SESSION IV

15 Measuring forest capital of India—its usefulness for forest regeneration

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ABSTRACT

There is an immediate need to develop uniform measurement tools, to appraise the current status of landscapes relative to their potential in the normally naturally forested zones. Spatial coverage as well as the quality of the forest interms of functionality and biodiversity of the fauna and flora has to be assessed not only to keep track of the forest wealth, but also to enhance it in a conscious manner. Such information is woefully inadequate in India. The forest area index shows that States (province) of Madhya Pradesh, Andaman Nicobar Island, and northeastern States of Arunachal Pradesh, Nagaland and Manipur are better off than the rest of India. Indian forest cover has declined since the mid-seventies by about ten million hectares. There seem to be an overlapping of dense forest area with tree crops and plantation crops. The areas of managed forest and prime forest are not available separately. Both commercial greed as well as poverty needs seem to cause degradation. Illegal felling, mining leases in dense forest areas and submerging forests in irrigation reservoirs are some of the causes. Clearing forest to extend the crop cultivation, shifting cultivation, excessive grazing on forest lands, and collection of fuel wood by millions of villagers also seem to cause degradation. Given the positive levels of carbon sequestration of Indian forests, the Kyoto Protocol, if negotiated well by the Government of India, could generate funds not only for regeneration, but also for joint forest management and poverty alleviation. The forest regeneration programme should not only ban commercial activities but also provide for livelihood generation for the poor.

WHAT IS FOREST CAPITAL?

In its 1999 final report, the World Commission on Forests and Sustainable Development (WCFSD) stated that: "We are drawing on the world's natural capital far more rapidly that it is regenerating. Rather than living off the 'interest' of the 'natural capital', we

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are borrowing from poorer communities and from future generations." Global forest area has declined from 44 percent about eight thousand years ago to 28 percent at present. About 14 million hectares of tropical forests have been lost annually since 1980. As a result changes have occurred in the watersheds, soil moisture, timber and non-timber forest products. Not only the special coverage, but also the quality of the forests in terms of crown density, functionality, fauna, flora and biodiversity has changed. There is an immediate need to develop uniform measurement tools such as "forest capital index" to record these changes.

"The health of the global ecosystems has been judged on the basis of their ability to produce the goods and services that the world currently relies on. These include production of food, provision of pure and sufficient water, storage of atmospheric carbon, maintenance of biodiversity and provision of recreation and tourism opportunities." (Pilot Analysis of Global Eco Systems [PAGE]). Similarly, "the value of the …forests as the largest reservoir for plants and animals on land, and their role in maintaining supplies of clean water, in creating and retaining soil, in stabilizing slopes and preventing erosion and landslides, in contributing to the productivity of fisheries and agriculture, in helping to regulate climate, as home for indigenous peoples, as a provider of recreational, aesthetic and other amenities" have to be taken into consideration and measured (Salim & Ullsten 1999).

FOREST COVER OF INDIA

The forest cover of India has declined over the last few decades. The depletion appears to be large, since the mid-seventies for which we have comparable remote sensing data. Between 1972–75 and 1993–95 the dense forest area in India declined from 46.42 million hectares to 36.73 million hectares, a decline of about 10 million hectares over two decades. The area under plantation crops, of tea, coffee and rubber has increased from 0.672 million hectares in 1970–71 to 1.269 million hectares in 1995–96. In 1996–98 the dense forest cover seems to have gone up slightly to 37.74 million hectares, an increase of about a million hectares in about five years (Table 3). This again could be due to the increase in the agricultural crop trees. The area under fruit trees has gone up. The area under coconut, areca nut and cashew nut has also gone up. The area under coffee and rubber plantations has also increased. In 1995–96 the area under fruit tree crops of banana, citrus, apple, grapes, guava, litchi, mango, sapota and papaya alone came to about 2.7 million hectares. The area under coconut, areca nut and cashew nut plantations in the major growing states alone is about 25.83 million hectares. The area under coffee and rubber constitutes 0.73 million hectares. All these add up to 29.26 million hectares, not considering the states that produce these tree crops in small quantities. At least parts of this area might have been overlapping the dense forest area in some states such as Kerala. The dense forest area for the country was 36.73 million hectares. However, the states in which plantation crops are widespread are not the states reporting a dense forest cover. Hence there is reason to believe that most of the plantation crops might have been excluded from the forest statistics, but, how much of it is overlapping is difficult to say. We therefore need to know more details about the forest area spread, before we can conclude about the prime forest cover, which is still intact in the country. As per the statistics, about 37 million hectares of dense forest area and more than 30 million hectares of tree cover exist. It is important to know the overlapping areas. Soon the plantation crops and other tree covers may exceed the dense forest area. It is also important to assess the functionality of such landscape. In recent years, the forest statistics have combined the remote sensing data with ground verification. Hence we hope that the overlapping of dense forest with plantation crops is minimal.

If we deduct the area under the managed forests, which contain timber trees planted and harvested, the prime forest would be even less. The actual planted forest area is also not available accurately. It is because some areas of the forests are planted with 7–10-year-old fast-growing species and clear felled and re-grown. They are counted twice. In some areas the planted areas may not have any survival rate. All areas are considered as planted forest areas. From 1951 to 1999 a total of about 31 million hectares were planted. However, nothing much can be said about the actual managed forest area of the country. Thus the area under prime forests and managed forests is not known. The only consolation is that tree cover of any sort is better than open forest area or scrubland.

The functionality and the biodiversity of the original dense forest cover have been lost forever. The plantation crops and fruit crops do not protect the soil moisture and soil organic matter in the same way as the original forest. The loss of prime forest is not exactly known in hectares. There is every reason to believe it has drastically decreased. From 1997 to 1999, an increase in the dense forest area by 10 098 square kilometres and a decrease in the open forest cover by 6 246 square kilometres have been reported. It is important to find out how much of the real forest has been restored and how much of the increase was due to non-forest tree cover.

Susceptibility to fire also increases as the soil moisture retention declines. Higher incidence of forest fires is another indication of the reduced forest wealth. More than 175 thousand hectares of forest land were reported as having been affected by fire in 1994–95. The unreported area would be more, since some states with large forest areas such as the State of Orissa did not collect the information on fires (Table 3).

About 25.50 million hectares of the forest land were under the category of open forest and 5.20 million hectares were under scrublands. The distributions of open and dense forests are almost equal in some states such as Andhra Pradesh, Bihar, Jammu and Kashmir and Tamil Nadu. In some states such as Manipur, Meghalaya, Mizoram and Nagaland, more than half the forest area is under the category of open forest. The dense forest area is less than the open forest area.

Madhya Pradesh is the only state with the largest area under dense forests in the country. Madhya Pradesh and the northeastern states account for about 47 percent of the forest area. More investment is required for regeneration work. About 81 million hectares in Madhya Pradesh and about 58 million hectares in Arunachal Pradesh have dense forest cover. The open forest areas ideally should be the first target for conversion into dense forests.

