parrotta, J.A., Quine, C.P., Sayer, J., 2008. Plantation forests and biodiversity: oxymoron or opportunity? Biodivers. Conserv. 17, 960–3115.
Brockerhoff, E.G., Jactel, H., Parrotta, J.A., Ferraz, S.F.B., 2013. Role of eucalypt and other planted forests in biodiversity conservation and the provision of biodiversity-related ecosystem services. Forest. Ecol. Manag. 301, 43–50.
Brockway, D.G., Outcalt, K.W., Tomczak, D.J., Johnson, E.E., 2005. Restoring longleaf pine forest ecosystems in the southern US. In: Stanturf, J.A., Madsen, P. (Eds.), Restoration of Boreal and Temperate Forests. CRC Press, Boca Raton, pp. 501–522.
Brockway, D.G., Outcalt, K.W., Estes, B.L., Rummer, R.B., 2009. Vegetation response to midstorey mulching and prescribed burning for wildfire hazard reduction and longleaf pine (*Pinus palustris* Mill.) ecosystem restoration. Forestry 82, 299–314.
Brose, P., Van Lear, D., Cooper, R., 1999. Using shelterwood harvests and prescribed fire to regenerate oak stands on productive upland sites. Forest. Ecol. Manag. 113, 125–141.
Brown, J.K., Smith, J.K. (Eds.), 2000. Wildland Fire in Ecosystems: Effects of Fire on Flora. USDA Forest Service, Rocky Mountain Research Station. Gen. Tech. Rep. RMRS-GTR-42-vol. 2, p. 257.
Brown, R.T., Agee, J.K., Franklin, J.F., 2004. Forest restoration and fire: principles in the context of place. Conserv. Biol. 18, 903–912.
Bruijnzeel, L.A., 2004. Hydrological functions of tropical forests: not seeing the soil for the trees? Agr. Ecosyst. Environ. 104, 185–228.
Brumelis, G., Jonsson, B.G., Kouki, J., Kuuluvainen, T., Shorohova, E., 2011. Forest naturalness in northern Europe: perspectives on processes, structures and species diversity. Silva Fenn. 45, 807–821.
Brunner, A., Hahn, K., Biber, P., Skovsgaard, J.P., 2006. Conversion of Norway spruce: a case study in Denmark based on silvicultural scenario modelling. In: Hasenauer, H. (Ed.), Sustainable Forest Management: Growth Models for Europe. Springer, Heidelberg, pp. 343–371.
Bullard, S., Hodges, J.D., Johnson, R.L., Straka, T.J., 1992. Economics of direct seeding and planting for establishing oak stands on old-field sites in the south. Southern J. Appl. Forest. 16, 34–40.
Buongiorno, J., 2001. Quantifying the implications of transformation from even to uneven-aged forest stands. Forest. Ecol. Manag. 151, 121–132.
Burbridge, P.R., 2012. The role of forest landscape restoration in supporting a transition towards more sustainable coastal development. In: Stanturf, J., Lamb, D., Madsen, P. (Eds.), Forest Landscape Restoration. Springer, Dordrecht, pp. 253–273.
Burton, P.J., 2014. Considerations for monitoring and evaluating forest restoration. J. Sustain. Forest. 33 (Suppl. 1), S149–S160.

Burton, P.J., Macdonald, S.E., 2011. The restorative imperative: challenges, objectives and approaches to restoring naturalness in forests. Silva Fenn. 45, 843–863.
Butterfield, R.P., 1995. Promoting biodiversity: advances in evaluating native species for reforestation. Forest. Ecol. Manag. 75, 111–121.
Callaham, M.A., Rhoades, C.C., Heneghan, L., 2008. A striking profile: soil ecological knowledge in restoration management and science. Restor. Ecol. 16, 604–607.
Camargo, J.L.C., Ferraz, I.D.K., Imakawa, A.M., 2002. Rehabilitation of degraded areas of central Amazonia using direct sowing of forest tree seeds. Restor. Ecol. 10, 636–644.
Campos-Filho, E.M., Da Costa, J.N., De Sousa, O.L., Junqueira, R.G., 2013. Mechanized direct-seeding of native forests in Xingu, Central Brazil. J. Sustain. Forest. 32, 702–727.
Carey, A.B., 2003. Biocomplexity and restoration of biodiversity in temperate coniferous forest: inducing spatial heterogeneity with variable-density thinning. Forestry 76, 127–136.
Carey, A.B., Calhoun, J.M., Dick, B., O'Halloran, K., Young, L.S., Bigley, R.E., Chan, S., Harrington, C.A., Hayes, J.P., Marzluff, J., 1999. Reverse technology transfer: obtaining feedback from managers. Western J. Appl. Forest. 14, 153–163.
CBD, 2010. COP10 Decision X/2. Strategic Plan for Biodiversity 2011–2020. Convention on Biological Diversity.
Chambers, R., 1994. Participatory rural appraisal (PRA): analysis of experience. World Develop. 22, 1253–1268.
Charnley, S., 2006. The northwest forest plan as a model for broad-scale ecosystem management: a social perspective. Conserv. Biol. 20, 330–340.
Chazdon, R.L., 2013. Making tropical succession and landscape reforestation successful. J. Sustain. Forest. 32, 649–658.
Chinnamani, S., Gupte, S., Rege, N., Thomas, P., 1965. Afforestation with broom as a nurse crop. Ind. Forest. 91, 573–576.
Choi, Y.D., 2007. Restoration ecology to the future: a call for new paradigm. Restor. Ecol. 15, 351–353.
Christie, K., Stokes, V.L., Craig, M.D., Hobbs, R.J., 2013. Microhabitat preference of *Egernia napoleonis* in undisturbed jarrah forest, and availability and introduction of microhabitats to encourage colonization of restored forest. Restor. Ecol. 21, 722–728.
Ciccarese, L., Brown, S., Schlamadinger, B., 2005. Carbon sequestration through restoration of temperate and boreal forests. In: Stanturf, J.A., Madsen, P. (Eds.), Restoration of Boreal and Temperate Forests. CRC Press, Boca Raton, pp. 111–120.
Ciccarese, L., Mattsson, A., Pettenella, D., 2012. Ecosystem services from forest restoration: thinking ahead. New Forest. 43, 543–560.
Clement, C.R., Junqueira, A.B., 2010. Between a pristine myth and an impoverished future. Biotropica 42, 534–536.
Clewell, A.F., Aronson, J., 2006. Motivations for the restoration of ecosystems. Conserv. Biol. 20, 420–428.
Cochrane, M.A., Laurance, W.F., 2008. Synergisms among fire, land use, and climate change in the Amazon. Ambio 37, 522–527.
Cogliastro, A., Paquette, A., 2012. Thinning effect on light regime and growth of underplanted red oak and black cherry in post-agricultural forests of south-eastern Canada. New Forest. 43, 941–954.
Cole, R.J., Holl, K.D., Keene, C., Zahawi, R.A., 2011. Direct seeding of late-successional trees to restore tropical montane forest. Forest. Ecol. Manag. 261, 1590–1597.
Colfer, C.J.P., 2011. Marginalized forest peoples' perceptions of the legitimacy of governance: an exploration. World Develop. 39, 2147–2164.
Conner, W.H., Hackney, C.T., Krauss, K.W., 2007. Tidal freshwater forested wetlands: future research needs and an overview of restoration. In: Conner, W.H., Doyle, T.W., Karauss, K.W. (Eds.), Ecology of Tidal Freshwater Forested Wetlands of the Southeastern United States. Springer, Dordrecht, pp. 461–488.
Conner, W.H., Krauss, K.W., Shaffer, G.P., 2012. Restoration of freshwater cypress-tupelo wetlands in the southeastern US following severe hurricanes. In: Stanturf, J., Madsen, P., Lamb, D. (Eds.), A Goal-Oriented Approach to Forest Landscape Restoration. Springer, Dordrecht, pp. 423–442.
Coppini, M., Hermanin, L., 2007. Restoration of selective beech coppices: a case study in the Apennines (Italy). Forest. Ecol. Manag. 249, 18–27.
Corbin, J.D., Holl, K.D., 2012. Applied nucleation as a forest restoration strategy. Forest. Ecol. Manag. 265, 37–46.
Covington, W.W., Fule, P.Z., Moore, M.M., Hart, S.C., Kolb, T.E., Mast, J.N., Sackett, S.S., Wagner, M.R., 1997. Restoring ecosystem health in ponderosa pine forests of the Southwest. J. Forest. 95, 23–29.
Crow, T.R., 2014. Functional restoration: from concept to practice. J. Sustain. Forest. 33 (Suppl. 1), S3–S14.
Cushman, S.A., McGarigal, K., Neel, M.C., 2008. Parsimony in landscape metrics: strength, universality, and consistency. Ecol. Indicators 8, 691–703.
D'Amato, A.W., Bradford, J.B., Fraver, S., Palik, B.J., 2013. Effects of thinning on drought vulnerability and climate response in north temperate forest ecosystems. Ecol. Appl. 23, 1735–1742.
Damnyag, L., Saastamoinen, O., Appiah, M., Pappinen, A., 2012. Role of tenure insecurity in deforestation in Ghana's high forest zone. Forest Policy Econ. 14, 90–98.
Daniels, S.E., Walker, G.B., Emborg, J., 2012. The unifying negotiation framework: a model of policy discourse. Conflict Resolution Quart. 30, 3–31.
Danielsen, F., Sørensen, M.K., Olwig, M.F., Selvam, V., Parish, F., Burgess, N.D., Hiraishi, T., Karunagaran, V.M., Rasmussen, M.S., Hansen, L.B., 2005. The Asian tsunami: a protective role for coastal vegetation. Science 310, 643.
D'Antonio, C.M., Chambers, J.C., 2006. Using ecological theory to manage or restore ecosystems affected by invasive plant species. In: Palmer, M.A., Falk, D.A., Zedler, J.B. (Eds.), Foundations of Restoration Ecology. Island Press, Washington, DC, pp. 260–279.
D'Antonio, C.M., Vitousek, P.M., 1992. Biological invasions by exotic grasses, the grass/fire cycle, and global change. Annu. Rev. Ecol. Syst. 23, 63–87.
Daume, S., Albert, M., von Gadow, K., 2014. Forest monitoring and social media–Complementary data sources for ecosystem surveillance? Forest. Ecol. Manag. 316, 9–20.
Davis, M.B., 1976. Quaternary history and the stability of forest communities. In: Shugart, H.H., Botkin, D.B. (Eds.), Forest Succession: Concepts and Application. Springer-Verlag, New York, pp. 132–153.
Davis, M.A., Chew, M.K., Hobbs, R.J., Lugo, A.E., Ewel, J.J., Vermeij, G.J., Brown, J.H., Rosenzweig, M.L., Gardener, M.R., Carroll, S.P., 2011. Don't judge species on their origins. Nature 474, 153–154.
Day Jr., J.W., Yañéz Arancibia, A., Mitsch, W.J., Lara-Dominguez, A.L., Day, J.N., Ko, J.-Y., Lane, R., Lindsey, J., Lomeli, D.Z., 2003. Using ecotechnology to address water quality and wetland habitat loss problems in the Mississippi basin: a hierarchical approach. Biotechnol. Adv. 22, 135–159.
De Frenne, P., Rodríguez-Sánchez, F., Coomes, D.A., Baeten, L., Verstraeten, G., Vellend, M., Bernhardt-Römermann, M., Brown, C.D., Brunet, J., Cornelis, J., 2013. Microclimate moderates plant responses to macroclimate warming. Proc. Natl. Acad. Sci. 110, 18561–18565.
de Souza, F.M., Batista, J.L.F., 2004. Restoration of seasonal semideciduous forests in Brazil: influence of age and restoration design on forest structure. Forest. Ecol. Manag. 191, 185–200.
Dey, D.C., Schweitzer, C.J., 2014. Restoration for the future: endpoints, targets and indicators of progress and success. J. Sustain. Forest. 33 (Suppl. 1), S43–S65.
Dey, D.C., Gardiner, E.S., Kabrick, J.M., Stanturf, J.A., Jacobs, D.F., 2010. Innovations in afforestation of agricultural bottomlands to restore native forests in the eastern USA. Scand. J. Forest Res. 25, 31–42.
Dey, D.C., Gardiner, E.S., Schweitzer, C.J., Kabrick, J.M., Jacobs, D.F., 2012. Underplanting to sustain future stocking of oak (*Quercus*) in temperate deciduous forests. New Forest. 43, 955–978.
Díaz, S., Cabido, M., 2001. Vive la différence: plant functional diversity matters to ecosystem processes. Trends Ecol. Evol. 16, 646–655.
Díaz-Rodríguez, B., Blanco-García, A., Gómez-Romero, M., Lindig-Cisneros, R., 2012. Filling the gap: restoration of biodiversity for conservation in productive forest landscapes. Ecol. Eng. 40, 88–94.
Doak, D.F., Estes, J.A., Halpern, B.S., Jacob, U., Lindberg, D.R., Lovvorn, J., Monson, D.H., Tinker, M.T., Williams, T.M., Wootton, J.T., 2008. Understanding and predicting ecological dynamics: are major surprises inevitable. Ecology 89, 952–961.
Dodd, M.B., Power, I.L., 2007. Direct seeding of indigenous tree and shrub species into New Zealand hill country pasture. Ecol. Manag. Restor. 8, 49–55.
Doley, D., Audet, P., 2013. Adopting novel ecosystems as suitable rehabilitation alternatives for former mine sites. Ecol. Process. 2, 1–11.
Doren, R.F., Trexler, J.C., Gottlieb, A.D., Harwell, M.C., 2009. Ecological indicators for system-wide assessment of the Greater Everglades Ecosystem restoration program. Ecol. Indicators 9, S2–S16.
Doust, S.J., Erskine, P.D., Lamb, D., 2008. Restoring rainforest species by direct seeding: tree seedling establishment and growth performance on degraded land in the wet tropics of Australia. Forest. Ecol. Manag. 256, 1178–1188.
Douterlungne, D., Thomas, E., 2013. Fast-growing pioneer tree stands as a rapid and effective strategy for bracken elimination in the Neotropics. J. Appl. Ecol. 50, 1257–1265.
Dreesen, D.R., Fenchel, G.A., 2010. Deep-planting techniques to establish riparian vegetation in arid and semiarid regions. Native Plants J. 11, 15–22.
Drouineau, S., Laroussinie, O., Birot, Y., Terrasson, D., Formery, T., Roman-Amat, B., 2000. Joint Evaluation of Storms, Forest Vulnerability and Their Restoration. European Forest Institute, Joensuu, Finland.
Dumroese, R.K., Landis, T.D., Luna, T., 2012. Growing Native Plants in Nurseries: Basic Concepts. USDA Forest Service, Rocky Mountain Research Station. Gen. Tech. Rep. RMRS-GTR-274, p. 84.
Ehrenfeld, J.G., 2000. Defining the limits of restoration: the need for realistic goals. Restor. Ecol. 8, 2–9.
El Houri Ahmed, A., 1986. Some aspects of dry land afforestation in the Sudan with special reference to *Acacia tortilis* (Forsk.) Hayne, A. senegal Willd. and *Prosopis chilensis* (Molina) stuntz. Forest. Ecol. Manag. 16, 209–221.
Elliott, S., Navakitbumrung, P., Kuarak, C., Zangkum, S., Anusarnsunthorn, V., Blakesley, D., 2003. Selecting framework tree species for restoring seasonally dry tropical forests in northern Thailand based on field performance. Forest. Ecol. Manag. 184, 177–191.
Elliott, S., Kuaraksa, C., Tunjai, P., Toktang, T., Boonsai, K., Sangkum, S., Suwannaratana, S., Blakesley, D., 2012. Integrating scientific research with community needs to restore a forest landscape in northern Thailand: a case study of Ban Mae Sa Mai. In: Stanturf, J., Madsen, P., Lamb, D. (Eds.), A Goal-Oriented Approach to Forest Landscape Restoration. Springer, Dordrecht, pp. 149–161.
Ellis, E.A., Porter-Bolland, L., 2008. Is community-based forest management more effective than protected areas? A comparison of land use/land cover change in two neighboring study areas of the Central Yucatan Peninsula, Mexico. Forest. Ecol. Manag. 256, 1971–1983.
Ellis, E.C., Kaplan, J.O., Fuller, D.Q., Vavrus, S., Klein Goldewijk, K., Verburg, P.H., 2013. Used planet: a global history. Proc. Natl. Acad. Sci. 110, 7978–7985.
Elmqvist, T., Wall, M., Berggren, A.-L., Blix, L., Fritioff, A., Rinman, U., 2002. Tropical forest reorganization after cyclone and fire disturbance in Samoa: remnant trees as biological legacies. Conserv. Ecol. 5, 10.

