Forests planted for ecosystem restoration or conservation

CONSTANCE A. HARRINGTON
Resource Management and Productivity Research Program, USDA Forest Service, Pacific Northwest Research Station, Olympia, WA, USA

Abstract. Although the phrase, "planting for ecosystem restoration," is of recent origin, many of the earliest large-scale tree plantings were made for what we now refer to as "restoration" or "conservation" goals. Forest restoration activities may be needed when ecosystems are disturbed by either natural or anthropogenic forces. Disturbances can impact (1) basic components of the system (e.g., plant and animal composition, soil pools, and atmospheric pools), (2) ecosystem processes, i.e., interactions among basic components, or (3) both components and processes. Early efforts at restoration or site rehabilitation focused primarily on reducing off-site impacts, such as sediment introduced into streams from ecosystems that had been severely disturbed. More recent restoration programs include ecosystems in which only some of the components are missing or some of the processes have been impacted. Restoration activities can begin immediately after the disturbance has ended. Although forest restoration projects can include many activities, planting is almost always a key component.

When planning an ecosystem restoration project, land managers need to be aware that commonly used plant establishment and management procedures may need to be altered to meet project objectives. Some systems may have been so severely impacted that ameliorative activities, e.g., fertilization, liming, land contouring, and microsite preparation, will be necessary prior to planting. Managers may also need to take special measures to reduce herbivory, control competing vegetation, or reduce physical damage from wind or sun. Choice of species needs careful consideration. Desired species may not grow well on degraded sites, may need a nurse species to become established, or may not provide an opportunity to harvest a short-term crop to reduce restoration costs. New methods may need to be developed for projects that require underplanting or interplanting. The end result of restoration should be an ecosystem with the same level of heterogeneity inherent in an undisturbed system; thus, managers should consider how pre- and postplanting activities will affect system variability.

As our understanding of ecosystems has increased, so has our expectation that restored ecosystems have the same components and function in the same manner as do undisturbed systems. These expectations require that land managers have more sophisticated information than was considered necessary previously. In the absence of more pertinent information, we can prescribe restoration activities based on results from related ecosystems or on theoretical considerations. Additional research, careful monitoring, and adaptive management are critical to our long-term success.

Introduction

Forests can be planted for many objectives. These include producing fiber, wood, or other forest products; providing services, such as recreational opportunities or watershed protection; and achieving ecological objectives, such as ecosystem restoration. Other papers in this proceedings deal with production of various products or a mix of products and services from planted forests. In this paper I deal specifically with forests planted for conservation objectives or for ecosystem restoration. Because these terms can mean different things to different people, I will start with some definitions. Next I will indicate which forces can trigger the need for conservation or restoration, stress the importance of having specific project objectives and the need to consider the constraints, provide examples of practices that might be used as part of conservation or restoration plantings, and, finally, conclude with a short discussion of future needs.

The fields of restoration ecology, habitat management or re-creation, watershed management, and mine spoil rehabilitation are not new ones; however, knowledge in all of these fields has expanded tremendously in recent years and several symposia or synthesis texts provide good overviews of the current state of knowledge (e.g., Jordan et al. 1987; Buckley 1989; Luken 1990; Chambers and Wade 1992; Naiman 1992; and Ferris-Kaan 1995). My purpose is not to summarize these diverse fields, but to provide a brief overview of some · of the concepts that should be of interest to resource managers, and to provide some references for the reader interested in pursuing the subject.

Definitions

There are many possible definitions of most of the terms that are used in this field. These range from terms having general meanings to those having very specific connotations, and terms defined by statute or other type of formal mechanism. A general definition of conservation is: "A careful preservation and protection of something: esp. ... planned management of a natural resource to prevent exploitation, destruction, or neglect" (Woolf 1977). Common conservation objectives include protecting soil and water resources by preventing erosion or altering water yields, or preserving wildlife diversity by preserving or creating suitable habitat conditions. The term "conservation" has been in use for so many years that more restrictive definitions are not usually used.

Defining restoration and associated terms is more complicated, because there are many alternative definitions, and, even within the field of restora-

tion ecology, they are not always used consistently. A general dictionary definition of restoration (Woolf 1977) is: "A bringing back to a former position or condition." People understand this definition when someone says that they are restoring a 1955 Chevrolet; that is, they are trying to re-create the vehicle condition as it would have been when it left the factory. But what factory did the ecosystem come from? And what model year are we trying to create?

I think it is helpful in this context to discuss ecosystems and their developmental pathways with the terms proposed by Magnuson et al. (1980) and the graphical approach as modified by Bradshaw (1987). In this approach ecosystems are described by two axes, one measuring species diversity and complexity and the other measuring biomass accumulation and nutrient cycling. In normal ecosystem development, systems aggrade along both axes (Figure 1A). If either structure or function has been reduced, then the ecosystem has been degraded. In this example I have assumed that an ecosystem has been degraded in both structure and function. It is possible, however, to have ecosystems that are degraded primarily in only one of the dimensions. Thus, it's important for foresters who are familiar with the term "site degradation" to realize that "ecosystem degradation" can occur without reducing the basic productivity potential of the site if the system is simplified (i.e., reduced in species and complexity).