Thus about 11.48 percent of the total geographical area is under dense forest cover of more than 40 percent crown density. About 7.76 percent of the geographical area is an open forest, with a crown density varying between 10 and 40 percent. About 1.58 per cent of the geographical area is under scrubs. Mangrove forests that constitute the special coastal ecological system constitute less than one percent of the total geographical area.

DEGRADATION OF FOREST LANDS—COMMERCIAL INTERESTS VS POVERTY NEEDS

There are several reasons for the decline of forest area. Commercial greed on one hand and the need of the poor on the other are the present challenges. Commercial felling of the forest continues both illegally and legally, despite the laws and regulations on felling of trees. The supreme court of India diluted the laws in 1996, by removing the ban on felling of the trees. Illegal felling and transport of timber are a common phenomenon. Even the protected forests and reserved forests are not free from felling. About 15.6 million hectares of forest area have been declared as protected area.

Though the value of the forests to the country is much more than the value of timber, commercial interests are the major reason for such activities. The volume of timber, as estimated in the states reporting the data, comes to about 2.37 million cubic metres in 1997–98 as per the Indian forest statistics. It also includes firewood and pulpwood in a few states. However, the estimation may not have a large error since it includes most of the states. In contrast, the FAO estimates of round wood were far higher. India is a net importer of wood and wood products.

Wood products including the value added through manufacturing in the national income accounting were estimated to fetch about 15 billion rupees or about US$300 million in India in the year 1995–96. This amount included the income of all the workers in the wood products industry including those in retailing and transportation. The value of Indian timber probably constitutes a small share of the total value. To keep the industry and the jobs going, it may not be necessary to log domestic timber. The country may use imported wood and non-wood substitutes.

There are certain collective needs that lead to the destruction of the forests. Mining activities destroy forests. It has been found with the help of the Geographical Information System, that about 53 thousand hectares, with 71 percent dense forest cover and 29 percent open forest cover, presently fall under the mining leases in the States of Orissa, Bihar and Madhya Pradesh. Bauxite, copper, iron, chromites and manganese are the important metals mined in the forest areas of these states (GoI 1999). Mining will lead to environmental degradation and the prime forests destroyed will be lost forever. Hence a special policy decision is necessary to avoid mining in the forest areas. The Indian Bureau of Mines and Metals should look for alternative sites for mining activities and protect the forests and cancel the leases.

Diversion of forest land to non-agricultural uses also contributes to forest loss. The land put to non-agricultural uses has increased to 7 percent of the geographical area in recent years from about 4 percent in early fifties. Another important destroyer of the forests is the reservoirs of the big irrigation dams and hydroelectric projects. Thousands of hectares of forests are submerged and permanently lost in the huge reservoirs of the irrigation projects, while the benefits of irrigation are short-lived and often less than expected. Out of the forest land uses permitted by the government, a large percentage is for major and medium irrigation projects in all the states. Such large-scale forest depletion and environmental disasters can be avoided by a change in the government policy.

The reason for such ambitious short-lived irrigation projects is two fold. The main reason is the increasing moisture scarcity for crops as the population crossed the one billion mark, leading to the search for water. Secondly, many technical persons, who are overawed by the technical achievements and the novelty of these big projects, do not pay attention to and try to understand the importance of forests to the health of agriculture and long-term water availability.

A number of the poor depend directly on the various physical and functional services provided free by the forest. With the degradation of the forests, moisture retention being low, the crop yields in the uplands have declined. Even water for drinking becomes difficult in the summer months. Tribal people walk long distances down hills to the valleys in search of water. The amount of fuelwood collected has been dwindling. Several other tradable forest products are non-existent today. A number of foods once available in the forests for the tribal people to eat in the lean months are not available any more. The hardship of those who live in the forests has increased many folds. Their natural habitat has been eroded over time through the felling of trees, for timber production, and through the conversion of forest land to non-forest uses. As a result of the disappearing forests, the tribal community has become the most vulnerable community from the point of view of food security. Very often whenever droughts and floods occur, the isolated tribes face starvation. This is an issue to be solved through immediate measures to provide sustainable alternate livelihoods for them through food for work programmes and establishment of grain banks.

A number of the rural people living in the villages close to the forest land also depend upon the forest. Due to the lack of alternative energy sources, and affordability of such fuels, many rural poor still depend on forests for fuelwood in India. Due to the exhaustion of common green areas, and vegetative cover in the outskirts of the villages, the villagers are forced to enter the forests for the collection of fuelwood, and non-timber forest products and the grazing of their cattle. The volume of fuelwood is estimated for the country as a whole at about 1.87 million cubic meters. This constitutes the fuel removed from the forest areas. The total fuelwood production for all the areas would be very much higher.

Social forestry of fuelwood planting may be encouraged closer to villages, where people cannot shift to alternate affordable sources of fuel. In some states (provinces) such as Andhra Pradesh, the Government has promoted schemes and successfully replaced firewood with gas in many villages, through microcredit organized by self-help groups. Such schemes not only reduce carbon dioxide emissions, but also reduce eye diseases in women due to continuous exposure to smoke during cooking. This livelihood promotion of the poor should be the key issue.

In some areas, tribal people continue to practise shifting cultivation. In the country more than 3.8 million hectares of forest land were adversely affected by shifting cultivation. The tribal people clear the forests for the cultivation of the crops for a few seasons and shift to other forest areas and cut the forest to make way for cropland. Activities such as fuelwood collection and shifting cultivation did not matter much when the forest cover was larger and the population lower in the forties and fifties. With a depleting forest cover, when lakhs of people enter the forests for their daily needs, the degradation increases. Shifting cultivation has to be stopped. Hence, while working towards the regeneration of forests, the needs of the poor dependent upon the forests should be built into the programmes. The tribal population should be settled on some plots of land and encouraged to grow high yielding varieties of crops to improve their livelihood and food security. Alternately, they can take up joint forest management of plots and be paid in wages for the work done.

The context of forest wealth helps us to reward the poor communities who do not degrade the forests, including those who participate in joint forest management and help us bring back forests. Without a system of rewards the forest cover cannot increase. It is also important to reward those who refrain from using fuelwood and are willing to shift to alternative fuels available, to using cattle feed instead of grazing, and to alternative livelihoods in place of shifting cultivation. Sustainable livelihoods of these people affect the health and wealth of the forests. The forest capital index becomes a guide to progress.