Emborg, J., Walker, G., Daniels, S., 2012. Forest landscape restoration decision-making and conflict management: applying discourse-based approaches. In: Stanturf, J., Lamb, D., Madsen, P. (Eds.), Forest Landscape Restoration. Springer, Dordrecht, pp. 131–153.
Engel, V.L., Parrotta, J.A., 2001. An evaluation of direct seeding for reforestation of degraded lands in central Sao Paulo state, Brazil. Forest. Ecol. Manag. 152, 169–181.
Eriksson, M., Lilja, S., Roininen, H., 2006. Dead wood creation and restoration burning: implications for bark beetles and beetle induced tree deaths. Forest. Ecol. Manag. 231, 205–213.
Esler, K.J., Prozesky, H., Sharma, G.P., McGeoch, M., 2010. How wide is the "knowing-doing" gap in invasion biology? Biol. Invasions 12, 4065–4075.
Evans, D.M., Zipper, C.E., Burger, J.A., Strahm, B.D., Villamagna, A.M., 2013. Reforestation practice for enhancement of ecosystem services on a compacted surface mine: path toward ecosystem recovery. Ecol. Eng. 51, 16–23.
Falk, D.A., 2006. Process-centred restoration in a fire-adapted ponderosa pine forest. J. Nature Conserv. 14, 140–151.
FAO, 2010. Global Forest Resources Assessment 2010, Forestry Paper 163. Food and Agriculture Organization, Rome.
Fenton, N.J., Simard, M., Bergeron, Y., 2009. Emulating natural disturbances: the role of silviculture in creating even-aged and complex structures in the black spruce boreal forest of eastern North America. J. Forest Res. 14, 258–267.
Ferraro, P.J., 2009. Counterfactual thinking and impact evaluation in environmental policy. In: Birnbaum, M., Mickwitz, P. (Eds.), Environmental Program and Policy Evaluation: New Directions for Evaluation. Wiley InterScience, New York, pp. 75–84.
Ferraro, P.J., Pattanayak, S.K., 2006. Money for nothing? A call for empirical evaluation of biodiversity conservation investments. PLoS Biology 4, e015.
Field, C.D., 1999. Rehabilitation of mangrove ecosystems: an overview. Mar. Pollut. Bull. 37, 383–392.
Fields-Johnson, C., Zipper, C., Burger, J., Evans, D., 2012. Forest restoration on steep slopes after coal surface mining in Appalachian USA: soil grading and seeding effects. Forest. Ecol. Manag. 270, 126–134.
Fischer, A., Fischer, H., 2012. Restoration of temperate forests: an European approach. In: Van Andel, J., Aronson, J. (Eds.), Restoration Ecology: The New Frontier. Wiley-Interscience, Oxford, pp. 145–160.
Flinn, K.M., Vellend, M., 2005. Recovery of forest plant communities in post-agricultural landscapes. Front. Ecol. Environ. 3, 243–250.
Flinn, K.M., Vellend, M., Marks, P., 2005. Environmental causes and consequences of forest clearance and agricultural abandonment in central New York, USA. J. Biogeogr. 32, 439–452.
Folke, C., Carpenter, S., Elmqvist, T., Gunderson, L., Holling, C.S., Walker, B., 2002. Resilience and sustainable development: Building adaptive capacity in a world of transformations. Ambio 31, 437–440.
Foley, J.A., DeFries, R., Asner, G.P., Barford, C., Bonan, G., Carpenter, S.R., Chapin, F.S., Coe, M.T., Daily, G.C., Gibbs, H.K., 2005. Global consequences of land use. Science 309, 570–574.
Foroughbakhch, R., Alvarado-Vazquez, M.A., Hernandez-Pinero, J.L., Rocha-Estrada, A., Guzman-Lucio, M.A., Trevino-Garza, E.J., 2006. Establishment, growth and biomass production of 10 tree woody species introduced for reforestation and ecological restoration in northeastern Mexico. Forest. Ecol. Manag. 235, 194–201.
Forrester, D.I., Bauhus, J., Cowie, A.L., Vanclay, J.K., 2006. Mixed-species plantations of Eucalyptus with nitrogen-fixing trees: a review. Forest. Ecol. Manag. 233, 211–230.
Foster, D.R., Knight, D.H., Franklin, J.F., 1998. Landscape patterns and legacies resulting from large, infrequent forest disturbances. Ecosystems 1, 497–510.
Foster, D., Swanson, F., Aber, J., Burke, I., Brokaw, N., Tilman, D., Knapp, A., 2003. The importance of land-use legacies to ecology and conservation. BioScience 53, 77–88.
Franklin, J.F., Berg, D.R., Thornburgh, D.A., Tappeiner, J.C., 1997. Alternative silvicultural approaches to timber harvesting: variable retention harvest systems. In: Kohm, K.A., Franklin, J.F. (Eds.), Creating a Forestry For the 21st Century: The Science of Ecosystem Management. Island Press, Washington, DC, pp. 111–139.
Franklin, J.F., Lindenmayer, D., MacMahon, J.A., McKee, A., Magnuson, J., Perry, D.A., Waide, R., Foster, D., 2000. Threads of continuity. Conserv. Practice 1, 8–17.
Franklin, J.F., Spies, T.A., Pelt, R.V., Carey, A.B., Thornburgh, D.A., Berg, D.R., Lindenmayer, D.B., Harmon, M.E., Keeton, W.S., Shaw, D.C., 2002. Disturbances and structural development of natural forest ecosystems with silvicultural implications, using Douglas-fir forests as an example. Forest. Ecol. Manag. 155, 399–423.
Franklin, J.F., Mitchell, R.J., Palik, BJ., 2007. Natural Disturbance and Stand Development Principles for Ecological Forestry. USDA Forest Service, Northern Research Station. Gen. Tech. Rep. NRS-19, p. 44.
Fraver, S., Palik, B.J., 2012. Stand and cohort structures of old-growth Pinus resinosa-dominated forests of northern Minnesota, USA. J. Veg. Sci. 23, 249–259.
Frelich, L.E., Lorimer, C.G., 1991. Natural disturbance regimes in hemlock-hardwood forests of the upper Great Lakes region. Ecol. Monogr. 61, 145–164.
Friday, K.S., Drilling, M.E., Garrity, D.P., 1999. Imperata Grassland Rehabilitation Using Agroforestry and Assisted Natural Regeneration. World Agroforestry Centre, Southeast Asian Regional Research Programme, Bogor, Indonesia.
Fridman, J., Walheim, M., 2000. Amount, structure, and dynamics of dead wood on managed forestland in Sweden. Forest. Ecol. Manag. 131, 23–36.
Friedman, J., Scott, M., Lewis, W., 1995. Restoration of riparian forest using irrigation, artificial disturbance, and natural seedfall. Environ. Manag. 19, 547–557.
Fulé, P.Z., 2008. Does it make sense to restore wildland fire in changing climate? Restor. Ecol. 16, 526–531.
Fulé, P.Z., Waltz, A.E.M., Covington, W.W., Heinlein, T.A., 2001. Measuring forest restoration effectiveness in reducing hazardous fuels. J. Forest., 24–29.
García-Frapolli, E., Ramos-Fernández, G., Galicia, E., Serrano, A., 2009. The complex reality of biodiversity conservation through Natural Protected Area policy: three cases from the Yucatan Peninsula, Mexico. Land Use Policy 26, 715–722.
Gardiner, E.S., Oliver, J.M., 2005. Restoration of bottomland hardwood forests in the Lower Mississippi Alluvial Valley, USA. In: Stanturf, J.A., Madsen, P. (Eds.), Restoration of Boreal and Temperate Forests. CRC Press, Boca Raton, pp. 235–251.
Gardiner, E.S., Yeiser, J.L., 2006. Underplanting cherrybark oak (*Quercus pagoda* Raf.) seedlings on a bottomland site in the southern United States. New Forest. 32, 105–119.
Gardiner, E.S., Stanturf, J.A., Schweitzer, C.J., 2004. An afforestation system for restoring bottomland hardwood forests: biomass accumulation of Nuttall oak seedlings interplanted beneath eastern cottonwood. Restor. Ecol. 12, 525–532.
Geldenhuys, C.J., 2010. Managing forest complexity through application of disturbance–recovery knowledge in development of silvicultural systems and ecological rehabilitation in natural forest systems in Africa. J. Forest Res. 15, 3–13.
Gilman, E.L., Ellison, J., Duke, N.C., Field, C., 2008. Threats to mangroves from climate change and adaptation options: A review. Aquat. Bot. 89, 237–250.
Gibbons, P., McElhinny, C., Lindenmayer, D.B., 2010. What strategies are effective for perpetuating structures provided by old trees in harvested forests? A case study on trees with hollows in south-eastern Australia. Forest. Ecol. Manag. 260, 975–982.
Goldstein, J.H., Pejchar, L., Daily, G.C., 2008. Using return-on-investment to guide restoration: a case study from Hawaii. Conserv. Letters 1, 236–243.
Göltenboth, F., Hutter, C.-P., 2004. New options for land rehabilitation and landscape ecology in Southeast Asia by "rainforestation farming". J. Nature Conserv. 12, 181–189.
González, E., Rochefort, L., Boudreau, S., Hugron, S., Poulin, M., 2013. Can indicator species predict restoration outcomes early in the monitoring process? A case study with peatlands. Ecol. Indicators 32, 232–238.
Goodchild, M.F., 2007. Citizens as sensors: the world of volunteered geography. GeoJournal 69, 211–221.
Goosem, S., Tucker, N.I., 1995. Repairing the Rainforest: Theory and Practice of Rainforest Re-establishment in North Queensland's Wet Tropics. Wet Tropics Management Authority, Cairns.
Graham, R.T., McCaffrey, S., Jain, T.B., 2004. Science Basis for Changing Forest Structure to Modify Wildfire Behavior and Severity. USDA Forest Service, Rocky Mountain Research Station. Gen. Tech. Rep. RMRS-GTR-120, p. 43.
Graves, A.T., Fajvan, M.A., Miller, G.W., 2000. The effects of thinning intensity on snag and cavity tree abundance in an Appalachian hardwood stand. Can. J. Forest Res. 30, 1214–1220.
Greenberg, C., Collins, B., Thompson, F. (Eds.), 2011. Sustaining Young Forest Communities. Springer, Netherlands.
Griscom, H.P., Ashton, M.S., 2011. Restoration of dry tropical forests in Central America: a review of pattern and process. Forest. Ecol. Manag. 261, 1564–1579.
Groninger, J.W., 2005. Increasing the impact of bottomland hardwood afforestation. J. Forest. 103, 184–188.
Grossmann, M., 2012. Economic value of the nutrient retention function of restored floodplain wetlands in the Elbe River basin. Ecol. Econ. 83, 108–117.
Grossnickle, S.C., 2012. Why seedlings survive: influence of plant attributes. New Forest. 43, 711–738.
Grove, S., Meggs, J., 2003. Coarse woody debris, biodiversity and management: a review with particular reference to Tasmanian wet eucalypt forests. Aust. Forest. 66, 258–272.
Grubb, P.J., 1977. The maintenance of species-richness in plant communities: the importance of the regeneration niche. Biol. Rev. 52, 107–145.
Guldin, J.M., Lorimer, C.G., 1985. Crown differentiation in even-aged northern hardwood forests of the Great Lakes region, USA. Forest. Ecol. Manag. 10, 65–86.
Gustafson, D.J., Gibson, D.J., Nickrent, D.L., 2005. Using local seeds in prairie restoration—data support the paradigm. Native Plants J. 6, 25–28.
Gustafsson, L., Kouki, J., Sverdrup-Thygeson, A., 2010. Tree retention as a conservation measure in clear-cut forests of northern Europe: a review of ecological consequences. Scand. J. Forest Res. 25, 295–308.
Gustafsson, L., Baker, S.C., Bauhus, J., Beese, W.J., Brodie, A., Kouki, J., Lindenmayer, D.B., Lõhmus, A., Pastur, G.M., Messier, C., 2012. Retention forestry to maintain multifunctional forests: a world perspective. BioScience 62, 633–645.
Guyette, R.P., Stambaugh, M.C., Dey, D.C., Muzika, R.M., 2012. Predicting fire frequency with chemistry and climate. Ecosystems 15, 322–335.
Haglund, E., Ndjeunga, J., Snook, L., Pasternak, D., 2011. Dry land tree management for improved household livelihoods: farmer managed natural regeneration in Niger. J. Environ. Manag. 92, 1696–1705.
Hahn, K., Emborg, J., Larsen, J.B., Madsen, P., 2005. Forest rehabilitation in Denmark using nature-based forestry. In: Stanturf, J.A., Madsen, P. (Eds.), Restoration of Boreal and Temperate Forests. CRC Press, Boca Raton, pp. 299–317.
Hallett, L.M., Diver, S., Eitzel, M.V., Olson, J.J., Ramage, B.S., Sardinas, H., Statman-Weil, Z., Suding, K.N., 2013. Do we practice what we preach? Goal setting for ecological restoration. Restor. Ecol. 21, 312–319.
Han, X., Oliver, C.D., Ge, J., Guo, Q., Kou, X., 2012. Managing forest stand structures to enhance conservation of the Amur tiger (*Panthera tigris altaica*). In: Stanturf, J., Madsen, P., Lamb, D. (Eds.), A Goal-Oriented Approach to Forest Landscape Restoration. Springer, Dordrecht, pp. 93–128.