We can discuss the alternative pathways that a degraded ecosystem can follow by seeing how the end result compares to the original or target system.[1] If no human activities occur, that is, if the system is neglected (Figure 1B), it could continue to degrade for some period of time, or it could begin to aggrade (i.e., increase in biomass and complexity). Another term that can be used to describe intentional neglect is "preservation." I think that it is important to recognize that neglect or preservation does not always result in an aggrading system (at least within human time frames). Neglect can result in a system that continues to degrade in productivity or a system that loses complexity. For example, it is clear that in a system where active erosion is occurring, the erosion will continue (and the productive capacity of the system will continue to decrease) until the land surface stabilizes. If a forest stand is just moving into the competitive exclusion phase of stand development (i.e., the canopy is closing and mortality is occurring), the stand is likely to lose additional understory and midstory plant species, and the vertebrates and invertebrates that depend on them. On the other hand, a neglected ecosystem could begin aggrading with respect to either or both axes as soon as a disturbance event ends. The pattern of ecosystem development in a neglected system could be either quite similar to the path of development the system had followed prior to being degraded, or very different, depending
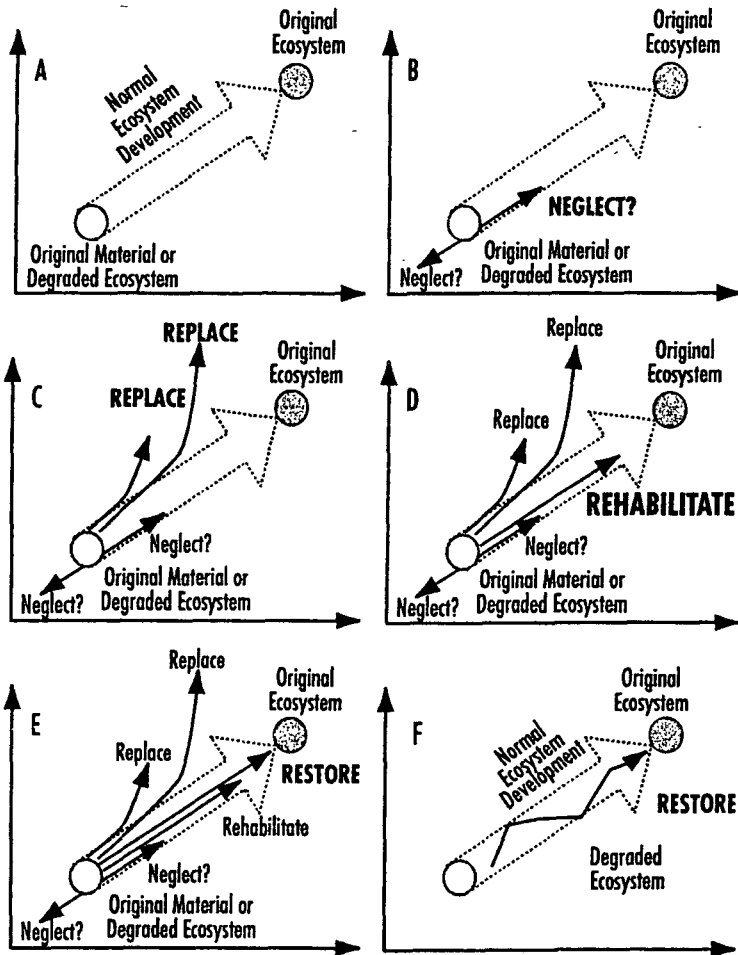
Figure 1. Ecosystems Can Be Characterized by their Function (biomass and nutrient content) and their Structure (species composition and complexity). (A) Systems are degraded if their function or structure is reduced. Normal ecosystem development may return the system to its previous status. (B) A neglected system may continue to degrade, or begin to recover. (C) A replacement system is one with less structure, and may be more or less productive than the original system. (D) A rehabilitated system is one with less structure and function than the original. (E) A restored system has the same structure and function as the original system. It may not follow the same path as the original system (*Modified from*: Bradshaw 1987).

on the condition of the system and the availability of colonizing plants and animals.

Instead of neglecting an ecosystem, one could intentionally plan to replace the original ecosystem with one that is structurally simpler (Figure 1C). The replacement system may be more or less productive than the original

ecosystem. For example, if a forested ecosystem had been severely degraded after years of row cropping, one could establish a grassland ecosystem which would have less structural complexity and be less productive than the original (i.e., nondegraded system). Alternatively, if a bottomland hardwood system had been degraded and then planted with *Populus* clones, the replacement system would have a simplified structure compared to the original system, but it might be more productive. It's important to remember that all of these comparisons are in relation to the original system.