It is simply not possible to engage all the people in joint forest management in a sustainable fashion. Priority should be given to the tribal persons presently living inside the forest areas. Normally, crop cultivation is more labour intensive than tree growing. Hence fewer people are required for joint forest management. Others should be provided with alternative livelihoods so that they will be able to afford more expensive fuels and more expensive cattle feed. The scenario has to be changed with the help of training and credit for ecologically friendly enterprises, such as poultry production, cattle rearing with improved breeds of cattle, and mushroom production, and education in the use of biopesticides, biofertilizers and so on. Provision of ecofriendly sustainable livelihoods with market links for the products is a pre-requisite to forest conservation and forest protection in the long run.

Hence the cost of forest regeneration is not only the actual cost of planting and caring but also the efforts of providing alternative and viable livelihoods for the people living in the vicinity of the forest, who have been suffering due to depletion of forests.

In the present system the states with large areas under dense forests are the states with fewer livelihood opportunities. The fact that these are more sparsely populated makes it even more costlier to bring the forest dependent people together and provide the infrastructure needed for the enterprises, including the market link-ups.

As the scheduled tribe populations dependent on forests are the poorest, it is important to devise special reward systems and additional funds to enable the people to preserve the forests and water. The aim should be a management based on integrated landscape rather than just the forests. Forests, soils, water bodies, vegetative cover, and agriculture that includes crop, animal and fish production are parts of joint management. Further development in non-agricultural enterprises is also vital to shift people to more viable livelihoods.

The pressure of more than a billion population has left its footprint on the forest land of India. At present, as against the recommended 30 percent of the geographical area to be under dense forest cover, only about 11.48 per cent of the total area is under forest cover of more than 40 percent crown density. About 7.76 percent of the forest area is open forest, with a crown density varying between 10 and 40 percent. And about 1.58 per cent of the geographical area is under scrubs. Mangrove forests that form the special coastal ecosystem constitute less than one per cent of the total forest area.

The state with the largest area under dense forest cover is Madhya Pradesh. Madhya Pradesh and the northeastern states contribute about 47 percent of the forest area. Madhya Pradesh has more than 81.6 thousand square kilometres of forest area, followed by Arunachal Pradesh with 57.8 thousand square kilometres of forest. The other important states with dense forest cover are Maharashtra, Orissa, Karnataka, Andhra Pradesh and Uttar Pradesh, having forest cover ranging from 22 thousand to 26 thousand square kilometres. Madhya Pradesh is also an important state for forests as it also has a large area under open forest. These states which have large areas of open forest possess the potential for forest regeneration, through converting the open forest areas into dense forest areas. Additional areas are denoted as cultivable waste lands.

From 1997 to 1999, an increase in dense forest area by 10 098 square kilometres and a decrease in open forest cover by 6 246 square kilometres have been reported. More investment is required for restoration work (GoI 2000).

INDEX OF FOREST AREA

The physical characteristics of the forest such as dense forest area, open forest area, level of degradation over a period, as well as the functional aspects of the forest need to be considered as a tool in the development of measurement. Biomass index, habitat value, mean annual increment in the above-ground biomass, leaf area index, and susceptibility to fires are the more easily measurable indices, if data exist. Efforts will have to be made to collect the information in India at the state and district levels. Data on many aspects are not available in India.

Due to the paucity of detailed state information in recent years on the exact area under well preserved prime forests, planted forest areas, areas under plantation crops and tree crops, data on flora and fauna and richness of species and so on, it is difficult to get a clear picture of the forest wealth. The potential to bring back the forests in the normally forested zones is another important information required. Unless we know the levels of degradation, it is difficult to know whether the degradation has reached a point of no return. All the same, on the basis of information available we have computed an index of forest area.

Only three indicators are considered at present for the calculation of the composite index of forest capital for various states in India, viz. area under dense forest cover, area under open forest and the degraded dense forest area in the past couple of decades. Each of these indicators is converted into individual indices and averaged together to get the composite forest area index. The indexing is similar to the human development index.

The method of calculating the index is simple. Each indicator is first converted into an individual index. The state (province of India) with the worst possible situation is equated to one and the state with the best possible situation is equated to zero. The others are between zero and one. Thus the index varies between one and zero. The individual index for an indicator measures the shortfall of the natural forest endowment of the state from the existing best level of forest endowment among the states, as a proportion of the difference between the best-endowed state, and the worst endowed state.[1] An index value of 0.85 for a state means that it has a shortfall of 85 percent of present and potential resources of the best endowed state in terms of forest wealth. A value of 0.15 means that the state has a shortfall of 15 percent of the natural endowment of the best naturally endowed state. The best state gets a value of zero, the worst endowed states gets a value of 1, indicating the worst state has 100 percent less endowment compared to the best state. The best state has zero shortfall. The composite forest area index is nothing but the average of all individual indices calculated from the chosen indicators. Equal weight is given to all the indicators in the group index.

The composite index has been calculated from the general formula,

$$I_1 = \frac{1}{n}\left[\sum_{i=1}^{n} \{(X_{ij} - X_{min}) / (X_{max} - X_{min})\}\right]$$

where,

I_1 = composite index one

X_{ij} = i^{th} indicator in the group for the j^{th} state

X_{min} = i^{th} indicator of the state with minimum value

X_{max} = i^{th} indicator in the state with maximum value

‘i’ = 1 to n indicators

‘j’ = 1 to k state considered in the group index.

[1] All the final data on indicators chosen are made unidirectional in the index form, so that larger values represent the worst situation. Hence the indexing formula adopted for dense forest area and open forest area subtracts the present value of the state from the maximum value among the states. The numerator of the formula is $(X_{max} - X_{ij})$. In the case of the magnitude of degraded dense forest area from 1972–75 to 1993–95, the numerator is $(X_{ij} - X_{min})$.

The numerator of the formula differs, depending upon the values of the indicators. The composite index also ranks the states. The rank one is given to the state with minimum forest wealth and the rank 28 goes to the state with maximum forest wealth (see Tables 1–4).

The islands of Andaman and Nicobar come out as the region with best forest cover followed by Arunachal Pradesh and Nagaland (Table 4). Manipur and Mizoram come next. The States of Assam, Mizoram, Meghalaya and Sikkim also fare well. Dadra and Nagar Haveli, Goa, Daman and Diu and Kerala get a rank of higher than 19. Assam gets a rank of 18. Among the bigger states, Madhya Pradesh fares better with a rank of 17. Madhya Pradesh is more important than the other states from the point of view of largest area under dense forests at 81.6 thousand square kilometres, as it has a larger area under forest than the other states followed by Arunachal Pradesh. Himachal Pradesh and Orissa appear to get the middle ranks of 16 and 15. Karnataka, Uttar Pradesh and Maharashtra are just below the half way mark with the ranks of 14, 13 and 12. The worst states in terms of forest wealth are Rajasthan, Punjab, Haryana and Andhra Pradesh. Andhra Pradesh fares badly due to high levels of degradation in recent years and the likely loss of even the existing forests.

