Restoration concepts for temperate and boreal forests of North America and Western Europe

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ABSTRACT - Throughout the boreal and temperate zones, forest restoration efforts attempt to counteract negative effects of conversion to other land use (afforestation and remediation) and disturbance and stress on existing forests (rehabilitation). Appropriate silvicultural practices can be designed for any forest restoration objective. Most common objectives include timber, wildlife habitat for game species, or aesthetics. Increasingly other objectives are considered, including carbon sequestration, biological diversity, non-game mammals and birds, endangered animals and plants, protection of water quality and aquatic resources, and recreation. Plantation forestry remains the most effective approach to restoration of forest cover to large areas, and recent trends toward more complex plantations are explored. Rehabilitation of degraded forests increasingly relies on re-establishing natural disturbance regimes and emphasizes "close-to-nature" approaches to regeneration and stand management. The objectives of this paper are to clarify concepts of forest restoration and to present examples of restoration activities in temperate and boreal forests of North America and Western Europe.

KEY WORDS - afforestation, biodiversity, disturbance, reforestation, rehabilitation

Forest cover in populated areas of the world is the reserve, land left over after clearing for agriculture and urban uses. Forest cover has declined globally, from an estimated 6 billion ha of original forest extent to the present 3.87 billion ha (KRISHNASWAMY & HANSON, 1999; FAO, 2001). The greatest loss in cover has occurred in Asia-Pacific, Africa, and Europe (all more than 60 percent loss of forest cover). Losses in North America are relatively low (25 percent), while Latin America (Central and South) has lost over 30 percent of the original forest cover (Figure 1). Forest cover is increasing in North America and Western Europe as a result of shifts from marginal agriculture. Many forests experience disturbances and stresses that negatively affect ecological stability (LARSEN, 1995) or maintain the forest in a condition that can be seen as unsustainable (KRISHNASWAMY & HANSON, 1999). Global assessments of forest condition identify the factors causing loss of forest cover and degradation of remaining forests, including changing land use, increasing demand for fibre, and exogenous

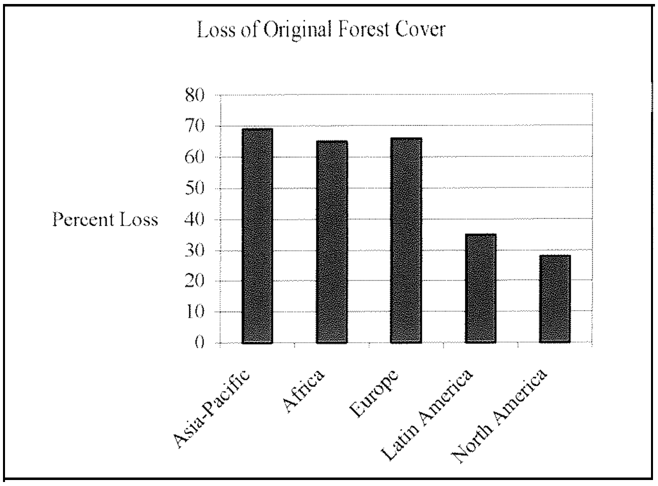

FIGURE 1 Loss of original forest cover, from 6 billion ha to 3.45 billion ha. (Source: KRISHNASWAMY & HANSON, 1999).

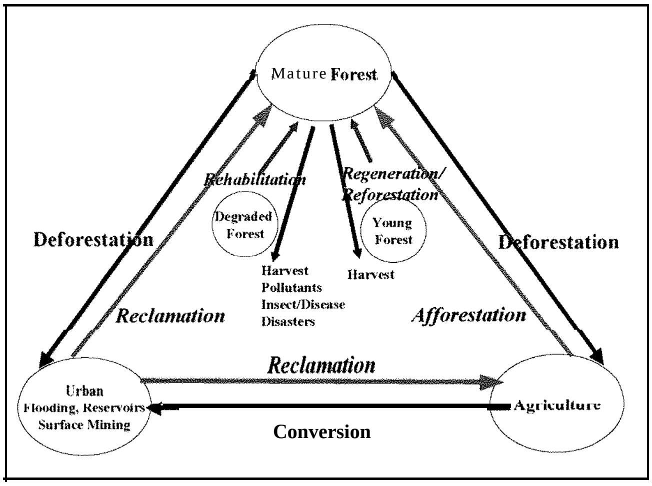

FIGURE 2 The terminology of forest restoration is best viewed in terms of land use as well as land cover change.

stresses such as global climate change and loss of biodiversity (KRISHNASWAMY & HANSON, 1999; WRI, 2000). Market forces, changing trade policies, agricultural reforms, and conservation efforts are driving conversion of cleared land back to trees in many countries. Nevertheless, the area in forest plantations is only 187 million ha, although increasing (KANOWSKI, 1997; FAO, 2001). Throughout the boreal and temperate zones, forest restoration efforts attempt to counteract negative trends. Plantation forestry remains the most effective approach to restoration of forest cover to large areas through afforestation, and recent trends point toward more complex plantations (KANOWSKI, 1997). Rehabilitation of degraded forests increasingly relies on re-establishing natural disturbance regimes and emphasises "close-to-nature" approaches to regeneration and stand management. The objectives of this paper are to clarify concepts of forest restoration and to present examples of restoration activities in temperate and boreal forests of North America and Western Europe.