Based on our graphical representation, if our goal is to establish an ecosystem that is simpler and less productive than the original, but similar in concept, we would be rehabilitating the ecosystem (Figure 1D). Our intent would be less ambitious than if our goal were complete restoration. The goal of ecological rehabilitation (a term more specific than just rehabilitation) is to use site-indigenous species to reestablish a stable ecosystem capable of replacing the ecological functions of the original (Newton 1992). In many situations, rehabilitation or partial restoration is much more feasible than complete ecosystem restoration.

Looking at our graph again, if ecosystem structure and function were brought back to the same level as had existed previously (or exists in an undisturbed system), we would say the system had been restored (Figure 1E). Ecosystem restoration has been defined by the Society for Ecological Restoration as, "The process of intentionally altering a site to establish a defined, indigenous, historic ecosystem. The goal is to emulate the structure, function, diversity and dynamics of the specified ecosystem" (Newton 1992). The emphasis in definitions of restoration is on re-creating or bringing back to a previous condition, or to a condition that might have occurred without disturbance. Although some may quibble about how one determines exactly what system was present on a particular site or what would have occurred, the important aspect of restoration is the intent to create an ecosystem based on a biological model. Depending on the degree of degradation and the resources available, restoration may be a multistep process. The path followed in each step may differ somewhat from the original path of ecosystem development (Figure 1F).

One other term that is worth mentioning is "reclamation." This term has been used for years in association with reclamation of mined lands or in the sense of "reclaiming lands from the sea" to describe activities in the Netherlands. There are many definitions of reclamation (Table 1); some are legal definitions provided in statutes, whereas others are focused on how the end result can be used. Although there is not complete consensus on this, I believe that most connotations of reclamation involve human use or impose a human value system, rather than describe the project's activities in ecological terms.

Table 1. Alternative definitions of reclamation.

Definition	Source
Combined processes that minimize adverse environmental effects of surface mining and return land to a beneficial end use.	California Surface Mining and Reclamation Act 1975
The act or process of making available for human use by changing natural conditions. Restoration to use; recovery.	Woolf 1977
An attempt to create an ecosystem similar to the original or predisturbance ecosystem. It can include introduced species that respond similarly to the native species which they replace.	National Academy of Sciences 1974 (in Wade and Chambers 1992)

To avoid shifting between biologically based and human-oriented terms, I will not use the term "reclamation" in this paper. However, readers should be aware that a great deal of pertinent work available in the literature is associated with this term.

Causes of degradation

Forest ecosystems can be degraded as a result of many different forces. Some of these forces are the result of human activities; others may be the result of natural phenomena. Some degrading forces can result from either natural or anthropogenic forces; for example, fire can result from natural ignition sources, can be prescribed, or can escape from a human source.

Activities which can result in degradation include mining; land clearing, with subsequent use for crops or pastures; traffic (mechanical or biological); chemical deposition; off-site nutrient or biomass export; mass soil movement off site (slope failure or erosion); flooding; volcanism; fire; and alteration of species, genotype, or stand structure. Some of these impacts are obvious, such as the degradation that occurs after years of cropping on steep slopes where, not only was the original vegetation completely destroyed, but also the surface soil layers were removed and what remained was often compacted and gullied. Other effects are more subtle, such as the loss of animals that may result from a simplification of stand structure.

The effect of a particular force depends on its nature and magnitude, and on the condition of the predisturbance system. For example, repeated light fires may maintain productivity and complexity, whereas high-intensity fires reduce site pools of nitrogen and organic matter (which could reduce produc-

tivity) and may reset succession (probably reducing species complexity). Although many restoration projects may have been triggered by human activities, it is important to keep in mind that even natural forces such as wildfires can result in ecosystem degradation. The issue is not whether the force acting on a system is a natural part of succession, but whether within some reasonable time period it results in loss of structure or productivity.

Objectives

In an idealized world, it might be possible to restore all ecosystems and also meet all other objectives. However, in most situations, there are priorities for setting objectives and for funding, and it is not reasonable to expect that meeting one objective will necessarily meet other objectives. Thus, it is important to clearly identify the priority objectives. Increasing diversity of bird species may require an entirely different strategy than preserving a particular rare species. Similarly, restoring an ecosystem may not be the most effective way to achieve a particular watershed objective. Allen and Hoekstra (1987) provide examples of how differences in the scale of a project may influence its objectives, and how an objective at one scale may preclude achieving an objective at a different spatial or temporal scale.

I heard a recent interview about the television series "Star Trek," in which the actors were laughing about the portions of the script that call for them to use technical jargon that has been invented by the script writer to discuss a particular problem or a proposed solution. The actors call the resulting dialogue "techno-babble." If you don't listen carefully or aren't familiar with the technical details, techno-babble appears to make sense. Unfortunately some of the dialogue associated with restoration and conservation plantings appears to me to be the ecological equivalent, or "eco-babble." Although "eco-babble" may sound OK, it almost always results in projects with "fuzzy" objectives. Without clear objectives it is almost impossible to prioritize projects or to judge whether or not a project was successful. In addition, because many conservation or restoration projects are very long term, changes in project personnel will probably be inevitable; thus, clear project objectives will help keep future efforts focused on the highest priority objectives.

