

Restoration of degraded ecosystems

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ABSTRACT

There are large areas of degraded lands throughout the world and the size of these are increasing. This report reviews 23 case studies dealing with attempts to restore some of these degraded lands or to prevent further degradation. The case studies include arid and semi-arid lands, tropical and sub-tropical forests and aquatic and marine ecosystems.

The review reveals very clearly that any restoration programme involves dealing with socio-economic problems as well as ecological problems. In fact, the former are often more intractable than the latter. Socio-economic issues emerging from the case studies concerned matters of land ownership, population growth, traditional knowledge, the role of governments, and how success can mean different things to different people.

In the case of ecological lessons the various case studies all highlighted the fact that the key to restoration of terrestrial ecosystem is revegetation. This tends to proceed faster if plants from the original ecosystem remain nearby or can be reintroduced once the disturbing agent is removed.

The report outlines a series of potential indicators of successful restoration. These include biophysical as well as socio-cultural indicators. In each case there are indicators concerned with stability, efficiency and flexibility of the new ecosystem.

This report concludes with a number of technical, social and policy recommendations aimed at improving attempts at ecosystem restoration.

INTRODUCTION

All plant and animal communities are subject to naturally occurring disturbances of various kinds such as wildfires, landslips, droughts or frosts, etc. Thus, all communities exist in a dynamic equilibrium with their environments and any ecosystem may include recently disturbed areas as well as older, less recently disturbed areas intermixed in a complex mosaic of patches. Constant change is a natural and normal condition. Indeed there is evidence that such disturbances help maintain ecosystem diversity.

Humans may influence the disturbance regime in any particular ecosystem. This may be done by affecting some of the naturally occurring disturbances such as by altering the seasonality and frequency of wildfires or by changing the density of grazing animals. But humans can also introduce entirely new types of disturbances not experienced before such as by introducing new kinds of grazing animals or by clear-felling forests using heavy machinery. For this reason, many natural ecosystems throughout the world are being changed beyond the limits within which they formerly varied.

In some cases, when the impact of the disturbance is not too great, these ecosystems respond by minor changes in species abundance or composition. In other cases, where the impacts are greater, ecosystems may suffer a significant loss of integrity. That is, constituent species may lose their ability to interact and maintain both their own status and the structure and function of the ecosystem. There may be a change of species diversity and reduction in overall productivity. In short, such ecosystems may become degraded.

But should all such altered ecosystems be considered "degraded"? Many would argue they should not and cite the example of highly altered but stable and productive agricultural lands. For this reason there is a certain subjectivity in the use of this term and it is difficult to formulate a universal definition. Blackie and Brookfield (1987) note that "degradation" is a perceptual term and implies at least a "rank" scale of relative measurement. That is, members of a particular society may agree that some areas of land are more or less degraded than others but others outside that society may hold a different view. Perhaps degradation can be best thought of as simply a decline in the capability to satisfy a particular use, whether that is agricultural production, nature conservation or some other objective.

Restoration is concerned with reversing such perceived adverse changes. There are various interpretations of what this might actually involve (e.g. Hamilton 1986, Bradshaw and Chadwick 1980, World Resources Institute 1988). In some cases ecological criteria may be of primary importance while in other cases economic criteria may be more important. So, in one situation, restoration may mean attempting to return an ecosystem to something close to the original species

diversity, biomass and mosaic of disturbance patches. Alternatively, it might mean re-establishing a stable and economically productive plant cover using plants and animals native to the area, or with others from outside it, with no particular attempt being made to regain the previous condition. In this report, restoration is used in its widest sense to describe the process of bringing a degraded ecosystem or landscape back to some prescribed, stable and productive condition. Productive, in this context, may mean commercial production or simply biological production. Methods of restoration will obviously vary in each situation.

Most biomes of the world contain areas that have been degraded in some way by human action. In many of these the degradation rates are rapid. For example, Mellilo *et al.* (1985) estimated that around 4.5 million ha of tropical closed broadleaved forest were being transformed into permanently cleared land each year by the late 1970's. Not all of this was necessarily being degraded. Some, for example, was being converted into productive and useful agricultural purposes. However, Grainger (1988) estimates there are at least 758 million ha of tropical land now needing reafforestation. In the case of arid zone ecosystems, Mabbutt (1984) estimated that in 1983 there were 4500 million ha threatened by desertification and that of these, 75 percent were already moderately desertified and 30 percent were severely or very severely desertified.

These rates are profoundly disturbing. Land degradation is not new and some scholars believe deforestation was a significant contributor to the political and economic demise of ancient Greece and Rome (Hughes and Thurgood, 1982). Likewise, Brookfield and Overton (1988) suggest deforestation in some of the higher islands of the Pacific Ocean (e.g. Fiji) may have occurred in prehistoric times rather than in the past millennium. But the magnitude of the degradation revealed by the figures above demands that action be taken to prevent further damage and to restore that which has occurred.

This report describes attempts to do just that. It relies heavily on a series of case studies from various parts of the world. Many of these were discussed at the Varanasi meeting while others have been gathered from the scientific literature. (In each case the author or reference is shown in parentheses at the commencement of the case study.) They vary greatly in detail and scope. In some cases they deal with attempts to restore degraded ecosystems while in others they deal primarily with approaches to developing sustained utilization methods in ecosystems not yet in a degraded state. Each contains lessons useful to those particularly concerned with ecosystem restoration. The report complements an earlier IUCN review by Lovejoy *et al.* (1985).

ECOLOGICAL PROCESSES AND DISTURBANCE

All ecosystems are sustained by a number of key ecological processes. These include:

- (i) the regeneration process: the way plant species are pollinated, their seeds are dispersed and the seedlings become established and the processes of animal reproduction and population dynamics;
- (ii) nutrient cycles: the cycle of nutrients between plants, animals, microbes and soils;
- (iii) hydrological cycles: the passage of water between the atmosphere, soils and plants.

Degradation can occur when these processes are altered or damaged. Thus, logging may alter a habitat by changing the conditions necessary for the regeneration of a particular species. Or the nutrient cycle may be altered when grazing removes too much plant cover and allows erosion to remove a nutrient-rich topsoil. Or the hydrological cycle may change when trees are cleared from a site and the evapotranspiration rate decreases. This may cause the water table to rise and mobilize salt stored deep in the soil profile creating salinity problems lower in the landscape.

Not all disturbances are the same

Although a disturbance may affect one or all of these processes it is important to recognize that not all disturbances are the same. They may differ in terms of their intensity, area, frequency and seasonality. Each element is critical. Thus, the intensity of a disturbance can affect the extent to which species in the original ecosystems remain at a site. It may also influence the nature of the soil surface on which regeneration must occur. The area of a disturbance is important because it may determine the distance over which colonists must disperse to occupy the newly vacant spaces. The frequency of a disturbance affects the types of species able to survive at a particular site; some species may need a long period without a disturbance because they take some years to reach reproductive maturity while others are favoured by more frequent disturbances because they can reproduce quickly but are poor competitors. Finally, the season in which a disturbance takes place can be important because this may determine which species are likely to be able to immediately colonize a site. These examples all relate to the regeneration process but the other key ecological processes can also be affected by different sorts of disturbances in different ways.

Rates of recovery

Some disturbances have little effect, regeneration is rapid and all the various ecological processes recover quickly. But often they have a more lasting impact and the recovery process may take longer. The rate at which an ecosystem can recover from a disturbance is sometimes referred to as its resilience. An ecosystem may be highly resilient because of *in situ* factors such as a persistent soil seed bank, the ability of most of its species to reproduce vegetatively or because its species can produce seed or off-spring quickly. High resilience might also be a consequence of the rapid dispersal or migratory ability of the constituent species. But recovery rates may be slow if these attributes are absent or growing seasons are brief.

Ecosystem resilience is often also related to the previous history of disturbances at a site. Thus, if an ecosystem has been frequently affected by, say, fire it may quickly recover from another such fire because all the constituent species are adapted to fire and the more sensitive species have been eradicated long before. But this does not necessarily mean that the ecosystem will also recover quickly from, say, overgrazing. The capacity of the ecosystem to respond to this new disturbance will depend on the ecological characteristics of the species it contains.

The Recovery Process – Succession

Once a disturbance ceases, some kind of recovery usually takes place. This process is known as succession. There are several views of how natural successions develop. One theory suggests that the disturbed site is quickly colonized by generalist plant species, sometimes referred to as pioneer or secondary species. These are often short lived plants able to quickly produce large numbers of easily dispersed seed. They are usually tolerant of the sometimes extreme or stressed conditions present at disturbed sites (e.g. low soil fertility, high radiation levels, shortage of water). Examples from moist tropical forest ecosystems are *Macaranga* and *Cecropia* species. These early colonists occupy the site but, in doing so, modify it such that more specialized species are then able to colonize. The process is repeated until the succession is dominated by species representative of mature undisturbed communities, i.e. the more specialized primary species. Another theory holds that the earliest site colonizers inhibit the ability of latecomers to colonize the site rather than facilitate their establishment. According to this theory, new species only enter the succession when some of the earlier individuals die (Connell and Slatyer 1977).

