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50. Different types of reforestation. Lamb, D. Chapter 4 in Regreening the bare hills. World Forests 8, p. 135-155. 2011.

Chapter 4
Different Types of Reforestation

> The art of forestry is different from that of paddy or dry field. Though one may be spared flood, drought, frost or snow, he still must give general care to the area for about ten years before withdrawing human effort. If this is done, the forest will be as though filled with a treasure whose virtue is so immense it will reach to one's children and grandchildren. Truly, one's prosperity will be eternal.
> Mikami Gennosuke, forester from Tsugaru during Japanese Edo period.
>
> (Quoted by Totman 1989, p. 124)

Introduction

Previous chapters have argued there are a number of potential advantages in reforesting degraded lands and that such reforestation has the potential to improve human well-being and help conserve biological diversity. But there are different ways of achieving this. In the recent past most large-scale industrial reforestation schemes have relied on even-aged plantations involving a single species. Many of these species were fast-growing exotics used for pulpwood and the rotation lengths used were often less than 10 years. Such plantations can produce large amounts of a homogenous timber product very efficiently and are ideally suited for industrial enterprises. However, they are as useful in situations where landholders have other objectives. For example, some growers might wish to produce higher value timbers that take longer to grow while others, including many smallholders, might wish to produce goods other than timber. Likewise, some government agencies and NGOs may be more interested in forms of reforestation that protect watersheds or provide habitats for threatened wildlife and have no intention of harvesting timber or NTFPs from their plantings. These quite contrasting objectives mean the standard industrial model should not be seen as the only way in which reforestation can be done. Rather, it is simply one of a variety of silvicultural options that might be used depending upon the land owner's objectives.

D. Lamb, *Regreening the Bare Hills*, World Forests 8,
DOI 10.1007/978-90-481-9870-2_4,

The situation is similar in agriculture. In discussing the reasons why large state-sponsored agricultural schemes often fail. Scott (1998, p. 262) wrote:

> The simple 'production and profit' model of agricultural extension and agricultural research has failed in important ways to represent the complex, subtle, negotiated objectives of real farmers and their communities. That model has also failed to represent the space in which farmer's plant crops – its microclimates, its moisture and water movement, its microrelief, and its local biotic history. Unable to effectively represent the profusion and complexity of real farms and real fields, high-modernist agriculture has often succeeded in radically simplifying those farms and fields so they can be more directly apprehended, controlled, and managed.

The objective of this chapter is to review the main methods that can be used to reforest cleared or degraded land. It emphasizes that there are a number of silvicultural approaches that might suit the 'profusion and complexity of real farms and real fields'. This chapter identifies three broad forms of reforestation. It also explores how new forests might be buffered against ecological and economic changes that could occur in the future and the implications this has for silvicultural practices.

A Conceptual Model of Degradation and Forest Restoration

We are primarily concerned here with the reforestation of 'degraded' land. As discussed earlier, 'degradation' is a term that is fraught with definitional problems and, depending on their condition, 'degraded' lands will differ in their ecological attributes and in their capacity to recover unaided. In Chapter 1 degradation was described as occurring when human activities had caused a reduction in the productivity, economic value or amenity of a site. This is shown conceptually in Fig. 4.1. At point A the undisturbed ecosystem has a certain level of biodiversity and structure or biomass. Changes caused by deforestation reduce both biodiversity and structure leaving the site in a degraded state (B). Further disturbances such as wildfire or overgrazing may lead to even more degradation (C). At this point few of the original species remain and the site is occupied by a variety of grasses and broad-leaved weeds. Logging (rather than agricultural clearing) may also cause changes although these are usually much less transformative. So, carefully managed Reduced Impact Logging might move the system to D while unregulated and poorly managed logging might move the system to E. Compared with the situation at D, some species may have been lost and there would be substantial changes to forest structure. In some cases a number of new, so-called secondary species may colonize the site. Some of these may be exotic weed species. Many would regard E as also being degraded like B and C.

Natural recovery can occur at some of these new states but not from others. So, regrowth from D may be sufficiently rapid to allow a subsequent logging operation after, say, 30 years and most of the original species will have remained present at the site. Indeed this is what happens in a well managed logging operation. Recovery after the poorly managed logging (E) may take much longer (and there may be some change in the final species composition because new species, possibly including some exotics, may have permanently colonized the site). Recovery from the degraded conditions at B and C are likely to be more problematic. Natural recovery may occur relatively

