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Ecosystem services from forest restoration: thinking ahead

Lorenzo Ciccarese · Anders Mattsson · Davide Pettenella

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Abstract Global deforestation and forest degradation have led to massive loss of biodiversity and decline of ecosystem services. Against this prospect, it is important not only to protect, but also to restore forest ecosystems. The paper analyzes the current and future role of the restoration of forests and degraded lands starting with the definition of various techniques, scales and objectives of forest restoration. Three key motivations for and targets of forest restoration are then discussed: forest biodiversity protection, biomass production, climate change mitigation and adaptation. The paper also briefly discusses three tools of increasing relevance for supporting forest restoration policies: the development of forest nursery techniques and the improvement of quality of forest reproductive material, the use of standard and certification tools, and financing of restoration investments, including projects aimed at reducing emissions from deforestation and forest degradation. We conclude by making some final remarks on the future challenges of forest restoration policies.

Keywords Ecosystem services · Forest restoration · Bioenergy · Climate change · Planting stock production · Economics

Introduction

Since publication of the Millennium Ecosystem Assessment (MEA 2005) ecosystem services provided by forests, such as climate change mitigation and adaptation, hydrological

L. Ciccarese (✉)
Nature Conservation Department, Italian Institute for Environmental Protection and Research, Via V. Brancati 48, 00144 Rome, Italy
e-mail: lorenzo.ciccarese@isprambiente.it

A. Mattsson
Department of Forest and Wood Technology, Dalarna University, Högskolegatan 2, 791 88 Falun, Sweden

D. Pettenella
Land, Environment, Agriculture and Forestry Department, University of Padua, Via Università 16, 35020 Legnaro PD, Italy

services, support to agricultural productivity, reduced erosion, increased wildlife habitat and wood or other forest products availability, have been gaining increasing recognition and attention from industry, government, the media, and private citizens. These individuals and entities are increasingly aware of the direct costs and missed benefits of allowing forest ecosystem services to become degraded or lost. In fact, forest loss and degradation can have local impacts, such as floods and landslides, or broader impacts, like global climate change (TEEB 2010). This is creating the prospect for substantial financial resources becoming available for forest protection and conservation, with potential positive impacts on employment and earnings (UNEP 2011).

Despite that, global deforestation and forest degradation rates remain alarmingly high (FAO 2010; Minnemeyer et al. 2011). Potapov et al. (2008) estimate that only 22 % of the world's old growth original forest cover remains intact.[1] Currently, the global forest land base (which covers almost 4 billion hectares or 30 % of the world's total land area) is shrinking at a rate of 13 million hectares (M ha) per year (year^{-1}), mainly because of land-use change in the Tropics and Oceania (FAO 2010). In addition, although forest cover in industrialized nations has reportedly expanded over the last decade, large portions of these forest ecosystems are heavily degraded, as they are subjected to more intense and frequent biotic and abiotic stresses, such as overexploitation, wildfires, environmental pollution, introduction of non-native invasive species, fragmentation, and the effects of climate change (Butchart et al. 2010; FAO 2010). Both the extent and quality of forest habitat continue to decrease and the associated loss of biodiversity jeopardizes forest ecosystem functioning and the ability of forests to provide ecosystem services (Naeem et al. 1994; Chomitz 2007; Norris 2012).

Against this backdrop, it is of major importance not only to conserve but also to restore forest ecosystems (Roberts et al. 2009a; Lambin and Meyfroidt 2011). This is why there is increasing interest worldwide in the science and practice of forest restoration.

The objective of this paper is to analyze the current and future role of the restoration of forests and degraded lands with a view to enhancing the full range of benefits they can provide, with the delivery of transformative change for landscapes and people. We start by defining and discussing some general issues connected to forest restoration and analyzing three key motivations for and targets of forest restoration: forest biodiversity protection, biomass production, climate change mitigation and adaptation. Next we discuss three tools of increasing relevance for supporting forest restoration policies: planting stock production, standard development and certification and forest restoration funding. We conclude by making some final remarks on the future challenges of forest restoration policies.

Forest restoration: what, why, how much and where?

The expression forest restoration is used indiscriminately and it is difficult to define in a way that comprises all situations observed in the literature and in practice, in different ecological and socio-cultural conditions.[2] Initially used to express landscaping and

[1] According to Potapov et al. (2008) an intact forest landscape is an unbroken extension of natural ecosystem within areas of current forest extent, without signs of significant human activity, and having an area of at least 500 km^2.

[2] Defining forest restoration is not merely an academic issue. Definitions related to forestry and restoration are used under several national laws and international environmental agreements and conventions. A clear definition and the reduction of nuance therefore have important policy implications.

planting to reclaim degraded sites (Wagner et al. 2000; Parrotta and Knowles 2001), forest restoration definition has developed to widen the more narrowly defined approach that has been tried in the past. Conceptually forest restoration has proceeded in step with the theories and principles of restoration ecology (Cairns and Heckman 1996). Crucial to this concept is the focus on restoring the relation between biodiversity and ecosystem functioning. An accredited definition of forest restoration is "to re-establish the presumed structure, productivity and species diversity of the forest originally present at a site. The ecological processes and functions of the restored forest will closely match those of the original forest" (Gilmour et al. 2000). Thus, forest restoration is an intentional activity that initiates, assists or accelerates the recovery of an ecosystem with respect to the presumed historical composition, structure, function, productivity and species diversity of an ecosystem present at a site. Restoration attempts to return an ecosystem to its historic trajectory. Historic conditions are therefore the ideal starting point for restoration design.