There is evidence that appears to support both these theories or models. For example, in some disturbed moist tropical forests the earliest colonists are usually shade intolerant species. However by occupying the site first these appear to

facilitate the colonization of the site by shade tolerant species. To this extent succession follows the first "facilitation" theory. But there is also evidence from moist tropical forest ecosystems of some early colonists occupying sites and excluding any further successional development. Such situations are referred to as blocked successions and exemplify the second "inhibition" model of succession.

A third view is that irrespective of whether early colonists facilitate or inhibit latecomers, the overwhelming influence in the longer term is simply chance. That is, the succession is determined by such things as the type of disturbance, the timing of species arrival, the nature of the residual community left after the disturbance and the climatic conditions following the disturbance.

At present, therefore, there is no comprehensive ecological theory to explain successional development from which we might derive guidelines for assisting ecosystem restoration. But there is little doubt that whatever might happen in the earlier stages, chance events have an important role in determining the long term outcome. This makes it very difficult to predict the eventual species composition of any restoration project.

Thresholds

There is one final class of disturbances that needs particular mention. In some cases it appears that the impact of a disturbance can be such as to push an ecosystem beyond a critical threshold condition from which recovery is extremely slow or perhaps impossible. This may be because all the original species have disappeared or because of some change in the habitat (e.g. a depletion of soil fertility below some minimum level). Ecological knowledge is usually too imprecise to predict without a series of empirical trials, just what this threshold condition might be. This is a significant deficiency since it may mean there is only a small difference between maximizing the sustained use of a particular ecosystem and pushing it into some permanently degraded condition.

If our understanding of the processes by which ecosystems respond to and recover from disturbances is incomplete, the question of what actually happens in field situations in which humans influence both degradation and restoration processes is even more complex and uncertain. It is at this point however that case studies become important sources of information.

CASE STUDIES – ARID AND SEMI-ARID LANDS

1. Livestock development project in the Kalahari, Botswana (*C. Skarpe*)

In the early 1970's, livestock projects commenced in the Kalahari. Their objective was to increase cattle production from the area and, at the same time, reduce overgrazing around villages and cattle posts by providing fenced "ranches" in other areas to the owners of large herds. At the same time, special camps for artificial insemination and for finishing and fattening were constructed. As well, stock routes leading to abattoirs were provided with water.

The main effort was made in western Kalahari where 25 ranches, each 8km x 8km, were constructed. The area has a rainfall of c. 300mm and has a relatively undisturbed savanna. The ranches were granted to the owners of large herds on a leasehold basis. No particular information or education was given to the leaseholders on how to manage their herds or ranges other than to recommend stocking rates that should be used.

Once the scheme started the stocking rates actually used were the same as those used in traditional cattle posts and were often double of those recommended. The cattle were looked after by boys and bushman servants who had neither the authority nor the interest in maintaining fences, or watering facilities, or in improving management methods.

As a result of overgrazing, the original plant cover quickly declined and areas of bare ground increased. At the same time, there was an increase in woody vegetation in many areas.

Although the scheme had been intended to also lead to reduced stocking rates back in the original village areas, this was not as successful as had been hoped. Various efforts were made to control grazing pressure and improve the infrastructure around the villages, but a series of wet years in the mid 1970's encouraged cattle owners to allow their stocking rates in villages to return to their original levels.

The project clearly shows something that was, in fact, known beforehand, namely that the provision of new water points and the spreading out of livestock does not solve overgrazing problems. On the contrary, it spreads it to more and larger areas as the herds multiply. Before any "new" lands are opened for grazing, it should be reasonably certain that stocking rates can be kept below the carrying capacity of the land. This requires an appreciation by livestock owners of the need to use a correct stocking rate. It may be possible to achieve this by education but effective legislation may also be necessary.

2. An integrated land restoration project in Tanzania

(C. Skarpe)

This project covered 125,000ha and was located near Kondoa in the Dodoma district of central Tanzania. The area is hilly with steep slopes, moderately sloping pediments and a fairly flat valley floor. It has an annual rainfall of 800mm and the original vegetation was probably miombo (*Brachystegia* woodland). In fact, the valley floors were cleared for agriculture many years earlier and the hills were largely cleared during the German colonial period in campaign to control tsetse fly. Heavy overgrazing has since caused sheet erosion on the hills and pediments as well as gully erosion up to 15m deep.

Various methods to control livestock numbers were tried and failed. So, in 1979, the drastic step of excluding all livestock from the area was taken. This was only achieved by promising people that animals would eventually be allowed back. Since then, grass cover and production has increased substantially although most species are still pioneers and not especially useful for grazing. The woody vegetation has also increased.

As a result of the improved vegetative cover, particularly of the field layer, erosion has decreased, soil water infiltration has increased and some springs which had been dry for decades are flowing again.

Other methods used to control erosion include contour bands, mainly on arable land, and tree planting. The wide sand riverbeds have been planted with elephant grass and, as the floods are now neither as strong nor as silt laden, channels are starting to form.

Crop production has increased qualitatively and quantitatively. The cultivated areas have increased since areas traditionally saved for dry season grazing can now be used as well. To compensate for the lack of milk, more legumes, beans and pulses, are cultivated. The nutritional status of children in the area is said to be good and certainly no worse than before cattle were removed. More tree crops are being grown and the traditional agroforestry system using *Acacia albida* is being extended to include other species as well.

There is a strong desire amongst the people to reintroduce livestock again. It has been suggested that this be in the form of a small number of "improved" dairy cows and that these be stall fed or grazed in small paddocks with cultivated fodder. People have already started growing grass for this purpose.

Up till the present, the project seems to have been a success. It is worth noting, however, that most of the grasses present are still early successional species. A crucial test of the system will be the reintroduction of livestock. Already the project has been followed by another of 71,000ha further to the south.

3. Restoration of land threatened by desertification in Nigeria (A.O. Isichei)

The dry sub humid zone of Nigeria next to the Sahel has been under threat of desertification since the recent cycle of drought started. Extensive devegetation had occurred in the area because of overgrazing and fuelwood harvesting. Subsequent wind erosion accelerated desertification.

Three approaches to combatting desertification have been initiated. The first of these was reafforestation. Attempts were made to plant fast growing exotic tree species in shelter belts to check soil erosion and reduce soil water evaporation, (Ojo *et al.* 1987). The species chosen were mainly *Eucalyptus* species, Neem (*Azadirachta indica*) and Jojoba (*Simmondsia chinensis*).

The shelterbelts have not been successful. In part this is because they have not been extensive enough but it is also because the original cause of the problem, namely overgrazing and fuelwood harvesting, remains. The reason for this is that the population density is high and unsuitable lands have been used for growing crops. Furthermore many of the introduced species often failed to establish. Local species were not tested because it was believed their growth rates would not match those of the introduced species. There is no doubt they should be extensively tested in future.

In a second approach an attempt was made to reduce the stocking rates of grazing animals. The approach failed because it was done only in a half-hearted manner.

The third approach was to introduce irrigation schemes to the areas near the Niger River and around Lake Chad. It is still too early to judge the success of these although "soil caking" has already been observed in the Lake Chad scheme. What is clear is that the schemes have resulted in an extensive change in land use, not all of which was foreseen or which may be beneficial.

4. Green belts in North Africa (N.H.A. Cole)

Green belts of vegetation have been successful in countries of North Africa from Egypt to Morocco, mainly because there have been no financial constraints to implementing the recommended measures. They have been less successful in other parts of Africa where financial constraints have operated. The green belt concept is simply to create a mosaic of green vegetation which is linked together in a continuous belt. The plants may be fruit trees, vegetable gardens, shelterbelts or village woodlots. Generally the belt is established around towns and villages in a swath several hundred metres wide. In Libya, Algeria and Egypt most of the belt consists of citrus, guava and apple orchards watered by drip irrigation from an

extensive network of pipes lying on the desert floor. Channel irrigation is also being used near the Nile River in Egypt.

5. Traditional environmental protection practices at Sheikh-el-Sadiq village, Sudan (N.H.A. Cole)

The village of Sheikh-el-Sadiq in the Kordofan region of the Sudan illustrates the influence of traditional culture in protecting land resources around a desert village community. The village is on the banks of the Nile River about 80km from Khartoum.

The community has maintained traditional laws and customs which help protect the environment. For example, there are prohibitions on cutting trees in farmlands, fires cannot be lit at certain times of the day because of the risk of wildfire and there are various cultural practices relating to trees. A key to the success of this village has been the support received by the village council from the national government of Sudan. This has helped the enforcement of traditional laws. The village has not acted as a model for others in the region. On the contrary, neighbouring desert villages without the same conservationist traditions have occasionally sent raiders to Sheikh-el-Sadiq to cut firewood. These have been repulsed by local vigilantes.

6. Sand dune stabilization in coastal areas in Africa (N.H.A. Cole)

Coastal sand dunes are common in Somalia along the eastern coast of Africa and in Mauritania along the western coast. In both situations sand dune movement has been caused by devegetation. In Mauritania the main cause was firewood cutting whilst in Somalia the problem was mainly overgrazing. In the latter case cattle have been brought from inland areas and kept in the coastal regions for fattening while awaiting export overseas. Erosion is primarily wind erosion and has caused dunes to move out and bury roads and farmlands.