TABLE 1
Comparison of terms commonly used to describe forest cover condition

Terms used in this paper	WESTHOFF (1993)	FRENKEL (1970) in GOUDIE (1986)	Extent of human influence
Idealized	Natural	Natural	No human disturbance
Natural	Subnatural	Degraded	Sporadic but incomplete disturbance
Managed, Naturally Regenerated	S&natural or Semi-natural	Degraded	Vegetation structure significantly altered
Managed, Artificially Regenerated	Semi-natural or cultivated	Cultivated	Constant disturbance accompanied by the intentional introduction of plants
Degraded	Seminatural	Ruderal	Sustained disturbance and altered structure but no introduction of plants
Cultivated	Cultural	Cultivated	Constant disturbance accompanied by the intentional introduction of plants
Artificial	Cultural	Artificial	Introduced plants and altered climate and soil

TERMIAJOLOGY

What constitutes restoration can be confusing when the term is used indiscriminately. Equally confusing is the use of terms such as natural, degraded, and semi-natural to describe forest cover conditions (Table 1). We find it helpful to consider the dynamic relationship between processes degrading and restoring forests in light of two dimensions, changes in land cover, land use, or both. If we consider the undisturbed, idealised natural mature forest (*sensu* WESTHOFF, 1983; GOUDIE, 1986) as a starting point (Figure 2), then conversions to other land use such as agriculture (cultural landscape) or pasture (semi-natural landscape) are through deforestation. Relatively frequent but moderate disturbance (plowing, herbicides, grazing) maintains the non-forest cover.

Similarly, a change in both land cover and land use occurs when forests are converted to urban areas, flooded by dams, or removed along with topsoil/overburden in mining and extractive activities. Such drastic conversion usually involves severe disturbance and the non-forest cover is maintained more or less permanently by structures, more so than by cultural activities (Figure 2).

Even-aged harvesting of mature forest in a sustainable manner is a change of land cover but not land use. A new, young forest will result from natural regeneration or by reforestation (i.e., planting trees in a cutover). Unsustainable harvesting without securing adequate regeneration, such as high-grading (as is true for many diameter-limit harvests or selective harvests), may degrade stand structure or diversity. Pollutant loading, outbreaks of insects or diseases (especially exotic species), fire suppression and disruption of natural fire regimes, invasion by aggressive exotic plants, or disasters such as hurricanes or wildfires can degrade forest stands and change attributes of land cover, but do not change land use. In all these instances, intervention to restore species diversity or stand structure can be termed rehabilitation (Figure 2).

Given sufficient time and the cessation of disturbances, agricultural land as well as urbanised land will revert to forest, if that is the potential natural vegetation as determined by climate. Abandonment and reversion to forests, although secondary, semi-natural, or degraded forest types, will be on a time scale of a few decades to centuries. Human intervention, however, can accelerate the reversion process. Afforestation of agricultural land may consist of simply planting trees, although tech niques that are more intensive are available. Reclamation of urbanised land usually requires extensive modification. This may include stabilisation of spoil banks or removal of water control structures, followed by tree planting. Because severe site degradation may limit the possibilities for reclamation, this is sometimes called replacement (BRADSHAW, 1997).

Generally, restoration connotes some transition from a degraded state to a former "natural" condition. All the restorative activities described (afforestation, reclamation, and rehabilitation) have been called forest restoration, although to the purist none would qualify as true restoration (BRADSHAW, 1997; HARRINGTON, 1999; but see VAN DIGGELEN et ***al.,*** 2001; WAGNER et al., 2000). In the narrowest sense, restoration requires a return to an ideal natural ecosystem with the same species diversity, composition, and structure as occurred before human intervention (BRADSHAW, 1997) and as such is probably impossible to attain (CAIRNS, 1986). We adopt an alternative approach and use the term forest restoration broadly to describe situations where forest land use and land cover are restored (afforestation or reclamation), as well as instances when an existing forest is rehabilitated (no change in land cover) such that structure or species composition are modified.

The ***Disturbance Model***

We view restoration as an element in a disturbance continuum of forest condition (WALKER & BOYER, 1993; STANTURF et ***al.,*** 2001). The state of the forest ecosystem ranges from natural to degraded. Levels of state factors such as biomass or biodiversity in forests subjected to human disturbance follow a degradation trajectory. At any point along the trajectory, recovery can be initiated once the stress or disturbance abates. The recovery pattern is divided into three levels of intervention: self-renewal, rehabilitation, or restoration. In the self-renewal phase, the forest can return to its original state, more or less, without human intervention in a relatively short time. Natural regeneration of forests managed for timber is an example of reliance on self-renewal processes. Plantations are within the scope of self-renewal, where intervention (reforestation) is undertaken to control species and stocking. At intermediate levels of disturbance, it will take longer to recover naturally but the time required may be shortened by human intervention. One example might be rehabilitation by reforestation of forests consumed by wildfire. At their most degraded state, forests may recover naturally after a century or more, but in decades by human intervention.

The forest that results from restoration or rehabilitation may never recover to the original state for all functions (see HARRINGTON, 1999 for a graphical representation of possible trajectories). Our usage of restoration differs from the otherwise very satisfactory terminology of BRADSHAW (1997), as we do not limit restoration to his "ideal state" endpoint. We accept as restoration any endpoint within the natural range of managed forests where self-renewal processes operate. Thus, restoration to an early seral stage would be acceptable for a forest that is likely to attain a more complex structure through typical stand dynamics. How quickly the forest moves to the self-renewal phase is a function of forest type, site resources, and the amount invested to overcome the degraded conditions. This model offers a broader context for restoration on private land and landowners with management objectives other than preservation are able to contribute to ecosystem restoration (STANTURF *et al.*, 1998a; STANTURF *et al.*, 2001).