Hanberry, B.B., Kabrick, J.M., He, H.S., 2014. Changing tree composition by life history strategy in a grassland-forest landscape. Ecosphere 5 (3), art34.
Hanewinkel, M., 2001. Economic aspects of the transformation from even-aged pure stands of Norway spruce to uneven-aged mixed stands of Norway spruce and beech. Forest. Ecol. Manag. 151, 181–193.
Hansen, J., Spiecker, H., 2005. Conversion of Norway spruce (*Picea abies* [L.] Karst.) forests in Europe. In: Stanturf, J.A., Madsen, P. (Eds.), Restoration of Boreal and Temperate Forests. CRC Press, Boca Raton, pp. 339–347.
Hansen, C.P., Lund, J.F., Treue, T., 2009. Neither fast, nor easy: the prospect of reduced emissions from deforestation and degradation (REDD) in Ghana. Int. Forest. Rev. 11, 439–455.
Hardwick, K., Healey, J., Elliott, S., Garwood, N., Anusarnsunthorn, V., 1997. Understanding and assisting natural regeneration processes in degraded seasonal evergreen forests in northern Thailand. Forest. Ecol. Manag. 99, 203–214.
Harmer, R., Morgan, G., 2009. Storm damage and the conversion of conifer plantations to native broadleaved woodland. Forest. Ecol. Manag. 258, 879–886.
Harmer, R., Thompson, R., Humphrey, J., 2005. Great Britain—conifers to broadleaves. In: Stanturf, J.A., Madsen, P. (Eds.), Restoration of Boreal and Temperate Forests. CRC Press, Boca Raton, pp. 319–338.
Harmer, R., Morgan, G., Beauchamp, K., 2011. Restocking with broadleaved species during the conversion of *Tsuga heterophylla* plantations to native woodland using natural regeneration. Eur. J. Forest Res. 130, 161–171.
Harmer, R., Kiewitt, A., Morgan, G., 2012. Effects of overstorey retention on ash regeneration and bramble growth during conversion of a pine plantation to native broadleaved woodland. Eur. J. Forest Res. 131, 1833–1843.
Harmon, M.E., Franklin, J.F., Swanson, F.J., Sollins, P., Gregory, S., Lattin, J., Anderson, N., Cline, S., Aumen, N., Sedell, J., 1986. Ecology of coarse woody debris in temperate ecosystems. Adv. Ecol. Res. 15, 302.
Harper, R., Smettem, K., Townsend, P., Bartle, J., McGrath, J., 2012. Broad-scale restoration of landscape function with timber, carbon and water investment. In: Stanturf, J., Lamb, D., Madsen, P. (Eds.), Forest Landscape Restoration. Springer, Dordrecht, pp. 275–292.
Harris, J.A., Hobbs, R.J., Higgs, E., Aronson, J., 2006. Ecological restoration and global climate change. Restor. Ecol. 14, 170–176.
Hart, P.B.S., West, A.W., Kings, J.A., Watts, H.M., Howe, J.C., 1999. Land restoration management after topsoil mining and implications for restoration policy guidelines in New Zealand. Land Degrad. Dev. 10, 435–453.
Hendriks, R., Boot, R., deHaas, W., Savenije, H., 2012. Forest landscape restoration in The Netherlands: policy aspects and knowledge management. In: Stanturf, J., Madsen, P., Lamb, D. (Eds.), A Goal-Oriented Approach to Forest Landscape Restoration. Springer, Dordrecht, pp. 21–40.
Hermann, S.M., Kush, J.S., Gilbert, J.C., 2013. A decision tree approach using silvics to guide planning for forest restoration. In: Guldin, J.M. (Ed.), Proceedings 15th Biennial Southern Silicultural Research Conference. USDA Forest Service, Southern Research Station. e-Gen. Tech. Rep. SRS-STR-175, pp. 115–122.
Herrick, J.E., Schuman, G.E., Rango, A., 2006. Monitoring ecological processes for restoration projects. J. Nature Conserv. 14, 161–171.
Hewitt, R., van Delden, H., Escobar, F., 2014. Participatory land use modelling, pathways to an integrated approach. Environ. Model. Software 52, 149–165.
Hiers, J.K., Mitchell, R.J., Barnett, A., Walters, J.R., Mack, M., Williams, B., Sutter, R., 2012. The dynamic reference concept: measuring restoration success in a rapidly changing no-analogue future. Ecol. Restor. 30, 27–36.
Hill, R., Thomson, A., 2005. Mapping woodland species composition and structure using airborne spectral and LiDAR data. Int. J. Remote Sens. 26, 3763–3779.
Hoag, J.C., Landis, T.D., 2001. Plant materials for riparian revegetation. Native Plants J. 2, 34–43.
Hobbs, R.J., Norton, D.A., 1996. Towards a conceptual framework for restoration ecology. Restor. Ecol. 4, 93–110.
Hobbs, R.J., Higgs, E., Harris, J.A., 2009. Novel ecosystems: implications for conservation and restoration. Trends Ecol. Evol. 24, 599–605.
Hobbs, R.J., Hallett, L.M., Ehrlich, P.R., Mooney, H.A., 2011. Intervention ecology: applying ecological science in the twenty-first century. BioScience 61, 442–450.
Hodge, S., Harmer, R., 1996. Woody colonization on unmanaged urban and ex-industrial sites. Forestry 69, 245–261.
Holl, K.D., Aide, T.M., 2011. When and where to actively restore ecosystems? Forest. Ecol. Manag. 261, 1558–1563.
Holl, K.D., Howarth, R.B., 2000. Paying for restoration. Restor. Ecol. 8, 260–267.
Holl, K.D., Zahawi, R.A., Cole, R.J., Ostertag, R., Cordell, S., 2011. Planting seedlings in tree islands versus plantations as a large-scale tropical forest restoration strategy. Restor. Ecol. 19, 470–479.
Holmgren, J., Persson, Å., Söderman, U., 2008. Species identification of individual trees by combining high resolution LiDAR data with multi-spectral images. Int. J. Remote Sens. 29, 1537–1552.
Hooper, R.G., McAdie, C.J., 1996. Hurricanes and the long-term management of the red-cockaded woodpecker. In: Haymond, J.L., Hook, D.D., Harms, W.R. (Eds.), Hurricane Hugo: South Carolina Forest Land Research and Management Related to the Storm. USDA Forest Service, Southern Research Station. Gen. Tech. Rep. SRS-5, pp. 417–436.
Hooper, E., Condit, R., Legendre, P., 2002. Responses of 20 native tree species to reforestation strategies for abandoned farmland in Panama. Ecol. Appl. 12, 1626–1641.
Hu, H., Wang, G.G., Walke, J.L., Knapp, B.O., 2012. Silvicultural treatments for converting loblolly pine to longleaf pine dominance: Effects on planted longleaf pine seedlings. Forest. Ecol. Manag. 276, 209–216.
Hubbard, R.M., Vose, J.M., Clinton, B.D., Elliott, K.J., Knoepp, J.D., 2004. Stand restoration burning in oak-pine forests in the southern Appalachians: effects on aboveground biomass and carbon and nitrogen cycling. Forest. Ecol. Manag. 190, 311–321.
Hughes, F.M.R., del Tánago, M.G., Mountford, J.O., 2012. Restoring floodplain forests in Europe. In: Stanturf, J., Madsen, P., Lamb, D. (Eds.), A Goal-Oriented Approach to Forest Landscape Restoration. Springer, Dordrecht, pp. 393–422.
Humphrey, J., 2005. Benefits to biodiversity from developing old-growth conditions in British upland spruce plantations: a review and recommendations. Forestry 78, 33–53.
Hunter, R.G., Faulkner, S.P., Gibson, K.A., 2008. The importance of hydrology in restoration of bottomland hardwood wetland functions. Wetlands 28, 605–615.
Hutto, R.L., Belote, R., 2013. Distinguishing four types of monitoring based on the questions they address. Forest. Ecol. Manag. 289, 183–189.
Hyman, J.B., Leibowitz, S.G., 2000. A general framework for prioritizing land units for ecological protection and restoration. Environ. Manag. 25, 23–35.
Hyvarinen, E., Kouki, J., Martikainen, P., Lappalainen, H., 2005. Short-term effects of controlled burning and green-tree retention on beetle (Coleoptera) assemblages in managed boreal forests. Forest. Ecol. Manag. 212, 315–332.
Igarashi, T., Kiyono, Y., 2008. The potential of hinoki (*Chamaecyparis obtusa* [Sieb. et Zucc.] Endlicher) plantation forests for the restoration of the original plant community in Japan. Forest. Ecol. Manag. 255, 183–192.
IPCC, 2007. Contribution of working groups I, II and III to the fourth assessment report of the Intergovernmental Panel on Climate Change. In: Pachauri, R.K., Reisinger, A. (Eds.), Climate Change 2007: Synthesis Report, Geneva, Switzerland, p. 104.
ITTO, 2002. ITTO Guidelines for the Restoration, Management and Rehabilitation of Degraded and Secondary Tropical Forests. Policy Development Series 13. International Tropical Timber Organization, Yokohama, Japan.
Iverson, L.R., Prasad, A.M., Matthews, S.N., Peters, M., 2008. Estimating potential habitat for 134 eastern US tree species under six climate scenarios. Forest. Ecol. Manag. 254, 390–406.
Jain, T.B., Graham, R.T., 2010. Restoring dry and moist forests of the inland northwestern US. In: Stanturf, J.A., Madsen, P. (Eds.), Restoration of Boreal and Temperate Forests. CRC Press, Boca Raton, pp. 463–480.
Jakobsen, C.H., Hels, T., McLaughlin, W.J., 2004. Barriers and facilitators to integration among scientists in transdisciplinary landscape analyses: a cross-country comparison. Forest Policy Econ. 6, 15–31.
Jarzemsky, R.D., Burchell II, M.R., Evans, R.O., 2013. The impact of manipulating surface topography on the hydrologic restoration of a forested coastal wetland. Ecol. Eng. 58, 35–43.
Jaunatre, R., Buisson, E., Muller, I., Morlon, H., Mesléard, F., Dutoit, T., 2013. New synthetic indicators to assess community resilience and restoration success. Ecol. Indicators 29, 468–477.
Jiang, L., Han, X., Zhang, G., Kardol, P., 2010. The role of plant–soil feedbacks and land-use legacies in restoration of a temperate steppe in northern China. Ecol. Res. 25, 1101–1111.
Jõgiste, K., Vares, A., Uri, V., Tullus, H., 2005. Baltic afforestation. In: Stanturf, J.A., Madsen, P. (Eds.), Restoration of Boreal and Temperate Forests. CRC Press, Boca Raton, pp. 225–234.
Johnson, R., Stritch, L., Olwell, P., Lambert, S., Horning, M.E., Cronn, R., 2010. What are the best seed sources for ecosystem restoration on BLM and USFS lands? Native Plants J. 11, 117–131.
Jones, T.A., 2014. Ecologically appropriate plant materials for functional restoration of rangelands. J. Sustain. Forest. 33 (Suppl. 1), S93–S103.
Jones, B.E., Rickman, T.H., Vazquez, A., Sado, Y., Tate, K.W., 2005. Removal of encroaching conifers to regenerate degraded aspen stands in the Sierra Nevada. Restor. Ecol. 13, 373–379.
Jonsson, B.G., Kruys, N., Ranius, T., 2005. Ecology of species living on dead wood—lessons for dead wood management. Silva Fenn. 39, 289–309.
Joyce, L.A., Blate, G.M., McNulty, S.G., Millar, C.I., Moser, S., Neilson, R.P., Peterson, D.L., 2009. Managing for multiple resources under climate change: national forests. Environ. Manag. 44, 1022–1032.
Kairo, J., Dahdouh-Guebas, F., Bosire, J., Koedam, N., 2001. Restoration and management of mangrove systems: A lesson for and from the East African region. South African J. Bot. 67, 383–389.
Kamada, M., 2005. Hierarchically structured approach for restoring natural forest—trial in Tokushima Prefecture, Shikoku, Japan. Landscape Ecol. Eng. 1, 67–70.
Kamali, B., Hashim, R., 2011. Mangrove restoration without planting. Ecol. Eng. 37, 387–391.
Kanowski, J., Catterall, C.P., 2010. Carbon stocks in above-ground biomass of monoculture plantations, mixed species plantations and environmental restoration plantings in north-east Australia. Ecol. Manag. Restor. 11, 119–126.
Kanowski, J., Catterall, C.P., Wardell-Johnson, G.W., 2005. Consequences of broadscale timber plantations for biodiversity in cleared rainforest landscapes of tropical and subtropical Australia. Forest. Ecol. Manag. 208, 359–372.
Kaplan, D., Muñoz-Carpena, R., Wan, Y., Hedgepeth, M., Zheng, F., Roberts, R., 2010. Linking river, floodplain, and vadose zone hydrology to improve restoration of a coastal river affected by saltwater intrusion. J. Environ. Qual. 39, 1570–1584.
Kapos, V., Balmford, A., Aveling, R., Bubb, P., Carey, P., Entwistle, A., Hopkins, J., Mulliken, T., Safford, R., Stattersfield, A., 2008. Calibrating conservation: new tools for measuring success. Conserv. Lett. 1, 155–164.
Kardol, P., Wardle, D.A., 2010. How understanding aboveground–belowground linkages can assist restoration ecology. Trends Ecol. Evol. 25, 670–679.
Kareiva, P., Watts, S., McDonald, R., Boucher, T., 2007. Domesticated nature: shaping landscapes and ecosystems for human welfare. Science 316, 1866–1869.