Reclamation of these mobile dunes involves stabilizing the dunes with native creeping xerophytic grasses and herbs related to the species common on tropical coastal sandy beaches (*Stylosanthes*, *Canavalia*, *Cynodon*, *Sporobolus*). For the xerophytic creepers to establish on the dunes, artificial checker board wind breaks of 0.5 to 1m high are created. Since sand dunes can hold adequate water for plant growth planting of the creepers and drought resistant trees making up the wind breaks (*Acacia tortilis*, *Prosopis juliflora*) and shrubs (*Opuntia*, *Ziziphus jujuba*) is generally done at the beginning of the rainy season in places with an annual rainfall of as little as 80-200mm. The spiny bushes prevent the plants being damaged by the cattle and help stabilize the sand dunes until a grass cover is re-established.

Coastal sand dune stabilization using these techniques has been carried out in Somalia and elsewhere and from the ground seems quite impressive. However, from the air it is clear that the overall impact is still small despite the considerable effort involved and that perhaps the strategy needs re-examination.

7. Reforestation of "Pampa del Tamaruga" in northern Chile
(C.L. Ocana)

A large reforestation project using tamaruga (*Prosopis tamarugo* Phil.) was commenced during the 1970's in the sandless, hyperarid, salty flat known as "Pampa del Tamaruga" in northern Chile. Tamaruga is an endemic leguminous species and was chosen because experiments showed it was able to absorb water through its leaves. Later research revealed it was a phreatophyte and that underground water was its major water source. The plantation programme has had to be slowed because it was discovered the plants were depleting water resources of nearby natural tamaruga forest and also the underground water used by towns on coastal areas to the west.

8. Differing perceptions of rangeland degradation - north eastern Botswana
(Fortmann 1989)

For over 50 years the rangelands of north eastern Botswana have been officially viewed as being heavily degraded and on the verge of an ecological catastrophe. Successive government reports have reiterated this conclusion and recommended drastic reductions in cattle numbers. Local cattle owners have not accepted this advice because their experience has been that the rangelands could and did carry an increased number of animals. In fact cattle numbers tripled over the 50 year period despite the occurrence of four major droughts. Where enforced destocking occurred local hardship resulted.

This contrast between local experience and official prescription over 50 years helps explain why present-day residents are sceptical of government advice even though, this time, it may be finally correct.

The case illustrates the need for official policy to take account of local historical experience when developing management prescriptions if that advice is to be heeded.

CASE STUDIES – TROPICAL AND SUB-TROPICAL FORESTS

9. Forest regeneration on degraded pasture lands in Amazonia (*Buschbacher et al. 1987, Uhl et al. 1987*)

Large areas of Amazonian tropical moist forest in Brazil have been cleared and converted to pasture. Many of these pastures have subsequently been abandoned after only four to eight years of use because of weed competition, insect attack and low soil fertility. The degree and rate of natural reforestation depends on the intensity of pasture use; that is on the length of cultivation, the number of times the site was weeded and burned and whether bulldozing had occurred.

Forest regenerated vigorously on sites having a low intensity of pasture use. It accumulated 80t/ha of above ground biomass after eight years and had a high species diversity. The species at these sites included light demanding pioneer species as well as some typical of undisturbed primary forest that developed vegetatively from old roots and stumps.

Pastures which had received a moderate intensity of use also developed forest after being abandoned but had only half as much above ground biomass, a lower species richness and increased dominance by shrubs and pioneer tree species. Abandoned pastures which had been bulldozed had variable patterns of succession, which in two of the three case studies were dominated by grasses and forbs with less than one tree per 100m. The reason for poor forest regeneration on these intensely disturbed sites was that the disturbance had destroyed the original soil seed pool and left no trees capable of resprouting. Further, little seed dispersal could occur because most tree species in the region depend on animals for seed dispersal and few of these entered these degraded areas from intact forest. Other limitations included soil compaction, seed predation and a harsh microclimate, which limited seedling establishment.

It seems clear that on lightly or moderately disturbed sites these forest ecosystems have a high recuperative potential. Only where the land has been severely disturbed is natural forest regeneration uncertain. This conclusion refers specifically to gross forest structure and function, and does not imply that all forest species with their manifold interactions will return after a disturbance. Furthermore, successional sites can be subject to later disturbances, such as fires, which severely upset the recovery process.

10. Taungya reafforestation and farm woodlots in Sri Lanka

(K.P. Sri Bharathie)

Teak (*Tectona grandis*) reafforestation using the taungya system was commenced in Sri Lanka about 100 years ago. In the north, central and eastern provinces of the island degraded, dry, semi-deciduous forests were leased to farmers for a period of three years. After the degraded forest was felled and burned, the farmer could plant a variety of vegetables on the site together with teak trees supplied by the Forestry Department. An incentive scheme operated to reward farmers for achieving 80 percent tree survival. Farmers were allowed to remove small timber and fuelwood at a concessionary rate. The latter material could be sold by the farmer in nearby towns. No permanent housing was allowed at the site.

Although the system was successful in developing a very valuable teak resource at a low cost to the government (around US\$22 per hectare) it was not entirely satisfactory. One difficulty was that wealthier individuals hired several farmers to act as labourers for them on large 50ha blocks of land. The living conditions of these people were not improved and no permanent villages were established. Only the wealthy individual benefited. Even when the government tried to limit individual holdings to 2ha, rich businessmen found ways of circumventing the restriction.

In 1980, the scheme was suspended in order to preserve the dwindling dry zone forest resources since large areas were also being opened up for irrigated agriculture.

A new Community Forest Programme has commenced to encourage farmers to grow their own wood. Plots up to 2.5ha are given to farmers on a 25 years lease. Propagules, fertilizer and advice are provided by the Forestry Department. As well as growing trees, farmers are entitled to grow cash crops such as potatoes. The scheme is successful since the farmer has a degree of security over his land and an income from the cash crop and from timber harvesting.

11. Wind belt pasture scheme, Sri Lanka

(K.P. Sri Bharathie)

Some parts of the dry montane zone of Sri Lanka were denuded several centuries ago by shifting cultivation and fire. These lands became coarse grassland or farmland and were extremely wind swept. The name "palugama" meaning barren village was given to part of the area.

In the 1950's the Forestry Department began the Wind Belt Pasture Scheme. Wind belts were created using *Eucalyptus grandis*, *E. microcorys*, *E. citriodora* and *Acacia decurrens* (all these are exotic species) and palatable pasture grasses were established between the wind belts. The wind belts became effective after ten years

and land that had been abandoned for a century or more was brought back to productivity. Animal husbandry commenced, vegetable production developed and the area is now heavily populated again.

12. Forest villages of Thailand

(Amyot, 1989)

Large areas of forest in north-east Thailand have been cleared by waves of legal and illegal logging followed by subsistence farmers who penetrated the forest along the logging roads to practice shifting cultivation. These farmers had no legal rights to the land and attracted no government services or infrastructure. Besides causing land degradation the communities remained poor.

Several attempts have been made to halt the practice of shifting cultivation and reforest the area. In one of the earlier attempts shifting cultivators were persuaded to abandon their former practice and to join a work force planting trees. Villages were constructed and provided with facilities such as water, electricity and schools and the workers were given rights to grow crops within the young tree plantations on a rotating basis corresponding to the growth cycle of the trees planted. The scheme worked well but it fell far short of meeting the size of the demand for reforestation and the needs of the rural poor.

A subsequent approach decided to separate the agricultural and food growing activities from the reforestation component of the scheme by creating a series of small scattered fuelwood plantations in combination with the agricultural resettlement component. The area chosen was mostly poor land which was either steep or had shallow soils. Only about 30 percent was flat land with deep soils.

Reforestation was carried out on the poorer land using *Eucalyptus camaldulensis* and *Leuceaena leucocephala*. Around 80 percent of the plantation target of 1,450ha was planted. The major difficulty limiting establishment was the *de facto* rights of squatters in the area planned for reforestation. These people had no legal land rights but, because they paid taxes to the government, felt they had some claim to the land. Reforestation could only proceed after lengthy negotiations. Subsequently all the plantations have been properly weeded and protected from fire indicating a high degree of community acceptance was eventually achieved.

Agricultural development was planned around the idea of relocating shifting cultivators into a series of villages. Each of these village communities would then be provided with basic physical and social facilities such as water, electricity, health and education services. In addition, each would be the focal point for a package of agricultural development programmes.

Farmers were to be allocated 2.4ha of land for their exclusive use plus another 1.6ha on a communal basis, mainly for the establishment of fruit trees. This matter

of land ownership caused major problems, especially in the case of farmers who claimed *de facto* rights to larger land holdings, and one of the most time consuming tasks in the project was the negotiation needed to persuade farmers to accept the need to limit their exclusive land entitlement to only 2.4ha.

One way of achieving this upper limit was to help farmers make more efficient use of their land by better farm management using a variety of crops and to introduce various sideline activities to supplement farm income. These included bee keeping, fish raising, charcoal production and various agro-forestry schemes. In addition, off-farm work in the tree plantations was also made available on a part time basis.