Common Challenges

Appropriate silvicultural practices can be designed for any forest restoration objective. Most common objectives include timber, wildlife habitat for game species, or aesthetics. Increasingly other objectives are considered, including carbon sequestration, biological diversity, non-game mammals and birds, endangered animals and plants, protection of water quality and aquatic resources, and recreation. Different outputs may be sought for each objective. A landowner managing for the timber, for example, must decide whether to emphasise sawlogs and veneer logs, or pulpwood. Appropriate management, in particular rotation length, will vary according to the desired product. Another landowner managing for wildlife must decide which species or species group to favour as species have different habitat requirements, from mature closed forests to early successional seres. Choosing appropriate silvicultural techniques presents the challenge of managing for apparently incompatible objectives. Slight modifications, however, may have negligible impact on outcomes or outputs for one objective but major effects on another objective. Clarity of objectives, combined with an adequate understanding of feasible goals developed from information on current conditions, allows the silviculturist to choose a silvicultural system that will maximise satisfaction of

TABLE 2
Examples of forest restoration efforts in various parts of the world

Type of restoration	Region	Former condition	Restored condition
Afforestation	Lower Mississippi Alluvial Valley, USA[1]	Agriculture	Bottomland hardwoods
Afforestation	Nordic Countries[2]	Agriculture	Hardwoods, sometimes Norway spruce
Afforestation	Tropical Countries[3]	Agriculture	Exotic and native hardwoods
Afforestation	Venezuela	Cerrado	Caribbean pine
Afforestation	Iceland[4]	Eroded grazing land	Birch, lupine/birch
Reclamation	Everywhere	Mined land	Various
Reclamation	Asia[5]	Shrimp ponds	Mangrove
Reclamation	Ireland	Mined peatland	Sitka spruce, various hardwoods
Reclamation	India[6]	Saline and sodic soils	Eucalyptus spp., *Acacia* spp., other native spp.
Rehabilitation	Southeastern US[7]	Loblolly pine plantations	Longleaf pine woodlands
Rehabilitation	Interior highlands, Southeastern US	Shortleaf pine/hardwood forests	Shortleaf pine/bluestem grass woodlands
Rehabilitation	Northern Europe[8]	Norway spruce plantations	Oak or beech woodlands
Rehabilitation	England, Scotland, Ireland, Germany[9]	Spruce or pine plantations	Mixed woodlands
Rehabilitation	Southwestern US[10]	Dense Ponderosa pine forests	Ponderosa pine woodlands

[1] ALLEN, 1990, 1997; GARDINER *et al.*, 2002; HAMEL et al., 2002; NEWLING, 1990; SAVAGE *et al.*, 1989; SCHWEITZER et *al.*, 1997; SHARITZ, 1992; STANTURF *et al.*, 1998a, b; STANTURF et al., 2000; STANTURF et al., 2001; TWEDT & PORTWOOD, 1997; TWEDT *et al.*, 1999.
[2] MADSEN *et al.*, 2002.
[3] ASHTON *et al.*, 1997; CHAPMAN & CHAPMAN, 1999; FISHER, 1995; ISLAM *et al.*, 1999; KNOWLES & PARROTTA, 1995; LAMB & TOMLINSON, 1994; OHTA, 1990; OTSMANO, 2000; PARROTTA, 1992; PARROTTA *et al.*, 1997.
[4] MADSEN *et al.*, 2002; SIGURDSSON, 1977.
[5] BURBRIDGE & HELLIN, 2002.
[6] WHALLEY, 1988.
[7] WALKER & BOYER, 1993.
[8] MADSEN et *al.*, 2002.
[9] HASENAUER, 2000.
[10] COVINGTON *et al.*, 1997

multiple objectives although no single objective will be optimised (VAN DIGGELEN et *al.,* 2001). Nevertheless, the chosen system may be adjusted to minimise impacts on other ecosystem functions, and many complementary benefits will be produced in addition to the primary benefit.

There are many examples of forest restoration that can be classified as afforestation, reclamation, or rehabilitation (Table 2). The challenges of forest restoration in different countries are surprisingly similar (KANOWSKI, 1997): overcoming site degradation or limitations; prescribing appropriate species; and applying cost-effective establishment methods. Several of these efforts are discussed in more detail below. Three steps are key to planning forest restoration: (1) understanding current conditions (the given conditions, a starting point); (2) clarifying objectives and identifying an appropriate goal (the desired future condition); and (3) defining feasible actions that will move toward the desired condition. In most cases, the silviculturist has several options for intervening, as there are multiple silvicultural pathways toward the desired future condition. The choice of intervention affects the financial cost, the nature of intermediate conditions, and the time it takes to achieve the desired condition. It is imperative that silvicultural decisions are made with clear objectives in mind and with an understanding of the probability that a particular intervention will be successful.

AFFORESTATION

Forest restoration on land cleared for agriculture is widespread, often termed afforestation. Land became available because it was economically marginal for continued agriculture (due to infertility, frequent flooding, or other site limitations) or because of changes in social policy (for example, government incentives). It should be self-evident that the first step in restoring a forest is to establish trees as the dominant vegetation. Although this is not full restoration in the sense of BRADSHAW (1997), it is a necessary step and far from a trivial accomplishment (STANTURF et *al.*, 1998b; STANTURF et al., 2001). Nevertheless, many people object to traditional plantations on the grounds of aesthetics or lack of stand and landscape diversity. The correct ecological comparison, however, is between forest plantations and continued agriculture, rather than between plantations and a mature natural forest (STANTURF *et* al., 2001). All forest alternatives provide at least some vertical structure, increased plant diversity, and some wildlife and environmental benefits (MITSCH & JØRGENSON, 1989; VAN DIGGELEN *et* al., 2001).

Afforestation of Bottomland Hardwoods in the Southern U.S.

The Lower Mississippi Alluvial Valley (LMAV) has undergone the most widespread loss of bottomland hardwood forests in the United States (MACDONALD et al., 1979; STANTURF et al., 2000a). Besides the extensive loss of forest cover by clearing for agriculture, regional and local hydrologic cycles were drastically changed by flood control projects that separated the Mississippi River and its tributaries from their floodplains. Deforestation and drainage resulted in a loss of critical wildlife and fish habitat, increased sediment loads, and reduced floodwater retention. Restoring these floodplain forests is the subject of considerable interest and activity (SHARITZ, 1992; KING & KEELAND, 1999; STANTURF et *al.*, 2000a).