Karr, J.R., Rhodes, J.J., Minshall, G.W., Hauer, F.R., Beschta, R.L., Frissell, C.A., Perry, D.A., 2004. The effects of postfire salvage logging on aquatic ecosystems in the American West. BioScience 54, 1029–1033.
Kates, R.W., Travis, W.R., Wilbanks, T.J., 2012. Transformational adaptation when incremental adaptations to climate change are insufficient. Proc. Natl. Acad. Sci. 109, 7156–7161.
Kaufmann, M.R., Fulé, P.Z., Romme, W.H., Ryan, K.C., 2005. Restoration of ponderosa pine forests in the interior western US after logging, grazing, and fire suppression. In: Stanturf, J.A., Madsen, P. (Eds.), Restoration of Boreal and Temperate Forests. CRC Press, Boca Raton, pp. 481–500.
Keddy, P.A., Drummond, C.G., 1996. Ecological properties for the evaluation, management, and restoration of temperate deciduous forest ecosystems. Ecol. Appl., 748–762.
Keefe, K., Alavalapati, J.A.A., Pinheiro, C., 2012. Is enrichment planting worth its costs? A financial cost–benefit analysis. Forest Policy Econ. 23, 10–16.
Keeley, J.E., Aplet, G.H., Christensen, N.L., Conard, S.C., Johnson, E.A., Omi, P.N., Peterson, D.L., Swetnam, T.W., 2009. Ecological Foundations for Fire Management in North American Forest and Shrubland Ecosystems. USDA Forest Service, Pacific Northwest Research Station. Gen. Tech. Rep. PNW-GTR-779, p. 92.
Keenan, R., Lamb, D., Woldring, O., Irvine, T., Jensen, R., 1997. Restoration of plant biodiversity beneath tropical tree plantations in Northern Australia. Forest. Ecol. Manag. 99, 117–131.
Kelty, M.J., Kittredge, J.D., Kyker-Snowman, T., Leighton, A., 2003. The conversion of even-aged stands to uneven-aged structure in southern New England. Northern J. Appl. Forest. 20, 109–116.
Kenk, G., Guehne, S., 2001. Management of transformation in central Europe. Forest. Ecol. Manag. 151, 107–119.
Kerr, G., 1999. The use of silvicultural systems to enhance the biological diversity of plantation forests in Britain. Forestry 72, 191–205.
Kerr, G., Harmer, R., Moss, S., 1996. Natural colonisation: a study of Broadbalk Wilderness. Aspects Appl. Biol. 44, 25–32.
Kettle, C.J., 2010. Ecological considerations for using dipterocarps for restoration of lowland rainforest in Southeast Asia. Biodivers. Conserv. 19, 1137–1151.
Kettle, W.D., Rich, P.M., Kindscher, K., Pittman, G.L., Fu, P., 2000. Land-use history in ecosystem restoration: a 40-year study in the prairie-forest ecotone. Restor. Ecol. 8, 307–317.
Khamzina, A., Lamers, J., Worbes, M., Botman, E., Vlek, P., 2006. Assessing the potential of trees for afforestation of degraded landscapes in the Aral Sea Basin of Uzbekistan. Agroforest. Syst. 66, 129–141.
Kindlmann, P., Burel, F., 2008. Connectivity measures: a review. Landscape Ecol. 23, 879–890.
Kjær, E.D., Hansen, C.P., Roulund, H., Graudal, L., 2005. Procurement of plant material of good genetic quality. In: Stanturf, J.A., Madsen, P. (Eds.), Restoration of Boreal and Temperate Forests. CRC Press, Boca Raton, pp. 139–152.
Klimas, C., Murray, E., Foti, T., Pagan, J., Williamson, M., Langston, H., 2009. An ecosystem restoration model for the Mississippi Alluvial Valley based on geomorphology, soils, and hydrology. Wetlands 29, 430–450.
Knight, A.T., Cowling, R.M., Rouget, M., Balmford, A., Lombard, A.T., Campbell, B.M., 2008. Knowing but not doing: selecting priority conservation areas and the research–implementation gap. Conserv. Biol. 22, 610–617.
Knight, A.T., Cowling, R.M., Difford, M., Campbell, B.M., 2010. Mapping human and social dimensions of conservation opportunity for the scheduling of conservation action on private land. Conserv. Biol. 24, 1348–1358.
Knoth, C., Klein, B., Prinz, T., Kleinebecker, T., 2013. Unmanned aerial vehicles as innovative remote sensing platforms for high-resolution infrared imagery to support restoration monitoring in cut-over bogs. Appl. Veg. Sci. 16, 509–517.
Kobayashi, S., 2004. Landscape rehabilitation of degraded tropical forest ecosystems: case study of the CIFOR/Japan project in Indonesia and Peru. Forest. Ecol. Manag. 201, 13–22.
Koch, J.M., 2007. Restoring a jarrah forest understorey vegetation after bauxite mining in Western Australia. Restor. Ecol. 15, S26–S39.
Koch, J.M., Samsa, G.P., 2007. Restoring jarrah forest trees after bauxite mining in Western Australia. Restor. Ecol. 15, S17–S25.
Kohler, M., Sohn, J., Nägele, G., Bauhus, J., 2010. Can drought tolerance of Norway spruce (*Picea abies* (L.) Karst.) be increased through thinning? Eur. J. Forest Res. 129, 1109–1118.
Kolstad, I., Søreide, T., 2009. Corruption in natural resource management: Implications for policy makers. Resour. Policy 34, 214–226.
Kropp, B.R., Langlois, C.-G., 1990. Ectomycorrhizae in reforestation. Can. J. Forest Res. 20, 438–451.
Kruys, N., Fridman, J., Götmark, F., Simonsson, P., Gustafsson, L., 2013. Retaining trees for conservation at clearcutting has increased structural diversity in young Swedish production forests. Forest. Ecol. Manag. 304, 312–321.
Kush, J.S., Meldahl, R.S., McMahon, C.K., Boyer, W.D., 2004. Longleaf pine: a sustainable approach for increasing terrestrial carbon in the southern United States. Environ. Manag. 33, S139–S147.
Kuuluvainen, T., 2002. Disturbance dynamics in boreal forests: defining the ecological basis of restoration and management of biodiversity. Silva Fenn. 36, 5–12.
Kuuluvainen, T., Aapala, K., Ahlroth, P., Kuusinen, M., Lindholm, T., Sallantaus, T., Siitonen, J., Tukia, H., 2002. Principles of ecological restoration of boreal forested ecosystems: Finland as an example. Silva Fenn. 36, 409–422.
Kuznetsova, T., Rosenvald, K., Ostonen, I., Helmisaari, H.-S., Mandre, M., Lõhmus, K., 2010. Survival of black alder (*Alnus glutinosa* L.), silver birch (*Betula pendula* Roth.) and Scots pine (*Pinus sylvestris* L.) seedlings in a reclaimed oil shale mining area. Ecol. Eng. 36, 495–502.
Laarmann, D., Korjus, H., Sims, A., Stanturf, J.A., Kiviste, A., Koster, K., 2009. Analysis of forest naturalness and tree mortality patterns in Estonia. Forest. Ecol. Manag. 258, S187–S195.
Laarmann, D., Korjus, H., Sims, A., Kangur, A., Stanturf, J.A., 2013. Initial effects of restoring natural forest structures in Estonia. Forest. Ecol. Manag. 304, 303–311.
Laarmann, D., Korjus, H., Sims, A., Kangur, A., Kiviste, A., Stanturf, J., in press. Evaluation of afforestation development and natural colonization on a reclaimed mine site. Restor. Ecol.
Lackey, R.T., 2001. Values, policy, and ecosystem health. BioScience 51, 437–443.
Lamb, D., 1998. Large-scale ecological restoration of degraded tropical forest lands: the potential role of timber plantations. Restor. Ecol. 6, 271–279.
Lamb, D., 2011. Regreening the Bare Hills: Tropical Forest Restoration in the Asia–Pacific Region. Springer Science + Business Media, Dordrecht.
Lamb, D., Gilmour, D., 2003. Rehabilitation and Restoration of Degraded Forests. IUCN, Gland.
Lamb, D., Erskine, P.D., Parrotta, J.A., 2005. Restoration of degraded tropical forest landscapes. Science 310, 1628–1632.
Lamb, D., Stanturf, J., Madsen, P., 2012. What is forest landscape restoration? In: Stanturf, J., Lamb, D., Madsen, P. (Eds.), Forest Landscape Restoration. Springer, Dordrecht, pp. 3–23.
Landis, T.D., Dumroese, R.K., 2006. Applying the target plant concept to nursery stock quality. In: Plant Quality: A Key to Success in Forest Establishment. Proceedings of the COFORD Conference. National Council for Forest Research and Development, Dublin, Ireland, pp. 1–10.
Landis, T.D., Dreesen, D.R., Dumroese, R.K., 2003. Sex and the single *Salix*: Considerations for riparian restoration. Native Plants J. 4, 110–117.
Landis, T.D., Dumroese, R.K., Haase, D.L., 2010a. The Container Tree Nursery Manual, Seedling Processing, Storage and Outplanting, vol. 7. USDA Forest Service, Agr. Hdbk 730, p. 199.
Landis, T.D., Steinfeld, D.E., Dumroese, R.K., 2010b. Native plant containers for restoration projects. Native Plants J. 11, 341–348.
Larson, A.J., Churchill, D., 2012. Tree spatial patterns in fire-frequent forests of western North America, including mechanisms of pattern formation and implications for designing fuel reduction and restoration treatments. Forest. Ecol. Manag. 267, 74–92.
Laurance, W.F., Sayer, J., Cassman, K.G., 2014. Agricultural expansion and its impacts on tropical nature. Trends Ecol. Evol. 29, 107–116.
Lausch, A., Herzog, F., 2002. Applicability of landscape metrics for the monitoring of landscape change: issues of scale, resolution and interpretability. Ecol. Indicators 2, 3–15.
Leak, W.B., 2003. Regeneration of patch harvests in even-aged northern hardwoods in New England. Northern J. Appl. Forest. 20, 188–189.
Lee, D.K., Park, Y.D. (Eds.), 2011. Keep Asia Green-Forest Restoration Across Boundaries. ASEAN Environmental Cooperation Project (AKECOP), Seoul.
Lee, D.K., Suh, S.J., 2005. Forest restoration and rehabilitation in Republic of Korea. In: Stanturf, J.A., Madsen, P. (Eds.), Restoration of Boreal and Temperate Forests. CRC Press, Boca Raton, pp. 383–396.
Lencinas, M.V., Pastur, G.M., Gallo, E., Cellini, J.M., 2011. Alternative silvicultural practices with variable retention to improve understory plant diversity conservation in southern Patagonian forests. Forest. Ecol. Manag. 262, 1236–1250.
Leopold, A.C., Andrus, R., Finkeldey, A., Knowles, D., 2001. Attempting restoration of wet tropical forests in Costa Rica. Forest. Ecol. Manag. 142, 243–249.
Lewis III, R.R., 2005. Ecological engineering for successful management and restoration of mangrove forests. Ecol. Eng. 24, 403–418.
Lhotka, J.M., Loewenstein, E.F., 2013. Development of three underplanted hardwood species 7 years following midstory removal. Southern J. Appl. Forest. 37, 81–90.
Lilja, S., De Chantal, M., Kuuluvainen, T., Vanha-Majamaa, I., Puttonen, P., 2005. Restoring natural characteristics in managed Norway spruce [*Picea abies* (L.) Karst.] stands with partial cutting, dead wood creation and fire: Immediate treatment effects. Scand. J. Forest Res. (Supplement 20), 68–78.
Lindenmayer, D.B., Franklin, J.F., 2002. Conserving Forest Biodiversity: A Comprehensive Multiscaled Approach. Island Press, Washington, DC.
Lindenmayer, D.B., Noss, R.F., 2006. Salvage logging, ecosystem processes, and biodiversity conservation. Conserv. Biol. 20, 949–958.
Lindenmayer, D., Hobbs, R.J., Montague-Drake, R., Alexandra, J., Bennett, A., Burgman, M., Cale, P., Calhoun, A., Cramer, V., Cullen, P., et al., 2008. A checklist for ecological management of landscapes for conservation. Ecol. Lett. 11, 78–91.
Lindenmayer, D.B., Welsh, A., Donnelly, C., Crane, M., Michael, D., Macgregor, C., McBurney, L., Montague-Drake, R., Gibbons, P., 2009. Are nest boxes a viable alternative source of cavities for hollow-dependent animals? Long-term monitoring of nest box occupancy, pest use and attrition. Biol. Conserv. 142, 33–42.
Lindenmayer, D.B., Franklin, J.F., Lõhmus, A., Baker, S.C., Bauhus, J., Beese, W., Brodie, A., Kiehl, B., Kouki, J., Pastur, G.M., Messier, C., Neyland, M., Palik, B., Sverdrup-Thygeson, A., Volney, J., Wayne, A., Gustafsson, L., 2012. A major shift to the retention approach for forestry can help resolve some global forest sustainability issues. Conserv. Lett. 5, 421–431.
Linder, M., 2000. Developing adaptive forest management strategies to cope with climate change. Tree Physiol. 20, 299–307.
Lindhe, A., Lindelöw, Å., 2004. Cut high stumps of spruce, birch, aspen and oak as breeding substrates for saproxylic beetles. Forest. Ecol. Manag. 203, 1–20.