On the whole the project has been very successful and has transformed an area with a degraded environment and unstable social situation into one more similar to the rest of rural Thailand. The major problem with the project is that it was conceived and implemented from the top down and the initial reaction by forest encroachers was very negative stemming from their impression of foresters as law enforcers. The success of the project is due in no small part to the ability of the project managers to overcome this initial hostility and to draw the villagers into the planning process.

13. Land rehabilitation in Madagascar

(J. Sayer)

In one scheme, shifting cultivators have been assisted in installing small scale irrigation works in valley bottoms to enable them to carry out sustained irrigated rice cultivation as an alternative to hill rice. The major obstacle to success has been the occasional large flood that has destroyed these irrigation works. It may be that the scheme will only be successful when the government provides concrete dams and channels. In some areas, tree crops have also been established but, for these to be successful, there needs to be a market for fruits, etc.

In another area a fuelwood planting scheme has been tied to land tenure. Villagers are given seedlings and a plot of land on which to plant them. The performance of the seedlings is monitored every five years, and if they are adequately cared for, the villager is given title to the land at the end of the period.

14. Treatments of degraded tropical moist forests in West Africa

(J. Sayer)

There have been numerous attempts to develop selection and uniform silvicultural systems in the forest of West Africa. Many attempts have also been made to improve forests degraded by logging by carrying out "enrichment planting"; that is, to enrich the logged forest by planting commercially valuable tree species amongst the residual stems. The most common problem with this approach has been that it is costly and that weed species have smothered the planted seedlings.

The current view of the Centre Technique Forestier Tropical, that has extensive experience in the area, is that no planting should be carried out. Instead, economically valuable residual trees should be encouraged by poisoning undesirable species that compete with them and by cutting climbers that impede their growth. This should be done in the years immediately following logging.

15. Reforestation of Imperata grasslands in Papua New Guinea

(D. Lamb)

There are large areas of anthropogenic grassland in Papua New Guinea often dominated by *Imperata cylindrica*. Techniques for reforesting these areas are well established. Provided trees are planted at spacings of about 3m x 3m and planting lines are manually tended about 3-4 times a year for 2-3 years to control grass competition, trees can usually become established and their shade will eradicate much of the grass. *Pinus* and *Acacia* species are especially suitable because their crowns cast a dense shade. Fertilizers can often reduce the time needed to control grass competition. Fire control is, of course, essential.

Although the technique has been successfully tried in many localities, large areas of grassland remain. The reason is that traditional village land owners are not especially interested in rehabilitating their grasslands and are not willing to allow the government to do it for them. Their concern is that by allowing someone else to plant trees on their land they are giving that person a claim to the land itself. In some locations the national government has been able to arrange leases over land to enable it to establish plantations. However, in very few locations has the government been able to buy land, even degraded land, outright.

The dilemma facing the government highlights the fact that ecosystem restoration is often concerned with social problems rather than ecological problems. Interestingly, a very similar situation occurs in parts of Indonesia where large areas of *Imperata cylindrica* grasslands also occur. In a case described by Sherman (1980) the local land users resented government attempts to reforest the lands and, indeed, disputed that the lands were even degraded. A farming system had been developed to make use of the land and the land users (who also claimed traditional ownership) could see no reason to disrupt this by tree planting.

16. Smallholder timber production in the Philippines

(Taguda 1978, Arnold 1979, Caulfield 1985)

On the southern Philippine island of Mindanao industrial pulpwood production has been carried out by a number of small farmers in an operation that helped satisfy the timber needs of a large papermill and, at the same time, successfully settled a number of shifting cultivators. The scheme started in 1968 when the Paper Corporation of the Philippines became concerned that its timber concession on the

island of Mindanao might be threatened by the land clearing activities of resident shifting cultivators. The company decided to try to stabilize the communities activities by fostering tree farming. Each farmer was helped to grow a small plantation of the leguminous tree *Albizia falcataria* on the "marginal" lands of his farm. This species can be grown large enough to fell for pulpwood in eight years. Furthermore, once planted, it can be cut and grown from coppice without the need for replanting. Thus, any farmer planting one hectare with trees each year for eight years would create a forest that provided a continuous financial income.

The idea proved to be very popular. By 1981, 4,000 farmers had joined the scheme. Between them their plantations covered 30,000ha and provided up to a third of the company's pulpwood. Each farm averaged about 10ha. Eight of these were planted with trees and the remainder were used for food production.

Subsequently, however, a number of difficulties have emerged. One was that many farmers found it easier to plant all of their trees at once rather than spreading the process out over eight years. Consequently, they had difficulties in handling the harvesting operation by themselves when all these trees reached maturity and had to pay contractors to help. The company also suffered because its rate of timber supply became more irregular.

A second problem occurred in 1982 when many plantations were badly damaged by a severe typhoon. The company decided to salvage its own trees in preference to those of the farmers. This meant many farmers were unable to sell their only cash crop and so suffered severe financial hardship. Other shortcomings have been that, in time, land other than degraded land has been used in the scheme and that some farmers had difficulties in repaying loans even before the 1982 typhoon.

The scheme was a clever solution to an emerging problem. However it highlights the difficulties that can occur when a rural society is dependent on an attractive but finite single market.

17. Improving shifting cultivation in north eastern India

(P.S. Ramakrishnan)

Shifting agriculture is widely practised in north eastern India where it is known as jhum. The length of the fallow period of the cycle used to be 20 years or more but has decreased in recent years as the population density has increased. In some places, the cycle is now only 4-5 years. This is too brief to allow sustained agricultural production and land degradation is occurring.

There is no scope for restoring a forest cover in the region because of the size of the human population. On the other hand, there does appear to be considerable scope for modifying the present jhum system to allow sustained agricultural

production and prevent further land degradation. This restoration programme has a number of elements.

The first of these is to reduce pressure on the land by developing horticultural or plantation system (e.g. coffee, tea, rubber, fuelwood), built around village cooperatives. People in the region live in small scattered villages and these form a natural basis for such cooperatives.

The second element follows from this and that is to improve the fallow period of the jhum cycle such that fertility is restored within the time period available. Studies by Ramakrishnan (1984) suggest this can be accomplished if the cycle is maintained at 10 years and if fast growing trees and shrubs, including nitrogen fixing such as *Alnus nepalensis*, are used. Fortunately, there are still small areas of the original forest vegetation preserved in sacred groves which act as potential seed sources for these new fallow stages.

The third element is to use shelter belts made up of forest and fruit trees along boundaries to limit leaching losses and losses of ash during the burning season. A fourth element is to improve the economic base of the villagers by introducing better breeds of swine and poultry, by introducing cash crops such as lemon grass or pepper and by facilitating village industries based on crafts such as leather work and blacksmithing.

All of these elements have been shown to help prevent land degradation in the region. However, there is no universal prescription by which they can be implemented. Artificial schemes which seek, for example, to allocate upper hill slopes to forestry, mid slopes to horticulture or plantation crops and lower slopes to cereal production are likely to fail because of the pattern of collective land ownership in the region. A scheme such as this would necessitate a drastic change in land ownership and the rights of individuals to land. Besides, one family might not be able to provide labour for this three tier system and it could disrupt the independence of the family unit. Changes in land use will only be accepted if they take local traditions and local experience into account and build on these. Halting the process of degradation is necessarily a slow process because of the need to demonstrate the efficiency and implications of new practices. Specially designed "packages" may have to be developed for a given cluster of villages.

18. Restoring a tropical dry forest: Guanacaste National Park, Costa Rica (Janzen 1986)

This project is seeking to restore a large area of tropical dry forest in western Costa Rica. The intention is to re-establish the forest on 470km of mostly degraded farmland that lies between two existing National Parks. This will create a new park covering 700km which will be called Guanacaste National Park.

The original landscape of the area included a complex mosaic of habitats. Many of these have been burned, grazed, overcut or farmed over the last 400 years and are now badly degraded. Much of the area is grassland and is subject to frequent wildfires. However, patches of these original habitats are still present and representatives of all the original plant and animal species still remain. These will be critical to the success of the project.

The first step in the restoration programme has involved acquiring ownership of the land. This is being achieved using funds raised by an international public appeal. The intention is that the land required will be bought from the present landowners at current market prices and will then be passed on to the Costa Rica National Parks Service.

The second step is to exclude wildfire. Nearly all fires in the area are anthropogenic. Fires originating outside the park are being excluded by firebreaks or fire lanes created along the boundaries that have grassland. These lanes are strips of land up to 200m wide that are deliberately burned each year to remove fuel and hence create a barrier against subsequent wildfire. Fires originating within the park are being controlled by other fire lanes that partition the area into smaller blocks and so help limit the spread of any fire.

The third step is to help foster recolonisation of the grassland sites by woody plants. In some areas, the exclusion of fires and grazing animals is all that is needed. In other areas, it is necessary to exclude fire but allow some cattle grazing to continue to ensure vigorously growing grasses do not overwhelm the new tree seedlings. Few of the woody plants are eaten by cattle unless grass is in short supply. So, provided the grasses are grazed for a few years, they will survive and eventually overtop the competition.