If strictly applied, this definition makes forest restoration almost impracticable: wherever forest restoration intervention is implemented on degraded and fragmented landscape, new forest emerging will not match the reference state, i.e. the original old-growth forest in species composition (Fagan et al. 2008).

Some restoration ecologists are moving away from the 'purist' position, especially the more ideological views that set the goal of restoration to be an idealized pristine state, which also implies a static view of ecosystems (Rey Benayas et al. 2009). Various authors view forest restoration as in symmetry with forest degradation and deforestation and the restored ecosystem will not necessarily recover its former state, since contemporary constraints and conditions may cause it to develop along an altered trajectory (Stanturf and Madsen 2005). Simply as forest ecosystem processes decline in a stepwise manner with increasing anthropogenic or natural impacts, restoration approaches can lift up a degraded or fragmented or completely altered forest to a higher level of the restoration staircase (Chazdon 2008) (Fig. 1). Depending on the state of degradation of an initially forested ecosystem, a range of management approaches can at least partly restore levels of biodiversity and ecosystem services given adequate time and investment of capital, infrastructure and labor. Escalating outcomes of particular approaches are: recovery of soil fertility for agricultural or forestry use (step 1); production of timber and non-timber forest products (step 2); or restoration of biodiversity and ecosystem services (step 3). It is open to discussion the idea that natural regeneration will lead to the highest level of biodiversity and ecosystem services, as expressed in Fig. 1. There are several examples that mixed planted forests may raise biodiversity and ecosystem service status if more tree species are mixed than those occurring after natural regeneration of one or few dominant tree species. Under this perspective forest restoration also includes establishing short-rotation single- or multiple-species plantations on abandoned or degraded soils (while offering little improvement of biodiversity), reclamation planting on former mining soils, where abiotic factors limit establishment and growth of native vegetation, restoration plantings in secondary forests or assisted regeneration in selectively logged forest, which are all instances of the wide ambit of forest restoration approaches. Forest restoration can be achieved either through controlling pressures on forests, such as fires, invasive species or unsustainable harvesting, or through techniques to accelerate forest recovery such as planting programs or attracting seed dispersers. These activities all have in common that they consist of active management interventions (Holl and Aide 2011). Hence forest restoration has to be distinguished from the natural forest succession, even though both processes lead to successional change: forest restoration is assisted, intentional, guided reconstruction of forests, whilst forest natural succession is regarded as unintended, nor prescribed or directed by humans.

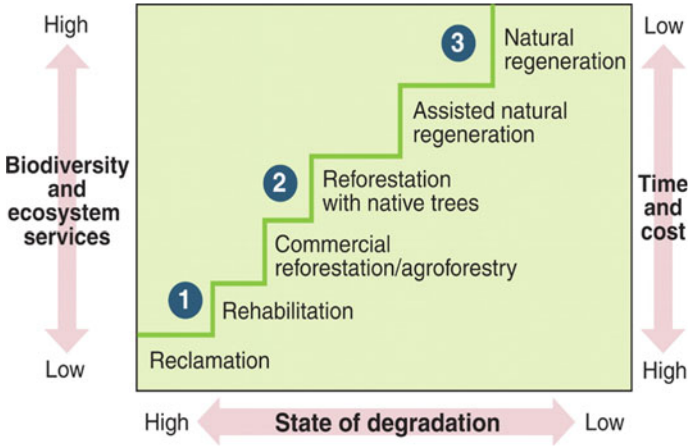

Fig. 1 The restoration staircase. Depending on the state of degradation of an initially forested ecosystem, a range of management approaches can at least partially restore levels of biodiversity and ecosystem services given adequate time (years) and financial investment (capital, infrastructure, and labor). Outcomes of particular restoration approaches are (1) restoration of soil fertility for agricultural or forestry use; (2) production of timber and non-timber forest products; or (3) recovery of biodiversity and ecosystem services. *Source:* Chazdon (2008)

Espousing this sensu lato definition of forest restoration, Minnemeyer et al. (2011) estimated that worldwide there are more than one and a half billion hectares that would be best-suited for mosaic restoration, in which forests and trees are combined with other land uses, including agro-forestry, smallholdings and settlements. Mosaic restoration includes interventions on deforested and degraded forest lands with medium to high human pressure, in more populated and higher-land-use areas with significantly reduced tree cover and forest fragmentation. Mosaic areas include other land-uses, e.g. agriculture. On the other hand, up to about half a billion hectares would be suitable for wide-scale restoration of closed forests. Wide-scale restoration includes interventions on sparsely populated deforested and degraded areas where the pressure from competing land-use is low and forests can grow more freely and, in areas where the land-use pressure is low and forests can grow more freely. While the challenge of restoration on a large scale is greater than at individual sites, it is accepted nowadays that the effectiveness of forest restoration and its chances of sustainability are both much greater on a large scale.