Restoration on the LMAV is driven primarily by actions on federal land and by federal incentive programs, although states have their projects on public land (NEWLING, 1990; SAVAGE et *al.*, 1989). Current plans for restoration on public and private land suggest that as many as 200,000 ha could be restored in the LMAV over the next decade (STANTURF et al., 2000a).

The dominant goal of all restoration programs in the LMAV, whether on public or private land, has been to create wildlife habitat and improve or protect surface water quality (KING & KEELAND, 1999). In practice, this means afforestation of small areas (usually no more than 100 ha) within a matrix of active agriculture. While we know how to afforest many sites (STANTURF et *al.*, 1998b), recent experience illustrates the difficulty of applying this knowledge broadly (STANTURF *et al.*, 2001).

Afforestation of bottomland hardwoods is a process where something can go wrong at any of several steps (GARDINER *et al.*, 2002). The most critical step is properly matching species and provenance to site, particularly to hydroperiod. Few species can tolerate continuous flooding. Even those few that can withstand extended soil saturation and root anoxia cannot tolerate submersion of all their leaves. Most flooding tolerant species can be planted on drier sites but not the reverse (STANTURF et *al.*, 1998a). Soil physical conditions, root aeration, nutrient availability, and moisture availability are other important site factors to consider.

Restoration on public land in the LMAV follows an extensive strategy of low cost per ha planting or direct seeding of heavy-seeded species of value to wildlife such as oaks. It relies on native species, planted mostly in single-species blocks within plantations containing three or more species. Choice of species to plant is guided by tolerance to flooding and soil characteristics. Hard mast producers such as the oaks (*Quercus* spp.) are favoured for their wildlife value and because they are the most difficult to obtain by natural processes. Oaks are planted on wide spacing (3.45 m by 3.45 m) as 1-O bareroot seedlings or direct-seeded as acorns on 1 m by 3.45 m spacing (to account for lower survival). Wind and water are relied upon to disperse light-seeded species such as ash (*Fraxinus* spp.), elm (*Ulmus* spp.), sycamore (***Platanus occidentalis*** L.), sweetgum (*Liquidambar styraciflua* L.), and maple (*Acer* spp.) (STANTURF et al., 1998b). The light-seeded species are needed for richness, stocking, and to create forested conditions (HAYNES *et* al., 1995).

The extensive strategy that predominates on public land has shaped the federal programs aimed at private land. The appropriateness of this strategy for private land has been questioned from several perspectives (STANTURF ***et*** al., 2001). First, wind and water dispersal of light seeded species to these small, isolated tracts is reliable only when natural seed sources are within 100 m (ALLEN, 1990, 1997). Failure to fill between the planted oaks means incomplete site occupancy by trees, lower species richness, and longer time needed to provide structural diversity. Second, more intensive strategies are available that provide wildlife benefits and restore forested wetland functions quicker. Many wildlife species at risk are those that require forests of complex structure. Extensive plantings, even if fully successful, require 60 years or more to attain a desirable structure (KING & KEELAND, 1999; TWEDT et ***al.,*** 1999). Third, the stocking that results from successful restoration under federal cost-share programs (i.e., 309 stems per ha at age 3) will not be sufficient to support commercial timber production. The lack of merchantable volume in these understocked stands not only will constrain timber management but also will limit stand manipulation for wildlife habitat, aesthetics, or forest health. Fourth, interest is increasing in afforestation to obtain carbon credits under the Kyoto Protocol (SCHLAMADINGER & MARLAND, 2000) but the ability to sequester carbon will be significantly lower in these understocked stands.

Strategies that are more intensive for quickly establishing closed canopy forests are available, although at higher initial costs than the extensive plantings. For example, a manager can establish a closed canopy forest 10 m or taller in three years, using fast growing native species such as Eastern cottonwood (*Populus deltoides* var. *deltoides* (Bartr.) ex Marsh.). One or two years after planting, this cottonwood nurse crop is established and slower growing species of oak can be interplanted between every other row. Later, the manager may intervene to shape stand structure and composition of the stand as it develops. Possibilities include harvesting the cottonwood at age 10, in the winter to maximise sprout regrowth and afford the manager a second coppice rotation of the cottonwood, or in the summer to minimise cottonwood sprouting and release the oak seedlings (**SCHWEITZER** et ***al.,*** 1997). The full benefits of this interplanting technique are being investigated but observations in operational plantings indicate that significant wildlife benefits are realised within five years (TWEDT & PORTWOOD, 1997).

Afforestation of **Broadleaves in the Nordic Countries**

The term "forest restoration" covers very different silvicultural challenges in the Nordic countries (Table 2). In Iceland, afforestation is attempted on barren land degraded by overgrazing. Special effort is made to restore birch (*Betula* spp.) woodlands, which covered more than 25 percent of the land area at the time of settlement in the 10th Century (SIGURDSSON, 1977; ARADOTTIR & **ARNALDS,** 2001). Contrary to the Icelandic situation, afforestation efforts in other Nordic countries and Estonia occurs on fertile farmland (Table 3). Aims of afforestation are rather different within and between the countries. In Finland, Sweden, and Norway the expected extent of afforestation is rather limited and serves mainly as an alternative land use to small scale

TABLE 3
Forestland and woodlands in the Nordic countries and Estonia. (Source: MADSEN *et al*, 2002)

Country	Forestland and woodlands, 1,000 km'	Forestland, % of total land area	Expected afforestation, % of total land area	Private (including companies) owned forestland, %
Finland	201	66	1	71
Sweden	244	60	1	78
Estonia	21	50	7	35
Norway	87	28	<1	85
Denmark	5	11	11	69
Iceland	1	1	2 - 5	70

and inefficient agriculture. In Estonia, the post-communist government has turned over many small farms to the descendants of the former owners. These largely urban owners have no experience or expertise with farming, so forestry may be an attractive, low-cost land use alternative. Consequently, a significant increase in forestland on abandoned farmland is expected in Estonia. In Denmark, the goal of the afforestation programme is to double the forested area within one tree generation (approximately 100 years). The several aims of this program include: increased concern for sustainability, nature conservation and biodiversity; protection of ground water resources; improvement of recreational values of the landscape; and reduction of subsidised agricultural production.