The above index is only an indication of the distribution of forest wealth in comparison to the requirement. More detailed information is necessary to assess the forest capital.

POLICY OPTIONS FOR FOREST REGENERATION AND IMPROVING THE FOREST WEALTH

The foremost concern is to stop further depletion of prime forest stock. The next priority is to reverse the process of degradation and bring back some of the lost forests. The forest wealth of a country can be increased with conscious effort by the government and people. All the open forest areas can be converted into dense forested areas, through special efforts of regeneration. India can improve the dense forest cover of the country by converting at least part of the 25.5 million hectares of open forest area into dense forest area, since it was a naturally forested area that had degraded in recent times.

A number of measures are necessary. Some of the important ones are listed here:

1. enlisting the support of NGOs and the general public through awareness campaign for joint forest management;
2. preventing illegal logging and protecting the prime forest areas;
3. preventing mining in the dense forest areas;
4. preventing submergence of forest lands in the irrigation projects;
5. preventing the diversion of forest land to crop production and other non-agricultural activities;
6. undertaking afforestation and reforestation of all naturally forested areas;
7. using food for work programmes to pay the local population for the forest regeneration work and joint forest management works;
8. setting aside funds for the poor for alternative livelihoods or alternative sources of animal feed and fuelwood.

Long-term planning and sustained efforts are necessary to bring back the forests.

These activities require large funds to sustain the activity over long periods of time:

a. borrowing from international agencies such as World Bank;
b. spending funds from the tax revenues of the state governments;
c. trading credit received for carbon sequestration in the forest regeneration programme.

Of these we shall consider the possibilities of financing forest regeneration through emission trading.

CARBON SEQUESTRATION AND CARBON TRADING TO RAISE FUNDS

The role of the forest ecosystem in storing carbon and stabilizing the atmospheric temperature is well known. The removal of the atmospheric carbon is known as carbon sequestration. It has been estimated that in 1996, carbon sequestration in Indian forests, net of carbon emission was 6.9 million tonnes (Ravindranath 1996). Estimation of net annual carbon sequestration from 1972–73 to 1999–2000 appears to be positive, mostly due to the plantation of secondary forests in the past two decades (Kanchan Chopra *et al*. 2002). Thus Indian forests can raise funds under the Kyoto Protocol by trading in the sequestrated carbon with the developed nations.

Things will now change under the new provisions of the Kyoto protocol. Once all the provisions are put in place, the third world countries may be left with very little opportunities to raise funds. It is time for India to wake up and take active interest and see if there is still some scope to raise funds for the forests and the poor that depend upon the forests through emission trading. Things are not rosy as they stand now! Yet India has a large scope for carbon trading, by converting the open forest areas into dense forest areas.

The Kyoto Protocol and its implications to funding forest regeneration

Many nations in the World have become more concerned about the increasing concentration of greenhouse gases such as carbon dioxide, causing global warming. They joined together in 1992 to sign the United Nations Framework Convention on Climate Change (UNFCCC). It included a legally non-binding, voluntary pledge that the major developed nations would reduce their greenhouse gas emissions to 1990 levels by the year 2000. It did not happen. The first commitment period now is extended to 2007–2012. Parties to the treaty decided in 1995 to enter into negotiations on a protocol to establish legally binding limitations or reductions in greenhouse gas emissions. The negotiations took place in 1997 at a meeting from 1–11 December in 1997 at Kyoto, Japan. Following completion of the Protocol in December of 1997, details of a number of the more difficult issues remain to be negotiated and resolved. The protocol allows the Annex One countries (developed and industrialized countries) to trade emissions to a limited extent with the Annex Two countries (developing countries). Eight Conferences of the Parties (COP) have been held since 1992. The Kyoto meeting was the fourth one. COP 8 was held at Delhi in October 2002.

The Kyoto protocol only recognizes the land use and land-use change in forestry activities (LULUCF) and the associated net carbon sequestration flows estimated for the purpose of emission trading in terms of net removal units.

At the COP 7 in the Marrakesh Accord, naturally occurring carbon removals, and removals as a result of anthopogenic effects were excluded from being traded. Any re-release of the greenhouse gases, through forest fires will have to be accounted for.

1. The forest is defined. A minimum tree height between 2 and 5 meters is necessary for a forest. These values will have to be chosen only once by the country and they remain fixed as a definition of forests. The activities such as afforestation and reforestation are defined.
2. The parties should choose other land-use activity for emission targets in addition to afforestation, reforestation and deforestation. The carbon sink activities in addition to forest regeneration are forest management, crop land management, grazing land management and re-vegetation.
3. Removal of greenhouse gases is measured in removal units called (RMUs). For the first commitment period there is a 4-tier capping system. Only afforestation and reforestation projects are eligible for the clean development mechanism. Removal units cannot be carried forward to the next year. Any emissions occurring from LULUCF including afforestation, deforestation and reforestation must be set off elsewhere.
4. Emissions and removals from crop land management, grazing land management and re-vegetation management can be accounted for on a net-to-net basis, meaning thereby the levels of removal that are over and above the 1990 level are taken into account. If the carbon removals are the same as the 1990 level there will not be any credits.
5. Issues such as emissions from forest harvesting and wood products have been resolved.

There are still many issues to be settled before the methodologies of computations of removal units and emission units are standardized and other issues such as verification and compliance are resolved. However, India has to closely follow the developments, collect more accurate statistics and compute an emission trading relevant to the net forest wealth index for various states. Long-term planning of reforestation is necessary to choose the tree size, non-forest activity and so on. More thorough and in-depth studies of implications are necessary for India to improve its forest cover and benefit from emission trading. One should not be under the impression that all the sequestrated carbon in the fast-growing plantations is tradable, without any reference to the level of activity in 1990, level of deforestation, timber removal and forest fire. There is an opportunity for the governments to improve the forest cover and the livelihoods of the poor, if only they are willing to act now!