In addition to these two billion hectares, there are 200 M ha of unpopulated lands, mainly in the far northern boreal forests, that have been degraded by fire. Croplands and densely populated rural areas on former forest lands amount to a further one billion hectares. They do not offer extensive restoration opportunities in terms of area, but some of these lands would benefit from having trees planted in strategic places to protect and enhance farm productivity and other ecosystem services.

Forest restoration for biodiversity conservation

In recent times forest restoration has developed new insights both in theoretical and in practical actions to integrate the interactions between biodiversity and ecosystem services. Many forest ecologists consider that restoring stable forest, able to provide long-term and broad flow of ecosystem services, requires multiple species. It is highly unlikely that species-poor plantations, which may be optimal for wood biomass production, will perform better than multiple-species assemblages (Aerts and Honnay 2011). Also plant genetic diversity and above—below-ground linkages should be considered during the restoration process, as these likely have significant—but until now poorly understood—effects at ecosystem level.

Several ecologists regard as nativeness of species a prerequisite for their use in ecological restoration and biodiversity conservation (Hall et al. 2011). Native species planting provides a wide range of benefits that include increasing biodiversity, creating habitat for and attracting native wildlife (insects, amphibians, reptiles and birds), stabilizing soil, recreating linkages and vegetation sequences, enhancing water quality and landscape and providing a sense of territorial identity (MacNamara et al. 2006). The restoration tree planting approach covers a range of species and densities. Dense planting of a large number of primary forest species (Miyawaki 1999), staggered planting of primary forest species and the framework species method (Griscoma and Ashton 2011) have all been implemented with promising results. One constraint to these methods is the high labor and financial inputs required, which limit their application to relatively small-scale projects.

Another method that can effectively switch deforested lands of degraded vegetation to healthier forests is the so-called Assisted Natural Regeneration (or ANR, Ganz and Durst 2003; Shono et al. 2007). The method aims to accelerate, rather than replace, natural successional processes by removing or reducing barriers to natural forest regeneration such as soil degradation, competition with weedy species, and recurring disturbances (e.g., fire, grazing, and wood harvesting). Compared to conventional reforestation methods involving planting of tree seedlings, ANR offers significant cost advantages because it reduces or eliminates the costs associated with propagating, raising and planting.

Priority areas for forest restoration for biodiversity purposes are the reclamation and rehabilitation of habitats of key species, isolated islands, in degraded areas within protected areas or in the buffer zones, corridors between intact fragments, riparian areas, or firebreaks around protected areas. Restoration planting can also be a compensation to remedy or mitigate the adverse impacts of development schemes and projects (new roads, industrial facilities, mines, quarries, dams, airports, and other infrastructure projects).

Forest restoration for biomass production

The production and consumption of forest products continue to grow and are expected to increase in the future because of many factors such as demographic changes, regional economic shifts, environmental policies and regulations, and energy policies encouraging the use of biomass. Global wood demand is projected to double by 2030 (FAO 2009) and to grow up to nearly sixfold by 2060, mainly because of the expected increasing demand for fuelwood (Raunikar et al. 2010). This poses severe concerns about and challenges for the availability of wood on a sustainable basis.

Plantation forestry can help meet the increasing demand for forest products, reducing degradation pressures on natural forests, such as old-growth and high biodiversity forests, and offering scope for mosaic and landscape forest restoration programs (Harrington 1999).

Bioenergy is the largest source of renewable energy, accounting for 50.3 EJ yr^{-1}, or 10.2 % of global total primary energy supply (Chum et al. 2011). More than 80 % of bioenergy is derived from trees and shrubs.[3] Chum et al. (2011) maintain that the potential deployment levels range from 100 to 300 EJ^{-1} by 2050. Beringer et al. (2011) estimate that achieving these levels of production by 2050—under a range of sustainability requirements to safeguard food production, biodiversity and terrestrial carbon storage—would require an average of 10–30 M ha $year^{-1}$ of new plantations of dedicated tree and grasses energy crops.

Plantation forestry remains the most effective approach for restoring large areas of forest cover and producing wood for energy and the industry. While the area of naturally regenerated forest is decreasing, the area of plantation forests is increasing worldwide. Planted forests account for about 7 % of global forest area or about 2 % of global land area, covering around 264 M ha $year^{-1}$, with a steady increase in all regions since 1990 (FAO 2010). They supply 40 % of the total global commercial wood requirements and their productivity is also increasing (FAO 2010). Indeed, intensive practices have increased plantation forest productivity by up to sixfold over the past 40 years relative to unmanaged, naturally regenerated stands (Vance 2010).

Conventional approaches to plantation forestry are seldom capable of delivering the multiple services provided by forests and adequately addressing the needs of all interest groups. In fact, such schemes can result in a reduction in the range, quality and volume of forest goods and services, social and economic dislocations and an increased vulnerability to climate change and other natural perturbations. Intensive management involves the manipulation of site resources, tree genetics and stand structure to optimize tree growth and is most common with industrial ownership. When practiced appropriately and under the guidance of best management practices and forest certification schemes, intensively managed stands and associated forested landscapes provide clean water and wildlife habitat, allow more wood to be grown on a limited land base, and provide economic incentives for landowners to retain their lands as forest. Afforestation and reforestation activities can support biodiversity if they: are done on degraded land or in ecosystems largely composed of invasive alien species; include native tree species; consist of diverse, multi-strata canopies; result in minimal disturbance; consider the invasiveness of non-native species; and are strategically located within the landscape to enhance connectivity.