Afforestation of broadleaves is preferred in Scandinavia, although conifers are allowed under certain conditions. Typically broadleaved seedlings are planted at densities up to 5,000 per ha. There must be a minimum of 3,000 to 4,000 saplings surviving at 8 to 12 years after planting. Additional subsidies are paid in Denmark for pesticide-free afforestation, fencing, and income compensation. Direct seeding of oak is gaining popularity on farmland in southern Sweden and Denmark (MADSEN *et* al., 2002). Costs of planting are higher in Denmark (Table 4) than in the southern United States (Table 5) and direct seeding costs are 30 percent to 50 percent lower than planting seedlings.

TABLE 4

Approximate costs for planting or direct seeding broadleaves in Denmark and southern Sweden. (US$ per ha). Costs depend on several factors management objectives, site quality, deer population, and area of the site (Source: MADSEN *et al.,* 2002)

	Direct seeding	Planting
Site preparation	0 700	O-700
Seeds or transplants	200 500	1,200 2,400
Sowing or planting	100 – 350	400 – 800
Fence	0 – 1,300	0 - 1,300
Total	$300 – $2,850	$1,600 – $5,200

REHABILITATION

Degradation of existing forests occurs from anthropogenic and natural disturbance. By degradation, we mean loss of species, simplification of stand structure, or invasion by exotic organisms. The first step in rehabilitation is to identify the cause of site or stand degradation. Stand degradation from high grading or fire exclusion may be remedied through vegetation manipulation alone. Alteration of the site by changed hydroperiod, atmospheric deposition, or catastrophic fires poses broader questions. Can the pre-disturbance conditions be restored or the effects of alteration somehow mitigated? Should the rehabilitation effort target a different vegetation assemblage, perhaps one more adapted to present conditions ? For example, hydroperiod alterations caused by flood control projects, dams, or highway construction tend to be irrevocable, at least in the short-term. Flooding caused by beaver dams, however, can be reduced by removing the dam but continued management of beaver population levels will be required to avoid recurring problems. The guiding principle for silviculturist should be to rehabilitate or restore in accordance with existing conditions, unless alteration is feasible, affordable, and within the control of the silviculturist.

At times, the current stand is so degraded that true site potential, in terms of species composition and productivity, is masked. Selectively logging the biggest and best trees of a few species may degrade the stand without lowering the potential of the site. On the other hand, one must be careful to avoid attributing a higher potential than is warranted and mistakenly blaming "degradation" for conditions on an inherently poor site. Site potential refers to the combination of relatively

TABLE 5

Typical direct costs ($ US per ha) for afforestation of bottomland hardwoods in the LMAV. (Source: STANTURF et al., 2000a)

Activity	Direct-Seed Oaks	Low-Intensity Bare-Root Seedlings	High-Intensity Bare-Root Seedlings	Interplant Cottonwood and Oak
Site preparation	$40	$40	$72	$146
Seeds or seedlings	$62	$185	$185	$212
Sowing or planting	$86	$86	$86	$124
Weed control			$77	$101
Insecticide				$22
TOTAL	$188	$311	$420	$605

unchanging physical factors which affect species composition and stand vigour. A site's potential, and whether it has been degraded, sets limits on what can be achieved by silvicultural intervention. Site potential also determines the general direction of stand development and the likely outcome of any major disturbance that replaces the existing stand. Site potential is not immutable, however. For example, changes in hydroperiod may degrade a site (lengthening inundation from periodic to continuous) or improve a site (drainage, the reverse situation, under some circumstances).

Rehabilitation of Broadleaved Woodlands in Northern Europe

Traditional forestry in northern Europe has mainly concentrated on growing conifers for timber and pulp in both the boreal and the nemoral zone (SPIECKER, 2000). During the past two decades, increased public concern for ecological sustainability, nature conservation and sustainable land use, along with economical constraints and reduced softwood timber prices, has led to increased focus on the use of broadleaved species and close-to-nature forest management. The more diverse and multifunctional aims of forestry have emphasised the need for flexibility in forest management with respect to future outputs as wood and non-wood products and values. Additionally, the importance of flexibility is underscored by the long production periods in European forestry, where rotation lengths usually range between 50 and 150 years. The challenge is to predict the primary role of the future forest.

Presently coniferous plantations are being transformed into broadleaved stands, particularly on the better soils in the deciduous zone of south Sweden and Denmark (ANGELSTAM, 1998; MADSEN *et al.*, 2002); in Germany and Austria (STERBA & HASENAUER, 2000); in England (FERRIS-KAAN, 1995); and in Ireland (JOYCE et *al.*, *1998).* Today, the main species in coniferous plantations are Norway spruce (*Picea abies* (L.) Karst.), Sitka spruce (*Picea sitchensis* (Bong.) Carr.), and pines. Norway spruce is outside or on the edge of its natural range in Denmark and south Sweden, and may be off-site in other areas. The conifers were initially planted due to high production value and lower cultivation costs. However, they have shown poor wind stability and health on many sites. Catastrophic winds not only destroy the existing forests (SPIECKER, 1995), but also create regeneration problems over large areas.

