A Stepwise Approach to Increasing Ecological Complexity in Forest Landscape Restoration

Nigel Dudley (corresponding author: School of Earth and Environmental Sciences, University of Queensland, Brisbane, QLD 4072, Australia; Equilibrium Research, 47 The Quays, Cumberland Road, Bristol BS1 6UQ, UK, nigel@equilibriumresearch.com) and Stewart Maginnis (International Union for Conservation of Nature, 28 rue Mauverney, CH1196 Gland, Switzerland).

Continuing deforestation (Keenan et al. 2015) and forest degradation (Sloan and Sayer 2015) reinforce the need for restoration (Aronson and Alexander 2013, Hanberry et al. 2015). Restoration will in turn be profoundly influenced by climate change (Harris et al. 2006). Even restoration projects with narrow objectives, such as fuelwood production (Montagnini and Nair 2004) or biodiversity conservation (Bullock et al. 2011), will be expected to contribute to climate mitigation (carbon sequestration and storage) and adaptation (ecosystem services). Restored forests, if they are to deliver effective ecosystem services, need to be resilient to changing conditions, which may require purposeful decisions about the direction of restoration. Furthermore, the long timescale involved (Maginnis and Jackson 2012) means that management aims and societal needs are likely to change during the life of a restoration program. Forest Landscape Restoration initiatives, from the outset, need to be adaptable and capable of modification (Mansourian et al. 2017).

Resilience is defined as: "the amount of change a system can undergo without changing state" (IPCC TAR 2001, 993). Ecologists distinguish between engineering resilience, the ability of an ecosystem to return to its pre-disturbance state, and ecological resilience or equilibrium dynamics, the ability of an ecosystem to absorb impacts and remain below a threshold of change into a different state (Walker et al. 2004). Engineering resilience—the ability to "bounce back" becomes rarer under climate change, while ecological resilience will likely result in modifications to an ecosystem's taxonomic composition and even its structure, albeit changes that retain many of the original ecosystem's functional characteristics (Stanturf et al. 2014). Ecosystems may exist in more than one stable state (Schroder et al. 2005), suggesting that there is no simple "right" and "wrong" restoration pathway, and that restoration goals must remain open-ended (Heller and Hobbs 2014) and, if necessary, adapted over time.

Forest restoration projects need to incorporate resilience into their objectives if they are to contribute to an ecosystem that functions in the long term. High diversity ecosystems are increasingly considered more resilient and provide a wider range and better-quality ecosystem services (Loreau et al. 2001), although simplistic, linear links between biodiversity and ecosystem function are to be treated with caution (Lasky et al. 2014). One hypothesis is that species richness increases ecosystem resilience by increasing the interdependencies and robustness of the system (the stability-diversity hypothesis, Doak et al. 1998). Others suggest that functional diversity plays the pivotal role (Díaz and Cabido 2001); including species that maintain biological functions (e.g., seed dispersers). Richness tends to increase redundancy and therefore buffers ecosystems against loss of individual species. Restoration projects are encouraged to increase diversity to increase resilience (Harris et al. 2006). This coincides well with the objectives of restoration projects aimed at biodiversity conservation, in which diversity also generally has a high value, particularly as an adaptation response to climate change (Foden et al. 2008).

The twin incentives of climate resilience and biodiversity conservation should encourage the modification of many existing forest restoration projects. The pursuit of these objectives can be enhanced through a stepwise approach to forest restoration, which aims to gradually increase ecological complexity. This could include, for example, increasing the mix of tree species (and hence associated species), encouraging a mixed age stand, planning to retain old-growth fragments in restored forests, and potentially reintroducing expected species that disappeared prior to restoration. We suggest that stepwise forest landscape restoration could be defined as: a process of deliberately pursuing incremental gains that supplement or speed up natural succession towards increased ecological complexity, increased resilience, and increased diversity of benefits.

A stepwise approach could be part of the original restoration plans or emerge over time, or be a reaction to a problem, possibly in an existing forest (Table 1). Complexity can be factored into restoration at any stage although the earlier it is anticipated, the easier it will be achieved. The principle of non-regression is important; responsible restoration projects should maintain complexity and avoid loss of diversity, such as might occur through replacing mixed woodland with a monoculture plantation.

The following examples are illustrative:

1. Pre-planned stepwise approach: in Guanacaste, Costa Rica, restoration began by planting fast-growing non-native *Gmelina arborea* (gamhar) on waste from orange plantations, but with the aim of recreating a near-natural forest. Once tree cover was restored, invasive grasses shaded out, and soil conditions and microclimate improved, native trees gradually replaced *Gmelina* (Janzen 2002).