In many parts of the world significant expansion of forest plantations for bioenergy or wood for industry may be constrained by impediments to investment such as conflicting land claims, insecure land tenure, risk of seizure and ineffective governance. Social issues that commonly occur when natural vegetation is replaced by commercially managed crops may also arise as a result of changes in property and land-use rights.

Yet, increased bio-energy and greater demand for woody feedstocks in the absence of monitoring and good governance of land use carries the risk of significant conflicts with respect to food security, sustainable land use, forest and water resources management, air quality, biodiversity, as well as a risk of low greenhouse gases (GHGs) benefits (Fargione et al. 2008; Cherubini and Hammer Strømman 2011). Increased biomass output for bio-energy can directly impact native biodiversity through conversion of natural ecosystems into bioenergy plantations or through changed forest management. Habitat and biodiversity loss may also occur indirectly, such as when productive land use displaced by energy crops is re-established elsewhere by converting natural ecosystems into croplands or pastures. Conversely, implementation that follows effective sustainability frameworks could mitigate such conflicts and lead to positive outcomes, for example, in rural development, land

[3] Biomass sources include residues from agriculture and forestry, organic wastes, surplus forestry, and energy crops.

amelioration and climate change mitigation, including opportunities to achieve climate change adaptation measures (Valentine et al. 2012).

The capacity of the plantation forestry to work out these problems and to respond to growing demand for forest products is highly dependent on research, where the most important areas, according to Vance et al. (2010) are: advance of understanding and prediction of forest response to intensive management; the integration of eco-physiological parameters of quality, genetics, and the site of the wood in improvement programs of tree species and growth patterns; the quantification of the influence of close and repeated harvesting of biomass productivity and sustainable cultural practices to avoid or mitigate adverse effects; the expansion of forestry research networks to examine the responses in a number of different sites, the extension of the technology transfer and the use of improved genetic material of a wider range of landowners.

Forest restoration to support climate change mitigation and adaptation

Forests have a major role in the global carbon cycle and in climate change as they store a large amount of carbon in vegetation and soils (Ciccarese et al. 2005; Pan et al. 2011). In addition, they exchanges massive amounts of CO_2 and non-CO_2 gases with the atmosphere through natural processes and biotic and abiotic disturbances. Forests act as carbon sources, adding CO_2 and non-CO_2 gases to the atmosphere, when total respiration or oxidation of plants, soil and dead organic matter exceed net primary productivity; they act as carbon sinks, removing CO_2 from the atmosphere, when agricultural land and pastures are abandoned and revert naturally to forests, or are restored to native forests or plantations through new forest planting.

Deforestation and forest degradation in the Tropics and forest re-growth in the temperate zone and parts of the boreal zone are the major factors responsible for emissions and removals, respectively. In the period 2000–2009, deforestation and forest degradation resulted in an estimated release to the atmosphere of about 1.3 GtC, approximately 12 % of total anthropogenic GHG emissions (van der Werf et al. 2009; Reich 2011).

Nabuurs et al. (2007), quoting bottom-up regional studies, proved that forestry mitigation options have the economic potential at costs of up to 100 US\$ tCO_2eq^{-1} to contribute 1.3–4.2 $GtCO_2eq$ $year^{-1}$ (average 2.7 $GtCO_2eq$ $year^{-1}$) in 2030. Global top-down models predict far higher mitigation potentials of 13.8 $GtCO_2eq$ $year^{-1}$ in 2030 at prices less than or equal to 100 US\$ tCO_2eq^{-1}, depending on a multitude of factors, such as changes in other economic sectors, political and social changes, the cost-competitiveness of forestry mitigation versus other sector options in achieving climate mitigation goals and the future impacts of climate change itself on growth and decomposition rates, on the frequency and intensity of natural disturbances, on land-use patterns, and on other ecological processes of forests.

The significance of both emissions and removals and the potential of humans to alter the magnitude of terrestrial carbon stocks and the direction of carbon fluxes explain why the United Nations Framework Convention on Climate Change (UN FCCC) and its Kyoto Protocol (KP) include forestry and land-based activities—dubbed land use, land-use change and forestry (LULUCF)—in the international climate change context.

Specifically, carbon stock changes and non-CO_2 emissions between 2008 and 2012 on new forest areas (afforestation and reforestation) created or deforested since 1990 must be included in the commitments of industrialized countries (KP's Article 3.3). Industrialized countries may also include carbon stock changes and non-CO_2 emissions between 2008 and 2012 on areas subject to forest management, up to a cap that is, in most cases, a fraction of the anticipated uptake; on areas subject to cropland management, grazing land management and revegetation relative to carbon stock changes and associated GHG emissions from these activities in 1990 (Article 3.4).