Planting broadleaves following a clearcut or under conifer shelterwood is increasing in frequency. Species typically include beech (*Fagus sylvatica* L.), pedunculate oak (*Q. robur* L.), ash (*Fraxinus excelsior* L.), and linden (*Tilia cordata* Mill. or *T. platyphyllos* Scop.). Direct seeding oaks and beech into shelterwoods and clearcuts has been attempted with some success in Germany, Sweden, and Denmark, although seed predation by rodents can be a problem. On oceanic islands such as Ireland, however, shelterwoods are uncommon as frequent high winds make the risk of blowdown of the residual stand high (MICHAEL KEANE, personal communication, 2000). Catastrophic windstorms in recent years have given impetus to finding reliable, low-cost methods such as direct seeding.

Rehabilitation of Shortleaf Pine Woodlands in the Interior Highlands, United States

The Interior Highlands in the southern United States refers to the broad plateaus and low mountains called the Ozark Plateaus of the Boston Mountains and the Ouachita Mountains (WALKER, 1994). High insolation, erratic rainfall, and high temperatures limit the forest over much of the area to those types adapted to poor soils and dry sites. Extensive pure stands of shortleaf pine (*Pinus echinata* Mill.) have been maintained in public and industrial management in the Ouachita Mountains (WALKER, 1994), although drought-tolerant families of loblolly pine (*P. taeda* L.) are managed intensively in plantations. Hardwoods encroach under the pine, and they will capture the site when the sub-climax pines are harvested or die, leading to pine-hardwood mixtures.

Prior to European settlement of the region, pines maintained dominance by their tolerance to periodic fire. In the Ouachita Mountains, pines dominated stands, primarily shortleaf pine with a minor hardwood component in the overstory of mostly oaks (*Quercus* spp). A native herbaceous understory dominated by bluestem (*Andropogon gerardi* Vitman, big bluestem, or *Schizachyrium scoparium* [Michx.] Nash), little bluestem) grasses was maintained by fire (GULDIN, 1986; GRANEY, 1986). Fire suppression for the last 60 years allowed substantial hardwood encroachment and build up of fuel loads.

Restoration is beginning in this region, designed to mimic stand conditions prior to European settlement and more natural fire regimes (STANTURF *et al.*, 2000b). Prescriptions call for commercial thinning of the overstory, reducing residual basal area of pines and scattered hardwoods in the main canopy by half, to 15 m^2 ha^{-1}. The predominantly hardwood midstory and understory is removed by hand labour (chainsaws or hand tools). Burning is conducted at 2 to 5 year intervals for 10 years, during the dormant or growing season, with moderate intensity fires. Over time, the resulting open and parklike stands will be maintained in this condition using two-aged shelterwood. Approximately 63,000 ha of shortleaf pine-bluestem ecosystems are planned to be restored on the Ouachita National Forest in Arkansas and Oklahoma.

DISCUSSION

Forest restoration over large areas through afforestation can be accomplished by artificial regeneration methods. Nevertheless, the resulting plantation forests are objectionable to some segments of society. In response, KANOWSKI (1997) argued for a dichotomy in concepts of plantations forests, between the traditional plantations organised for fibre production and more complex plantation systems that seek to maximise social benefits other than wood. Kestoration goals can be met by developing a concept of complex plantations that retain the economic and logistic advantages of simple plantations.

Simple Plantations

Simple plantations are single purpose, usually even-aged monocultures that can produce as much as ten times greater wood volume as natural forests (KANOWSKI, 1997). Simple plantations, nevertheless, provide multiple benefits when compared to alternatives such as continuous agriculture. Significant advantages of simple plantations are that they easily can be established using proven technology, their management is straightforward, and they benefit from considerable economies of scale. If financial return is the primary objective of a landowner, simple plantations may be preferred and some restoration goals will be attained (STANTURF *et al.*, 2001). Nevertheless, complex plantations can be established that provide greater social benefit at a reasonable cost, perhaps as little as a **10** percent reduction in timber returns compared to a simple plantation (KANOWSKI, 1997), or even at a net financial gain to the landowner (e.g., STANTURF & PORTWOOD, 1999). In Europe where rotations are longer, the lack of flexibility with respect to potential products increasingly is viewed as a disadvantage of simple plantations **(LARSEN,** 1995).

Complex Plantations

Objections to plantations are often cast in terms of aesthetics. The sharp boundary between a plantation and other land uses may be objectionable to some, as is the uniformity of trees planted in rows. This aesthetic objection to plantations may be more prevalent in North America, where to many preservationists and restorationists, seemingly wild and natural are synonymous and managed seems to connote artificial and unnatural. The sharp edges of plantations can be "softened" by fuzzy or curved boundaries, in order to integrate the plantation with other land uses.

Where plantations are on small farm holdings, agroforestry systems of intercropping can blend land uses. Forested riparian buffers are established in agricultural fields to protect water quality by filtering sediment, nutrients, and farm chemicals, and they bar easy access by livestock to stream banks (although fencing is still needed). Riparian buffers add diversity to the landscape and serve as wildlife corridors between patches of fragmented forests. In floodplain landscapes such as bottomland hardwoods, areas of permanently saturated or inundated soil (respectively, moist soil units and open water areas) are common and diversify the interior of plantations.

Several options are available to overcome the uniformity of rows. Perhaps the simplest technique is to offset the rows. Uniform spacing between rows and between seedlings within a row is common, resulting in a square pattern. Rows can be offset to produce a parallelogram instead of a square. Hand planting instead of machine planting also will result in less uniform spacing. Plantations can be planned with a recreational viewer in mind so that the view from trails and roads is always oblique to the rows, thereby escaping notice. Alternatively, plantations can be broadcast direct seeded, which will prevent the development of recognisable rows. At any rate, once the canopy reaches sufficient height that ground flora and midstory plants can establish, most plantations take on the appearance of natural stands, at least to the casual observer.