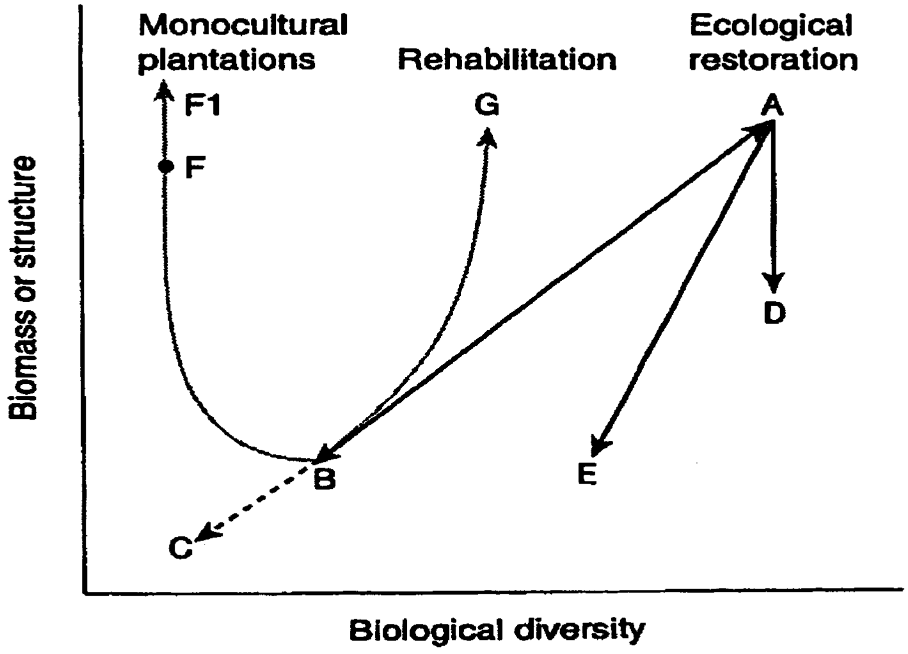

Fig. 4.1 A conceptual diagram showing the relationship between ecological restoration, rehabilitation and monocultural plantations. At point A the original forest has a certain biomass/structure and biodiversity. Various types of disturbance can change its condition. It is considered degraded when it loses both biomass/structure and biodiversity and arrives at point B. See text for further explanation

rapidly where the degraded site is not large, soils remain intact and where species remain on the site (as seed stored in the soil, as seedlings or as old root material) or can disperse into the site from nearby intact forest. Such might be the conditions after a site has been briefly used for, say, shifting cultivation. But this recovery may not occur where the site has been cropped for a number of years or has been occupied by grasses. In this case changes to key processes (e.g. nutrient cycling) or natural feedback mechanisms (e.g. seed dispersal) may have caused the system to move to an alternative state from which recovery is difficult or, at best, very slow.

Under these circumstances there are three ways in which reforestation might be undertaken. One is to restore the original forest and re-establish the former composition and structure. This means promoting the transition from state B or C to state A. This can be done by facilitating natural regrowth or by planting seedlings of the original species. This approach will be described here as *Ecological Restoration*. The second is to forgo trying to regain state A but to plant a monoculture timber plantation (or agricultural crop) using a species that is commercially attractive and able to tolerate the conditions now present (e.g. the site might now have less fertile soils). In this case, a new state (F) is established. If various forms of site amelioration including fertilizers are used the biomass may increase beyond that of the undisturbed forest (F1). There is no particularly appropriate term to describe this and so it will be simply referred to here as a *Monoculture Planting* (cf. Lamb 2001; Lamb and Gilmour 2003). The third approach lies between these two. It involves fostering the establishment of some, but not all, of the original species such that the biomass and most of the structure are re-established though not the original biodiversity. The new state (G) may eventually have a similar biomass or structure

Fig. 4.2 A plantation monoculture of *Eucalyptus urophylla* in Vietnam. Over time a thick groundcover of grasses and herbs develops and provides good protection against erosion

to that of the original forest but a lower level of biodiversity. This approach will be referred to as *Rehabilitation*. Examples of the three approaches being used in the field are shown in Figs. 4.2, 4.3, and 4.4.

The three approaches are necessarily a simplification of the much wider variety of ways in which reforestation of a degraded site might be undertaken and each will be described in rather more detail below. All are similar in that they attempt to develop productive forests. However, they differ in the extent to which biodiversity or structural complexity is regained and in their capacity to supply various goods and ecosystem services. They also differ in the rate at which their objectives are likely to be achieved. Many Monoculture Plantations achieve their objective and are felled after less than 10 years while some Ecological Restoration projects may take more than 100 years to be completed. Some of these terminological issues are discussed further in Box 4.1.

Choosing Between Ecological Restoration, Plantation Monocultures and Rehabilitation

The choice between these three reforestation alternatives depends on the land owner's objectives and whether they are interested in forests producing goods, ecosystem services or a mixture of both. The advantages of each reforestation approach are

Fig. 4.3 Ecological restoration of rainforest in central Thailand. The site was restored using seedlings and seed and is now about 15 years old and contains a large number of the original tree species

reasonably clear but any choice must also pay attention to some of the disadvantages each has. Some of these advantages and disadvantages are outlined below.

Advantages and Disadvantages of Ecological Restoration

Restoring forests on degraded lands to recreate the former forest is surely a worthy goal since it will restore biodiversity and generate a variety of ecological services although not necessarily commercial goods. It might be achieved using natural regeneration or by planting seedlings (Table 4.1). But restoration, as defined in this way, can present a host of difficulties. The first of these is that the target may be unclear, especially when deforestation took place many years earlier and no remnants of the original forest now remain. This is an obvious problem for those in highly modified and long-settled landscapes such as those in Europe but it also applies to many locations in the Asia-Pacific region where all that may be known is perhaps the names of a handful of the more dominant former canopy tree species.