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Table 1. Extents of dense forest, open forest and mangrove in States (sq.km)

S .No.	State/Union territory	Dense forest	Open forest	Mangrove	Total forest cover	Scrub
1	Andaman & Nicobar	6 515.00	125.00	966.00	7 606.00	0.00
2	Andhra Pradesh	24 190.00	19 642.00	397.00	44 229.00	9 559.00
3	Arunachal Pradesh	57 756.00	11 091.00	0.00	68 847.00	104.00
4	Assam	14 517.00	9 171.00	0.00	23 688.00	324.00
5	Bihar	13 274.00	13 200.00	0.00	26 474.00	1 914.00
6	Chandigarh	6.00	1.00	0.00	7.00	0.00
7	Dadra & Nagar Haveli	159.00	43.00	0.00	202.00	10.00
8	Delhi	35.00	53.00	0.00	88.00	3.00
9	Goa, Daman, Diu	995.00	251.00	5.00	1 251.00	16.00
10	Gujarat	6 430.00	5 504.00	1 031.00	12 965.00	2 948.00
11	Haryana	449.00	515.00	0.00	964.00	191.00
12	Himachal Pradesh	9 120.00	3 962.00	0.00	13 082.00	566.00
13	Jammu & Kashmir	11 019.00	9 422.00	0.00	20 441.00	3 089.00
14	Karnataka	24 832.00	7 632.00	3.00	32 467.00	4 489.00
15	Kerala	8 429.00	1 894.00	0.00	10 323.00	91.00
16	Madhya Pradesh	81 619.00	50 211.00	0.00	131 830.00	3 853.00
17	Maharashtra	26 613.00	19 951.00	108.00	46 672.00	7 160.00
18	Manipur	5 936.00	11 448.00	0.00	17 384.00	177.00
19	Meghalaya	5 925.00	9 708.00	0.00	15 633.00	261.00
20	Mizoram	3 786.00	14 552.00	0.00	18 338.00	125.00
21	Nagaland	5 137.00	9 027.00	0.00	14 164.00	14.00
22	Orissa	26 073.00	20 745.00	215.00	47 033.00	5 439.00
23	Punjab	517.00	895.00	0.00	1 412.00	107.00
24	Rajasthan	4 309.00	9 562.00	0.00	13 871.00	6 921.00
25	Sikkim	2 363.00	755.00	0.00	3 118.00	386.00
26	Tamil Nadu	8 659.00	8 398.00	21.00	17 078.00	2 836.00
27	Uttar Pradesh	22 902.00	11 114.00	0.00	34 016.00	1 177.00
28	West Bengal	3 565.00	2 672.00	2 125.00	8 362.00	98.00
	All India	377 358.00	255 064.00	4 871.00	637 293.00	51 896.00

Table 2. Percentages of forest area to the total geographical area

S. No.	State/Union Territory	Total geographic area (TGA)	Percentage of dense forest to TGA	Percentage of open forest to TGA	Percentage of mangrove to TGA	Percentage of forest cover to TGA	Percentage of scrub to TGA
1	Andaman & Nicobar	824.90	78.98	1.52	11.71	92.21	0.00
2	Andhra Pradesh	27 504.50	8.79	7.14	0.14	16.08	3.48
3	Arunachal Pradesh	8 374.30	68.97	13.24	0.00	82.21	0.12
4	Assam	7 843.80	18.51	11.69	0.00	30.20	0.41
5	Bihar	17 387.70	7.63	7.59	0.00	15.23	1.10
6	Chandigarh	11.40	5.26	0.88	0.00	6.14	0.00
7	Dadra & Nagar Haveli	49.10	32.38	8.76	0.00	41.14	2.04
8	Delhi	148.30	2.36	3.57	0.00	5.93	0.20
9	Goa, Daman, Diu	381.40	26.09	6.58	0.13	32.80	0.42
10	Gujarat	19 602.40	3.28	2.81	0.53	6.61	1.50
11	Haryana	4 421.20	1.02	1.16	0.00	2.18	0.43
12	Himachal Pradesh	5 567.30	16.38	7.12	0.00	23.50	1.02
13	Jammu & Kashmir	22 223.50	4.96	4.24	0.00	9.20	1.39
14	Karnataka	19 179.10	12.95	3.98	0.00	16.93	2.34
15	Kerala	3 886.30	21.69	4.87	0.00	26.56	0.23
16	Madhya Pradesh	44 344.60	18.41	11.32	0.00	29.73	0.87
17	Maharashtra	30 771.30	8.65	6.48	0.04	15.17	2.33
18	Manipur	2 232.70	26.59	51.27	0.00	77.86	0.79
19	Meghalaya	2 242.90	26.42	43.28	0.00	69.70	1.16
20	Mizoram	2 108.10	17.96	69.03	0.00	86.99	0.59
21	Nagaland	1 657.90	30.98	54.45	0.00	85.43	0.08
22	Orissa	15 570.70	16.74	13.32	0.14	30.21	3.49
23	Punjab	5 036.20	1.03	1.78	0.00	2.80	0.21
24	Rajasthan	34 223.90	1.26	2.79	0.00	4.05	2.02
25	Sikkim	709.60	33.30	10.64	0.00	43.94	5.44
26	Tamil Nadu	13 005.80	6.66	6.46	0.02	13.13	2.18
27	Uttar Pradesh	29 441.10	7.78	3.77	0.00	11.55	0.40
28	West Bengal	8 875.20	4.02	3.01	2.39	9.42	0.11
	All India	328 730.00	11.48	7.76	0.15	19.39	1.58

Table 3. Deforestations and areas in affected by fires

S. No.	State/Union Territoty	Deforestation (1972–1995) (Lakhs hectares)	Area Involved in forest fire ha (1995–96)
1	Andaman & Nicobar	–3.200	6.000
2	Andhra Pradesh	17.300	n.a.
3	Arunachal Pradesh	–3.700	219.120
4	Assam	3.200	0.000
5	Bihar	4.900	n.a.
6	Chandigarh	0.000	n.a.
7	Dadra & Nagar Haveli	–0.100	526.590
8	Delhi	–0.010	2.000
9	Goa, Daman, Diu	0.100	19.000
10	Gujarat	0.700	0.000
11	Haryana	–0.100	1 254.000
12	Himachal Pradesh	2.900	57 143.000
13	Jammu & Kashmir	8.300	680.000
14	Karnataka	1.300	n.a.
15	Kerala	–0.800	1 821.570
16	Madhya Pradesh	6.000	1 578.204
17	Maharashtra	5.400	21 613.000
18	Manipur	8.700	n.a.
19	Meghalaya	6.100	n.a.
20	Mizoram	8.900	876.330
21	Nagaland	3.600	n.a.
22	Orissa	11.200	n.a.
23	Punjab	0.400	9 637.330
24	Rajasthan	4.700	n.a.
25	Sikkim	–1.100	0.000
26	Tamil Nadu	4.800	2 192.000
27	Uttar Pradesh	1.200	77 610.000
28	West Bengal	2.200	n.a.
	All India	96.900	175 178.144