Lithgow, D., Martínez, M., Gallego-Fernández, J., Hesp, P., Flores, P., Gachuz, S., Rodríguez-Revelo, N., Jiménez-Orocio, O., Mendoza-González, G., Álvarez-Molina, L., 2013. Linking restoration ecology with coastal dune restoration. Geomorphology 199, 214–224.
Litvaitis, J.A., 2001. Importance of early successional habitats to mammals in eastern forests. Wildlife Soc. Bull. 29, 466–473.
Liu, Z., He, H.S., Yang, J., 2012. Emulating natural fire effects using harvesting in an eastern boreal forest landscape of northeast China. J. Veg. Sci. 23, 782–795.
Liu, Y., Goodrick, S., Heilman, W., 2014. Wildland fire emissions, carbon, and climate: Wildfire–climate interactions. Forest. Ecol. Manag. 317, 80–96.
Lockaby, G., Stanturf, J.A., 2002. Potential effects of restoration on biogeochemical functions of bottomland hardwood ecosystems. In: Holland, M.M., Warren M.L., Stanturf, J.A. (Eds.), Proceedings of a Conference on Sustainability of Wetlands and Water Resources: How Well Can Riverine Wetlands Continue to Support Society into the 21st Century? USDA Forest Service, Southern Research Station. Gen. Tech. Rep. SRS-50, pp. 116–119.
Lockhart, B.R., Keeland, B., Mccoy, J., Dean, T.J., 2003. Comparing regeneration techniques for afforesting previously farmed bottomland hardwood sites in the Lower Mississippi Alluvial Valley, USA. Forestry 76, 169–180.
Lockhart, B.R., Ezell, A.W., Hodges, J.D., Clatterbuck, W.K., 2006. Using natural stand development patterns in artificial mixtures: a case study with cherrybark oak and sweetgum in east-central Mississippi, USA. Forest. Ecol. Manag. 222, 202–210.
Lockhart, B.R., Gardiner, E., Leininger, T., Stanturf, J., 2008. A stand-development approach to oak afforestation in the Lower Mississippi Alluvial Valley. Southern J. Appl. Forest. 32, 120–129.
Loewenstein, E.F., 2005. Conversion of uniform broadleaved stands to an uneven-aged structure. Forest. Ecol. Manag. 215, 103–112.
Löf, M., Thomsen, A., Madsen, P., 2004. Sowing and transplanting of broadleaves (*Fagus sylvatica* L., *Quercus robur* L., *Prunus avium* L. and *Crataegus monogyna* Jacq.) for afforestation of farmland. Forest. Ecol. Manag. 188, 113–123.
Löf, M., Paulsson, R., Rydberg, D., Welander, N.T., 2005. The influence of different overstory removal on planted spruce and several broadleaved tree species: Survival, growth and pine weevil damage during three years. Ann. For. Sci. 62, 237–244.
Löf, M., Brunet, J., Hickler, T., Birkedal, M., Jensen, A., 2012. Restoring broadleaved forests in southern Sweden as climate changes. In: Stanturf, J., Madsen, P., Lamb, D. (Eds.), A Goal-Oriented Approach to Forest Landscape Restoration. Springer, Dordrecht, pp. 373–391.
Lorimer, C.G., Chapman, J.W., Lambert, W.D., 1994. Tall understorey vegetation as a factor in the poor development of oak seedlings beneath mature stands. J. Ecol., 227–237.
Lovett, G.M., Burns, D.A., Driscoll, C.T., Jenkins, J.C., Mitchell, M.J., Rustad, L., Shanley, J.B., Likens, G.E., Haeuber, R., 2007. Who needs environmental monitoring? Front. Ecol. Environ. 5, 253–260.
Lundmark, T., Hällgren, J.-E., 1987. Effects of frost on shaded and exposed spruce and pine seedlings planted in the field. Can. J. Forest Res. 17, 1197–1201.
Luoranen, J., Rikala, R., Konttinen, K., Smolander, H., 2005. Extending the planting period of dormant and growing Norway spruce container seedlings to early summer. Silva Fenn. 39, 481.
Luoranen, J., Rikala, R., Konttinen, K., Smolander, H., 2006. Summer planting of *Picea abies* container-grown seedlings: effects of planting date on survival, height growth and root egress. Forest. Ecol. Manag. 237, 534–544.
Lupold, H.M., 1996. Salvage of storm damaged timber. In: Haymond, J.L., Hook, D.D., Harms, W.R. (Eds.), Hurricane Hugo: South Carolina Forest Land Research and Management Related to the Storm. USDA Forest Service Southern Research Station. Gen. Tech. Rep. SRS-5, pp. 21–27.
Madsen, P., Hahn, K., 2008. Natural regeneration in a beech-dominated forest managed by close-to-nature principles—a gap cutting based experiment. Can. J. Forest Res. 38, 1716–1729.
Madsen, P., Löf, M., 2005. Reforestation in southern Scandinavia using direct seeding of oak (*Quercus robur* L.). Forestry 78, 55–64.
Madsen, P., Aradóttir, Á., Gardiner, E., Gemmel, P., Høie, K., Löf, M., Stanturf, J., Tigerstedt, P., Tullus, H., Valkonen, S., Uri, V., 2002. Forest restoration in the Nordic countries. In: Holland, M.M., Warren M.L., Stanturf, J.A. (Eds.), Proceedings of a Conference on Sustainability of Wetlands and Water Resources: How Well Can Riverine Wetlands Continue to Support Society into the 21st Century? USDA Forest Service, Southern Research Station. Gen. Tech. Rep. SRS-50, pp. 120–125.
Madsen, P., Jensen, F.A., Fodgaard, S., 2005. Afforestation in Denmark. In: Stanturf, J.A., Madsen, P. (Eds.), Restoration of Boreal and Temperate Forests. CRC Press, Boca Raton, pp. 211–224.
Maestre, F.T., Cortina, J., 2004. Are *Pinus halepensis* plantations useful as a restoration tool in semiarid Mediterranean areas? Forest. Ecol. Manag. 198, 303–317.
Maginnis, S., Sayer, J.A.A., Laurie, M., 2012. Forests in Landscapes: Ecosystem Approaches to Sustainability. Earthscan, London.
Malcolm, D., Mason, W., Clarke, G., 2001. The transformation of conifer forests in Britain—regeneration, gap size and silvicultural systems. Forest. Ecol. Manag. 151, 7–23.
Mann, C.C., Plummer, M.L., 1995. Are wildlife corridors the right path? Science 270, 1428–1430.
Manning, A.D., Fischer, J., Lindenmayer, D.B., 2006. Scattered trees are keystone structures–implications for conservation. Biol. Conserv. 132, 311–321.
Martin, F., Dutrieux, E., Debry, A., 1990. Natural recolonization of a chronically oil-polluted mangrove soil after a de-pollution process. Ocean Shoreline Manag. 14, 173–190.
Martínez Pastur, G.J., Cellini, J.M., Lencinas, M.V., Barrera, M., Peri, P.L., 2011. Environmental variables influencing regeneration of *Nothofagus pumilio* in a system with combined aggregated and dispersed retention. Forest. Ecol. Manag. 261, 178–186.
Maschinski, J., Ross, M.S., Liu, H., O'Brien, J., von Wettberg, E.J., Haskins, K.E., 2011. Sinking ships: Conservation options for endemic taxa threatened by sea level rise. Climatic Change 107, 147–167.
Mascia, M.B., Pailler, S., Thieme, M.L., Rowe, A., Bottrill, M.C., Danielsen, F., Geldmann, J., Naidoo, R., Pullin, A.S., Burgess, N.D., 2014. Commonalities and complementarities among approaches to conservation monitoring and evaluation. Biol. Conserv. 169, 258–267.
Mason, W., 2002. Are irregular stands more windfirm? Forestry 75, 347–355.
Matthews, J.W., Spyreas, G., 2010. Convergence and divergence in plant community trajectories as a framework for monitoring wetland restoration progress. J. Appl. Ecol. 47, 1128–1136.
Mbow, C., Smith, P., Skole, D., Duguma, L., Bustamante, M., 2014. Achieving mitigation and adaptation to climate change through sustainable agroforestry practices in Africa. Curr. Opin. Environ. Sustain. 6, 8–14.
McCaw, Lachlan, W., 2013. Managing forest fuels using prescribed fire–a perspective from southern Australia. Forest. Ecol. Manag. 294, 217–224.
McCoy, E.D., Mushinsky, H.R., 2002. Measuring the success of wildlife community restoration. Ecol. Appl. 12, 1861–1871.
McCreary, D., Cañellas, I., 2005. Restoration of oak woodlands in Mediterranean ecosystems. In: Stanturf, J.A., Madsen, P. (Eds.), Restoration of Boreal and Temperate Forests. CRC Press, Boca Raton, pp. 253–266.
McIver, J.D., Stephens, S.L., Agee, J.K., Barbour, J., Boerner, R.E., Edminster, C.B., Erickson, K.L., Farris, K.L., Fettig, C.J., Fiedler, C.E., 2012. Ecological effects of alternative fuel-reduction treatments: highlights of the National Fire and Fire Surrogate study (FFS). Int. J. Wildland Fire 22, 63–82.
McKenney, D.W., Pedlar, J.H., Lawrence, K., Campbell, K., Hutchinson, M.F., 2007. Beyond traditional hardiness zones: Using climate envelopes to map plant range limits. BioScience 57, 929–937.
McLachlan, J.S., Hellmann, J.J., Schwartz, M.W., 2007. A framework for debate of assisted migration in an era of climate change. Conserv. Biol. 21, 297–302.
McNab, W.H., Edwards, M.B., Hough, W.A., 1978. Estimating fuel weights in slash pine-palmetto stands. Forest Sci. 24, 345–358.
McNamara, S., Tinh, D.V., Erskine, P.D., Lamb, D., Yates, D., Brown, S., 2006. Rehabilitating degraded forest land in central Vietnam with mixed native species plantings. Forest. Ecol. Manag. 233, 358–365.
Menzies, N., 1988. Three hundred years of taungya: a sustainable system of forestry in south China. Human Ecol. 16, 361–376.
Mercer, D.E., 2005. Policies for encouraging forest restoration. In: Stanturf, J.A., Madsen, P. (Eds.), Restoration of Boreal and Temperate Forests. CRC Press, Boca Raton, pp. 97–109.
Meyn, A., White, P.S., Buhk, C., Jentsch, A., 2007. Environmental drivers of large, infrequent wildfires: the emerging conceptual model. Progr. Phys. Geogr. 31, 287–312.
Miettinen, J., Shi, C., Liew, S.C., 2012. Two decades of destruction in Southeast Asia's peat swamp forests. Front. Ecol. Environ. 10, 124–128.
Millar, C.I., 2014. Historic variability: informing restoration strategies, not prescribing targets. J. Sustain. Forest. 33 (Suppl. 1), S28–S42.
Millar, C.I., Stephenson, N.L., Stephens, S.L., 2007. Climate change and forests of the future: Managing in the face of uncertainty. Ecol. Appl. 17, 2145–2151.
Minnemayer, S., Laestadius, L., Sizer, N., 2011. A World of Opportunity. World Resource Institute, Washington, DC.
Miyawaki, A., 1998. Restoration of urban green environments based on the theories of vegetation ecology. Ecol. Eng. 11, 157–165.
Mize, C., Brandle, J.R., Schoeneberger, M., Bentrup, G., 2008. Ecological development and function of shelterbelts in temperate North America. In: Jose, S., Gordon, A.M. (Eds.), Toward Agroforestry Design-An Ecological Approach. Springer, New York, pp. 27–54.
Moberg, F., Ronnback, P., 2003. Ecosystem services of the tropical seascape: interactions, substitutions and restoration. Ocean Coast. Manag. 46, 27–46.
Montagnini, F., Eibl, B., Grance, L., Maiocco, D., Nozzi, D., 1997. Enrichment planting in overexploited subtropical forests of the Paranaense region of Misiones, Argentina. Forest. Ecol. Manag. 99, 237–246.
Moore, E.H., Witham, J.W., 1996. From forest to farm and back again: land use history as a dimension of ecological research in coastal Maine. Environ. History 1, 50–69.
Moore, M.M., Covington, W.W., Fulé, P.Z., 1999. Reference conditions and ecological restoration: a southwestern ponderosa pine perspective. Ecol. Appl. 9, 1266–1277.
Moreira, F., Ferreira, A., Abrantes, N., Catry, F., Fernandes, P., Roxo, L., Keizer, J., Silva, J., 2013. Occurrence of native and exotic invasive trees in burned pine and eucalypt plantations: implications for post-fire forest conversion. Ecol. Eng. 58, 296–302.
Morimoto, J., Morimoto, M., Nakamura, F., 2011. Initial vegetation recovery following a blowdown of a conifer plantation in monsoonal East Asia: impacts of legacy retention, salvaging, site preparation, and weeding. Forest. Ecol. Manag. 261, 1353–1361.
Morrison, B., Lamb, D., Hundloe, T., 2005. Assessing the likelihood of mine site revegetation success: a Queensland case study. Australasian J. Environ. Manage. 12, 165–182.
Mouquet, N., Gravel, D., Massol, F., Calcagno, V., 2013. Extending the concept of keystone species to communities and ecosystems. Ecol. Lett. 16, 1–8.

Mueller, J.M., Swaffar, W., Nielsen, E.A., Springer, A.E., Lopez, S.M., 2013. Estimating the value of watershed services following forest restoration. Water Resour. Res. 49, 1773–1781.

Mulligan, M.K., Kirkman, L.K., Mitchell, R., 2002. *Aristida beyrichiana* (wiregrass) establishment and recruitment: Implications for restoration. Restor. Ecol. 10, 68–76.

Munro, N.T., Fischer, J., Wood, J., Lindenmayer, D.B., 2009. Revegetation in agricultural areas: The development of structural complexity and floristic diversity. Ecol. Appl. 19, 1197–1210.

Munro, N.T., Fischer, J., Wood, J., Lindenmayer, D.B., 2012. Assessing ecosystem function of restoration plantings in south-eastern Australia. Forest. Ecol. Manag. 282, 36–45.

Murdiyarso, D., Brockhaus, M., Sunderlin, W.D., Verchot, L., 2012. Some lessons learned from the first generation of REDD+ activities. Curr. Opin. Environ. Sustain. 4, 678–685.

Murgueitio, E., Calle, Z., Uribe, F., Calle, A., Solorio, B., 2011. Native trees and shrubs for the productive rehabilitation of tropical cattle ranching lands. Forest. Ecol. Manag. 261, 1654–1663.

Myers, R.L., 2006. Living with Fire-Sustaining Ecosystems & Livehoods Through Integrated Fire Management. The Nature Conservancy, Tallahassee, FL.

Nagaike, T., Yoshida, T., Miguchi, H., Kamitani, T., Nakashizuka, T., 2005. Rehabilitation for species enrichment in abandoned coppice forests in Japan. In: Stanturf, J.A., Madsen, P. (Eds.), Restoration of Boreal and Temperate Forests. CRC Press, Boca Raton, pp. 371–381.

Nagy, R.C., Lockaby, B.G., 2012. Hydrologic connectivity of landscapes and implications for forest restoration. In: Stanturf, J., Lamb, D., Madsen, P. (Eds.), Forest Landscape Restoration. Springer, Dordrecht, pp. 69–91.

Nave, A.G., Rodrigues, R.R., 2007. Combination of species into filling and diversity groups as forest restoration methodology. In: Rodrigues, R.R., Martins, S.V., Gandolfi, S. (Eds.), High Diversity Forest Restoration in Degraded Areas. Nova Science Publishers, New York, pp. 103–126.

Newmark, W.D., 1993. The role and design of wildlife corridors with examples from Tanzania. Ambio 22, 500–504.

Newton, A.C., Hodder, K., Cantarello, E., Perrella, L., Birch, J.C., Robins, J., Douglas, S., Moody, C., Cordingley, J., 2012. Cost–benefit analysis of ecological networks assessed through spatial analysis of ecosystem services. J. Appl. Ecol. 49, 571–580.

Nichols, J.D., Carpenter, F.L., 2006. Interplanting *Inga edulis* yields nitrogen benefits to *Terminalia amazonia*. Forest. Ecol. Manag. 233, 344–351.

Nordén, B., Ryberg, M., Götmark, F., Olausson, B., 2004. Relative importance of coarse and fine woody debris for the diversity of wood-inhabiting fungi in temperate broadleaf forests. Biol. Conserv. 117, 1–10.

Nowacki, G.J., Abrams, M.D., 2008. The demise of fire and "mesophication" of forests in the eastern United States. BioScience 58, 123–138.

Nuttle, T., Haefner, J.W., 2005. Seed dispersal in heterogeneous environments: Bridging the gap between mechanistic dispersal and forest dynamics models. Am. Natural. 165, 336–349.

Nuttle, T., Royo, A.A., Adams, M.B., Carson, W.P., 2013. Historic disturbance regimes promote tree diversity only under low browsing regimes in eastern deciduous forest. Ecol. Monogr. 83, 3–17.

Nyland, R.D., 2003. Even-to uneven-aged: the challenges of conversion. Forest. Ecol. Manag. 172, 291–300.

Nysten-Haarala, S., 2013. Creating trust in institutions in Russian forest localities. Forest Policy Econ. 31, 12–19.

O'Brien, J., Hiers, J., Mitchell, R., Varner, J., Mordecai, K., 2010. Acute physiological stress and mortality following fire in a long-unburned longleaf pine ecosystem. Fire Ecol. 6, 1–12.

Oelbermann, M., Paul Voroney, R., Gordon, A.M., 2004. Carbon sequestration in tropical and temperate agroforestry systems: a review with examples from Costa Rica and southern Canada. Agr. Ecosyst. Environ. 104, 359–377.