A second difficulty concerns changes to the physical environment. Degradation can change soil chemical and physical properties, hydrological conditions and fire regimes. Such changes may make it impossible for the original species to re-establish at the site,

Fig. 4.4 Forest rehabilitation at a former open-cut bauxite mine in northern Australia. A new forest with a variety of trees and understorey plants has been established. After 15 years it resembles the original open monsoonal forest although the species composition is different because of the changed environmental conditions (Photo: Peter Erskine)

at least in the short term, because these can no longer tolerate the present site conditions. Again, a species-rich forest may develop but it will not match the original forest.

A third problem is that, following deforestation, some original species may have been lost through extinction or exotic species may have invaded and become naturalized and be impossible to eradicate. Such changes can affect ecological processes within the new ecosystem which, in turn, affect some of the remaining native species. Obvious examples are where a missing species was an important seed disperser or a new species is an aggressive weed. These may not prevent a species-rich new forest being established but it will be qualitatively different from the original forest. And fourthly, environmental conditions at the site may be changing as part of a longer-term climatic change perhaps induced by global warming. Thus there might be might be changes in temperatures, rainfall seasonality or fire regimes. These may alter the capacity of some of the original biota to regenerate or reproduce at particular sites and

Box 4.1 Some Definitions

There is considerable variation in the terminology used to describe the ways forests can be established and this debate continues (Carle and Holmgren 2003). The terms below will be used as follows:

Reforestation is used here as an all-embracing term covering the development of forests by both natural regeneration and planting irrespective of the species or planting designs that are used. Thus it includes forests created using Monoculture Plantations, Rehabilitation and Ecological Restoration. Although the term *restoration* is also often widely used as a general descriptor of reforestation it will be avoided here to avoid confusion with the more specific term Ecological Restoration (see below). In most of the cases discussed it is assumed that forests occupied the sites being reforested within the previous 50 years. It contrasts with the term *afforestation* which is generally used to describe reforestation at sites that have never been occupied by trees or have not had trees for >50 years.

Natural regeneration is the re-establishment of native trees and other plants by self-sown seed or by vegetative regrowth.

Monoculture plantations are plantings of single species carried out at the same time. The species may be indigenous or exotic species and are commonly established at densities of around 1,100 trees per hectare. Most are grown for a fixed period or rotation after which time the plantation is harvested and re-established. Only some of the natural processes and functions are recovered. The productivity of the plantation may exceed that of the natural forest because of the species used, site preparation or fertilizer applications.

Rehabilitation describes the development of new forests made up of some, but not necessarily all of the original species at a site. Rehabilitated forests may also include some exotic species. Most are developed by planting or seeding but some natural regeneration may also be allowed to develop. There can be considerable variation in the number of species used and in the management methods applied. The former productivity and many of the original ecological processes are usually recovered.

Ecological Restoration is the process of assisting the recovery of an ecosystem that has been degraded, damaged, or destroyed (SER 2004). Recovery takes times and an ecosystem can be said to be restored when it contains sufficient biotic and abiotic resources to continue its development without further assistance or external subsidy. In contrast to those establishing monocultural plantations or rehabilitating degraded lands, those seeking to ecologically restore forests often aspire to re-establish the pre-existing biotic integrity in terms of species composition, community structure and ecological functioning. Ecological Restoration might be achieved through natural regeneration or by a combination of planting, seed sowing and natural regeneration.

Table 4.1 Reforestation methods to suit different objectives

Reforestation method	Reforestation objective		
	Monoculture plantings	Rehabilitation	Ecological restoration
Natural regeneration (discussed further in Chapter 5)		Is the outcome when complete natural regeneration is not possible; may also be achieved through enrichment planting using native or exotic species	Likely to be achieved where undisturbed natural forests are nearby
Single-species plantings (discussed further in Chapter 6)	Achieved with native or exotic species grown using short or long rotations		
Mixed-species plantings (discussed further in Chapter 7)		Achieved when multiple species of trees and shrubs grown in temporary or permanent mixtures at the same site	
Restoration plantings (discussed further in Chapter 8)			Likely to be achieved when a high proportion of native plant species are planted or sown and colonists from nearby intact forests are able to reach the site

so change their spatial and altitudinal distribution. On top of these difficulties are the practical problems inherent in trying to re-assemble an ecosystem about which the restorationist has incomplete knowledge and, moreover, having to do this at a scale that will allow some of the key ecological processes to operate. In the case of plants, how might one regenerate the many hundreds of species and life forms once present?

All this means that the task of restoring former forests is indeed a formidable one. But it is not necessarily an impossible undertaking and some very promising attempts have been made despite the difficulties listed here. These have involved using natural regeneration, plantings and direct seeding and will be discussed further in Chapters 5 and 8 respectively. Interestingly, they do not necessarily involve tracking directly back up the B-to-A pathway as Fig. 4.1 implies. Because of this it is useful to have a series of benchmarks with which to monitor the system's development and show whether the new system is on an appropriate successional trajectory. Some possible benchmarks are shown in Box 4.2.