Ecological Restoration Vol. 36, No. 3, 2018
ISSN 1522-4740 E-ISSN 1543-4079

Table 1. Types of stepwise restoration for forest landscape restoration.

Pre-planned stepwise approach	Developing stepwise approach	Responsive stepwise approach
Either there are efforts to incorporate elements of ecological complexity from the start of restoration, *or* although early stages of restoration focus on tree cover and basic services, plans to increase the ecological complexity of the system incrementally exist from the beginning.	The restoration program starts with narrow aims like timber stock, providing fuelwood or stabilising soil, but goals are consciously and systematically modified to include ecological complexity.	There is no systematic effort to restore ecological complexity within restoration, but specific actions are taken that either capitalise on the serendipitous introduction of ecological complexity or address problems that arise from a lack of ecological complexity.

2. Developing stepwise approach: South Korea's government undertook ambitious restoration following deforestation during the Second World War and civil war. The country now has a high level of even-aged, low diversity forest. The government aims to increase structural and species diversity (Lee et al. 2015), particularly in protected areas.
3. Responsive stepwise approach: Nuuksio National Park, outside Helsinki, Finland, is established on previously managed forest. Lack of dead wood created threats to fungi and insect species. Managers took the counter-intuitive approach of felling some healthy trees in a one-off exercise, to create dead-wood habitat until the forest developed a more natural age succession (Gilligan et al. 2005).

The direction and priorities of a stepwise approach to forest restoration need to be decided by relevant stakeholders. However, resilience to climate change will likely be a constant feature, and factors such as diversity and connectivity are increasing recognised as supporting forest resilience (Timpane-Padgham et al. 2017). In these cases, the stepwise approach might include a greater variety of forest functions over time and a more complex forest ecosystem. Changes of this nature often also require changes in societal values, for example, falling market demand for particular forest goods that stimulates communities to look at forests in a different way. Regaining resilience is not a simple process and practitioners can tackle different elements piecemeal: several are identified in Table 2 (adapted from Dudley et al. 2006) with suggestions for incorporating into restoration.

Recognizing a stepwise approach to forest restoration increases opportunities to regain natural forest functioning, thus providing maximum resilience to environmental change. It allows a flexible approach that can encompass past changes and novel ecosystems. Finally, it acknowledges that resilience will not always be the first priority of restoration projects, particularly when these are aimed at the immediate needs of local communities but can be addressed gradually, as restoration progresses.

References

Aronson, J. and S. Alexander. 2013. Ecosystem restoration is now a global priority: Time to roll up our sleeves. *Restoration Ecology* 21:293–296.

Bullock, J.M., J. Aronson, A.C. Newton, R.F. Pywell and J.M. Rey-Benayas. 2011. Restoration of ecosystem services and biodiversity: conflicts and opportunities. *Trends in Ecology and Evolution* 26:541–549.

Díaz, S. and M. Cabido. 2001. Vive la différence: plant functional diversity matters to ecosystem processes. *Trends in Ecology and Evolution* 16:646–655.

Table 2. Elements of a resilient forest with examples of restoration options using a step-wise approach.

Element	Description	Examples of restoration options
Composition	Species, ecosystems and genetic variation within species	Supplementary planting of native tree species or local varieties; attempts to attract animals (bird nesting sites, microhabitats); potential species translocation.
Pattern	Spatial variation of forest with respect to age, size etc	Selective planting (or removal) to increase age variation in restored forests; management to boost natural regeneration; retention of old trees.
Function	Continuity, proportion of old and dead timber, presence of ecological interactions	Retention (or creation) of dead timber in restored forests; reintroduction of symbiotic fungi.
Process	Disturbance patterns, renewal processes	Management to simulate disturbances, such as prescribed burning and recreation of natural flooding.
Continuity	Age, total area, fragmentation	Use of biological corridors and stepping stones to increase the functional size of restored forest
Resilience	Tree health, presence of stress factors	Resilience increased by addressing the five elements above; management may also be needed to control invasive species and diseases.

Doak, D.F., D. Bigger, E.K. Harding, M.A. Marvier, R.E. O'Malley and D. Thomson. 1998. The statistical inevitability of stability-diversity relationships in community ecology. *The American Naturalist* 151:264–276.

Dudley, N., R. Schlaepfer, W. Jackson, J.P. Jeanrenaud and S. Stolton. 2006. *Forest Quality: Assessing Forests at a Landscape Scale*. London, UK: Earthscan.