Since the adoption of the UN FCCC millions of hectares have been afforested or reforested or managed specifically for carbon credits (Neeff et al. 2009). Yet, LULUCF provisions in the KP's first commitment period (2008–2012) restraint the mitigation potential of LULUCF activities (Schlamadinger et al. 2007). Firstly, they do not address deforestation and forest degradation in developing countries, the major source of land-based anthropogenic emissions. In addition, they do not allow countries to make ample use of the options offered by LULUCF activities to sequestering carbon in terrestrial ecosystems and reduce net GHG emissions to fulfill the GHG reductions commitments. At EU scale, for example, a report from the European Environmental Agency (EEA 2011) shows that the projected use of carbon sinks under the KP provisions for the 2008-2012 period by the EU-15 is relatively small: about 40 Mt CO_2 $year^{-1}$ of the commitment period (1.0 % of EU-15 base-year emissions).

What is missing in the actual LULUCF provisions is the whole field of forest restoration, which is indeed probably the most promising option and the bulk of the land requirements for mitigation activities. Forest restoration is an issue in industrialized (Annex I of the KP) as well as in developing countries (non-Annex I), where investments Reducing Emissions from Deforestation and Forest Degradation (REDD) are also considered. Forest restoration as carbon sequestration strategy may be addressed through forest management, but also through REDD projects. In addition forest management can reduce GHG emissions through reduced impact logging and other measures, including improvements in transport. Blaser and Sabogal (2002) estimated that a total area of about 850 M ha of degraded forests in the Tropics would be under some form of mitigation activity. Fully stocked through forest restoration, these forests would sequester 32 GtC (or 117 $GtCO_2eq$) up to 2030.

Natural forest is a biodiversity repository as well as storage and sink of carbon. Concerns are raised on the fact that forest activities with a carbon component may conflict with biodiversity considerations (Canadell and Raupach 2008; Diaz et al. 2009). A main issue both for biodiversity and carbon is that forest ecosystems are naturally dynamic and subject to disturbances and successions. These disturbances (including climate change itself) should be maintained from a biodiversity point to allow survival of species adapted to the different succession stages while the potential carbon release needs to be minimized. To mitigate such threats to forest-based climate mitigation strategies, forest management needs to be improved by promoting greater diversity in tree species and age class and by considering the possible impacts of climate change. Strategic management of forest landscapes for biodiversity as well as for carbon sequestration is discussed, for example, by Diaz et al. (2009).

Upcoming negotiations on a post-2012 agreement and the propensity to move from a narrow approach of the first commitment period of the KP to the so-called full carbon accounting, provide an opportunity to reassess, simplify and enlarge LULUCF mitigation activities and include forest restoration, as a separate activity or integrated in REDD.

Discussion of forests in relation to climate change tends to focus on their role in mitigation (Campbell et al. 2009). However forests also play a significant role in the arena of climate change adaptation[4] (FAO 2011). Forest-based climate change adaptation

[4] According to the Intergovernmental Panel on Climate Change Fourth Assessment Report, adaptation can be defined as the 'adjustment in natural or human systems in response to actual or expected climatic stimuli

involves two related components: strengthening the capacity of forests to deal with climate change, and using forests to help society strengthen resilience to climate change and support livelihood strategies. Addressing the threats to forests, maintaining natural forests intact and selecting appropriate mixes of species for forest restoration is likely to enhance their resilience to climate change, supporting their contribution to both mitigation and societal adaptation (Innes et al. 2009). Forest-based adaptation activities include: monitoring and maintaining forest health, vitality and diversity; implementing integrated forest fire management; enhancing landscape connectivity and reducing forest fragmentation; monitoring and removing invasive species and addressing pest and disease threats; undertaking forest restoration and rehabilitation, particularly on slopes; implementing reduced-impact logging; selecting appropriate species for use in planted forests.

The scientific literature on the role of forest restoration in climate change adaptation is quite limited, but there is a growing body of evidence suggesting that forest-based (and more in general ecosystem-based) climate change adaptation policies and actions can be more cost-effective than those that tend to rely on technological and engineering adaptation measures (Roberts et al. 2009b). Adaptation strategies that aim to enhance the resilience of forest ecosystems can be particularly important for vulnerable areas and societies, especially in front of abrupt climate changes, in areas where adaptation capacity is low and are directly dependent upon their natural resources (Seppäla et al. 2009; Kolström et al. 2011). Forest restoration for climate change purposes can be incorporated into wider adaptation planning as a component of, rather than an alternative to, structural measures. Specific forest restoration responses to climate change adaptation might comprise: reducing the impact of stresses that can exacerbate the effects of climate change (wildfire, insects, air pollution, etc.); intensifying measures to prevent and control the expansion of invasive species; avoid or reducing obstructions to species migration; helping forests regenerate after large-scale disturbances; taking historical climate changes into account in planning forest management; considering the future impacts of climate change in selecting genotypes and planting stock types, and choosing the proper planting methods.

Tools of emerging importance for supporting forest restoration

Looking ahead there are numerous important factors that will influence the development of forest restoration policies. Among them we think that three tools will be of increasing relevance in shaping the future of forest restoration: the availability of planting stock, the development and use of standard and certification tools and forest financing of restoration investments.

Planting stock production

Depending on the objectives of the forest restoration project, there are a number of strategic factors that land managers should consider, including site preparation, land

Footnote 4 continued
or their effects, which moderates harm or exploits beneficial opportunities'. Adaptation strategies aim to reduce the vulnerability or enhance resilience in response to these 'actual or expected changes' and associated extreme events, and will be required in both human and ecological systems (Adger et al. 2007).

contouring, fertilization, choice of species, plant establishment, early maintenance, and management procedures. A key factor for successful forest restoration project is matching planting stock type and quality to requirements.