Table 4. Forest area indices of India

S. No.	State/Union Territory	Percentage of dense forest to TGA	Dense forest area index	Rank	Percentage of open forest to TGA	Open forest area index	Rank	Deforestation (1972–1995) (million hectares)	Deforestation index	Rank 0.1	Weighted composite index *	Rank
1	Andaman & Nicobar	78.98	1.0000	28	1.52	0.0094	3	–0.320	0.98	27	0.75	28
2	Andhra Pradesh	8.79	0.0998	13	7.14	0.0919	17	1.730	0.00	1	0.09	4
3	Arunachal Pradesh	68.97	0.8716	27	13.24	0.1815	23	–0.370	1.00	28	0.71	27
4	Assam	18.51	0.2244	19	11.69	0.1587	22	0.320	0.67	13	0.25	18
5	Bihar	7.63	0.0849	10	7.59	0.0985	18	0.490	0.59	9	0.14	11
6	Chandigarh	5.26	0.0545	8	0.88	0.0000	1	0.000	0.82	21	0.12	9
7	Dadra & Nagar Haveli	32.38	0.4023	25	8.76	0.1156	19	–0.010	0.83	23	0.37	21
8	Delhi	2.36	0.0172	4	3.57	0.0396	8	–0.001	0.82	22	0.10	6
9	Goa, Daman, Diu	26.09	0.3216	21	6.58	0.0837	15	0.010	0.82	20	0.31	20
10	Gujarat	3.28	0.0290	5	2.81	0.0283	6	0.070	0.79	18	0.11	8
11	Haryana	1.02	0.0000	1	1.16	0.0042	2	–0.010	0.83	23	0.08	3
12	Himachal Pradesh	16.38	0.1971	15	7.12	0.0916	16	0.290	0.69	14	0.22	16
13	Jammu & Kashmir	4.96	0.0506	7	4.24	0.0493	11	0.830	0.43	5	0.09	5
14	Karnataka	12.95	0.1530	14	3.98	0.0455	10	0.130	0.76	16	0.19	14
15	Kerala	21.69	0.2652	20	4.87	0.0586	12	–0.080	0.86	25	0.27	19
16	Madhya Pradesh	18.41	0.2231	18	11.32	0.1533	21	0.600	0.54	7	0.24	17
17	Maharashtra	8.65	0.0979	12	6.48	0.0823	14	0.540	0.57	8	0.14	12
18	Manipur	26.59	0.3280	23	51.27	0.7395	26	0.870	0.41	4	0.44	25
19	Meghalaya	26.42	0.3258	22	43.28	0.6222	25	0.610	0.53	6	0.42	23
20	Mizoram	17.96	0.2173	17	69.03	1.0000	28	0.890	0.40	3	0.43	24
21	Nagaland	30.98	0.3844	24	54.45	0.7861	27	0.360	0.65	12	0.51	26
22	Orissa	16.74	0.2018	16	13.32	0.1826	24	1.120	0.29	2	0.21	15
23	Punjab	1.03	0.0001	2	1.78	0.0132	4	0.040	0.80	19	0.08	2
24	Rajasthan	1.26	0.0031	3	2.79	0.0281	5	0.470	0.60	11	0.07	1
25	Sikkim	33.30	0.4141	26	10.64	0.1432	20	–0.110	0.88	26	0.39	22
26	Tamil Nadu	6.66	0.0724	9	6.46	0.0819	13	0.480	0.60	10	0.13	10
27	Uttar Pradesh	7.78	0.0868	11	3.77	0.0425	9	0.120	0.77	17	0.14	13
28	West Bengal	4.02	0.0385	6	3.01	0.0313	7	0.220	0.72	15	0.10	7
	All India	11.48	0.1342		7.76	0.1010		9.69				

* The composite index gives 0.65 weight to dense forest, 0.25 weight to open forest, and 0.15 weight to deforestation

16 How can silviculturists support the natural process of recovery in tropical rain forests degraded by logging and wild fire?

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ABSTRACT

In all regions with tropical rain forests there are secondary forests degraded by insensitive logging and by wild fires. The demand for rehabilitation of these most degraded forests is set by conservationists and sometimes by forest owners wishing to certify their forest. Most rain forests have the capacity to gradually recover from selective harvesting, but after repeated harvests at too short intervals or if the forest is damaged by wildfires "rehabilitation plantation" is probably necessary. This paper shares the experience of a collaborative project (INIKEA) between the Swedish foundation, "Sow a Seed", sponsored by IKEA of Sweden, and the latter's customers and local counterpart in Sabah, Innoprise Corporation Sdn Bhd. The project is funded by the foundation and supervised by the Swedish University of Agriculture Sciences. The aim of our programme is primarily to improve the biodiversity of a heavily degraded tropical rain forest. Natural fauna and flora are expected to migrate into the area after the rehabilitation plantation. In the current study, located in Sabah, we investigate the feasibility of rehabilitation plantation in a secondary tropical rain forest degraded by harvesting and by wildfire in 1983. Under the canopy of a Macaranga-dominated forest, more than 25 species mainly belonging to the Dipterocarpaceae family, and some fruit trees are planted using two different plantation concepts, i.e. line plantation and gap plantation. In the first phase of the project from 1998 to 2003, an area of 4 000–5 000 ha will be enrichment planted with seedlings and wildings. The study also includes tests of different techniques for seedling and wilding production and in the forest different shade adjustment procedures that involve girdling and felling in the upper and lower canopies of the pioneer vegetation. The main results so far are that gap plantation is cheaper than line plantation, mainly because the required number of compass lines in line planting is double that for gap planting. Gap plantation

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seems to create a more natural structure of the new Dipterocarpaceae forest because the 100 small groups of 3 seedlings per hectare are more irregularly distributed in the forest than in line plantation. The survival of the seedlings in this environment is high during the first year but natural damage and some mortality to the seedlings take place later even after intensive maintenance.

INTRODUCTION

In the late 1982 and early 1983, a severe prolonged drought triggered forest fires all over Sabah causing extensive and severe damage to the forest. The rain forest which does not readily burn is not adapted to fire. The impact was devastating. Although the fire crept on the forest floor, seldom up to the canopy, most of the forest species were destroyed. Some bigger trees suffered partial damage in the trunk and survived. But the smaller ones succumbed. The areas badly burnt were immediately infested by pioneer trees and vines. The once complex structure of the rain forest changed to a simpler forest structure with fewer plant species. The surviving larger trees interspersed the continuous canopy of mostly *Macaranga*. Regeneration of the primary species depends very much on the surviving mother trees and in some areas, this is very limited to a few primary species.

In June 1998, Innoprise Corporation of Sabah and Sow-A-Seed Foundation of Sweden signed a Memorandum of Agreement to collaborate in a forest rehabilitation project (INIKEA project) in the Kalabakan Forest Reserve within the Yayasan Sabah Concession area. The project area was severely damaged during the drought in 1982/83, followed by log extraction a few years later. The aim of the project is to improve the biodiversity in this forest. Sow-A-Seed Foundation provides financial assistance for five years and Innoprise Corporation sees to the implementation of the project.

THE PROJECT AREA

The project area is 14 300 ha located west of Tawau. A major part of the forest within this area suffered wildfire in 1983 followed by logging a few years later. This severely degraded forest is now characterized by a continuous canopy of mostly *Macaranga* sparsely interspersed with dipterocarps. The task of the project for the first five years is to rehabilitate 4 000 to 5 000 ha of severely degraded forest by enrichment planting with timber and fruit tree species.