Oestreicher, J.S., Benessaiah, K., Ruiz-Jaen, M.C., Sloan, S., Turner, K., Pelletier, J., Guay, B., Clark, K.E., Roche, D.G., Meiners, M., 2009. Avoiding deforestation in Panamanian protected areas: an analysis of protection effectiveness and implications for reducing emissions from deforestation and forest degradation. Global Environ. Change 19, 279–291.

O'Hara, K.L., 1998. Silviculture for structural diversity: a new look at multiaged systems. J. Forest. 96, 4–10.

O'Hara, K.L., Waring, K.M., 2005. Forest restoration practices in the Pacific Northwest and California. In: Stanturf, J.A., Madsen, P. (Eds.), Restoration of Boreal and Temperate Forests. CRC Press, Boca Raton, pp. 445–461.

O'Hara, K.L., Nesmith, J.C., Leonard, L., Porter, D.J., 2010. Restoration of old forest features in coast redwood forests using early-stage variable-density thinning. Restor. Ecol. 18, 125–135.

Oliver, C.D., 1980. Even-aged development of mixed-species stands. J. Forest. 78, 201–203.

Oliver, C.D., 2014. Functional restoration of social-forestry systems across spatial and temporal scales. J. Sustain. Forest. 33 (Suppl. 1), S123–S148.

Oliver, C.D., Larson, B.C., 1996. Forest Stand Dynamics. John Wiley & Sons, New York.

Oliver, C.D., O'Hara, K.L., 2005. Effects of restoration at the stand level. In: Stanturf, J.A., Madsen, P. (Eds.), Restoration of Boreal and Temperate Forests. CRC Press, Boca Raton, pp. 31–59.

Oliver, C.D., Clatterbuck, W.K., Burkhardt, E., 1990. Spacing and stratification patterns of cherrybark oak and American sycamore in mixed, even-aged stands in the southeastern United States. Forest. Ecol. Manag. 31, 67–79.

Oliver, C.D., Covey, K., Hohl, A., Larsen, D., McCarter, J.B., Niccolai, A., Wilson, J., 2012. Landscape management. In: Stanturf, J., Lamb, D., Madsen, P. (Eds.), Forest Landscape Restoration. Springer, Dordrecht, pp. 39–65.

O'Loughlin, C.L., 1984. Effectiveness of introduced forest vegetation for protection against landslides and erosion in New Zealand steep lands. In: O'Loughlin, C.L. (Ed.), Symposium on Effects of Forest Land Use on Erosion and Slope Stability. East-West Center, Honolulu, Hawaii, pp. 275–280.

Onaindia, M., Mitxelena, A., 2009. Potential use of pine plantations to restore native forests in a highly fragmented river basin. Ann. For. Sci. 66, 1–11.

Orni, E., 1969. Afforestation in Israel. Keren Kayemeth LeIsrael, Jerusalem.

Orsi, F., Church, R.L., Geneletti, D., 2011. Restoring forest landscapes for biodiversity conservation and rural livelihoods: a spatial optimisation model. Environ. Model. Software 26, 1622–1638.

Osem, Y., Zangy, E., Bney-Moshe, E., Moshe, Y., Karni, N., Nisan, Y., 2009. The potential of transforming simple structured pine plantations into mixed Mediterranean forests through natural regeneration along a rainfall gradient. Forest. Ecol. Manag. 259, 14–23.

Otsamo, R., 2000. Secondary forest regeneration under fast-growing forest plantations on degraded *Imperata cylindrica* grasslands. New Forest. 19, 69–93.

Paine, R.T., Tegner, M.J., Johnson, E.A., 1998. Compounded perturbations yield ecological surprises. Ecosystems 1, 535–545.

Palik, B.J., Goebel, P.C., Kirkman, L.K., West, L., 2000. Using landscape hierarchies to guide restoration of disturbed ecosystems. Ecol. Appl. 10, 189–202.

Palik, B.J., Mitchell, R.J., Hiers, J.K., 2002. Modeling silviculture after natural disturbance to sustain biodiversity in the longleaf pine (*Pinus palustris*) ecosystem: balancing complexity and implementation. Forest. Ecol. Manag. 155, 347–356.

Palmer, M.A., Ambrose, R.F., Poff, N.L., 1997. Ecological theory and community restoration ecology. Restor. Ecol. 5, 291–300.

Paquette, A., Bouchard, A., Cogliastro, A., 2006. Survival and growth of under-planted trees: a meta-analysis across four biomes. Ecol. Appl. 16, 1575–1589.

Parkyn, S.M., Davies-Colley, R.J., Halliday, N.J., Costley, K.J., Croker, G.F., 2003. Planted riparian buffer zones in New Zealand: Do they live up to expectations? Restor. Ecol. 11, 436–447.

Parrott, D.L., Lhotka, J.M., Stringer, J.W., Dillaway, D.N., 2012. Seven-year effects of midstory removal on natural and underplanted oak reproduction. Northern J. Appl. Forest. 29, 182–190.

Parrotta, J.A., 1992. The role of plantation forests in rehabilitating degraded tropical ecosystems. Agr. Ecosyst. Environ. 41, 115–133.

Parrotta, J.A., Knowles, O.H., 2001. Restoring tropical forests on lands mined for bauxite: examples from the Brazilian Amazon. Ecol. Eng. 17, 219–239.

Parrotta, J.A., Turnbull, J.W., Jones, N., 1997. Catalyzing native forest regeneration on degraded tropical lands. Forest. Ecol. Manag. 99, 1–7.

Pastorok, R.A., MacDonald, A., Sampson, J.R., Wilber, P., Yozzo, D.J., Titre, J.P., 1997. An ecological decision framework for environmental restoration projects. Ecol. Eng. 9, 89–107.

Pastur, G.M., Lencinas, M.V., Cellini, J.M., Peri, P.L., Soler Esteban, R., 2009. Timber management with variable retention in *Nothofagus pumilio* forests of Southern Patagonia. Forest. Ecol. Manag. 258, 436–443.

Pausas, J.G., Bladé, C., Valdecantos, A., Seva, J.P., Fuentes, D., Alloza, J.A., Vilagrosa, A., Bautista, S., Cortina, J., Vallejo, R., 2004. Pines and oaks in the restoration of Mediterranean landscapes of Spain: new perspectives for an old practice—a review. Plant Ecol. 171, 209–220.

Pedlar, J.H., McKenney, D.W., Aubin, I., Beardmore, T., Beaulieu, J., Iverson, L., O'Neill, G.A., Winder, R.S., Ste-Marie, C., 2012. Placing forestry in the assisted migration debate. BioScience 62, 835–842.

Pejchar, L., Press, D.M., 2006. Achieving conservation objectives through production forestry: the case of *Acacia koa* on Hawaii Island. Environ. Sci. Policy 9, 439–447.

Peña-Claros, M., Boot, R.G.A., Dorado-Lora, J., Zonta, A., 2002. Enrichment planting of B*ertholletia excelsa* in secondary forest in the Bolivian Amazon: effect of cutting line width on survival, growth and crown traits. Forest. Ecol. Manag., 159–168.

Peppin, D., Fulé, P.Z., Sieg, C.H., Beyers, J.L., Hunter, M.E., 2010. Post-wildfire seeding in forests of the western United States: an evidence-based review. Forest. Ecol. Manag. 260, 573–586.

Phillips, R.J., Waldrop, T.A., Brose, P.H., Wang, G.G., 2012. Restoring fire-adapted forests in eastern North America for biodiversity conservation and hazardous fuels reduction. In: Stanturf, J., Madsen, P., Lamb, D. (Eds.), A Goal-Oriented Approach to Forest Landscape Restoration. Springer, Dordrecht, pp. 187–219.

Phillips, C.J., Marden, M., Lambie, S., Watson, A., Ross, C., Fraser, S., 2013. Observations of below-ground characteristics of young redwood trees (*Sequoia sempervirens*) from two sites in New Zealand–implications for erosion control. Plant Soil 363, 33–48.

Pichancourt, J.B., Firn, J., Chadès, I., Martin, T.G., 2014. Growing biodiverse carbon-rich forests. Global Change Biol. 20, 382–393.

Pinto, J.R., Dumroese, R.K., Davis, A.S., Landis, T.D., 2011. Conducting seedling stocktype trials: a new approach to an old question. J. Forest. 109, 293–299.

Pommerening, A., 2006. Transformation to continuous cover forestry in a changing environment. Forest. Ecol. Manag. 224, 227–228.

Pommerening, A., Murphy, S., 2004. A review of the history, definitions and methods of continuous cover forestry with special attention to afforestation and restocking. Forestry 77, 27–44.

Prach, K., Hobbs, R.J., 2008. Spontaneous succession versus technical reclamation in the restoration of disturbed sites. Restor. Ecol. 16, 363–366.

Prach, K., Pysek, P., 2001. Using spontaneous succession for restoration of human-disturbed habitats: experience from Central Europe. Ecol. Eng. 17, 55–62.

Prach, K., Řehounková, K., Řehounek, J., Konvalinkova, P., 2011. Ecological restoration of central European mining sites: a summary of a multi-site analysis. Landscape Res. 36, 263–268.

Præstholm, S., Reenberg, A., Kristensen, S.P., 2006. Afforestation of European landscapes: how do different farmer types respond to EU agri-environmental schemes? GeoJournal 67, 71–84.

Pratihast, A.K., Herold, M., De Sy, V., Murdiyarso, D., Skutsch, M., 2013. Linking community-based and national REDD+ monitoring: a review of the potential. Carbon Manag. 4, 91–104.

Preece, N.D., Oosterzee, P., Lawes, M.J., 2013. Planting methods matter for cost-effective rainforest restoration. Ecol. Manag. Restor. 14, 63–66.

Prestemon, J.P., Wear, D.N., Stewart, F.J., Holmes, T.P., 2006. Wildfire, timber salvage, and the economics of expediency. Forest Policy Econ. 8, 312–322.

Preti, F., 2013. Forest protection and protection forest: tree root degradation over hydrological shallow landslides triggering. Ecol. Eng. 61, 633–645.

Prévosto, B., Balandier, P., 2007. Influence of nurse birch and Scots pine seedlings on early aerial development of European beech seedlings in an open-field plantation of Central France. Forestry 80, 253–264.

Priadjati, A., Smits, W.T., Tolkamp, G.W., 2001. Vegetative propagation to assure a continuous supply of plant material for forest rehabilitation. In: Hillegers, P.J.M., Iongh, H.H.D. (Eds.), The Balance Between Biodiversity Conservation and Sustainable Use of Tropical Rain Forests. The Tropenbos Foundation, Wageningen, the Netherlands, pp. 19–30.

Pritchard, D.J., 2013. Community-based biodiversity monitoring in Mexico: current status, challenges, and future strategies for collaboration with scientists. In: Porter-Bolland, L., Ruiz-Mallén, I., Camacho-Benavides, C., McCandless, S.R. (Eds.), Community Action for Conservation-Mexican Experiences. Springer, New York, pp. 135–157.

Pullar, D., Lamb, D., 2012. A tool for comparing alternative forest landscape restoration scenarios. In: Stanturf, J., Madsen, P., Lamb, D. (Eds.), A Goal-Oriented Approach to Forest Landscape Restoration. Springer, Dordrecht, pp. 3–20.

Pullin, A.S., Knight, T.M., Stone, D.A., Charman, K., 2004. Do conservation managers use scientific evidence to support their decision-making? Biol. Conserv. 119, 245–252.

Putz, F.E., Nasi, R., 2009. Carbon benefits from avoiding and repairing forest degradation. In: Angelsen, A., Brockhaus, M. (Eds.), Realising REDD+: National Strategy and Policy Options. CIFOR, Bogor, Indonesia, pp. 249–262.

Putz, F.E., Redford, K.H., 2010. The importance of defining 'forest': Tropical forest degradation, deforestation, long-term phase shifts, and further transitions. Biotropica 42, 10–20.

Raftoyannis, Y., Spanos, I., 2005. Evaluation of log and branch barriers as post-fire rehabilitation treatments in a Mediterranean pine forest in Greece. Int. J. Wildland Fire 14, 183–188.

Ramos, J.M., Del Amo, S., 1992. Enrichment planting in a tropical secondary forest in Veracruz. Mexico. Forest Ecol. Manag. 54, 289–304.

Raup, H.M., 1966. The view from John Sanderson's farm: a perspective for the use of the land. Forest Conserv. History 10, 2–11.

Ravenscroft, C., Scheller, R.M., Mladenoff, D.J., White, M.A., 2010. Forest restoration in a mixed-ownership landscape under climate change. Ecol. Appl. 20, 327–346.

Redpath, S.M., Young, J., Evely, A., Adams, W.M., Sutherland, W.J., Whitehouse, A., Amar, A., Lambert, R.A., Linnell, J.D., Watt, A., 2013. Understanding and managing conservation conflicts. Trends Ecol. Evol. 28, 100–109.

Reeve, T., Lichatowich, J., Towey, W., Duncan, A., 2006. Building science and accountability into community-based restoration: Can a new funding approach facilitate effective and accountable restoration? Fisheries 31, 17–24.

Ren, H., Shen, W.-J., Lu, H.-F., Wen, X.-Y., Jian, S.-G., 2007. Degraded ecosystems in China: status, causes, and restoration efforts. Landscape Ecol. Eng. 3, 1–13.

Renou, F., Farrell, E.P., 2005. Reclaiming peatlands for forestry: the Irish experience. In: Stanturf, J.A., Madsen, P. (Eds.), Restoration of Boreal and Temperate Forests. CRC Press, Boca Raton, pp. 541–557.

Renou-Wilson, F., Keane, M., Farrell, E.P., 2008. Establishing oak woodland on cutaway peatlands: effects of soil preparation and fertilization. Forest. Ecol. Manag. 255, 728–737.

Rey Benayas, J.M., Bullock, J.M., Newton, A.C., 2008. Creating woodland islets to reconcile ecological restoration, conservation, and agricultural land use. Front. Ecol. Environ. 6, 329–336.

Ribe, R.G., Ford, R.M., Williams, K.J.H., 2013. Clearfell controversies and alternative timber harvest designs: how acceptability perceptions vary between Tasmania and the US Pacific Northwest. J. Environ. Manage. 114, 46–62.

Robichaud, P.R., Lewis, S.A., Wagenbrenner, J.W., Ashmun, L.E., Brown, R.E., 2013a. Post-fire mulching for runoff and erosion mitigation: part I: effectiveness at reducing hillslope erosion rates. Catena 105, 75–92.

Robichaud, P.R., Wagenbrenner, J.W., Lewis, S.A., Ashmun, L.E., Brown, R.E., Wohlgemuth, P.M., 2013b. Post-fire mulching for runoff and erosion mitigation part II: effectiveness in reducing runoff and sediment yields from small catchments. Catena 105, 93–111.

Robinson, B.E., Holland, M.B., Naughton-Treves, L., in press. Does secure land tenure save forests? A meta-analysis of the relationship between land tenure and tropical deforestation. Global Environ. Change. <http://dx.doi.org/10.1016/j.gloenvcha.2013.05.012>.