In general, even though important advances have been made in certain countries and nurseries, it is recognized that standards of production technology for all types of forest nursery stock have to be raised.

There is a need to improve the biological, physiological and genetic quality of forest planting stock. In addition, a lack of capital investment in technical developments has created a situation where cost efficiency in the production of forest nursery plants is low and nurseries are often burdened with environmental problems, including the excessive use of water, fertilizers, pesticides and energy.

Furthermore, as plantation forestry expands into a much broader range of species, e.g. broadleaved and wildlife-crop species, native species and local provenances, it will be necessary for plant growers to adapt to changing objectives. The often low standards of forest nursery technology have also contributed to a situation where improvements in seed quality and the possibilities to produce forest planting stock based on cuttings or tissue culture have been little utilized in practice.

To more effectively support forest restoration, nursery technology for producing forest planting stock therefore has to be improved within important areas such as mass production methods, genetic gains and reducing environmental impact. This also refers to future improvements in plant quality and the way to assess this quality (Mattsson 1997; Grossnickle 2005). In this regard, the introduction in many countries of the containerized forest planting stock production has potential to improve these areas compared to traditional bare-root production.

Nevertheless, greenhouse based containerized production can have disadvantages under many aspects, like environmental impact and energy consumption. New technologies therefore have to be introduced for more effectively supporting forest plantations in the future. This refers first of all to the above-mentioned areas of mass production methods of forest reproductive material, genetic gains and reducing environmental impact.

In the future, plant biotechnology will be a very strong tool for supporting forest restoration. In this respect an interesting strategy is the possibility to produce future forest plants by pre-cultivation in growth chambers followed by automatic transplanting to any optional container system, without using traditional greenhouses (Mattsson et al. 2010).

To further improve future genetic gains and mass propagation techniques of forest reproductive material the high level of environmental control in the growth chamber also opens up possibilities to produce forest planting stock from somatic embryogenesis, where individual cultured cells or small groups of cells undergo development resembling that of the zygotic embryo (Haines 1994; Hannrup et al. 2009; Weng et al. 2012).

Transnational co-operation is important for improving technology and standards, as well as co-operation between nurseries and research institutions. New technologies, including improved forms of direct sowing (Wang et al. 2011), better ways of introducing mycorrhizae or nitrogen-fixing bacteria, or more robust methods of matching species with sites, can help reduce nursery and establishment costs.

New market conditions may also help; a market for high-value native timber or fruit and medicinal species (Ræbild et al. 2011) could reverse the trend towards large monoculture plantations of exotic species. Compact germination facilities, combined with innovative transplanting techniques, should be preferred to expensive and high input-demanding and habitually unsustainable conventional greenhouse techniques.

Standard development and forest certification

Forest certification is a market-based, non-regulatory, forest conservation tool that recognizes and promotes environmentally responsible forestry (Holvoet and Muys 2004). The basic component of any certification activity is the definition of a standard, a set of unambiguous, well-defined, largely accepted rules to be used consistently as good principles, practices or guidelines for managing a system (Hickey et al. 2006). This is a process of fundamental importance for defining how to restore and adequately manage a forest unit. Stakeholders' participation in the process of standard definition and their consultation during the certification are essential steps in giving transparency and credibility to the process of forest restoration (Dare et al. 2011). Stakeholders' involvement allows the adaptation to the different social and environmental local conditions of the general principles and criteria for the restoration activities defined in the standards (Barrow et al. 2002; De Pourc et al. 2009).

In general terms the goal of the standard definition and certification processes is to move away from destructive techniques like large-scale clear-cutting, logging in endangered and old-growth forests and destruction of natural forests and to verify that all forest practices, from forest planting stock production to wood harvesting, sustain wildlife, soil, water and other environmental values, and are socially and economically sustainable over a long period of time. To ensure that these goals are met, an independent third party evaluates a forest according to a set of standards established by a specific forest certifications system.

There are several standards defined and implemented in forest restoration activities, representing somewhat different approaches to defining management practices to improve the status of forest ecosystems. According to TNC (2011) at this time there are nearly 60 forest certification systems operating around the world, most of them designed for country-level application, This figure gives a good picture of the complexity of defining guidelines to improve forest management, the different perspectives that can be assumed in dealing with this issue, the lack of coordination among the different agencies and, finally, is providing an indirect indicator that we are still in an initial phase of standard definition, the phase of development of many independent initiatives before few, more reliable and practical, standards will emerge. The Forest Stewardship Council (FSC) and the Programme for the Endorsement of Forest Certification (PEFC) schemes are by far the most implemented and successful in terms of numbers certified and area covered (see Table 1). FSC in particular has developed a scheme currently involving 12 African, 11 Asian and 17 Latin American countries with more than 25 M ha of certified forests (for PEFC these data are respectively: 0, 1 and 2, with 7.7 M ha certified) (Fig. 2).