If the factor that caused the system degradation has not ceased, e.g., if atmospheric deposition continues, then the best that can be hoped for is system rehabilitation, rather than complete restoration (Lenz and Haber 1992). In addition, the degree of degradation sets practical limits on what types of restoration goals are reasonable (Werner 1987). For example, if soil layers as well as vegetation have been removed, the likely goal is to restore

basic ecosystem functions; if the soil layer is intact but the vegetation has been severely impacted, then the goal may be to restore specific growth forms of vegetation; and if the composition or structure of the vegetation has merely been simplified, then the goal may be community or species restoration. Based on the definitions discussed previously, if the goal is not a complete ecosystem restoration, then it is usually better termed "replacement" or "rehabilitation."

Determine the constraints

Once the biological objectives have been clearly determined, then it is important to clearly understand the legal and social considerations involved in implementation. In reality, these steps (objective setting and recognition of constraints) often proceed jointly. Thus, if there is a legal mandate to return the land to a specified condition and to do so within a specified time period, it is clear that meeting these legal requirements will be at least part of the project objectives. Other considerations in defining project objectives include current attitudes of opinion makers, the need for short- versus long-term inputs, and costs. In addition, if the system was degraded by human activities, are there alternative areas readily available for those activities? If not, the project may be doomed from the beginning. It is clear to most people that, if an area has traditionally been used for agriculture or livestock grazing, it is not reasonable to expect the users to react positively to new fences and a planting project which restrict their access (Michaelson 1994). These considerations do not just apply to developing countries. Closing off an area popular with drivers of off-road vehicles or trying to reduce public access for harvesting of special forest products (e.g., berries, floral greens, and mushrooms) may also require substantial preproject planning to ensure that users accept the need for reduced access and are aware of alternative sites for their activities.

In addition to clearly specifying objectives, resource managers also need to identify reasonable goals or short-term targets by which to judge project success. For example, we have known for many years that planting eroded land can help achieve soil and water conservation objectives (c.f., Duffy and Ursic 1991). The success of a project with soil or water conservation objectives should not be judged primarily on a forestry measure, such as the number of trees planted, but rather on the actual benefits associated with that particular project. An example may make this clearer. It has been shown that older teak plantations can actually result in greater erosion than if the area had never been planted (Michaelson 1994). This occurs because the large leaves of the genus collect rain, and this results in a canopy drip with much larger drop size than exists above the canopy. As the tree crowns lift over time,

the force at which the drops impact the ground increases. Teak leaf litter decomposes rapidly, and the ground is not protected during much of the year and substantial erosion can result. Thus, if the project objective is primarily one of soil conservation, then the benefits of the project should be judged by measuring change in soil parameters rather than by counting numbers of trees planted.

Practices associated with conservation and restoration Plantings

Once project objectives have been set, the next step is to determine which activities need to be accomplished, and in what order. It is clearly unreasonable to be considering fine points like how to increase stand structure if the topography is not stable. For severely degraded sites, the first priorities are usually site-related; that is, how can we stabilize soil, reduce erosion, reduce compaction, improve macroporosity, increase nitrogen and organic matter, and reduce toxicity (Table 2)? Most of the answers are based on years of experience in rehabilitating mine spoils or other special sites. Forest managers should be aware of the voluminous literature on this topic, and not assume that their experiences in revegetating cut-over forest land are comparable.

Some people may question the need to plant degraded areas, and suggest that neglect will result in normal ecosystem development. However, planting for conservation or restoration objectives is done for the same reasons as planting for timber production or other objectives – it allows greater control of species composition and spacing, and can result in a forested area more rapidly than the no-action alternative (Bradshaw 1987; Harmer and Kerr 1995). The presence of many invasive weed species worldwide and the lack of seed sources for some desirable species may also mean that historical patterns of ecosystem development will not occur without intervention.

Once the decision has been made to plant, there are several considerations. First, can the desired species be directly planted, or must other species be planted first to ameliorate the site conditions or the exposure? Some plants can alter soil conditions in very specific ways; thus, a manager could slowly increase soil nitrogen levels by planting species capable of nitrogen fixation, could increase soil organic matter by planting species capable of producing large amounts of biomass, or could utilize species that act as cation "pumps" (Alban 1982; Aber 1987). (Cation pumps take up high levels of cations from lower soil levels, and this increases pH and cation availability in surface soil.) Species might also be selected for their berry or mast production, their ability to provide cattle forage or a cash crop, their ability to penetrate compacted soils or tolerate sodic conditions, the type of shade they provide, the lack of root competition, or merely their availability at a particular point in time.