Foden, W., G. Mace, J.-C, Vié, A. Angulo, S. Butchart, L. DeVantier, et al. 2008. Species susceptibility to climate change impacts. In: J.-C. Vié, C. Hilton-Taylor and S.N. Stuart (eds). *The 2008 Review of The IUCN Red List of Threatened Species*. IUCN Gland, Switzerland.

Gilligan, B., N. Dudley, A. Fernandez de Tejada and H. Toivonen, 2005. *Management Effectiveness Evaluation of Finland's Protected Areas*. Helsinki: Nature Protection Publications of Metsähällitus Series A 147.

Hanberry, B.B., R.F. Noss, H.D. Safford, S.K. Allison and D.C. Dey. 2015. Restoration is preparation for the future. *Journal of Forestry* 113:1–5.

Harris, J.A., R.J. Hobbs, E. Higgs and J. Aronson. 2006. Ecological restoration and climate change. *Restoration Ecology* 14:170–176.

Heller, N.E. and R.J. Hobbs. 2014. Development of a natural practice to adapt conservation goals to global change. *Conservation Biology* 28:696–704.

IPCC TAR. 2001. *Climate Change 2001: Impacts, Adaptation and Vulnerability*. IPCC Third Assessment Report. Cambridge, UK: Cambridge University Press.

Janzen, D.H. 2002. Tropical dry forest: area de conservacion Guanacaste, north-western Costa Rica. Pages 559–583 in M. Perrow and A.J. Davy (eds), *Handbook of Ecological Restoration, vol. II*. Cambridge, UK: Cambridge University Press.

Keenan, R.J., G.A. Reams, F. Achard, J.V. de Freitas, A. Grainger and E. Lindquist. 2015. Dynamics of global forest area: Results from the FAO Global Forest Resources Assessment 2015. *Forest Ecology and Management* 352:9–20.

Lasky, J.R., M. Uriate, V.K. Boukili, D.L. Erikson, W.J. Kress and R.L. Chazdon. 2014. The relationship between tree biodiversity and biomass dynamics changes with tropical forest succession. *Ecology Letters* 17:158–1167.

Lee, S.K., P.S. Park and Y.D. Park. 2015. Forest restoration and rehabilitation in the Republic of Korea. Pages 217–232 in J.A. Stanturf (ed), *Restoration of Boreal and Temperate Forests,* 2nd edition. London, UK: CRC Press.

Loreau, M., P. Naeem, P. Inchauti, J. Bengtsson, J.P. Grime, A. Hector, et al. 2001. Biodiversity and ecosystem functioning: Current knowledge and future challenges. *Science* 294:801–808.

Maginnis, S. and W. Jackson. 2012. What is FLR and how does it differ from current approaches? Pages 5–20 in Maginnis, S., J. Rietbergen-McCracken and A. Sarre (eds), *The Forest Landscape Restoration Handbook*. London, UK: Earthscan.

Mansourian, S., N. Dudley and D. Vallauri. 2017. Forest Landscape Restoration: Progress in the last decade and remaining challenges. *Ecological Restoration* 35:281–288.

Montagnini, F. and P.K.R. Nair, 2004. Carbon sequestration: An underexploited environmental benefit of agroforestry systems. *Agroforestry Systems* 61:281–295.

Schroder, A., L. Persson and A.M. de Roos. 2005. Direct experimental evidence for alternative stable states: a review. *Oikos* 110:3–19.

Sloan, S. and J.A. Sayer. 2015. Forest Resource Assessment of 2015 shows positive trends but forest loss and degradation persist in poor tropical countries. *Forest Ecology and Management* 352:134–145.

Stanturf, J.A., B.J. Palik and R.K. Dumroese. 2014. Contemporary forest restoration: a review emphasizing function. *Forest Ecology and Management* 331:292–323.

Timpane-Padgham, B.L., T. Beechie and T. Klinger. 2017. A systematic review of ecological attributes that confer resilience to climate change in environmental restoration. *PLoS One* 12: e0173812.

Walker, B., C.S. Holling, S.R. Carpenter, and A. Kinzig. 2004. Resilience, adaptability and transformability in social–ecological systems. *Ecology and Society* 9: www.ecologyandsociety.org/vol9/iss2/art5.

***Vicia americana.* USDA-NRCS PLANTS Database. Britton, N.L. and A. Brown. 1913. *An Illustrated Flora of the Northern United States, Canada and the British Possessions.* New York, NY: Charles Scribner's Sons.**