The project makes two important distinctions—one is the engagement of directly-employed locals for all its operations, except for the road-making and maintenance by a contractor, and two is the restricted use of chemicals in all its operations, especially herbicides. In the nursery it may be necessary to resort to fungicides and insecticides to control pests and diseases.

ENRICHMENT PLANTING

There has been numerous mentions of rehabilitation projects in many countries for various reasons. However, the project drew a lot of direct experience from projects in Sabah, especially the Luasong project (Awang Mohdar 1995), Innoprise Corporation–FACE

Foundation project (INFAPRO) (Moura-Costa *et al*. 1993), and the Deramakot project by the Forestry Department of Sabah (Martin *et al*. 2001). The project adopted the line-planting method as practised in INFAPRO at 3 m (within the lines) by 10 m (between the planting lines). The gap-cluster planting was formulated to simulate natural openings in the forests. In this case rather small gaps are created by selectively removing overhead shade.

Sub-blocking

In the INIKEA project, the area is divided into blocks of about 200–300 ha. These blocks are then further sub-divided into sub-blocks or work areas of 10–50 ha which are the basic work units for operational practicality during planting and tending. The boundaries are surveyed and the roads built before site preparation begins. Generally, there is already a ready network of ex-logging roads that need only to be upgraded.

Species

For biodiversity a minimum of 25 species is dispatched to the sub-blocks. The nursery ensures that no single species makes up more than 20 percent of the total to be dispatched. In the field these species are planted in a mix. In the lot 5 percent are fruit tree species. Generally, a majority of the dispatch plants are the dipterocarps.

Line planting

The planting lines are created at intervals of 10 m apart. These lines are cleared to 2 m wide and the planting points staked with a belian marker every 3 m (Figure 1). *Macaranga* trees in and between the lines are selectively ring-girdled to open up the upper canopy. Non-commercial small trees, shrubs and undergrowth along the lines are also cleared. This is followed by a 100 percent climber cutting.

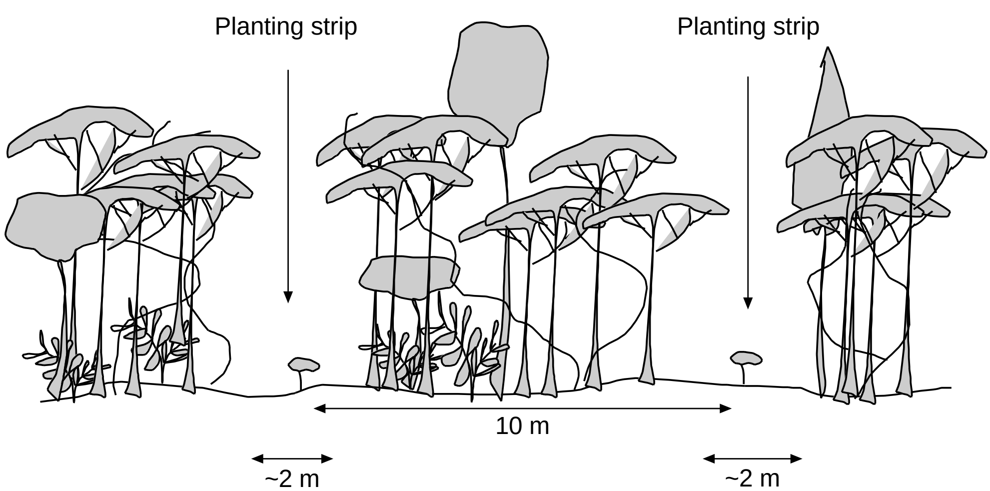

Figure 1. The layout of the planting strips in line planting

Normally, the opening of the canopy is rather gradual. First removal of small trees, shrubs and undergrowth along the lines creates an immediate opening at the lower canopy. Next the drying up of the leaves of the lianas in a week or two again adds up to the opening. Finally, the girdled trees will slowly dry up. This could start as early as three months up to a year.

Open areas of shrubs and grasslands pose a special problem. They occur in small patches scattered all over, marking ex-landings, ex-camps and along the roadsides. Planting in these highly degraded sites has always resulted in high mortality rates, mainly because of the very poor soils and the intense weed competition. In the Deramakot project it is recommended using tall plants raised in larger polythene bags (Martin *et al.* 2001). The plants may have a better chance to survive against the weeds.

In the INIKEA project, the open areas are planted with *Pterocarpus indicus*. Potted plants and stick cuttings are used. Using stick cuttings, however, is tricky. They have to be planted during continuous rainy days. Once established they are able to grow normally putting on numerous heavy branches providing shade.

Gap-cluster planting

Forest gaps are the results of the fall of canopy trees. Normally such gaps are small if they involve few trees. In gap-cluster planting, gaps are deliberately created by girdling unwanted trees, bringing about a gradual change in the opening of the forest.

In the INIKEA project, the gap-planting method allows great flexibility of locating the planting points compared to the systematic lines approach. The gap location is selected inside a 10 x 10 m sub-quadrate.

A 20 x 20 m grid is created by cutting systematic lines 20 m apart (see Figure 2 below). These lines serve as access and reference to the quadrate centers. Every 20 m along the line is marked with a stake indicating the quadrate center. The quadrate is halfway to the previous stake (10 m) and halfway to the next stake (10 m) and another halfway to the lines left and right. So each quadrate is 20 by 20 m on each side. The quadrate is further sub-divided into 4 sub-quadrates of 10 by 10 m each. Within each sub-quadrate, the gap is located at the most suitable place for planting.

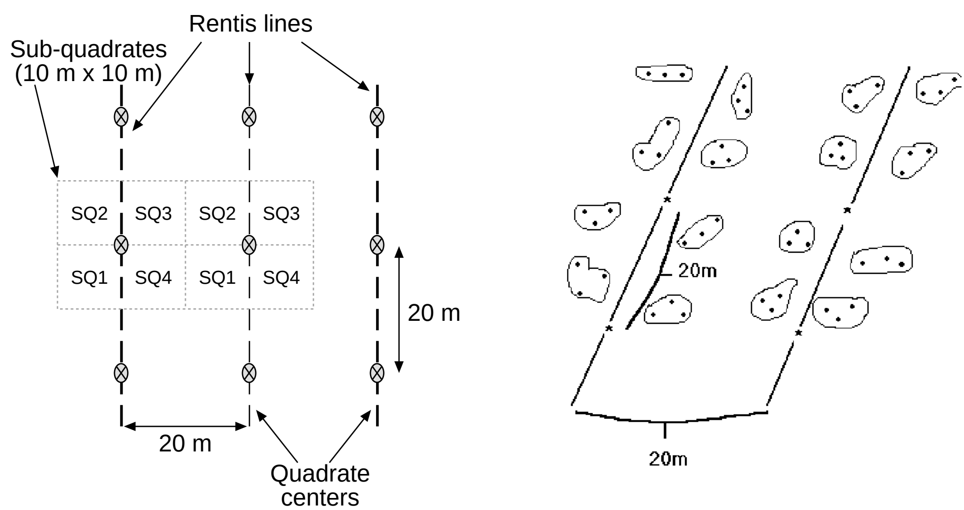

Figure 2. The gap-planting arrangement

The field crew has first of all to decide whether planting is necessary in the sub-quadrate based on the presence or absence of natural regeneration. If there are fewer than five species within the sub-quadrate, the sub-quadrate should be planted. Once that is decided, the choice of placing the gap inside the sub-quadrate rests on the crew according to certain criteria:

- the spot has already a natural gap to minimize further openings;
- the spot is suitable for planting, i.e. away from obstacles, e.g. rocks, streams, steep slopes, buttresses of big trees, etc.;
- if there is no natural gap, there should be a possibility of creating one by girdling some undesirable trees.