From the data presented in Table 1 the main problem connected to the use of standards and certification systems appears clear: the area where well managed forest initiatives are more needed (i.e. the Amazon region in Latin America, the Congo basin countries in central Africa and the South-East Asian region) are those lagging behind in forest certification activities. This is one of the basic reasons for the implementation of a phased approach to forest restoration and, in general, to the improvement of forest management practices starting from low requirements (e.g. legality verification with a check that local regulations related to proper forest management practices are respected) and moving towards more advanced standards (Nussbaum et al. 2003) in line with the stepwise approach as defined in Fig. 1.

Funding

Until relatively recently tree planting, also as a form of land restoration, has been strongly subsidized by government and development agencies. For example, in many parts of Latin

Table 1 Certified forest area under the FSC and PEFC schemes and potential supply of roundwood from certified resources, 2009-2011

	Total forest area (M ha)	Certified forest area (M ha)			Certified forest area (%)			Estimated volume of timber from certified forest (M m^3)			Estimated volume of timber from certified forest (%)		
		2009	2010	2011	2009	2010	2011	2009	2010	2011	2009	2010	2011
North America	614.2	180.3	199.8	201.0	29.4	32.6	32.7	175.6	194.6	201.0	9.8	10.9	11.3
Western Europe	168.1	82.2	85.0	85.3	46.5	51.2	50.8	238.1	261.7	227.5	13.3	14.6	12.8
CIS	836.9	25.2	29.9	44.3	3.0	3.6	5.3	4.9	5.8	8.5	0.3	0.3	0.5
Oceania	191.4	10.3	11.6	12.3	5.0	5.6	6.4	2.5	2.8	3.5	0.1	0.2	0.2
Africa	674.4	5.6	7.3	7.6	0.9	1.2	1.1	0.6	0.8	0.8	0.0	0.0	0.0
Latin America	955.6	14.6	14.4	16.1	2.1	1.6	1.7	3.6	2.7	3.2	0.2	0.1	0.2
Asia	592.5	3.0	8.6	8.1	1.4	1.5	1.4	3.1	3.4	2.8	0.2	0.2	0.2
World total	4033.1	321.2	356.7	374.9	8.2	9.0	9.3	428.4	471.8	447.3	24.0	26.4	25.3

Source: UNECE/FAO (2011)

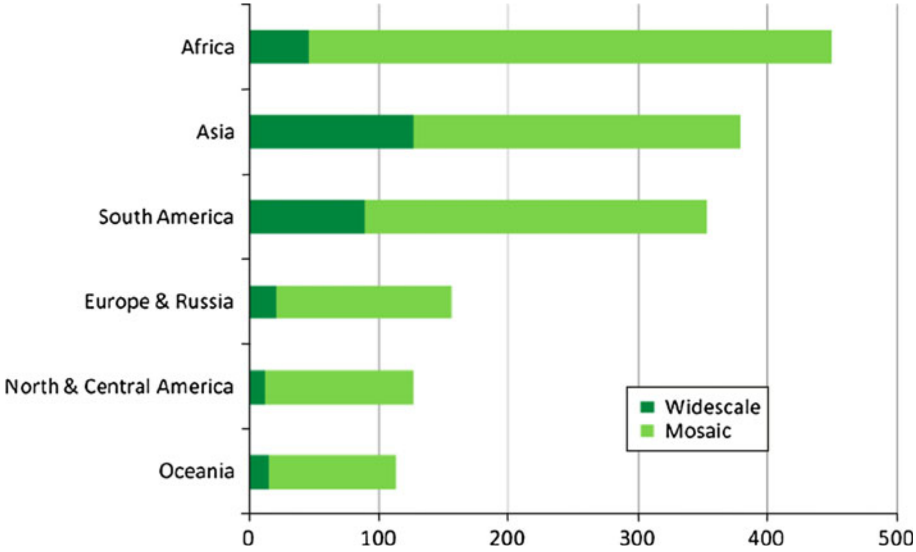

Fig. 2 Opportunities wide-scale and mosaic for forest restoration per continent (million hectares). *Source:* Laestadius et al. (2011)

America, Oceania and Asia, plantation programs paid more than 75 % of the establishment costs with additional allowances made for land, maintenance and many other costs (Brown 2000). According to one estimate, around US$2 billion were granted each year in subsidies to industrial forest plantations: this sum is four times greater than the annual development assistance given to forest conservation (White et al. 2006).

In the last years the role of subsidies has been integrated with direct investments from large industrial and financial institutions attracted by new business opportunities in the forestry sector. Critics observed that both public policies and private financial institutions have favored big companies and encouraged large-scale planting of monocultures, with a limited involvement of any stakeholders other than industry and government (Bass et al. 1996). As a matter of fact, small and medium-sized enterprises have normally been excluded from access to financial support for forest restoration projects. Thus, when external finance is available, it is normally from the informal or non-institutional credit suppliers, and many enterprises, although being too small to benefit from significant access to capital and other resources, still come under the same rules as the large companies when delivering their products to the market. However, with the increased role of microfinance, small-scale investments are developing, benefiting forest-based enterprises and communities, especially in those cases where basic requirements related to food security are satisfied: most small scale enterprises operate their forest-based activities jointly with other processing, service or agricultural activities, so they seldom occur as separate enterprises (FAO 2005).