Rochefort, L., Lode, E., 2006. Restoration of degraded boreal peatlands. In: Wieder, R.K., Vitt, D.H. (Eds.), Boreal Peatland Ecosystems. Springer, pp. 381–423.

Rodrigues, R.R., Lima, R.A.F., Gandolfi, S., Nave, A.G., 2009. On the restoration of high diversity forests: 30 years of experience in the Brazilian Atlantic Forest. Biol. Conserv. 142, 1242–1251.

Rodrigues, R.R., Gandolfi, S., Nave, A.G., Aronson, J., Barreto, T.E., Vidal, C.Y., Brancalion, P.H., 2011. Large-scale ecological restoration of high-diversity tropical forests in SE Brazil. Forest. Ecol. Manag. 261, 1605–1613.

Roni, P., Beechie, T.J., Bilby, R.E., Leonetti, F.E., Pollock, M.M., Pess, G.R., 2002. A review of stream restoration techniques and a hierarchical strategy for prioritizing restoration in Pacific Northwest watersheds. North Am. J. Fish. Manag. 22, 1–20.

Rose, R., Hasse, D.L., 1995. The target seedling concept: Implementing a program. In: Landis, T.D., Cregg, B. (Tech. Coords.), National Proceedings, Forest and Conservation Nursery Associations. USDA Forest Service, Pacific Northwest Research Station. Gen. Tech. Rep. PNW-GTR-365, pp. 124–130.

Rosengren, L., 2012. Planted forests and trees can restore landscapes and alleviate poverty. In: Stanturf, J., Madsen, P., Lamb, D. (Eds.), A Goal-Oriented Approach to Forest Landscape Restoration. Springer, Dordrecht, pp. 443–463.

Roshetko, J.M., Rohadi, D., Perdana, A., Sabastian, G., Nuryartono, N., Pramono, A.A., Widyani, N., Manalu, P., Fauzi, M.A., Sumardamto, Kusumowardhani, N., 2013. Teak agroforestry systems for livelihood enhancement, industrial timber production, and environmental rehabilitation. Forests, Trees and Livelihoods 22, 241–256.

Ruiz-Jaén, M.C., Aide, T.M., 2005a. Restoration success: How is it being measured? Restor. Ecol. 13, 569–577.

Ruiz-Jaén, M.C., Aide, T.M., 2005b. Vegetation structure, species diversity, and ecosystem processes as measures of restoration success. Forest. Ecol. Manag. 218, 159–173.

Rumpff, L., Duncan, D., Vesk, P., Keith, D., Wintle, B., 2011. State-and-transition modelling for adaptive management of native woodlands. Biol. Conserv. 144, 1224–1236.

Ryan, K.C., 2002. Dynamic interactions between forest structure and fire behavior in boreal ecosystems. Silva Fenn. 36, 13–39.

Ryan, K.C., Knapp, E.E., Varner, J.M., 2013. Prescribed fire in North American forests and woodlands: history, current practice, and challenges. Front. Ecol. Environ. 11, e15–e24.

Saha, S., Kuehne, C., Kohnle, U., Brang, P., Ehring, A., Geisel, J., Leder, B., Muth, M., Petersen, R., Peter, J., Ruhm, W., Bauhus, J., 2012. Growth and quality of young oaks (*Quercus robur* and *Quercus petraea*) grown in cluster plantings in central Europe: a weighted meta-analysis. Forest. Ecol. Manag. 283, 106–118.

Sarewitz, D., Pielke Jr, R.A., 2007. The neglected heart of science policy: reconciling supply of and demand for science. Environ. Sci. Policy 10, 5–16.

Sarr, D.A., Puettmann, K.J., 2008. Forest management, restoration, and designer ecosystems: integrating strategies for a crowded planet. EcoScience 15, 17–26.

Sarr, D., Puettmann, K., Pabst, R., Cornett, M., Arguello, L., 2004. Restoration ecology: new perspectives and opportunities for forestry. J. Forest. 102, 20–24.

Saure, H.I., Vetaas, O.R., Odland, A., Vandvik, V., 2013. Restoration potential of native forests after removal of *Picea abies* plantations. Forest. Ecol. Manag. 305, 77–87.

Sayer, J., Campbell, B., Petheram, L., Aldrich, M., Ruiz Perez, M., Endamana, D., Nzooh Dongmo, Z., Defo, L., Mariki, S., Doggart, N., Burgess, N., 2007. Assessing environment and development outcomes in conservation landscapes. Biodivers. Conserv. 16, 2677–2694.

Sayer, J., Sunderland, T., Ghazoul, J., Pfund, J.-L., Sheil, D., Meijaard, E., Venter, M., Boedhihartono, A.K., Day, M., Garcia, C., 2013. Ten principles for a landscape approach to reconciling agriculture, conservation, and other competing land uses. Proc. Natl. Acad. Sci. 110, 8349–8356.

Schelhas, J., Samar, S., Johnson, C., Asamadu, A., Tease, F., Stanturf, J., Blay, D., 2010. Opportunities and capacity for community-based forest carbon sequestration and monitoring in Ghana. Nature & Faune 25, 41–45.

Schelhas, J., Miller, J.H., Chambers, J., 2012. Non-native plants and adaptive collaborative approaches to ecosystem restoration in the United States. In: Stanturf, J., Madsen, P., Lamb, D. (Eds.), A Goal-Oriented Approach to Forest Landscape Restoration. Springer, Dordrecht, pp. 163–186.

Schlönvoigt, A., Beer, J., 2001. Initial growth of pioneer timber tree species in a Taungya system in the humid lowlands of Costa Rica. Agroforest. Syst. 51, 97–108.

Schmiegelow, F.K., Stepnisky, D.P., Stambaugh, C.A., Koivula, M., 2006. Reconciling salvage logging of boreal forests with a natural-disturbance management model. Conserv. Biol. 20, 971–983.

Schneider, E., 2010. Floodplain restoration of large European rivers, with examples from the Rhine and the Danube. In: Eiseltová, M. (Ed.), Restoration of Lakes, Streams, Floodplains, and Bogs in Europe. Springer, Netherlands, Dordrecht, pp. 185–223.

Schönenberger, W., 2001. Cluster afforestation for creating diverse mountain forest structures—a review. Forest. Ecol. Manag. 145, 121–128.

Schröder, R., Prasse, R., 2013. Cultivation and hybridization alter the germination behavior of native plants used in revegetation and restoration. Restor. Ecol. 21, 793–800.

Schultz, R., Collettil, J., Isenhart, T., Simpkins, W., Mize, C., Thompson, M., 1995. Design and placement of a multi-species riparian buffer strip system. Agroforest. Syst. 29, 201–226.

Schwilk, D.W., Keeley, J.E., Knapp, E.E., McIver, J., Bailey, J.D., Fettig, C.J., Fiedler, C.E., Harrod, R.J., Moghaddas, J.J., Outcalt, K.W., 2009. The national Fire and Fire Surrogate study: effects of fuel reduction methods on forest vegetation structure and fuels. Ecol. Appl. 19, 285–304.

Scowcroft, P.G., Yeh, J.T., 2013. Passive restoration augments active restoration in deforested landscapes: the role of root suckering adjacent to planted stands of *Acacia koa*. Forest. Ecol. Manag. 305, 138–145.

Seabrook, L., Mcalpine, C.A., Bowen, M.E., 2011. Restore, repair or reinvent: options for sustainable landscapes in a changing climate. Landscape Urban Plan. 100, 407–410.

Seifert, J.R., Jacobs, D.F., Selig, M.F., 2006. Influence of seasonal planting date on field performance of six temperate deciduous forest tree species. Forest. Ecol. Manag. 223, 371–378.
SERI, 2004. The SER International Primer on Ecological Restoration. Society for Ecological Restoration International, Washington, DC.
Seymour, R.S., 1992. The red spruce-balsam fir forest of Maine: evolution of silvicultural practice in response to stand development patterns and disturbances. In: Kelty, M., Larson, B., Oliver, C. (Eds.), The Ecology and Silviculture of Mixed-Species Forests: A Festschrift for David M. Smith. Kluwer Academic, Dordrecht, pp. 217–244.
Shackelford, N., Hobbs, R.J., Heller, N.E., Hallett, L.M., Seastedt, T.R., 2013. Finding a middle-ground: the native/non-native debate. Biol. Conserv. 158, 55–62.
Shepperd, W.D., Rogers, P.C., Burton, D., Bartos, D.L., 2006. Ecology, Biodiversity, Management, and Restoration of Aspen in the Sierra Nevada. USDA Forest Service, Rocky Mountain Research Station. Gen. Tech. Rep. RMRS-GTR-178, p. 122.
Shinneman, D.J., Cornett, M.W., Palik, B.J., 2010. Simulating restoration strategies for a southern boreal forest landscape with complex land ownership patterns. Forest. Ecol. Manag. 259, 446–458.
Shinneman, D.J., Palik, B.J., Cornett, M.W., 2012. Can landscape-level ecological restoration influence fire risk? A spatially-explicit assessment of a northern temperate-southern boreal forest landscape. Forest. Ecol. Manag. 274, 126–135.
Shono, K., Cadaweng, E.A., Durst, P.B., 2007. Application of assisted natural regeneration to restore degraded tropical forestlands. Restor. Ecol. 15, 620–626.
Shuman, C.S., Ambrose, R.F., 2003. A comparison of remote sensing and ground-based methods for monitoring wetland restoration success. Restor. Ecol. 11, 325–333.
Sileshi, G., Akinnifesi, F.K., Ajayi, O.C., Chakeredza, S., Kaonga, M., Matakala, P., 2007. Contributions of agroforestry to ecosystem services in the miombo eco-region of eastern and southern Africa. African J. Environ. Sci. Technol. 1, 68–80.
Simmons, M.E., Wu, X.B., Whisenant, S.G., 2012. Responses of pioneer and later-successional plant assemblages to created microtopographic variation and soil treatments in riparian forest restoration. Restor. Ecol. 20, 369–377.
Singh, K.P., Mandal, T.N., Tripathi, S.K., 2001. Patterns of restoration of soil physciochemical properties and microbial biomass in different landslide sites in the sal forest ecosystem of Nepal Himalaya. Ecol. Eng. 17, 385–401.
Sirigar, U., Siregar, I., Budi, S., Hero, Y., Suharjito, D., Hardjanto, 2012. Incorporating social and natural science in the restoration of an Indonesian conservation forest: a case study from Jambi. In: Stanturf, J., Madsen, P., Lamb, D. (Eds.), A Goal-Oriented Approach to Forest Landscape Restoration. Springer, Dordrecht, pp. 41–62.
Smit, B., Wandel, J., 2006. Adaptation, adaptive capacity and vulnerability. Global Environ. Change 16, 282–292.
Smith, S.E., Winslow, S.R., 2001. Comparing perceptions of native status. Native Plants J. 2, 5–11.
Sousa, N.R., Franco, A.R., Oliveira, R.S., Castro, P.M.L., 2014. Reclamation of an abandoned burned forest using ectomycorrhizal inoculated *Quercus rubra*. Forest. Ecol. Manag. 320, 50–55.
Spiecker, H., Hansen, J., Klimo, E., Skovsgaard, J.P., Sterba, H., von Teuffel, K. (Eds.), . Norway Spruce Conversion-Options and Consequences. Brill, Leiden.
Sprugel, D.G., 1991. Disturbance, equilibrium, and environmental variability: what is 'natural' vegetation in a changing environment? Biol. Conserv. 58, 1–18.
Stanford, J.A., Ward, J., Liss, W.J., Frissell, C.A., Williams, R.N., Lichatowich, J.A., Coutant, C.C., 1996. A general protocol for restoration of regulated rivers. Regul. Rivers: Res. Manag. 12, 391–413.
Stanturf, J.A., 2005. What is forest restoration? In: Stanturf, J.A., Madsen, P. (Eds.), Restoration of Boreal and Temperate Forests. CRC Press, Boca Raton, pp. 3–11.
Stanturf, J.A., Madsen, P., 2002. Restoration concepts for temperate and boreal forests of North America and Western Europe. Plant Biosyst. 136, 143–158.
Stanturf, J., van Oosten, C., 2014. Operational poplar and willow culture. In: Isebrands, J.G., Richardson, J. (Eds.), Poplars and Willows—Trees for Society and the Environment. CABI.
Stanturf, J.A., Schweitzer, C.J., Gardiner, E.S., 1998. Afforestation of marginal agricultural land in the Lower Mississippi River Alluvial Valley, USA. Silva Fenn. 32, 281–297.
Stanturf, J.A., Gardiner, E.S., Hamel, P.B., Devall, M.S., Leininger, T.D., Warren, M.E., 2000. Restoring bottomland hardwood ecosystems in the Lower Mississippi Alluvial Valley. J. Forest. 98, 10–16.
Stanturf, J.A., Schoenholtz, S.H., Schweitzer, C.J., Shepard, J.P., 2001. Achieving restoration success: myths in bottomland hardwood forests. Restor. Ecol. 9, 189–200.
Stanturf, J.A., Conner, W.H., Gardiner, E.S., Schweitzer, C.J., Ezell, A.W., 2004. Recognizing and overcoming difficult site conditions for afforestation of bottomland hardwoods. Ecol. Restor. 22, 183–193.
Stanturf, J.A., Goodrick, S.L., Outcalt, K.W., 2007. Disturbance and coastal forests: a strategic approach to forest management in hurricane impact zones. Forest. Ecol. Manag. 250, 119–135.
Stanturf, J.A., Gardiner, E.S., Shepard, J.P., Schweitzer, C.J., Portwood, C.J., Dorris Jr., L.C., 2009. Restoration of bottomland hardwood forests across a treatment intensity gradient. Forest. Ecol. Manag. 257, 1803–1814.
Stanturf, J., Lamb, D., Madsen, P., 2012a. Forest Landscape Restoration. Springer, Dordrecht, p. 330.
Stanturf, J., Madsen, P., Lamb, D., 2012b. A Goal-Oriented Approach to Forest Landscape Restoration. Springer, Dordrecht, p. 474.
Stanturf, J.A., Palik, B.J., Williams, M.I., Dumroese, R.K., Madsen, P., 2014. Forest restoration paradigms. J. Sustain. Forest. 33 (Suppl 1), S161–S194.
Steffen, W., Crutzen, P.J., McNeill, J.R., 2007. The Anthropocene: are humans now overwhelming the great forces of nature. Ambio 36, 614–621.
Stem, C., Margoluis, R., Salafsky, N., Brown, M., 2005. Monitoring and evaluation in conservation: a review of trends and approaches. Conserv. Biol. 19, 295–309.
Stephens, S.L., Millar, C.I., Collins, B.M., 2010. Operational approaches to managing forests of the future in Mediterranean regions within a context of changing climates. Environ. Res. Letters 5, 024003. http://dx.doi.org/10.1088/1748-9326/1085/1082/024003.
Stokes, A., 2006. Selecting tree species for use in rockfall protection forests. Forest, Snow Landscape Res. 80, 77–86.
Stringham, T.K., Krueger, W.C., Shaver, P.L., 2003. State and transition modeling: an ecological process approach. J. Range Manag., 106–113.
Suding, K.N., Gross, K.L., Houseman, G.R., 2004. Alternative states and positive feedbacks in restoration ecology. Trends Ecol. Evol. 19, 46–53.
Sullivan, T.P., Sullivan, D.S., Lindgren, P.M., 2001. Influence of variable retention harvests on forest ecosystems. I. Diversity of stand structure. J. Appl. Ecol. 38, 1221–1233.
Sunderland, T., Sunderland-Groves, J., Shanley, P., Campbell, B., 2009. Bridging the gap: how can information access and exchange between conservation biologists and field practitioners be improved for better conservation outcomes? Biotropica 41, 549–554.
Sutherland, W.J., Pullin, A.S., Dolman, P.M., Knight, T.M., 2004. The need for evidence-based conservation. Trends Ecol. Evol. 19, 305–308.
Svenning, J.C., Skov, F., 2007. Ice age legacies in the geographical distribution of tree species richness in Europe. Global Ecol. Biogeogr. 16, 234–245.
Swanson, M.E., Franklin, J.F., Beschta, R.L., Crisafulli, C.M., DellaSala, D.A., Hutto, R.L., Lindenmayer, D.B., Swanson, F.J., 2010. The forgotten stage of forest succession: early-successional ecosystems on forest sites. Front. Ecol. Environ. 9, 117–125.
Tabuti, J.R.S., Muwanika, V.B., Arinaitwe, M.Z., Ticktin, T., 2011. Conservation of priority woody species on farmlands: a case study from Nawaikoke sub-county, Uganda. Appl. Geogr. 31, 456–462.
Temperton, V.M., 2004. Assembly Rules and Restoration Ecology: Bridging the Gap Between Theory and Practice. Island Press, Washington, DC.
Thompson, I., 2012. Biodiversity, ecosystem thresholds, resilience and forest degradation. Unasylva 62, 25–30.
Thompson, R., Humphrey, J., Harmer, R., Ferris, R., 2003. Restoration of Native Woodland on Ancient Woodland Sites. Forestry Commission UK, Edinburgh.
Thorpe, A.S., Stanley, A.G., 2011. Determining appropriate goals for restoration of imperilled communities and species. J. Appl. Ecol. 48, 275–279.
Tierney, G.L., Faber-Langendoen, D., Mitchell, B.R., Shriver, W.G., Gibbs, J.P., 2009. Monitoring and evaluating the ecological integrity of forest ecosystems. Front. Ecol. Environ. 7, 308–316.
Tomaz, C., Alegria, C., Monteiro, J.M., Teixeira, M.C., 2013. Land cover change and afforestation of marginal and abandoned agricultural land: a 10 year analysis in a Mediterranean region. Forest. Ecol. Manag. 308, 40–49.
Toth, L.A., Anderson, D.H., 1998. Developing expectations for ecosystem restoration. In: Transaction on North American Wildlife Natural Resources Conference, vol. 63, pp. 122–134.
Townsend, P., Harper, R., Brennan, P., Dean, C., Wu, S., Smettem, K., Cook, S., 2012. Multiple environmental services as an opportunity for watershed restoration. Forest Policy Econ. 17, 45–58.
Tulloch, A.I., Possingham, H.P., Joseph, L.N., Szabo, J., Martin, T.G., 2013. Realising the full potential of citizen science monitoring programs. Biol. Conserv. 165, 128–138.
Turner, M.G., 1989. Landscape ecology: the effect of pattern on process. Annu. Rev. Ecol. Syst. 20, 171–197.
Turner, M.G., 2010. Disturbance and landscape dynamics in a changing world. Ecology 91, 2833–2849.
Twedt, D.J., 2006. Small clusters of fast-growing trees enhance forest structure on restored bottomland sites. Restor. Ecol. 14, 316–320.
Twedt, D.J., Portwood, J., 1997. Bottomland hardwood reforestation for Neotropical migratory birds: are we missing the forest for the trees? Wildlife Soc. Bull. 25, 647–652.
Van Der Heijden, M.G., Bardgett, R.D., Van Straalen, N.M., 2008. The unseen majority: soil microbes as drivers of plant diversity and productivity in terrestrial ecosystems. Ecol. Lett. 11, 296–310.
Van Lear, D.H., Wurtz, T.L., 2005. Cultural practices for restoring and maintaining ecosystem function. In: Stanturf, J.A., Madsen, P. (Eds.), Restoration of Boreal and Temperate Forests. CRC Press, Boca Raton, pp. 173–192.
van Noordwijk, M., Suyamto, D.A., Lusiana, B., Ekadinata, A., Hairiah, K., 2008. Facilitating agroforestation of landscapes for sustainable benefits: tradeoffs between carbon stocks and local development benefits in Indonesia according to the FALLOW model. Agr. Ecosyst. Environ. 126, 98–112.
van Rooyen, M., van Rooyen, N., Stoffberg, G., 2013. Carbon sequestration potential of post-mining reforestation activities on the KwaZulu-Natal coast, South Africa. Forestry 86, 211–223.
Vanha-Majamaa, I., Jalonen, J., 2001. Green tree retention in Fennoscandian forestry. Scand. J. Forest Res. 16, 79–90.
Vanha-Majamaa, I., Lilja, S., Ryoma, R., Kotiaho, J.S., Laaka-Lindberg, S., Lindberg, H., Puttonen, P., Tamminen, P., Toivanen, T., Kuuluvainen, T., 2007. Rehabilitating boreal forest structure and species composition in Finland through logging, dead wood creation and fire: the EVO experiment. Forest. Ecol. Manag. 250, 77–88.
Varner, J.M., Gordon, D.R., Putz, F.E., Hiers, J.K., 2005. Restoring fire to long-unburned *Pinus palustris* ecosystems: novel fire effects and consequences for long-unburned ecosystems. Restor. Ecol. 13, 536–544.