Recolonization of the grasslands by woody plants depends, of course, on there being seed sources of these plants nearby. In this respect, Guanacaste National Park is fortunate since remnants of all habitat types remain scattered through the area. These remnants contain the plant species as well as the animals needed by many plants for dispersal.

Experience has shown that the first wave of dispersal into a grassland is often mostly wind dispersed seed. This occurs on the downwind side of forest margins and seed can be moved in abundance over 200m. Dispersal across larger areas by such species needs deliberate intervention. Seed can be scattered by hand or seedlings can be planted in groves or strips. Trees with animal dispersed seed have a more diverse pattern of input into degraded areas. This depends on the behaviour of the animals. Some seeds are concentrated in ravines, or on rock outcrops, or around isolated trees used as bird perches. The pattern of succession that occurs on any degraded area therefore depends on a variety of factors and is not entirely predictable.

The final element of the programme concerns the social environment in which the operation is taking place. The programme is fortunate to have available to it considerable information about the ecological requirements of the area's biota. But by itself this knowledge does not guarantee success. Perhaps more important is the requirement that management prescriptions based on this knowledge are consistently applied over the long period necessary for restoration to succeed (perhaps 100–1,000 years). It is for this reason that the programme's managers have already made considerable efforts to ensure that the local population view the project as being economically and culturally beneficial to themselves and their community, even though the actual restoration project itself has only recently commenced. These efforts include explaining to people the nature and value of the resource in their midst as well as offering employment. Those employed are helping to stop fires and poaching as well as plant seed.

19. Restoration of sub-tropical woodland after mining in Australia (D. Lamb)

Stradbroke Island is a large sub-tropical island off the east coast of Australia. The soils are deep podzolic sands and the island is mostly covered by *Eucalyptus* woodlands and heath vegetation. Parts of the island are being mined by open cut mining for the heavy minerals rutile, zircon and ilmenite. The island is close to a large urban area and the miners have been required to attempt to restore the vegetation to its original condition following mining.

The first stage of this restoration programme commences prior to mining when the top 30cm of soil are stripped from the mine sites and stockpiled. Following mining this topsoil is spread over the reconstituted landscape. The purpose of this operation is to save the limited site nutrients as well as the seeds and mycorrhiza contained in the topsoil.

The second stage involves protecting the loose sandy soil from wind erosion prior to the new vegetative cover being established. This is accomplished by spreading brush matting about and sowing a sorghum (*S. alnum*) cover crop which germinates and quickly grows to about 50cm but lasts only about 12 months and does not reproduce.

The third stage involves sowing seed of species originally present at the site. The species sown are mainly the tree species (e.g. *Eucalyptus*, *Banksia*, *Lophostemon*) that are not present in topsoil seed banks or in brush matting. But in addition, various indigenous *Acacia* species are also sown because they are fast growing (and will therefore provide additional protection from wind erosion) as well as being nitrogen fixers. A single dressing of NPK fertiliser is also given to help the new seedlings become established quickly.

The initial results with this method appeared promising. Within a few months about 30-40 species were present at the sites in addition to the *Acacia*. Within a year or so the sites were reasonably well protected from wind erosion by a diverse cover made up entirely of native species. This included both overstorey and understorey species.

After about 6 years however, it became clear that the restoration program badly needed modification. *Acacia* is a component of the woodlands present on the island prior to mining but they were also deliberately added to the new succession to act as "facilitator" species. However the seed sowing densities were too great (enough seed was added to provide several thousand plants per hectare). Instead of facilitating the succession the fast growing *Acacia* quickly overtopped everything else and, by their shade, commenced to exclude these other species.

After a process of trial and error the original 700gm *Acacia* seed per hectare has now been reduced to less than 50gm which allows the other species to persist. The *Acacia* die out after about 15 years by which time the other longer-lived tree species are able to take over their normal role as overstorey species.

CASE STUDIES – AQUATIC AND MARINE ECOSYSTEMS

20. Chinese Dyke – Pond system (*J. Furtado*)

This system, widely used by Chinese in Asia and in Malaysia, has been established on lands badly degraded by tin mining. Following the construction of a series of ponds, the water in these is neutralized by lime, if necessary, and stocked with carp. The adjoining lands are fertilized with 20-40t/ha of organic manure to increase the organic colloids. Vegetable and fruit crops are then planted on these lands, followed by commercial crops such as sugar cane, mulberry or rice. Fenced areas are then built to contain animals such as pigs, poultry and goats. The key to the system is integrating these three elements. This is done by optimizing harvests from each and cycling waste products between each element. While plant products are harvested, waste material can be fed to the animals. These too are harvested but faeces and other wastes are washed into the fishponds together with various human settlement waste. Fish are harvested and sludge from the bottom of the ponds is spread on the crop plants. The cycle is shown in **Figure 1**.

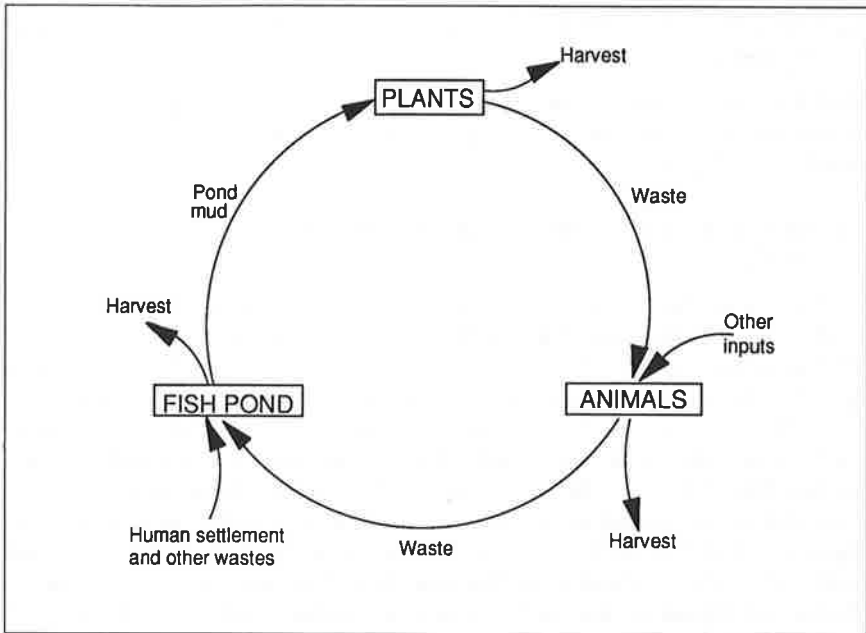


Figure 1: Cycle between fishponds, plants and animals in Chinese Dyke-pond system. The system has several important features. First, water is conserved. Second, nutrients are cycled and also conserved, although it should be noted that the system can easily utilize eutrophified or nutrient-enriched waters. Third, it leads to a diversity of produce and, therefore, income sources. Finally it creates links between rural families and urban-industrial sectors.

21. Mangrove afforestation project in Bangladesh

(Muhmud-ul Ameen)

The coastal areas of Bangladesh are frequently affected by severe cyclones. These and tidal bores have caused serious damage in low lying areas in the Bay of Bengal. The problem is particularly acute in newly formed land areas at the mouth of some of the country's major rivers. A major afforestation programme was commenced in 1973 to protect coastal areas exposed to cyclones and tidal bores and to stabilize the new land areas. Between 1973 and 1985 some 71,000ha of plantation were established using *Avicennia alba*, *Avicennia officinalis* and *Sonneratia apetala* on newly formed land areas, *Acacia arabica* on embankments needing stabilisation and *Casuarina* in sandy beach soils. The trees were planted, mostly as seedlings, about 1.2m apart and recently planted areas have had a 90 percent survival rate. In the beginning, trees were established in May-June. However, many of these were washed away by waves in the next monsoon. Current practice is to mostly plant in

September-October, which gives the trees more time to become established before the next monsoon.

Recent cyclonic events have demonstrated the efficiency of the programme. Newly afforested areas have withstood the cyclones quite well while unprotected areas have been badly affected.

22. Sustainable harvesting of mangrove forest, Malaysia

(J. Davie)

In many parts of the world, mangrove forests have been exploited with devastating results. One mangrove forest that has been successfully exploited, however, is that at Matang on the west coast of peninsular Malaysia. The essence of the silvicultural system is that even aged stands of *Rhizophora* are clear felled in small patches every 30 years. Forest productivity reaches a peak after only 18 years but the longer cycle is maintained to ensure sufficient propagules are produced to allow regeneration. The scale of the operation is large with over 600 charcoal kilns being sustained by the operation; the forest is now in its fourth cutting cycle and regeneration is still being successfully achieved. A similar forest is also being exploited in nearby Thailand. In this case, however, the cutting cycle is much shorter and regeneration is poor. The system requires a good deal of skill and community participation to work. Besides integrating the cycle within the wider economic and social context, benefits and profits must also be fairly shared.