A more serious objection to plantations is their frequent lack of diversity, in terms of species composition and vertical structure. Essentially, simple plantations are not as diverse as natural stands, at least for many years. In truth, many natural forests are simple as well. Boreal forests can be dominated by a single tree species, and many fire-dominated forest types can appear to be composed of one or a few tree species and frequently large areas are even-aged. Where fire exclusion has allowed encroachment of diverse midstory and understory woody species, as in the shortleaf pine-oak system of the Southern United States, restoring natural (or at least pre-European settlement) fire regimes may simplify stand structure and reduce woody species diversity. The public does not always appreciate these complexities of nature, and some segments of the public have challenged restoration efforts (JAMES **GULDIN,** personal communication, 2001). Foresters have devised several methods to establish multiple species stands. For example, planting several blocks of different species in a stand, or even alternate rows of different species is possible and creates some diversity at the stand level. Distribution, however, remains more clumped than would be typical of a natural stand.

Other methods are available, including nurse crops of faster growing native species (SCHWEITZER et al., 1997) or exotics (ASHTON *et al.*, 1997; LAMB & TOMLINSON, 1994). In this approach, there is no intention of retaining the nurse crop species throughout the rotation of the slower growing species (this could also be termed relay intercropping). While the nurse crop method has many advantages, and in the short-tern provides species diversity and probably vertical structure, once the nurse crop is removed the residual stand may lack diversity. The challenge is to develop methods for establishing several species in intimate group mixtures, such as would occur in a natural stand, but avoiding excessive mortality during the self-thinning or stem exclusion stage of stand development. Such methods must account for the growth patterns of the species, relative shade tolerances, and competitive ability.

Vertical structure is an important feature of forests for wildlife (DEGRAAF, 1987; TWEDT & PORTWOOD, 1997; HAMEL et *al.*, 2002). Early stages of stand development, whether in natural forests or plantations, are characterised by low light in the understory until crowns differentiate. In most restoration forests, it takes years for native forest plants to develop in the understory and midstory. Annual disturbance while in agriculture removed buried seed and rootstocks of native plants and low light levels in the young forest preclude understory development from invaders. Such legacies of previous land use may account for subtle differences in understory diversity. For example, loblolly pine plantations in the southern U.S. had more diverse understories if they had been planted on cutover land, rather than old fields (HEDMON *et* al., 2000). The manager can intervene to plant understory species; at present, little research affords guidance on methods, planting density, or probable success rates. As indicated above, relay intercropping provides vertical structure for a time. Natural dispersal into gaps can also encourage understory development, whether gaps are created by thinning or left during planting (ALLEN, 1997; OTSAMO, 2000). The critical factor limiting understory development by natural invasion is whether there are seed sources for the understory plants within dispersal range (CHAPMAN & CHAPMAN, 1999; JOHNSON, 1988).

The benefits of restoration are usually identified in terms of government priorities or social benefits; seldom are the diverse objectives of landowners recognised (but see SELBY & PETÄJÏSTO, 1995). In most market economies where rights and obligations of ownership rest with private landowners, what is appropriate for public land may not be the most attractive restoration option for private landowners (STANTURF *et al.*, 2001). Nevertheless, there can be considerable overlap in the expected benefits to society and the affected landowner. The array of possible objectives can be illustrated with a limited set of management scenarios (Table 6). For simplification, three scenarios are presented: production forest, conservation forest, or preservation forest. The production forest option can be further divided into low versus high intensity management.

Benefits include financial, recreational, and environmental outcomes. Because cash flow is important to many landowners, and the adjustment from annual to periodic income is often cited as a barrier to afforesta-

TABLE 6
Expected benefits from afforestation, depending upon objectives and management intensity

	Expected Benefit Level					
	Financial		Recreational		Environmental	
Scenario	Short-term	Long-Term	Hunting	Non-Consumptive	Conservation Practices	Land Retirement
Production Forest-High Intensity (Short Rotation: Pulpwood, Fuelwood)	High	High	High	Medium	Medium	NO
Production Forest-Low Intensity (Long-Rotation: Timber, Wildlife)	Medium	High	High	High	High	NO
Conservation Forest	Low	Medium	High	High	High	Low
Preservation Forest	Low to No	NO	LOW	Medium	Medium	High

tion, financial benefits must be considered as both short-term and long-term (AMACHER et al., 1998; NISKANEN, 1999). Recreational benefits are hunting and non-consumptive benefits such as bird watching or hiking. Environmental benefits are separated into conservation practices (such as those installed to control soil erosion and protect water quality, enhance wildlife habitat, or sequester carbon) and land retirement, where there is no on-going management activity.

Financial Benefits

Financial returns from active management (production or conservation forests) are substantial relative to the preservation or no-management scenario. Fibre and timber production will drive expansion of plantations in many parts of the world (CARNEIRO & BROWN, 1999). Other income can be realised by some landowners from hunting leases and potentially from carbon sequestration payments (BARKER et al., 1996). Despite considerable uncertainty over the accounting for carbon credits under the Kyoto Protocol, there seems to be agreement that afforestation will be eligible for offset credit (SCHLAMADINGER & MARLAND, 2000). Current projections in the United States for the value of a carbon credit are on the order of $2.72 to $4.54 per ton of CO, sequestered, but the value is much higher in Europe. In Norway, for example, there is already a carbon tax on gasoline equivalent to $49 per ton CO_2 (SOLBERG, 1997). Estimates from economic models suggest that a carbon tax of $27 to $109 per ton CO_2 would be necessary to stabilize global emissions at the 1990 level (SOLBERG, 1997). Under conditions of substantial taxes on CO_2 emissions, growing biomass for fuel would become an attractive alternative to fossil fuel because biofuels have no net impact on global carbon levels. Biofuels represent atmospheric carbon momentarily fixed in living tissue. When oxidized in combustion, the carbon is returned to the atmosphere with no net impact on global carbon levels.