The extent of changes induced by humans and the difficulty of restoring degraded lands led Oosthoek (2008) to argue (under a sub-heading 'Nature is finished;

Box 4.2 Attributes of Restored Ecosystems (Society for Ecological Restoration International 2004)

1. The restored ecosystem contains a characteristic assemblage of species that occur in the reference ecosystem and that provide appropriate community structure.
2. The restored ecosystem consists of indigenous species to the greatest practical extent.
3. All functional groups necessary for the continued development and/or stability of the restored ecosystem are present or have the potential to colonize by natural means.
4. The physical environment of the restored ecosystem is capable of sustaining reproducing populations of the species necessary for its continued stability or development along the desired trajectory.
5. The restored ecosystem apparently functions normally for its ecological stage of development and signs of dysfunction are absent.
6. The restored ecosystem is suitably integrated into the landscape with which it interacts through abiotic and biotic flows and exchanges.
7. Potential threats to the health and integrity of the restored ecosystem from the surrounding landscape have been eliminated or reduced as much as possible.
8. The restored ecosystem is sufficiently resilient to endure the normal periodic stresses in the local environment that serve to maintain the integrity of the ecosystem.
9. The restored ecosystem is self-sustaining to the same degree as its reference ecosystem and has the potential to persist indefinitely under existing environmental conditions although the composition and other attributes may evolve as environmental conditions change.

conservationists admit defeat') that future restoration would largely be concerned with re-assembling new ecosystems using non-native species rather than trying to return to the historic state. Hobbs et al. (2009) have referred to these as 'novel' ecosystems. As a generalization this may be an excessively gloomy prognosis but it is likely to be correct in at least some degraded landscapes. In these cases the best options may be to develop multi-species, self-sustaining and resilient ecosystems that contain as many as possible of the original biota but which also make use some non-indigenous species. Although these will not be identical with the original ecosystems they may be able to restore most of the original functionality and provide a good starting point for adapting to future changes such as those induced by global warming. In the present terminology these types of plantings might be described as 'rehabilitation' and will be discussed further below.

The problems involved in restoring wildlife populations deserve particular comment. Deforestation and fragmentation will have made some species locally extinct but allowed the population of some others to increase. In most cases restorations can only seek to restore habitats and food supplies and hope that sites will be naturally recolonized from residual populations of these species still present elsewhere in the region. Such recovery may or may not occur. When it does occur it will usually take time because some habitat features only develop slowly (e.g. hollow-bearing trees, logs on ground). Wildlife translocation programs are rarely possible even though these species may influence pollination, seed dispersal, seed predation and regulate trophic structures. And some wildlife such as large herbivores (e.g. elephants) or large top-level carnivores (e.g. tigers) are unlikely to be welcomed by nearby human communities. The functional consequences arising from the absence of species such as top-order predators in newly restored forests are mostly unknown although Soule and Terborgh (1999) argue they may be profound. Large areas of fully restored forests are needed for the conservation of these species but may be hard to re-establish. On the other hand, some species may be able to use the so-called novel ecosystems referred to above and survive in a mixture of fully restored forest and rehabilitated forest.

Advantages and Disadvantages of Plantation Monocultures

Large plantations involving a single tree species have been established in many parts of the world and they are common throughout the Asia-Pacific region. These can use native or exotic species and may be grown on short or long rotations (Table 4.1). Some have been profitable and regarded by their owners as highly successful. Others have failed because the species chosen were unsuited to the site, seedlings were of poor quality, site preparation was insufficient or weed control, fire control, pests, diseases or a host of other issues were not dealt with. Few have involved the species forming natural mono-dominant forests (Box 1.1) presumably because any ecological advantages these species have is outweighed by their economic disadvantages.

Intensively managed plantation monocultures can suffer productivity declines over time. Pulpwood plantations that use fast-growing exotic species are very prone to nutrient losses because the logs being harvested contain a high proportion of nutrient-rich sapwood and because many nutrients can be lost by leaching each time the site is cleared and replanted. This nutrient drain can lead to productivity declines in later rotations unless the loss is remedied. Of course such problems face all those seeking to reforest degraded sites but the problems can be more acute if only a single species is being relied upon.

But other kinds of failure have occurred as well. In some cases market conditions have changed after the plantations were established and the species prove to be unsuited to the new timber markets. In other cases the expectations of society change as living standards rise. People want cheap timber but they also want recreational opportunities, wildlife conservation and aesthetically pleasing landscapes. Monoculture plantations are efficient at producing particular goods but may be much less able to generate these various ecosystem services.

Advantages and Disadvantages of Rehabilitation Plantings

Rehabilitation plantings form much of the continuum between restoration plantings and monoculture plantations. These plantings are not attempts to restore a forest to some bygone condition nor do they necessarily seek to maximize the production of a single product. Instead they can be seen as a way of accommodating the objectives of a variety of stakeholders and as a means of adapting to the new environmental and economic conditions now present (or likely to develop in future). Plantings such as these were referred to earlier as 'novel ecosystems'. Rehabilitation can involve planted seedlings, natural regeneration or a combination of the two (Table 4.1). If they are well-designed rehabilitation plantings can improve both human well-being and ecosystem integrity (Lamb and Gilmour 2003). The former occurs when there are direct financial benefits generated by reforestation. The latter is improved by increased functional effectiveness and ecological naturalness. The dilemma for those interested in using this approach lies in designing types of reforestation that achieve both elements. What form should these take? Just how many species are needed? Which particular species should be used and in what proportions should these be planted? The answers to these questions depend on the circumstances at particular sites meaning that the label 'rehabilitation' covers a variety of silvicultural approaches and techniques.