Table 2. Project activities and methods used in restoration and conservation plantings.[a]

Goal of activity	Possible methods
Stabilize soil surface	Contour. Construct debris dam. Mulch. Drain.
Reduce compaction	Use ripping (mechanical disruption).
Improve macroporosity	Incorporate wood or shale. Plant deep/strong "rooters." Tolerate burrowing animals.
Reduce toxicity (pH, metals, and salts)	Have patience (natural weathering). Replace soil. Use irrigation. Lime if pH is too low. Provide other amendments. Plant resistant species or cultivars.
Increase organic matter	Mulch with organic matter. Establish vegetation.
Increase nitrogen	Fertilize. Establish nitrogen-fixing plants.
Increase other nutrients	Fertilize or add other soil amendments. Establish selected plants.
Improve microsite conditions	Scalp. Do microsite preparation. Add shade or shelter. Use irrigation. Use snow fence, clumped plantings.
Reduce herbivory or physical damage by animals	Control access. Use repellents, protectors. Provide alternative browse. Use direct methods such as trapping.
Alter species composition of plants	Have patience. Do planting, seeding. Attract plant disseminators (e.g., with artificial perches).
Alter composition of vertebrate and invertebrate species	Have patience (suitable habitat). Use inoculation. Relocate.

[a] See Bradshaw 1987; MacMahon 1987; Gupta 1990; Luken 1990; and Moffat and Buckley 1995 for greater detail.

For example, species planting decisions after the 1980 eruption of Mount St. Helens (state of Washington, United States) were partially based on what species were already growing in the nurseries or for which seed had already been collected and could be sown in a greenhouse or nursery.

Genetic considerations are also important in selecting plant materials. For some situations it may be necessary to select adapted populations or even specific cultivars to grow on toxic surfaces (McNeilly 1987). If the goal is ecosystem restoration, rather than replacement or rehabilitation, then the manager will want to select native species and local sources. When ecological variants occur that differ in form or tolerances, managers must also take care to select the appropriate variants. Even with the most diligent care, it is almost inevitable that the resulting gene pools will be different from what would have been present without the degrading and rehabilitation activities. This may not

always be a serious problem, though, as selection pressures may act on the new gene pool to result in similar selection pressure, and thus the population may evolve in a similar way (McNeilly 1987).

When dealing with severely degraded systems, managers should consider that there may be several alternative approaches to meet their long-term objectives. Lugo et al. (1993) have suggested that with suitable adjustments in management activities, monoculture tree plantations in the tropics can represent a pathway to restore biodiversity. With proper attention to species-site relationships, a tree species can be selected which can tolerate the stressful conditions that exist on sites abandoned for agricultural production, and begin the process of soil rebuilding. Once a plantation is well established, it can begin to function as a nurse crop, shading the ground, modifying the microclimate, and adding organic matter to the soil. If the species are chosen properly and later management practices are evaluated for their compatibility with long-term objectives, then the number of understory species should begin to increase. In the scenario proposed by Lugo et al. (1993), the overstory would probably be managed for wood yields to recover the initial investments in plantation establishment. However, the incorporation of management practices that facilitate natural successional processes (or avoidance of those which would impede them) would help ensure meeting the long-term conservation or restoration goals. This concept is supported by data on understory development from several monoculture tree plantations in the tropics (Lugo et al. 1993; Figure 2). These plantations were not managed for goals other than production of wood or other forest products; presumably, we could do at least as well in encouraging understory development if we were trying to do so deliberately. Some people will have philosophical disagreements with this approach (especially if it involves the use of exotic species in the overstory), because they might think that restoration or rehabilitation would occur more rapidly under an alternative approach (especially if one did not need to wait until products were harvested). The pragmatic approach suggested by Lugo et al. (1993), however, might allow many more hectares to be rehabilitated than would be possible in a scenario that required large front-end costs without any likelihood of a future return.

Similarly, some non-native, nontree species can be beneficial in the restoration process, and the timing of their eradication should be carefully evaluated. For example, recovery of species diversity in a forest in Argentina that had been subject to fire, overgrazing, and overtrampling was improved by the nurse crop behavior of a non-native shrub (Pietri 1992). The native species had not evolved with the current disturbances and had not developed strategies for dealing with them.
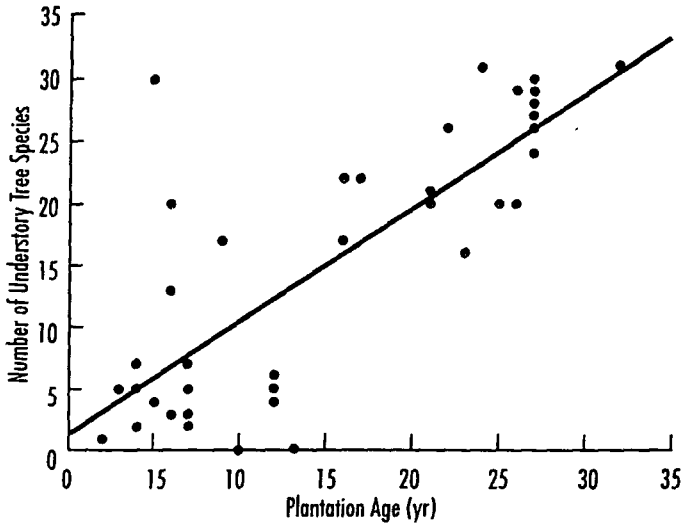
35