Recreational Benefits

The primary recreational benefits assumed in the examples are from creating and enhancing wildlife habitat. Not all wildlife species require the same kind of habitat, so for simplicity the expected benefits can be separated into recreational hunting by the landowner (rather than lease fees) and non-consumptive wildlife activities, such as bird watching or simply the existence value of wildlife to the landowner.

Environmental Benefits

Water quality benefits of afforestation accrue from reducing soil erosion especially in upland catchments but also in floodplains (Joslin & Schoenholtz, 1998), and filtering, retaining, and assimilating nutrients and farm chemicals from surface runoff and groundwater (Huang et *al.*, 1990). Planted forested buffer strips in an agricultural landscape are uncommon, although several studies have examined the filtering action of natural forested riparian zones (COOPER et *al.*, 1987; COOPER & GILLIAM 1987; LOWRANCE et *al.*, 1983; LOWRANCE et *al.*, 1984a, 1984b; LOWRANCE et al., 1986; PETERJOHN & CORRELL 1984; TODD et al., 1981). COMERFORD et *al.* (1992) summarised these studies and concluded that buffer strips are quite effective in removing soluble nitrogen and phosphorus (up to 99 percent) and sediment. The efficiency of pesticide removal by forested buffer strips has been examined in some environmental fate studies that concluded that buffer strips 15 m or wider were generally effective in minimising pesticide contamination of streams from overland flow (COMERFORD et al., 1992). Afforestation of biofuel plantations would have substantial environmental benefits, in terms of effects on atmospheric carbon levels. Burning biofuels instead of fossil fuels would initially sequester carbon from the atmosphere, and further reduce the net CO_2 emissions by substituting for fossil fuel. Further benefits would accrue from conserving fossil petroleum for manufacturing feedstock and future uses.

Rehabilitation

Attempts at rehabilitating existing forests are diverse in terms of rationale, pre- and post-rehabilitation conditions, and methods. Generally, rehabilitation requires changing species composition and sometimes stand structure. The impetus for rehabilitation is usually the result of social choices. For example, traditional forestry in northern Europe has mainly concentrated on growing conifers for timber and pulp. Over the past two decades, concern has increased for ecological stability in order to obtain more flexibility in the types of products available from forests and in the face of unknown future benefits and risks (LARSEN, 1995). Recently, focus has shifted toward nature conservation, and sustainable land use. One response to this concern is often termed close-to-nature silviculture, which is characterised by greater use of broadleaved species, less reliance on artificial regeneration and plantation culture, and attempts to restore forests that are more diverse.

In many European countries, rehabilitation of largely coniferous plantations to mixed deciduous woodlands is aided by stand disturbing windstorms. The existing conifer plantations have been labelled unstable, where stability of forests is expressed in terms of resistance and resilience of the forest ecosystem (LARSEN, 1995). Poor resistance is expressed as susceptibility of the forest to damage or destruction by strong winds, drought, fire or a complex of factors. Poor resilience is characterised as difficulty in regaining pre-disturbance conditions, stemming from regeneration problems.

In North America, seventy years of attempted fire exclusion in fire prone ecosystems has allowed development of forest communities that did not exist before organised fire suppression (MUTCH, 1970; BROWN & SMITH, 2000). Re-establishing disturbance regimes, using prescribed fire, is the goal in several ecosystems in the southern United States (WADE et *al.,* 2000). Many of these ecosystems can still be restored with the judicious reintroduction of fire, sometimes in combination with herbicides or mechanical methods. The long association between fire and vegetation has resulted in key species developing traits that favor them in fire-prone ecosystems (MILLER, 2000).

Shortleaf pine is one of several species in the southern and western United States with marked adaptations to periodic ground fire. It forms dense sapling stands that are favoured over competing hardwoods by frequent fire. Shortleaf pine can repeatedly sprout from the base if the tree is topkilled, at least until trees are 15 to 30 years old (LITTLE & SOMES, 1956). Ability to re-sprout, abundant seed crops, rapid juvenile growth (especially of sprouts) and a low resin content of the wood make this species markedly tolerant of fire (MATTOON, 1915). Because fire exclusion allowed development of a substantial hardwood midstory, however, restoration treatments require removal of midstory and overstory trees prior to burning. Similarly, restoring many western forests by reintroducing natural fire regimes requires removing substantial amounts of woody biomass before prescribed fire can be safely used (COVINGTON et *al.,* 1997; LYNCH et *al.,* 2000). In other conifer forests, however, the natural fire regime may be of a stand replacing crown fires. For example, sand pine (*P. clausa* Chapm. (ex Engelm.) Vasey ex Sarg.) in Florida may be restored in natural areas using crown fire, but fire would not be used if timber production were an objective (STANTURF *et al., 2002).*

In general, forest restoration has been approached at the stand level with little concern for landscape level effects. There is often a bias toward natural, mature forests as if the landscape should be maintained in old growth everywhere, at all times. In most landscapes, plant or wildlife diversity will be maximised if forests exhibit a range of stand development or successional stage. In North America and Western Europe, forest restoration is costly and has been driven primarily by governmental incentives. Where funding is limited, simple wood production plantations may be the only feasible way to begin to restore large areas of agricultural land or degraded forests. Over the longer term, however, simple plantations can be converted into complex plantations and eventually, natural forests. Such a strategy has been suggested for severely degraded tropical land (PARROTTA *et al.,* 1997) and in the Lower Mississippi Alluvial Valley in the southern United States (STANTURF et *al.,* 2000a).

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