How do people make choices between Ecological Restoration, Monoculture Plantations or Rehabilitation? Some people will have an over-riding preference for one particular approach because of their wish to generate a financial return or to improve ecosystem functioning at a particular location. Others will choose after considering what each alternative offers and what it might cost to implement. But attitudes and preferences can change over time as changes occur in the economic or ecological environment or as landowners personal circumstances change. For example, extensive natural regeneration in the understorey of a plantation might lead to the decision that a production forest has more value for conservation that for timber production. Likewise, a landowner may choose to delay felling a mature plantation forest because of it's aesthetic appeal. Other ways in which the balance may change over time as new forms of management are adopted are shown in Fig. 4.5. One consequence is that while it might not be possible to achieve the preferred balance immediately, it may be possible to work towards this over several decades as economic and social circumstances allow (Lamb et al. 2005).

Degradation and Resilience

There is an additional element that can help inform this design process and that concerns the desirability of making the new forests more resilient to future disturbances. Ecologists use the term resilience to refer to the capacity of any system to absorb disturbances and remain in the same state with essentially the

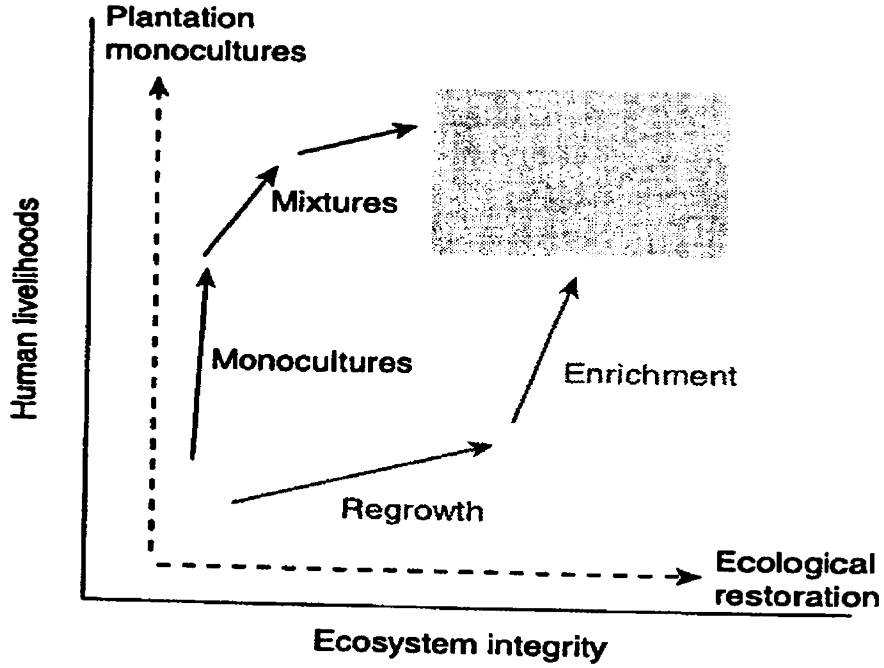

Fig. 4.5 Those undertaking reforestation must make a trade-off between improving human livelihoods and improving ecosystem integrity. Plantation monocultures can help improve livelihoods while Ecological Restoration is best able to improve ecosystem integrity. But, over time, it may be possible to modify the forms of silviculture being used to achieve elements of both goals

same structure, functioning and feedback mechanisms (Berkes et al. 2003; Gunderson 2002). The more resilient the system, the greater the amount of change it can undergo and still maintain these same controls. A little background about what is known as resilience is necessary before exploring the implications it has for reforestation choices.

The current 'best practice' in agriculture and plantation forestry seeks to increase the productivity of certain species. This is done by breeding productive varieties of preferred species, fertilizing these and taking the system to some optimum state. Managers then seek to hold that level of productivity and make that state sustainable (Walker and Salt 2006). Productivity is maximized by controlling each aspect of the production cycle. Managers usually assume that incremental improvements can be made and that change is linear (thus better site preparation and improved fertilizer technology will lead to more production) but rarely take account of what might be happening elsewhere in the landscape away from the farm or in processes operating at smaller scales such as among microbial populations in topsoils. In addition, they often ignore the changing environmental and economic conditions in which their production system is enveloped. This approach contrasts with the various forms of agriculture practiced by most traditional farmers where a variety of species were grown, often on the same piece of land to generate a diversity of foods and other goods and build a degree of insurance into the system.

Over the years, the 'best practice' model has worked reasonably well in agriculture as well as in plantation forestry and productivity levels in both have increased. Or, at least the model has worked until recently. There are now signs in many parts of the world that it has some critical weaknesses and that it is working less well now than it did in the past. Sometimes the model has even failed after a comparatively short period of farming. Examples of these failures are the increasing levels of chemicals (fertilisers and pesticides) needed to sustain productivity and the increasing areas of degraded lands that are beginning to appear in many agricultural landscapes.