Vesk, P.A., Nolan, R., Thomson, J.R., Dorrough, J.W., Nally, R.M., 2008. Time lags in provision of habitat resources through revegetation. Biol. Conserv. 141, 174–186.
Wagenbrenner, J.W., MacDonald, L.H., Rough, D., 2006. Effectiveness of three post-fire rehabilitation treatments in the Colorado Front Range. Hydrol. Process. 20, 2989–3006.
Wagner, S., Lundqvist, L., 2005. Regeneration techniques and the seedling environment from a European perspective. In: Stanturf, J.A., Madsen, P. (Eds.), Restoration of Boreal And Temperate Forests. CRC Press, Boca Raton, pp. 153–171.
Wagner, M.R., Block, W.M., Geils, B.W., Wenger, K.F., 2000. Restoration ecology: a new forest management paradigm, or another merit badge for foresters? J. Forest. 98, 22–27.
Walker, J.L., Silletti, A.M., 2006. Restoring the ground layer of longleaf pine ecosystems. In: Jose, S., Jokela, E., Miller, D. (Eds.), The Longleaf Pine Ecosystem, Ecology, Silviculture, and Restoration. Springer, New York, pp. 297–333.
Wallenius, T., Kuuluvainen, T., Heikkila, R., Lindholm, T., 2002. Spatial tree age structure and fire history in two old-growth forests in eastern Fennoscandia. Silva Fenn. 36, 185–199.
Waring, K.M., O'Hara, K.L., 2005. Silvicultural strategies in forest ecosystems affected by introduced pests. Forest. Ecol. Manag. 209, 27–41.
Weaver, P.L., 1987. Enrichment planting in tropical America. In: Figueroa, J.C., Wadsworth, F.H., Branham, S.J. (Eds.), Management of the Forests of Tropical America: Prospects and Technologies. USDA Forest Service, International Institute of Tropical Forestry, pp. 258–278.
Weber, N., 2005. Afforestation in Europe: lessons learned, challenges remaining. In: Stanturf, J.A., Madsen, P. (Eds.), Restoration of Boreal and Temperate Forests. CRC Press, Boca Raton, pp. 121–135.
Weber, M., Günter, S., Aguirre, N., Stimm, B., Mosandl, R., 2008. Reforestation of abandoned pastures: silvicultural means to accelerate forest recovery and biodiversity. In: Beck, E., Bendix, J., Kottke, I., Makeschin, F., Mosandl, R. (Eds.), Gradients in a Tropical Mountain Ecosystem of Ecuador. Springer, pp. 431–441.
Weber, M., Stimm, B., Mosandl, R., 2011. Plantations for protective purposes and rehabilitation. In: Günter, S., Weber, M., Stimm, B., Mosandl, R. (Eds.), Silviculture in the Tropics. Springer, Dordrecht, pp. 475–490.
Weekley, C.W., Menges, E.S., Craddock, A.L., Yahr, R., 2013. Logging as a pretreatment or surrogate for fire in restoring Florida scrub. Castanea 78, 15–27.
Weersum, K., 1982. Tree gardening and taungya on Java: Examples of agroforestry techniques in the humid tropics. Agroforest. Syst. 1, 53–70.
Weiler, A., Holle, B., Nickerson, D.M., 2013. Reducing biotic and abiotic land-use legacies to restore invaded, abandoned citrus groves. Restor. Ecol. 21, 755–762.
Weiss, G., 2004. The political practice of mountain forest restoration—comparing restoration concepts in four European countries. Forest. Ecol. Manag. 195, 1–13.
Westgate, M.J., Likens, G.E., Lindenmayer, D.B., 2013. Adaptive management of biological systems: a review. Biol. Conserv. 158, 128–139.
Williams, J., 2013. Exploring the onset of high-impact mega-fires through a forest land management prism. Forest. Ecol. Manag. 294, 4–10.
Williams, M.I., Dumroese, R.K., 2013. Preparing for climate change: forestry and assisted migration. J. Forest. 114, 287–297.
Williams, M.I., Dumroese, R.K., 2014. Planning the future's forests with assisted migration. In: Sample, V.A., Bixler, R.P. (Eds.), Forest Conservation and Management in the Anthropocene. USDA Forest Service, Rocky Mountain Research Station. Proc. RMRS-P-71, pp. 133–144.
Williams, B., Johns, D., Williams, H., Ledbetter, W., 2002. Converting pine plantations to bottomland hardwood wetlands: lessons learned from a unique restoration effort at the Nature Conservancy Roy E. Larsen Sandyland Sanctuary in Southeast Texas. Ecol. Restor. 20, 88–95.
Willoughby, I., Jinks, R.L., Kerr, G., Gosling, P.G., 2004. Factors affecting the success of direct seeding for lowland afforestation in the UK. Forestry 77, 467–482.
Wilson, K.A., Lulow, M., Burger, J., Fang, Y.C., Andersen, C., Olson, D., O'Connell, M., McBride, M.F., 2011. Optimal restoration: accounting for space, time and uncertainty. J. Appl. Ecol. 48, 715–725.
Wilson, K.A., Lulow, M., Burger, J., McBride, M.F., 2012. The economics of restoration. In: Stanturf, J., Lamb, D., Madsen, P. (Eds.), Forest Landscape Restoration. Springer, Dordrecht, pp. 215–231.
Wimberly, M.C., Boyte, S.P., Gustafson, E.J., 2012. Understanding landscapes through spatial modeling. In: Stanturf, J., Lamb, D., Madsen, P. (Eds.), Forest Landscape Restoration. Springer, Dordrecht, pp. 111–128.
Winter, S., 2012. Forest naturalness assessment as a component of biodiversity monitoring and conservation management. Forestry 85, 293–304.
Witman, J., Ellis, J., Anderson, W., 2004. The influence of physical processes, organisms, and permeability on cross-ecosystem fluxes. In: Polis, G., Power, M., Huxel, G. (Eds.), Food Webs at the Landscape Level. The University of Chicago Press, Chicago, pp. 335–358.
Wohl, E., 2005. Compromised rivers: understanding historical human impacts on rivers in the context of restoration. Ecol. Soc. 10, 2.
Wollenberg, E., Moeliono, M., Limberg, G., Iwan, R., Rhee, S., Sudana, M., 2006. Between state and society: local governance of forests in Malinau, Indonesia. Forest Policy Econ. 8, 421–433.
Wortley, L., Hero, J.-M., Howes, M., 2013. Evaluating ecological restoration success: a review of the literature. Restor. Ecol. 21, 537–543.
Woziwoda, B., Kopeć, D., 2014. Afforestation or natural succession? Looking for the best way to manage abandoned cut-over peatlands for biodiversity conservation. Ecol. Eng. 63, 143–152.
WRI, 2012. First Global Commitment to Forest Restoration Launched. World Resources Institute, New York.
Wu, T., Kim, Y.S., Hurteau, M.D., 2011. Investing in natural capital: using economic incentives to overcome barriers to forest restoration. Restor. Ecol. 19, 441–445.
Xi, W., Bi, H., He, B., 2012. Forest landscape restoration in China. In: Stanturf, J., Madsen, P., Lamb, D. (Eds.), A Goal-Oriented Approach to Forest Landscape Restoration. Springer, Dordrecht, pp. 65–92.
Yaalon, D.H., Yaron, B., 1966. Framework for man-made soil changes: an outline of metapedogenesis. Soil Sci. 102, 272–277.
Yamagawa, H., Ito, S., Nakao, T., 2010. Restoration of semi-natural forest after clearcutting of conifer plantations in Japan. Landscape Ecol. Eng. 6, 109–117.
Yemshanov, D., Koch, F.H., Ducey, M., Koehler, K., 2013. Mapping ecological risks with a portfolio-based technique: incorporating uncertainty and decision-making preferences. Divers. Distrib. 19, 567–579.
Young, J.C., Jordan, A., Searle, K.R., Butler, A., Chapman, D.S., Simmons, P., Watt, A.D., 2013. Does stakeholder involvement really benefit biodiversity conservation? Biol. Conserv. 158, 359–370.
Zahawi, R.A., 2008. Instant trees: using giant vegetative stakes in tropical forest restoration. Forest. Ecol. Manag. 255, 3013–3016.
Zahawi, R.A., Holl, K.D., 2009. Comparing the performance of tree stakes and seedlings to restore abandoned tropical pastures. Restor. Ecol. 17, 854–864.
Zalasiewicz, J., Williams, M., Steffen, W., Crutzen, P., 2010. The new world of the Anthropocene. Environ. Sci. Technol. 44, 2228–2231.
Zenner, E.K., 2000. Do residual trees increase structural complexity in Pacific Northwest coniferous forests? Ecol. Appl. 10, 800–810.
Zerbe, S., 2002. Restoration of natural broad-leaved woodland in Central Europe on sites with coniferous forest plantations. Forest. Ecol. Manag. 167, 27–42.
Zhang, K., Liu, H., Li, Y., Xu, H., Shen, J., Rhome, J., Smith Iii, T.J., 2012. The role of mangroves in attenuating storm surges. Estuar. Coast. Shelf Sci. 102–103, 11–23.
Zipper, C.E., Burger, J.A., Barton, C.D., Skousen, J.G., 2013. Rebuilding soils on mined land for native forests in Appalachia. Soil Sci. Soc. Am. J. 77, 337–349.