In restoration investments the traditional wood production function still remains important, but is being increasingly complemented (and sometimes overtaken) by a wider recognition of the economic role of Non-Timber Forest Products (NTFPs) and of the functions based on ecosystem services like recreation, landscape, biodiversity and, above all, carbon sequestration. Carbon offsetting forest projects have received high global attention with the establishment of Clean Development Mechanism and Joint

Implementation projects within the framework of the KP. Moreover, the development of REDD projects will undoubtedly widen the interest of potential investors in the forestry sector. REDD projects represent the most advanced form of investment, being aimed at preventing deforestation and forest degradation and enhancing active protection and amelioration of already existing forests. Governments should encourage financial opportunities that allow the provision of credit, leases, concessions and other securities, clarifying the forest land tenure regime (Kanowski et al. 2011) and assuring an equitable allocation of carbon rights.

REDD investments normally represent the most efficient forest activities in terms of carbon storage (i.e. the lowest unit costs of carbon sequestered); at the same time these investments, if carried out according to the best practices implemented in the carbon quota market, assure important co-benefits (soil and biodiversity protection, water cycle regulation, coverage of the local population's basic needs for wood, etc.). Co-benefit provision is and essential component of the success of REDD initiatives: only considering the full range of needs of the local population and involving in an active participation forest investments' direct stakeholders it is possible to implement successful REDD projects. The active and informed participation by the local actors represents a clear advancement with respect to the old approaches adopted in the Clean Development Mechanism and Joint Implementation projects.

A total of 30.1 MtCO_2eq were contracted across the primary and secondary markets in 2010[5] (Peters-Stanley et al. 2011). The estimated total value of these transactions was US$178 million. The historical scale of the forest carbon markets climbed to 75 MtCO_2eq, valued at an estimated US$432 million with projects impacting more than 7.9 M ha in 49 countries from every region of the world. The average price for offsets across the primary forest carbon markets rose from US$3.8 t$CO_2$eq in 2008^{-1}, to US$4.5 tCO_2eq^{-1} in 2009, and up to US$5.5 t$CO_2$eq^{-1} in 2010. The 2010 surge in the forest carbon market was fuelled to a great extent by contracting from large REDD projects, which supplied 19.5 MtCO_2eq out of the total 29.0 MtCO_2eq contracted in the primary market.

Two additional forms of REDD have also been discussed: REDD+ and REDD++. REDD+ includes the role of conservation, sustainable management of forests and increasing of carbon stocks. This would mean that a country could generate carbon credits in managed forests as well as from reforesting a degraded area. REDD++ (also known as Reducing Emissions from All Land Uses or REALU) includes all land uses that reduce deforestation, creating a landscape-based approach for reducing GHG emissions. Some REDD projects are already underway, but today the credits can only be sold on the voluntary, not regulatory markets. If REDD(+/++) is included in a post-Kyoto agreement, carbon credits generated will be permitted on the regulatory markets.

Although the impacts and benefits of REDD on biodiversity and ecosystem services will depend on the exact mechanism decided upon at the UNFCCC negotiations, REDD is likely to have net biodiversity benefits through tropical forest conservation, as habitat conversion is the major cause of biodiversity loss (Sala et al. 2000; Ravindranath 2007). The potential for generation of finance at levels of US$1–10 billion is also at a scale not previously seen for forest conservation (Peters-Stanley et al. 2011). Even though forest restoration is widely used to combat environmental degradation, very few studies have assessed the cost-effectiveness of this approach. The costs of forest restoration can be sizeable, especially in terms of opportunity costs related to alternative use of the land.

[5] The primary market refers to original transactions of credits directly from a project; the secondary market refers to all ensuing transactions.

Increased prices of farm commodities and, in general, the instability of the market process is creating an unfavorable climate for investing in forest restoration. There is a need to identify where restoration projects are most likely to produce net benefits for conservation and human well-being, so that efforts can be effectively targeted. The values of specific ecosystem services need to be mapped, supported by the use of a spatially explicit model of forest dynamics. Even in places where forest restoration is expected to be cost-effective, financial support will need to be provided for restoration actions. Potential approaches include improved markets and payment schemes for ecosystem services (Wunder 2007; Engel et al. 2008).

Final remarks

While there has been significant progress in conservation during the 20th century, as shown by the establishment of a global protected area network, the twenty-first century will be a time of forest restoration. In this respect, Wangari Maathai, awarded the 2004 Nobel Peace Prize, founder of The Green Belt Movement, which engages communities in forming tree nurseries and planting seedlings on public lands, degraded forest areas and private farms—is the vanguard of this new wave.

Despite significant progress in science and in policies implementation, forest restoration is still a highly complex and multi-faceted activity and ongoing initiatives are decidedly inadequate to balance the process of deforestation and forest degradation. The forestry sector can contribute to restoration efforts through the conservation and sustainable use of forests, but integration of different disciplines and sectors is needed, particularly agriculture, soil science, energy, economics and sociology, to formulate sustainable land-use policies and planning processes. Public participation, involving landowners as well as the general public, will be a key factor in the forest restoration planning process. The scope of forest restoration should always be defined with the support of local people as this is a prerequisite for any successful investment. There are numerous examples around the world showing that forest restoration programs that engage communities and offer alternative livelihoods can be remarkably successful (see, for example, Hall and Romijn 2010). Traditional practices that have been working for generations are often still viable today, instead of top-down, government imposed forest protection programs that violate human rights and ultimately result in further deforestation and degradation.

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