Walker and Salt (2006) point to a paradox. Optimizing agricultural or forestry production is supposed to be about promoting efficiency. This might be expressed as greater food production or timber volumes per hectare. But optimization is also about reducing redundancies by eliminating all those species that are not immediately valuable. The problem with this is that ecological systems are usually configured by interactions between a number of species and these relationships are mostly defined by extreme events and not average conditions. Many species may appear redundant but, in fact, play an important role in maintaining the system when environmental circumstances change (Folke et al. 2004; Walker et al. 1999). In other words, systems with many such species are more resilient. As a result, the more a manager seeks to reduce diversity and optimize components of a production system in isolation from the remainder of the ecosystem as a whole, then the more vulnerable such a system becomes to changes and disturbances. That is, the optimized systems lack insurance. These simplified systems may be temporarily 'efficient' but they are also fragile. This sounds counter-intuitive but it appears to be the conclusion emerging from a number of studies. As Walker and Salt (2006, p. 7) note:

> The paradox is that while optimization is supposedly about efficiency, because it is applied to a narrow range of values and a particular set of interests, the result is major inefficiencies in the way we generate values for societies

In the present context one of the aims of reforestation is to improve the livelihoods of smallholders by reducing their vulnerability to future shocks. If Walker and Salt (2006) are correct the 'maximum sustained yield' model may be a flawed and risky way forward.

Resilience in Social-Ecological Systems

This issue forms part of a broader question concerning the way ecosystems function in the face of change or disturbances. It is well-known amongst ecologists that ecological systems are non-linear in their trajectories of change and have the capacity to exist in a number of alternative, stable states or regimes in which their structure, function and feedback mechanisms are different (as are the goods and services they are able to provide).

Systems are thought to move through four stages of what is known as an adaptive cycle (Gunderson 2002). The commencement of the cycle is a colonisation or exploitation stage when un-utilised resources are acquired. This is followed by a conservation stage as the system matures and inter-connections between components of the system develop. But, the more inter-connections and the stronger these are, then the less flexible the system becomes and the more susceptible it is to external shocks. Eventually a disturbance will cause the system to break up and pass into a re-organization phase and the cycle begins again. The release and re-organization phases are both chaotic and rapid. It is during these stages that innovations and adjustments can be made.

The operation of this cycle can be seen in natural ecosystems that acquire biomass and diversity as they mature. Over time, a greater proportion of the system's nutrients are immobilised in biomass and more of the species become long-lived habitat specialists to the exclusion of shorter-lived, generalist species. Many form highly specialised mutualistic relationships. Eventually the system loses resilience and becomes less able to tolerate disturbances or shocks and the system collapses when the inevitable fire, storm or insect outbreak eventually occurs. A similar pattern can be found in socio-economic systems. In the early stages of a cycle the participants are innovative and non-hierarchical. Over time there is an increase in social and economic capital. However, the society gradually evolves into a more staid and socially conservative system with strong conventions and less flexibility. There are connections across a network of relationships in this system but information in these tends to flow from a centralised decision-making body. Innovation and experimentation decline. Over time the system becomes increasingly brittle until, finally, it is confronted by political or economic challenges it has not faced before and is unable to respond (Homer-Dixon 2008).

If the disturbance forms part of the historical disturbance regime the system will probably recover and the cycle will begin once more. If, on the other hand, the disturbance or shock is unusually severe the system may be pushed over a threshold into a new state from which recovery is slow or impossible. The conversion of forests to grasslands seen in some tropical areas and caused by the unusual combination of agricultural clearing and fire is an example of such a transition.

Rather than thinking of just ecological or social or economic systems it is more useful to think of a combined entity or what Gunderson (2002) and Walker et al. (2006) have referred to as a social-ecological system. Following a disturbance a social-ecological may recover and re-establish the same adaptive cycle with essentially the same biota and controlling economic variables. But if the system has been forced across a threshold then an entirely new set of biological communities, socio-economic structures and controlling variables will develop. Such changes occur when the adaptive capacity of the system has been exceeded and it is 'degraded'. Crossing one threshold in a social-ecological system can trigger changes in other components of the system. This means that ecological degradation may be caused by socio-economic events but this, in turn, is likely to generate other economic changes and force the system to cross additional economic and social thresholds as well.

In assembling new social-ecological systems or re-organising degraded ones it is important to find ways by which resilience is enhanced to avoid the development of fragile conditions that pre-dispose the system to collapse. Diversity is at the core of resilience. In ecological systems there are three types of diversity that are important. One is the diversity of *functional types* or species having a similar impact on ecosystem processes. For example, whether the ecosystem has shade-tolerant as well as light-demanding species, nitrogen-fixers, decomposers, herbivores, carnivores, pollinators and seed dispersers. Representatives of all these groups are needed if the system is to function effectively. A second type is the diversity of species able to generate a particular *functional response*. Resilience is increased if there are several species able to perform each of these various functions with some being most effective under some environmental conditions (e.g. dry weather) and different species able to do so in other conditions (e.g. in wet weather). A seemingly redundant species may, under changed environmental conditions, become very important to the way a system functions (Diaz and Cabido 2001; Elmqvist et al. 2003). A third type of diversity is that occurring at a *landscape* level rather than just at a site level. A species-rich landscape means that local extinctions can be overcome by recolonisation from populations elsewhere in the landscape. A small amount of diversity can often restore a significant proportion of ecosystem functioning but, in the longer term, and over larger areas, a much greater degree of functional diversity is needed to ensure ecosystems are able to function consistently.