23. Degraded Coral Islands – Australia

(J. Davie and E. Winter)

The Great Barrier Reef on the east coast of Australia contains a large number of continental islands and coral cays. At the southern end of the reef complex there are 15 coral cays formed on patch reefs. These vary in size from one hectare to 110ha. Many have a long history of use; but on most the vegetation and the fauna are still largely intact and are national parks. Several, including some that are also now national parks were briefly exploited for guano, and one of these – Lady Elliot Island was essentially cleared of its forest cover as rich and deep guano deposits were removed between the 1860's and the turn of the century. This island of 40ha, and Heron Island further to the north now contain tourist resorts. Heron Island was never mined but recreational use, the development of the resort from the 1930's to the present day, and the development of a research station, resulted in the alienation of almost half of the 23ha of the cay, and the loss of a very significant proportion of its tree vegetation cover. On both islands a number of non-indigenous weed species have been introduced.

Restoration of the island environments in both cases have been promoted by the Queensland National Parks and Wildlife Service (QNPWS) and the Great Barrier

Reef Marine Parks Authority (GBRMPA) because of the significance of the islands themselves to the Great Barrier Reef Marine Park, but also because of the need to reduce the risk of undesirable plant and animal species migrating to neighbouring islands. The origins of restoration work are different between the islands but share commonalities because of severe climatic and edaphic constraints. Both cays are comprised entirely of coral sand or rock, while average annual rainfall varies between about 1200mm and 800mm. There is a tendency towards summer rainfall but this is extremely patchy and highly variable from one year to the next. The characteristic vegetation of the islands are closed forests or low closed forests of *Pisonia grandis* with several other species characteristic of the coastal low closed vine forests occurring in gaps or on the peripheries of the *Pisonia*. A number of shrubs or low trees, including *Casuarina equisetifolia*, *Argusia argentea*, *Scaevola sericea*, and a species of *Pandanus* occur as woody strand plants over a typically dense ground cover dominated by several species of native grass and herbs.

When restoration began on Lady Elliot Island in the early 1960's little of the original *Pisonia* forest remained. That which did was not thriving. The strong persistent winds had resulted in wind shearing with a strong tendency towards horizontal growth habits and growing tips were salt stressed and the leaves small and chlorotic. Restoration was initiated by the first leasee of a tourist venture on the island by planting *Casuarina equisetifolia*. Despite the difficult conditions these plantings thrived and the species has subsequently regenerated naturally throughout the island even on areas where there is little or no soil on the underlying cemented coral shingle.

The *Casuarinas*, which now form a dense forest up to 15m high, have diminished the impact of the prevailing winds to the extent that the remnant *Pisonia* stands have recovered and are expanding in area through vegetative propagation. The altered microclimate is now suitable for planting a range of other native species and this is now being pursued by the present leasees on the basis of a landscape plan prepared for the resort area by landscape ecologists from the QNPWS.

The success of the regeneration has created some management problems. Lady Elliot Island is an important roosting and nesting area for many species of seabirds, despite the destruction brought about by mining. Vegetation restoration has to be balanced against the significance of a large portion of the island for this conservation purpose. This is especially so as the seabirds are one of the most significant elements of the region requiring careful management for conservation. A further problem associated with the most equitable environment sheltered by the casuarinas is the proliferation of many weed species. One of the most concerning is *Lantana camara* which has rapidly expanded in area. This sprawling perennial shrub is being removed under special project funding because of its capacity to "lock up" sites where it is established, preventing natural establishment of other species.

On Heron Island the problem of restoration is somewhat different. Establishment of appropriate species is easier because there is soil and because the tree cover has not been removed to the extent that suitable micro environments no longer exist. Accelerated development of the built environments of the resort and the research station during the 1970's and 1980's created large areas with no vegetation cover other than invading weed species introduced inadvertently by people visiting the island. Apart from the ugliness there was a continuing incremental decay of the native vegetation cover around the buildings, while reflected heat from exposed white coral sand created an unpleasant environment for people. The need to soften the built environment and control weeds had to be balanced against a perceived discomfort among resort management and a number of visitors during the summer bird nesting season when upward of 100,000 black noddies, *Anous minutus*, nest in the trees.

The problems of restoration were therefore three fold. First, to establish species which were native to the island and could therefore intergrate easily with the indigenous vegetation in the resort area and the national park; second, to choose species that would not promote tree nesting birds in public thoroughfare and open meeting areas; third, to choose flora that would lend some design interest to the main area of the resort, linking the buildings with the essence of the island atmosphere. The human dimension was a very important aspect of the project as it was essential that resident managements were strongly committed to the value of the recreated landscape to the extent that staff would be dedicated to maintenance and extension of the plantings.

To achieve restoration, comprehensive landscape design plans were prepared by a landscape architect and an ecologist from the QNPWS in collaboration with management and consultant staff from the research station and resort. Planting stock was made available commercially to the two leasees from a mainland nursery that had volunteered to experiment with and grow island and coastal species which had not previously formed part of the commercially available stock. Development and progress of the project has been monitored and discussed through community fora developed under a management plan for the island. After three years the environment has been substantially improved and responsibility for landscape maintenance and further planting has been assumed by the leasees.

PRINCIPLES EMERGING FROM THESE CASE STUDIES

Socio-economic principles

A number of lessons emerge from these case studies. Perhaps the most striking is that while restoration is commonly thought of as primarily an ecological problem, the studies show it is often also a socio-economic problem. In many cases these socio-economic problems can prove to be more intractable than the ecological problems. Thus the livestock project in the Kalahari, Botswana failed because farmers were not willing to reduce or manage their stocking rates. On the other hand, the livestock project in Tanzania seems likely to succeed precisely because farmers were willing to remove stock for a period.

There are a variety of reasons why these social impediments exist. In some situations, the human or livestock populations are just too large or the availability of fertile land is too low. In these circumstances farmers are forced to adopt practices that cause land degradation simply to feed themselves even though they may recognize the long-term damage taking place. Alternatively, as the north eastern Botswana case study showed, it might be because the land owners have an entirely different view of the nature and cause of the problem to that held by government officials.

Social impediments may also exist because certain more powerful members of a society are able to benefit from a particular practice at the expense of that society as a whole. Such persons might be unwilling to forego their privileged position. Or it may be that landowners are suspicious of government attempts to rehabilitate their land and make it more productive. This was the case with reafforestation of the *Imperata* grasslands in Papua New Guinea.

In the face of such a variety of causes, there can be no universal solutions. But certain lessons do emerge from the case studies. First, land ownership is often critical. If people are given long leases or, better still, ownership of the land they are using, they are much more likely to participate in its restoration and management. The Thai and Madagascan forest village schemes are both good examples.

Second, in densely populated areas, the land must be managed to maximize its productivity and in some situations where fertile land is especially short, part of the population may have to be offered an alternative to farming (e.g. light industry). In such circumstances, long-term success will depend on a reduction in the rate of population increase.

Third, it is desirable to build on traditional methods and social structures when implementing new land management methods, since this often means that the projects are more readily accepted. Many local practices may have been developed

by a process of trial and error over a long time period and therefore have a sound ecological backing. As such, they are important intellectual resources. It may sometimes be possible to transfer this knowledge to other societies living in similar ecosystems, although cultural differences between the societies can determine the success of such transfers. This is not to say, however, that all traditional practices are necessarily ecologically sound. Some traditional practices may have developed because of religious beliefs or certain social obligations. Or they may have arisen because land was abundant and there was no perceived need to conserve natural resources. The large areas of *Imperata* grassland throughout the tropics are, in many cases, the result of "traditional" practices. What can be said, however, is that traditional practices should be carefully evaluated before embarking on any restoration programme.

Fourthly, success can mean different things to different people. In the case of the Sri Linka taungya system, the government's tree planting objectives were satisfactorily met. Likewise, the scheme was successful for those unscrupulous individuals able to obtain more than the normal quota of land. But the scheme was not a success for the farmers actually doing the work because they were not able to obtain a very significant economic return or able to build up any equity in the project. This all suggests criteria defining success should be determined well before a project commences.

Finally, governments have a major role in landscape restoration. They can provide organization and financial assistance for large scale projects beyond the means of individual communities (e.g. arid zone shelter belts), they can create linkages between elements of a society not previously linked (e.g. between widely separated producers and their markets such as in Thailand and north east India) and they can help reinforce useful traditional environmental safeguards by giving them formal legal authority. Not all government actions are beneficial, of course. In many cases they have been responsible for the introduction of inappropriate technologies or methods. And not all projects need governments (e.g. the Chinese fish pond system established after mining in Malaysia). But for many large scale restoration projects, governments are often the only bodies with the resources to carry them out.

Ecological

Although the case studies highlight the importance of socio-economic matters to ecosystem restoration, they also provide a number of ecological lessons. The first of these is that in terrestrial ecosystems revegetation is usually the key to successful restoration. Once a plant cover is established, erosion is reduced, microhabitats are ameliorated, and there is a chance for successional development to take place.