30

Number of Understory Tree Species

25

20

15

10

5

0

0   15   10   15   20   25   30   35

Plantation Age (yr)

Figure 2. Understories of native tree species developed inside tree plantations in Puerto Rico and India, and the number of species present generally increased over time (*Source*: Lugo et al. 1993).

If there are native species available that are suited to the current soil and site conditions, the regeneration methods have been worked out for the desired species, and the resources are available to cover the project's costs, then clearly the reestablishment of native species rather than the use of exotics would be preferred for a project with restoration goals. Recent work (e.g., Butterfield 1995) has increased our knowledge of the growth rates and reforestation technology for several tropical tree species; however, there are many species for which our knowledge base is still extremely limited.

Once the plant materials have been chosen, managers must decide on the appropriate spacing and spatial pattern. Most undisturbed forest ecosystems are more heterogeneous than those that have been planted or managed. Natural systems (and, thus, the targets of our restoration activities) generally have greater species diversity, structural features, and spatial heterogeneity than planted stands. Ignoring the desirability of this variation can result in stands that are less functional than might otherwise be the case. For example, Maehr and Marion (1984) and Marion et al. (1981) report less species diversity of small mammals and birds on mined lands planted with trees than on lands unplanted. They attribute these results to the fact that the preplanting (site preparation) and planting activities reduced microsite variation. Planting in clumps rather than in a uniform distribution (Figure 3) may be more effective in re-creating desired forest conditions. Initial establishment of clumps can alter microclimate, can trap blowing seeds of other species, and may serve
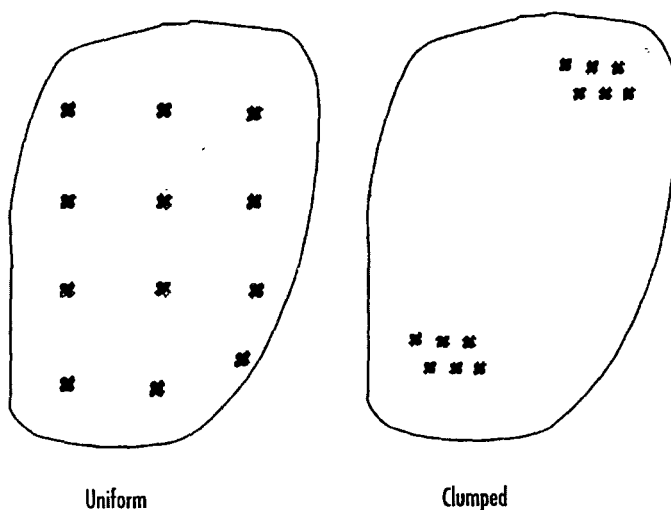
Uniform   Clumped

Figure 3. Planting can be planned for a uniform or clumped pattern. Although uniform plant-ings are simpler to administer, clumped plantings may result in a more natural pattern of variation in both plant distribution and microclimate.

as perches or cover for birds or mammals important in seed dissemination (Luken 1990). Future management activities, such as underplanting or thin-ning, should also be conducted with some knowledge of the spatial pattern that we are trying to emulate.

Those involved in planning restoration or conservation plantings may also want to consider incorporating wildlife enhancement activities such as adding artificial perches or nest boxes, or creating cavities. Such practices can be quite effective in shortening the time necessary for an area to serve as habitat or increasing the carrying capacity for desired species of birds (Caine and Marion 1991) and arboreal rodents (Carey and Gill 1983; Carey et al. 1996).

Future needs

Conservation and restoration projects are usually very long term. It is impor-tant to have continuity through time; however, the methods for achieving this continuity are not clear. Ashby (1987) suggests that preestablished institu-tional arrangements may be a necessity and that biologists (researchers or managers) should be aware of these long-term needs before establishing a project. Legislation to encourage forest restoration projects would be helpful (as suggested by Ashby 1987), but, if such legislation exists, I am unaware of it. For example, last year I began working on a project on the Olympic Peninsula that was started with congressional direction to "begin a restoration