Within the economic and social components of a social-ecological system a diversity of markets, institutions and sources of knowledge is also important. Thus a system where income is derived from a variety of goods and services that are sold into a number of separate markets is preferable to a system that depends on a single product and a single buyer. Likewise, management systems that use knowledge gained from a diversity of sources, including external sources and traditional ecological knowledge, and that use inputs from a variety of stakeholders to make decisions about natural resources are usually more resilient than top-down forms of management informed from a single perspective. Diversity in social-ecological systems increases the systems capacity for self-organization following a disturbance or shock.

Resilience has a cost. In the short term it is likely to be far more profitable to maximize production and not worry about building resilience. But the longer a system is managed in this way the more likely it is there will be an unexpected ecological or economic shock that will push the system across a threshold (Anderies et al. 2006). Somehow managers must strike a balance between the cost of the short-term benefits foregone by building resilience and the longer-term likelihood of the system collapsing and moving to a new state when resilience is ignored.

Building Resilience During Reforestation

Overcoming degradation usually involves transforming the system to a new state which can generate a larger amount of natural, financial and human capital. As capital increases so does flexibility. There are several implications arising from resilience theory for the ways in which reforestation should be carried out.

Ecological: The first is that patches of remnant forests or areas of secondary regrowth should be protected, however small these are. Such forests can help protect the genetic diversity of plant species needed in reforestation programs. They may also provide habitats for wildlife such as birds or bats able to carry seeds across the landscape. This will be discussed further in Chapter 5. The second implication is that any plantings should involve a variety of species and functional types. Ideally, this diversity should be sought at every site but this might not always be realistic. When it is not possible then diversity should be sought at a landscape scale (i.e. if not alpha diversity then gamma diversity). This will be discussed further in Chapter 7.

Economic: The third implication is that plantings should take account of economic circumstances and, where-ever possible, those designing plantations should seek to provide goods and services for a variety of markets. A plantation producing a single product sold to a single buyer places a grower in a highly vulnerable position and sensitive to economic as well as biological misfortunes. Agricultural and forestry history is littered with examples of problems arising from over-reliance on a single species (Boxes 4.2 and 4.3).

Social: Finally, resilience requires that any reforestation program should ensure that people and institutions are in place to absorb feedback and to innovate, research and develop new knowledge rather than being largely dependent on an external source of technical advice. Ways must also be found to spread this newly developed knowledge amongst those carrying out reforestation. This is often most easily done by developing learning networks which bring together researchers and practitioners. This will be discussed further in Chapter 10.

Reforesting degraded lands is an uncertain business. In many cases new silvicultural techniques must be developed and it is inevitable that mistakes will be made. Adaptive management treats the management process as a series of experiments which are carefully monitored such that adjustments to management inputs can be made if this is necessary (Anderies et al. 2006). The process involves learning-by-doing. Resilient systems are those that use this approach and have the stakeholder networks and monitoring systems in place to respond to ecological, social and economic feedback. They also enable the institution and policy settings to be adjusted where this is found to be necessary. The point of all these interventions is to generate flexibility so that the system can adjust to change and not be degraded again in future.

Some Problems for Those Seeking to Design Resilient Forms of Reforestation

The task of building resilience raises several interesting questions for those undertaking reforestation.

What Sort of Resilience – Specific or More General?

When building resilience should one seek to build resilience towards a particular form of disturbance that is perceived to be more likely such as a wildfire, a windstorm or a change in the market for certain timber products? Or should a more general form of resilience be sought that buffers the system against a variety of disturbances? Choosing to guard against specific stresses such as wildfires may reduce the overall resilience of the system to a wider variety of disturbances or changes such as climate change.

Box 4.3 The Hazards of Single Markets

Fluctuations in prices of agricultural products such as coffee, cocoa or sugar cane are well-known but similar price fluctuations can occur in forest products. Large numbers of people have sometimes been affected when these occur. In the nineteenth century NTFPs rather than timber were the major products harvested from tropical forests and a number of these went through boom and then bust cycles in Southeast Asia. These include gutta percha from *Palaquium* (Knapen 1997; Potter 1997), jelatong or rubber from *Dyera* (Potter 1997) and gambier from *Uncaria gambier* (Colombijn 1997). In all cases attempts were made to domesticate the crop but these attempts eventually failed. The failures were caused by alternative products entering the market (e.g. *Hevea brasiliensis* from Brazil replacing gutta percha and jelatong) or site degradation (e.g. gambier).