A second lesson is that succession is likely to proceed faster if some of the plants in the original ecosystem remain at a site or in close proximity to it. If so, the

process of ecosystem restoration may sometimes begin rapidly as soon as the disturbing factor is removed without the need for any further intervention. The more individuals and species are remaining, the faster will be the succession. The case study concerning forest regeneration in Amazonia illustrates the point. As a corollary of this, succession may be hastened in more degraded ecosystems without many residual plants by deliberately introducing some of the original species. This hastens recovery by removing the need to depend entirely on natural seed dispersal. Since primary species usually found in more mature successional phases are often slow to disperse, these species, as well as earlier secondary species, should form part of any such programme. Revegetation and ecosystem productivity should not be sought at the expense of a limitation on diversity. This interventionist approach presupposes, of course, that there are intact ecosystems containing these species somewhere in the region.

Third, if no residual plants remain at a site, a "nurse crop" may be needed to facilitate the establishment of some of the original species. This principle is used in most sand dune stabilization schemes and in many post mining rehabilitation projects. In some cases naturally dispersed colonisers of disturbed sites can act in this way (Iverson and Wali 1982). But in other cases particular species may have to be deliberately added to a site. Not a great deal seems to be known about the best species to use as such "nurse crops" although plants capable of nitrogen fixation are obviously suitable and have been used in many restoration programmes (e.g. *Acacia* is used in many grassland reafforestation schemes). Other candidates might be those species particularly suited to the degraded conditions of the site or species native to a site and having a role in attracting frugivores capable of facilitating seed dispersal. One problem is knowing the appropriate stocking rate to use for these species. Too high a density may result in a succession being blocked rather than hastened. This occurred in the post-mining restoration programme on Stradbroke Island in Australia. Though native species should be used wherever possible, exotic weeds can sometimes be beneficial by trapping nutrients otherwise likely to be lost by leaching or erosion. In this role, they may assist early stages of restoration.

Fourth, restoration efforts can sometimes produce unexpected results because of incomplete knowledge of the processes that operate in certain ecosystems. Thus the *Prosopis* revegetation scheme in Chile led to a change in water availability some distance away. Better ecological knowledge may, in future, reduce such problems but there will always be a need to monitor all restoration projects and modify their management accordingly.

MONITORING

Environmental degradation can often occur quite rapidly but post disturbance successional development may be slow and the restoration of former ecological processes may take years. Further, as already noted, there are difficulties in predicting the outcome of successional development. Weeds may enter a site in large numbers or one species of the many originally established during the restoration programme may dominate a site causing a decline in species diversity. Sometimes successions may even be blocked. Or unusual climatic conditions such as a drought may follow shortly after a restoration programme commences which causes widespread plant death. Or perhaps a wildfire may burn through an area before plants have reached reproductive maturity. For these reasons any restoration programme should include a monitoring component such that the development of the new ecosystem towards the prescribed condition can be followed and corrective action be taken if necessary.

The problem in developing monitoring programmes lies in determining just what it is that should be measured. To use a stock market analogy, what are the "leading indicators"? Moreover, it is not enough to simply observe change, rather it is the direction of change that must be determined.

There appear to be two classes of leading indicators that may be relevant to restoration ecology. One of these concerns biophysical factors and the other concerns socio-cultural factors. In each class there are factors concerned with measures of stability, factors that assess the efficiency of the new system and factors that assess the degree of flexibility that has been achieved. These are summarized in **Table 1**.

In the case of biophysical indicators, the aim of any monitoring programme should be to assess progress towards ecosystem stability bearing in mind it may take some time to be achieved. Indeed, some might argue that many ecosystems are never truly stable. Furthermore, the factors that indicate stability in moist tropical forest ecosystems may be different to those appropriate in arid zone ecosystems. Nonetheless, certain generalizations can be made. In most cases, stability implies that erosion has ceased, that the land surface is protected by a plant cover, that this is composed of a variety of species and that these are all reproducing and regenerating in the ecosystem. Many of these indicators must be measured by on-site inspection but remote sensing techniques may also be appropriate. In this respect, changes in the land surface albedo may be a useful approach for large scale monitoring. Where erosion or salinity were once problems, monitoring of changes in water quality may integrate many ecological changes higher in the watershed.

The second group of indicators of progress towards some prescribed condition are concerned with the extent to which the ecosystem has become self sufficient; that

is, whether or not the ecosystem requires inputs such as seed, chemicals or water, or whether the plant community must be regulated by weed control. For some land uses inputs, or subsidies such as these might always be necessary. In principle, however, successful restoration implies a gradual reduction in their magnitude.

The third category of biophysical indicators concerns the degree to which multiple land uses are possible. Early in the restoration process it might be necessary to restrict the land use because a site is too sensitive and prone to further degradation. But as soil surfaces stabilize and a plant cover develops, it may be possible to utilize one or more of the land's resources without compromising further successional development.

Of the various socio-cultural indicators, those concerned with stability are probably the most important. In this case, it is the stability of the human population density and of the economic system that sustains these populations that is being assessed. Thus, the indicators might include the extent to which migration in or out of an area occurs, whether cash crops are being grown at the expense of food crops, whether food is being imported into the area, whether stock numbers are stable and whether the number of watering points for these are the same or increasing in number (an increase would, of course, imply a greater risk of overgrazing).

A socio-cultural measure of restoration efficiency is the extent to which the community is involved in the restoration programme. Do all members see it to be in their self interest to be involved? Or is it only the wealthier members or those with higher social status?

Finally, the degree to which the restoration program confers greater flexibility on the land users may be a useful indicator. Can they grow two crops instead of one? Is cash cropping possible? Is it possible to accumulate cash or surplus foodstore against future bad seasons and have members of the public benefited educationally? That is, have they gained a greater ecological awareness? This point may be of particular significance in areas where the human population is new to an area and have no strong tradition of local ecological knowledge.

TABLE 1

Potential indicators of success for a restoration monitoring programme.

BIOPHYSICAL

SOCIO-CULTURAL

(a) Stability

stable soil surfaces	stable human population
adequate plant cover	stable market prices
adequate crop yields	adequate food supply and standard of living
appropriate plant species composition and structure	stable land use pattern
appropriate animal population	stable and equitable land tenure system
adequate regeneration or reproduction of preferred species	appropriate balance between subsistence crops and cash crops
acceptable water quality (surface and groundwater)	stable rate of fuelwood consumption
appropriate albedo	stable rate of water use (in arid zones)
	equity in access to resources (e.g. land)

(b) Efficiency

decreasing need for inputs of fertilizer	level of public involvement or participation in the programme
decreasing need for weed control	
decreasing need for irrigation	

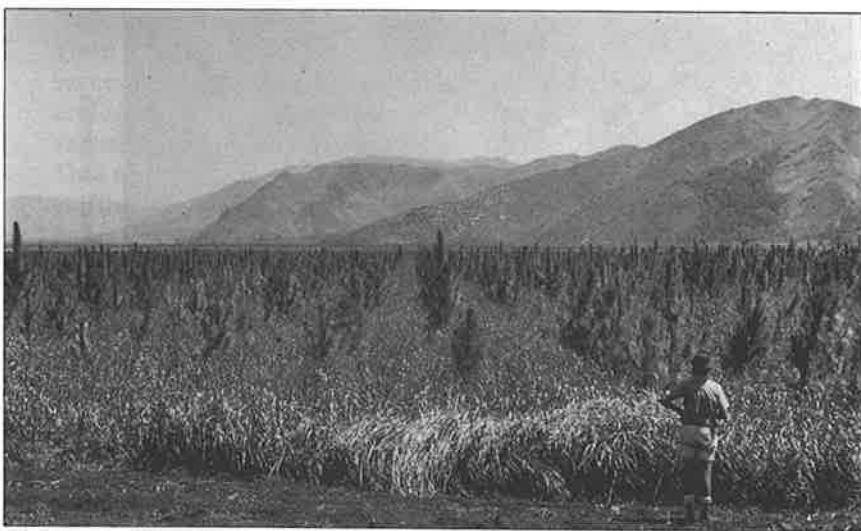
(c) Flexibility

increasing alternative uses of land	increasing economic flexibility
	increasing public ecological awareness



Australia

Trees killed by salinity induced by excessive forest clearing in the upper watershed. The clearing altered the hydrological cycle, raised the water table and mobilised salt stored low in the soil profile. *Photo by David Lamb.*



Papua New Guinea

Pinus plantation on grassland in Papua New Guinea. Note residual rainforest in fire shadow in moist, gully on hill in background. *Photo by David Lamb.*



Sulawesi, Indonesia
Overcutting of forested hillside in Sulawesi, Indonesia caused by agricultural clearing.
Photo by David Lamb.



East Kalimantan, Indonesia
Acacia mangium plantation in East Kalimantan, Indonesia one year after planting on a formerly degraded rainforest site. Illustrates that growth rates can be rapid.
Photo by David Lamb.