demonstration in young forests." The funding for the project was for 1 year. We have received funding for the second year, but the lack of an alternative funding mechanism to appropriations that must be spent in 1 fiscal year makes long-term project planning a very frustrating exercise. Although we have accumulated a substantial body of information on rehabilitating mine spoils in some parts of the world, our knowledge of the best way to proceed in many site-specific and objective-specific conservation or restoration projects is quite limited. Werner (1987) suggests that two types of research are needed in the future. First, we need manipulative studies – studies in which we make a change, step back, and see what happens. These studies are relatively easy to carry out and can result in rules-of-thumb for future activities. These types of "black-box" studies (i.e., you know what went in and what goes out, but don't understand what happens inside the box) are hard to extrapolate to other situations. These black-box studies are needed to provide answers to urgent questions as quickly as possible (Werner 1987). On the other hand, mechanistic studies are designed to provide information about why a particular result occurs under a given set of conditions. This type of "microscope" study provides a lot of detail, but with a limited field of vision (Werner 1987). Mechanistic studies should ultimately allow better prediction of results under a range of conditions. Thus, both types of studies[2] need to be included in planning research for restoration or conservation objectives. In addition to research activities, substantial information on effective and ineffective practices could also be gained by monitoring operational activities.

Notes

1. Substantial differences may exist in the desired ecosystem depending on whether one is targeting the re-creation of a previous system or the system as it would have developed without the degrading activities. See Bonnicksen 1988 and Cairns 1989 for discussions of this issue. For our purposes, however, the important issue is that one must determine the basis for system comparisons.
2. It would also be desirable to include studies which meld the two approaches. That is, mechanistic approaches can be used in manipulative studies.

References

Aber, J.D. 1987. Restored forests and the identification of critical factors in species-site interactions, pp. 241–250. In: Jordan III, W.R., Gilpin, M.E. and Aber, J.D. (Eds) Restoration Ecology: A Synthetic Approach to Ecological Research. Cambridge University Press, Cambridge.

Alban, D.H. 1982. Effects of nutrient accumulation by aspen, spruce and pine on soil properties. Soil Sci. Soc. Am. J. 46: 853–861.

Allen, T.F.H. and Hoekstra, T.W. 1987. Problems of scaling in restoration ecology: A practical application, pp. 289–305. In: Jordan III, W.R., Gilpin, M.E. and Aber, J.D. (Eds) Restoration Ecology: A Synthetic Approach to Ecological Research. Cambridge University Press, Cambridge.

Ashby, W.C. 1987. Forests, pp. 89–108. In: Jordan III, W.R., Gilpin, M.E. and Aber, J.D. (Eds) Restoration Ecology: A Synthetic Approach to Ecological Research. Cambridge University Press, Cambridge.

Bonnicksen, T.M. 1988. Restoration ecology: Philosophy, goals, and ethics. Envirn. Prof. 10: 25–35.

Bradshaw, A.D. 1987. The reclamation of derelict land and the ecology of ecosystems, pp. 53–74. In: Jordan III, W.R., Gilpin, M.E. and Aber, J.D. (Eds) Restoration Ecology: A Synthetic Approach to Ecological Research. Cambridge University Press, Cambridge.

Buckley, G.P. (Ed). 1989. Biological Habitat Reconstruction. Belhaven Press, London.

Butterfield, R.P. 1995. Promoting biodiversity: Advances in evaluating native species for reforestation. For. Ecol. Manage. 75: 111–121.

Caine, L.A. and Marion, W.R. 1991. Artificial addition of snags and nest boxes to slash pine plantations. J. Field Ornithol. 62: 97–106.

Cairns, J., Jr. 1989. Restoring damaged ecosystems: Is predisturbance condition a viable option? Envirn. Prof. 11: 152–159.

Carey, A.B. and Gill, J.D. 1983. Direct habitat improvements – some recent advances, pp. 80–87. In: Snag Habitat Management: Proceedings of a Symposium. General Technical Report RM-99. Rocky Mountain Forest and Range Experiment Station, Fort Collins, CO.

Carey, A.B., Thysell, D.R., Villa, L.J., Wilson, T.M., Wilson, S.M., Trappe, J.M., Colgan III, W., Ingham, E.R. and Holmes, M. 1996. Foundations of biodiversity in managed Douglas-fir forests, pp. 62–82. In: Pearson, D.L. and Klimas, C.V. (Eds) The Role of Restoration in Ecosystem Management. Society for Ecological Restoration, Madison, WI.

Chambers, J.C. and Wade, G.L. (Eds). 1992. Evaluating Reclamation Success: The Ecological Consideration – Proceedings of a Symposium. Northeastern Forest Experiment Station GTR-NE-164. Northeast Forest Experiment Station, Radnor, PA.

Duffy, P.D. and Ursic, S.J. 1991. Land rehabilitation success in the Yazoo basin, USA. Land Use Policy 8: 196–205.

Ferris-Kaan, R. (Ed). 1995. The Ecology of Woodland Creation. John Wiley and Sons, London.

Gupta, G.N. 1990. Integration of moisture and fertilizer management practices for early growth and establishment of *Eucalyptus* on a skeletally degraded dry land. Int. Tree Crops J. 6: 123–142.