A more recent example of a fluctuating market is that of rattan in Kalimantan (De Jong et al. 2003; Michon 2005). In some cases this has been due to drought but in others it was caused by misguided government policies that attempted to regulate export markets. These eventually led to a market collapse. Indonesia has tended to dominate the international rattan trade so that these factors, as well as changes in the Indonesian exchange rate, have had dramatic effects on the profitability of growing rattan elsewhere in the region.

Smallholder production of *Gmelina arborea* in parts of the southern Philippines is an example of a heavily promoted timber species becoming unprofitable. In this case large numbers of farmers successfully grew the trees but were unable to obtain a worthwhile price when timber from these plantations flooded the market at the same time. The experience has driven many farmers in this region out of tree-growing (Pasicolan and Macandog 2007). Something similar appears to have occurred in parts of Vietnam where farmers were encouraged to grow *Eucalyptus* spp. The fast growth of eucalypts and their ability to tolerate degraded sites made them attractive to many farmers. They remain so for farmers near pulpwood markets but are now regarded much less favourably by growers distant from these markets because the market value of small eucalypt logs is low (Hawkes 2000; McElwee 2009; Raintree et al. 2002; Rambo and Le 1996). Both *Gmelina* and *Eucalyptus* remain popular and important plantation species in other places but the examples show that an over-reliance on even widely-used species can sometimes have unexpected consequences, especially where transport cost preclude long distant transport.

How Much Diversity is Needed in Plantations to Generate (Sufficient) Resilience?

Should growers focus on just one single plantation species that is productive in the sites they have available and for which there is presently a good market? Or should they include additional species that are not necessarily as productive or valuable in order to hedge their ecological and economic bets in case present circumstances change? The sheer number of sparsely distributed species in tropical forests suggests many are probably truly functionally redundant. So what is the risk of not using many of these? Risk involves two elements; one is the chance that an event will occur and the other is the magnitude of the adverse consequences if it does. Different plantation owners are likely to have quite contrasting perspectives on both elements with large industrial plantation owners taking a different view than, say, a small landholder with a limited income. The former, having assessed their circumstances, may decide they are able to continue growing trees for pulpwood using monocultures, especially if they are able to use short rotations and have various financial instruments to shelter them from risk. Some of the latter might well take a different view especially if they are living some distance from industrial markets and the identity of their future market is still unclear. But, even so, these farmers are unlikely to seek to duplicate the diversity present in natural forests.

How to Encourage the Development of Resilient Forms of Reforestation?

Many farmers from across the Asia-Pacific region traditionally practiced forms of agriculture such as shifting cultivation that were highly resilient. These systems evolved over time through experience of change and crisis. But many of these practices are being swept away by deliberate government policies prompting a switch to more sedentary forms of agriculture as well as by exposure to new cash crops, new markets and changes to land tenure systems. There is now a tendency to simplify and intensify cropping systems. In the light of these trends, what decision should a smallholder proposing to reforest part of their land make about resilience? Should they simply focus on maximizing productivity and generating an early cashflow or should they try mimic their former agroforestry systems and reduce vulnerability by establishing mixed-species plantations? And who can advise them? Government agencies advocating simplification and intensification are unlikely to be supportive of a system that gives weight to resilience. These questions are discussed further in Chapter 10 in a discussion about farmers and the partnerships they may form.

Might It Be Easier to Enhance Resilience at a Landscape Scale Rather Than at a Particular Site?

It may be difficult – or unnecessary - to establish highly resilient plantations at every site and perhaps the diversity of functional types may be more easily achieved by aiming to develop a variety of types of plantations in different parts of the landscape? Thus the landscape may become a mosaic of vegetation types including undisturbed natural forests, regrowth forests, plantation monocultures and perhaps rehabilitation plantings. Designing such a mosaic to balance financial and ecological needs is likely to be difficult when only a single landowner is involved but will be even more difficult when there are a range of landowners and other stakeholders. The topic is discussed further in Chapter 11.

Conclusion

Notwithstanding the simple monocultures of exotic species that are commonly used there are, in fact, a variety of ways in which degraded lands might reforested. These differ in the numbers of species planted and in the extent to which they restore ecosystem integrity and improve human well-being. They also differ in their functional effectiveness and in their resilience. Some forms of reforestation are very suitable for producing large quantities of industrial timbers but are less suited for producing the variety of forest goods that are desired by many smallholders. Some forms of reforestation are able to generate ecosystem services such as protecting watersheds but will be much less able to create the habitats needed by certain wildlife.

The circumstances and objectives of landowners or manager will determine which type of reforestation is ultimately carried out. In the past the dominant factor determining this choice for most industrial growers was the expected financial return. But smaller private growers may take a different view. Planted forests differ from most other land uses because of the length of time between when an investment is made and there is a benefit to growers. This means risks are greater and more resilient types of reforestation that can minimize these risks deserve greater consideration.

The following chapters provide a more detailed examination of different forms of reforestation. At its simplest there are two ways in which reforestation can be achieved and these are by natural regeneration or by some form of planting. Natural regeneration is the least costly form of reforestation where it is able to occur although its capacity to produce particular goods and services varies a good deal. Natural regeneration and so-called secondary forests will be discussed in the next chapter. Subsequent chapters will address some of the ways reforestation might be carried out using planted seedlings.

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