CONCLUSIONS AND RECOMMENDATIONS

These have been grouped into three categories:

Technological – biological recommendations

1. It is important that completely protected areas be designated to preserve species that may be needed in restoration programmes. Such areas should preferably be as undisturbed as possible and should be replicated to include the diversity within a particular biome. In passing it might be noted that, in this sense, restoration is a further justification for nature reserves. Moreover, restoration of already degraded lands may remove some of the need to disrupt existing natural areas.
2. Critical sites of special importance should be given particular priority. These might be areas especially prone to erosion, source areas for saline water in the upper areas of some watersheds or areas having some particular importance as a habitat for a threatened species.
3. Where possible restoration should be carried out using primary plant species as well as secondary plant species. That is, plants should come from various successional stages to avoid the possibility of successions being blocked and to facilitate the inclusion of species able to disperse only slowly.
4. There is a need to identify those species that play a key role in facilitating successional development or establishing and maintaining important ecological processes in different environments. These species may be vascular plants such as trees or micro organisms such as mycorrhizal fungi. They may be nitrogen fixers, plants with roots able to penetrate deep into soil profiles such that infertile upper soil horizons are enriched by their litter fall, plants able to absorb excess amounts of nutrients such that they limit nutrient leaching losses, plants particularly adapted to heavy grazing, plants able to attract a variety of seed dispersers to an area thereby aiding the dispersal of other species' seed, plants that help structure an ecosystem or simply plants that were abundant and widespread in the original communities at a site. If possible, these key species should not have a high economic value to society that may cause them to be prematurely harvested from an area being rehabilitated.
5. The role of exotic species needs to be critically evaluated. In many cases, introduced plants and animals have been major causes of ecosystem degradation. Their removal may allow these symptoms to recover without the need for any further action.

6. It should be an objective of most restoration programmes that productivity be optimized using the widest possible range of species. That is, any increase in productivity should not be at the expense of species diversity.
7. Efforts should be made to facilitate the transfer of appropriate ecological knowledge from different parts of the world that share similar biomes. Thus *Prosopis* is widespread in various parts of the Americas and different societies have learned to use and manage ecosystems dominated by this species in different ways. Much more could be gained by sharing this knowledge more widely.
8. Current national and international programmes seeking to monitor environmental conditions should have a special focus on degraded landscapes. Monitoring should address the conservation status of these lands, the degree of degradation and the extent to which restoration efforts have succeeded. Degraded sites should be monitored periodically to assess changes in time as well as being compared with other more or less degraded sites within the same biome at the same time. Monitoring should be carried out, if possible, every one or two years and include socio-cultural factors as well as bio-physical factors.
9. More research should be carried out on the dynamics of ecosystems. For successful management and restoration, more needs to be known about how particular ecosystems respond to stress and disturbances of various kinds, how successional development occurs, why certain ecosystems seem to be more resilient to particular perturbations than others and the nature of ecological thresholds beyond which recovery to something like the original condition is problematic.

Social recommendations

10. In attempting the restoration of any ecosystem, researchers and decision makers should seek to understand the social conditions of the people living in the area. That is, how is the society structured? Who actually owns the land? Why do people manage the land the way they do? What are their economic circumstances? To what extent might they be able to afford to spend money or time on restoration?
11. It follows, therefore, that social scientists should be involved from the earliest stages of any restoration programme.
12. Any new technology or management method should complement existing or traditional methods wherever this is possible. Many such traditional methods have been developed over time by a process of trial and error and are based on sound ecological principles. It is important to recognize, however, that this is not always the case and that sometimes factors concerned with the social structure of a particular society dictate land use decisions. Efforts should be made, therefore, to scientifically evaluate traditional methodologies and use those that are appropriate.
13. Many traditional societies are changing as they become more involved in the wider world. As a consequence, much important ethno-ecological knowledge is being lost. Training programmes should be developed to train indigenous people as "decoders" of this traditional knowledge such that the ecological principles are uncovered.

Policy recommendations

14. Any restoration programme should be integrated within the wider economic and social situation of a particular region. Every effort should be made to ensure local land users or land owners become involved in the programme and receive an economic return for their efforts. New crops or produce should be marketable and transport systems should be available. At the same time, the impact of the programme on surrounding land owners should be monitored to ensure they are not adversely affected.
15. Planning should be carried out in cooperation with local people. This will help ensure that the programme meets their real needs and that they actively cooperate in its implementation. If land use planners and managers are not seen as collaborators but as government regulators or law enforcers, it may make their task more difficult and perhaps even impossible.
16. If it is necessary or desirable to alter patterns of land tenure to implement a restoration programme, it should be done in such a way as to promote confidence amongst the eventual land users. Any modification should be made in sympathy with local practice and ideally the land users should also be the land owners.
17. Old legislation and legal systems should be periodically reviewed to ensure it is appropriate for present circumstances. Societies, environments and economic situations all change and legislation should keep pace with these changes.
18. Any new laws should be enforceable and should be enforced. Desired outcomes may be achieved more easily by creating incentives for certain courses of action rather than by threatening punitive action if these are not adopted. It may be more appropriate to promote the idea that acts causing environmental degradation are shameful rather than merely legal crimes.
19. When tree plantations are being established, they should preferably be located on degraded lands rather than on other productive areas or undisturbed natural areas.
20. In any restoration programme criteria for success should be defined early in the planning process. Such criteria should include socio-economic criteria as well as ecological criteria.

REFERENCES

- AMYOT J., 1989. *Forestland for the People: a forest village project in northeast Thailand*. Food and Agriculture Organisation of the United Nations, Bangkok.
- ARNOLD M., 1979. New approaches to tropical forestry: a habitat for more than just trees. *Ceres* 12: 32-37.
- BLACKIE P., BROOKFIELD H., 1987. *Land Degradation and Society*. Methuen.
- BRADSHAW A.D., CHADWICK M.J., 1980. *The Restoration of Land*. Blackwell Scientific Publications.
- BROOKFIELD H., OVERTON J., 1988. How old is the deforestation of the Pacific? In: Dargavel J., K. Dixon, and N. Semple (eds), *Changing Tropical Forests: Historical Perspectives on Today's Challenges in Asia, Australasia and Oceania*. Centre for Resource and Environmental Studies, Australian National University, Canberra. Pp. 89-102.
- BUSCHBAKER R., UHL C., SERRAO E.A.S., 1987. *Reforestation of degraded Amazon pasture lands*. Presented at International Conference on Rehabilitation of Disturbed Ecosystems, 11-16 December 1987, Varanasi, India.
- CAULFIELD C., 1985. *In the Rainforest*. Alfred A. Knopf, New York.
- CONNELL J., SLATYER, R., 1977. Mechanisms for succession in natural communities and their role in community stability and organisation. *American Naturalist* 111: 1119-1144.
- FORTMANN L., 1989. Peasant and official views of rangeland use in Botswana: fifty years of devastation? *Land Use Policy* 6: 197-202.
- GRAINGER A., 1988. Estimating areas of degraded tropical lands requiring replenishment of forest cover. *International Tree Crops Journal* 5: 31-61.
- HAMILTON L.S., 1988. Restoration of degraded tropical forests. Paper presented at "Restoring the Earth Conference", 13-16 January 1988, University of California, Berkeley.
- HUGHES J.D., THIRGOOD J.V., 1982. Deforestation in ancient Greece and Rome: a cause of collapse. *The Journal of Forest History* 26(2).
- IVERSON L., WALI M., 1982. Reclamation of coal mined lands: the role of *Kochia scoparia* and other pioneers in early succession. *Reclamation and Revegetation Research* 1: 123-160.
- JANZEN D.H., 1986. *Guanacaste National Park: tropical ecology and cultural restoration*. Editorial Universidad Estatal a Distancia, San Jose, Costa Rica.
- LOVEJOY T.E. and Working Group, 1985. *Rehabilitation of degraded tropical forest lands*. Commission on Ecology Occasional Paper No. 5, IUCN, Gland.

- MABBUT J.A., 1984. A new global assessment of the status and needs of desertification. *Environmental Conservation* 11: 103-113.
- MELLILO J.M., PALM C.A., HOUGHTON R.A., WOODWELL G.M., MYERS N., 1985. A comparison of two recent estimates of disturbance in tropical forests. *Environmental Conservation* 12: 37-40.
- MYERS N., 1980. *The conversion of tropical moist forest*. National Academy of Sciences, Washington.
- OJO G.O.A., ONYEWOTU L.O.Z., UJAH J.E., 1987. Use and management of shelterbelts. In: Sagua, V.O., Enabor, Kio, Ojanuga, Mortimore, Kalu (eds), *Ecological disasters in Nigeria: Drought and Desertification*. Federal Ministry of Science and Technology, Lagos, Nigeria.
- RAMAKRISHNAN P.S., 1984. The science behind rotational bush fallow agricultural system (jhum). Proceedings of the Indian Academy of Sciences. *Plant Sciences* 93: 379-400.
- SHERMAN G., 1980. What "Green Desert"? The ecology of Batak grassland forming. *Indonesia* 29: 112-148.
- TAGUDAR E.T., 1978. Agro-forestry as practised in the Paper Industry Corporation of the Philippines. *Forest News for Asia and the Pacific* 2(1): 24-26.
- UHL C., BUSCHBACHER R., SERRAO E., 1988. Abandoned pastures of Eastern Amazonia. I. Patterns of Plant Succession. *Journal of Ecology* 76: 663-681.
- WORLD RESOURCES INSTITUTE, 1988. *World Resources 1988-89*. Basic Books Inc.

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