Harmer, R. and Kerr, G. 1995. Creating woodlands: To plant trees or not, pp. 113–128? In: Ferris-Kaan, R. (Ed) The Ecology of Woodland Creation. John Wiley and Sons, New York.

Jordan III, W.R., Gilpin, M.E. and Aber, J.D. (Eds) 1987. Restoration Ecology: A Synthetic Approach to Ecological Research. Cambridge University Press, Cambridge.

Lenz, R. and Haber, W. 1992. Approaches for the restoration of forest ecosystems in northeastern Bavaria. Ecol. Model. 63: 299–317.

Lugo, A.E., Parrotta, J.A. and Brown, S. 1993. Loss of species caused by tropical deforestation and their recovery through management. Ambio 22(2–3): 106–109.

Luken, J.O. 1990. Directing Ecological Succession. Chapman and Hall, London.

Alban, D.H. 1982. Effects of nutrient accumulation by aspen, spruce and pine on soil properties. Soil Sci. Soc. Am. J. 46: 853–861.

Allen, T.F.H. and Hoekstra, T.W. 1987. Problems of scaling in restoration ecology: A practical application, pp. 289–305. In: Jordan III, W.R., Gilpin, M.E. and Aber, J.D. (Eds) Restoration Ecology: A Synthetic Approach to Ecological Research. Cambridge University Press, Cambridge.

Ashby, W.C. 1987. Forests, pp. 89–108. In: Jordan III, W.R., Gilpin, M.E. and Aber, J.D. (Eds) Restoration Ecology: A Synthetic Approach to Ecological Research. Cambridge University Press, Cambridge.

Bonnicksen, T.M. 1988. Restoration ecology: Philosophy, goals, and ethics. Envirn. Prof. 10: 25–35.

Bradshaw, A.D. 1987. The reclamation of derelict land and the ecology of ecosystems, pp. 53–74. In: Jordan III, W.R., Gilpin, M.E. and Aber, J.D. (Eds) Restoration Ecology: A Synthetic Approach to Ecological Research. Cambridge University Press, Cambridge.

Buckley, G.P. (Ed). 1989. Biological Habitat Reconstruction. Belhaven Press, London.

Butterfield, R.P. 1995. Promoting biodiversity: Advances in evaluating native species for reforestation. For. Ecol. Manage. 75: 111–121.

Caine, L.A. and Marion, W.R. 1991. Artificial addition of snags and nest boxes to slash pine plantations. J. Field Ornithol. 62: 97–106.

Cairns, J., Jr. 1989. Restoring damaged ecosystems: Is predisturbance condition a viable option? Envirn. Prof. 11: 152–159.

Carey, A.B. and Gill, J.D. 1983. Direct habitat improvements – some recent advances, pp. 80–87. In: Snag Habitat Management: Proceedings of a Symposium. General Technical Report RM-99. Rocky Mountain Forest and Range Experiment Station, Fort Collins, CO.

Carey, A.B., Thysell, D.R., Villa, L.J., Wilson, T.M., Wilson, S.M., Trappe, J.M., Colgan III, W., Ingham, E.R. and Holmes, M. 1996. Foundations of biodiversity in managed Douglas-fir forests, pp. 62–82. In: Pearson, D.L. and Klimas, C.V. (Eds) The Role of Restoration in Ecosystem Management. Society for Ecological Restoration, Madison, WI.

Chambers, J.C. and Wade, G.L. (Eds). 1992. Evaluating Reclamation Success: The Ecological Consideration – Proceedings of a Symposium. Northeastern Forest Experiment Station GTR-NE-164. Northeast Forest Experiment Station, Radnor, PA.

Duffy, P.D. and Ursic, S.J. 1991. Land rehabilitation success in the Yazoo basin, USA. Land Use Policy 8: 196–205.

Ferris-Kaan, R. (Ed). 1995. The Ecology of Woodland Creation. John Wiley and Sons, London.

Gupta, G.N. 1990. Integration of moisture and fertilizer management practices for early growth and establishment of *Eucalyptus* on a skeletally degraded dry land. Int. Tree Crops J. 6: 123–142.

Harmer, R. and Kerr, G. 1995. Creating woodlands: To plant trees or not, pp. 113–128? In: Ferris-Kaan, R. (Ed) The Ecology of Woodland Creation. John Wiley and Sons, New York.

Jordan III, W.R., Gilpin, M.E. and Aber, J.D. (Eds) 1987. Restoration Ecology: A Synthetic Approach to Ecological Research. Cambridge University Press, Cambridge.

Lenz, R. and Haber, W. 1992. Approaches for the restoration of forest ecosystems in northeastern Bavaria. Ecol. Model. 63: 299–317.

Lugo, A.E., Parrotta, J.A. and Brown, S. 1993. Loss of species caused by tropical deforestation and their recovery through management. Ambio 22(2–3): 106–109.

Luken, J.O. 1990. Directing Ecological Succession. Chapman and Hall, London.