The chosen spot is then staked to mark the gap centre. In these gaps of about 3 to 4 m diameter, a cluster of three seedlings is planted, each 1–1½ m away from the gap centre.

As in line planting, climber cutting is done for the whole area.

POST-PLANTING OPERATION

Maintenance and shade adjustment

The project recognizes the need for frequent maintenance when the plants are still small. In the first two years, weeding was three times annually. After that the weeding was less frequent. If necessary, the maintenance will follow up to 10 years.

After 1½ to 2 years planting, a shade manipulation operation was carried out to open up the overhead shade. Initially, the shade adjustment took out more upper-canopy trees, the *Macaranga*. The result was a thickening of the foliage of the lower-storey vegetation giving a lot of shade on the planted seedlings. So in the subsequent operations the focus was equally on the removal of the lower-canopy shade as well as the upper canopy. In the lower canopy shrubs and small trees of no commercial value were removed.

Two rounds of shade adjustment may be necessary. The second round should be about four years after planting.

Survival

A 10% census was carried out three months after planting. The survival after the first census averaged over 90%. The survival was especially poor on open sites infested by *Imperata* grass and shrubs. Now these sites are planted with *Pterocarpus indicus* which is adapted for very open sites. Damage to the surviving plants occurs in many forms. Physical damage leading even to mortality from falling twigs, branches and even stems is common. This is especially after the girdled trees begin to fall. So far the damage has not been quantified.

Damage by deer and wild boars has also been detected. Deer rubbing their antlers on the trees can most of the times completely debark the trees and kill them. Wild boars are especially destructive during their breeding season. They would snap thumb-sized plants and even bigger trees for their nests.

Insect damage although quite common on some species, particularly *Parashorea*, is at least not fatal. In the forest most of the species are free of major pest and disease problems.

PLANT PRODUCTION

The nursery is located in Luasong. When required, the nursery can be made to hold 1 million plants at any one time. The source material for planting stock production is from seeds or wildings. Although propagation by means of rooted cuttings is possible, this method is not considered for the project for reasons of biodiversity. Procuring regular supply of seeds and the difficulty of storing fruits have always been a problem to rehabilitation projects. Since the project started in 1998, there has been no major fruiting in Sabah. Several rather localized flowering and fruiting amounted to modest quantities of fruits. Poor fruit harvest has much to do with infestation by insects when the fruits are on the trees and mammals, especially wild boars, when the fruits fall to the ground. It was only in early and mid-2002 that there was substantial flowering and fruiting of dipterocarps and non-dipterocarps near Luasong.

The nursery now has a stock of about 500 000 plants comprising more than 60 species, mostly dipterocarps.

For the first years of the project, there was a heavy dependence on wildings. The collection of wildings compelled the nursery staff to explore further into the surrounding forests since there had been no major fruiting the previous years. Luckily, surplus stock was available for purchase from the INFAPRO nursery, another of ICSB's collaborative forest rehabilitation project with FACE Foundation in Lahad Datu. These supplemented the requirement to make up the required quantity and the minimum number of 25 species per sub-block planting.

The plants are raised in 3" x 8" black polybags, except for species with larger fruits, for example, belian (*Eusideroxylon zwageri*), tengkawang (*Shorea mecistopteryx*, *S. macrophylla*) and merbau (*Intsia palembanica*), requiring larger bags of 6" x 9". The potting mixture is wholly forest topsoil, of heavy clay loam with poor drainage. Sand and peat to improve the soil mix are presently not easily available. Aerial growth is apparently not seriously impaired using this soil, but inspection of the roots revealed inadequate development of tertiary roots.

With the prohibition of using herbicides, thick black plastic sheets are placed at the base of the beds to suppress weed development. Weeds in the pot are manually removed. The use of fungicides and insecticides is allowed only when absolutely necessary. So far there has not been any major pest and disease outbreaks in the nursery. Those species known to be susceptible to fungus, for example, mengaris (*Koompassia excelsa)*, keranji (*Dialium indum*) and kayu malam (*Diospyros* spp.), especially at germination and very young stages, are kept in small isolated batches to minimize spread of disease.

Each pot is given a one-time application of Agroblen®, a controlled release fertilizer at 4 g per pot just after transplanting.

WILDINGS

The use of wildings adds an extra step to the nursery process which is the acclimatization stage in humidity chambers. The wildings collected in the field are kept in moist cool boxes and transferred promptly to the nursery. The roots are trimmed to fit into the polybags and the leaves clipped to minimize dehydration. The plants potted into bags are placed in the chambers. These chambers are bamboo or wooden frames covered with transparent plastic sheets. In the chambers the wildings are watered and sealed in to maintain high humidity. The plants remain inside the cover for 2 to 3 months, depending on the species, after which the plastic covering is gradually removed over a few days until the plants are ready for the open.

Ideally, smaller wildings are preferred. They recover and reestablish much quicker than taller ones. Plants more than 40 cm height are less able to survive and slower to recover. The hardier species are *Dryobalanops lanceolata, Aquilaria malaccensis* and *Pentace laxiflora.* Overall, most species have good survival rates, for example, most *Dipterocarpus* spp., *Shorea oleosa* and *S. parvifolia.* The leguminous species, *Koompassia excelsa*, *Sindora* sp., *Intsia palembanica* and *Canarium* sp., are also easy to transfer to the nursery.

RESEARCH

Canopy opening before and after planting is crucial in canopy under-planting. The question is whether the opening should be drastic or gradual and by how much. A study was recently started as part of a Ph.D. programme of the Swedish University of Agriculture Science to test different pre-planting shade adjustment procedures involving girdling and felling in the upper and lower canopies of the secondary forest (Romell 2002). The eventual outcome of the study will assist in refining the present site preparation procedures.

The factorial design's main treatment is the removal of shade at the upper canopy (more than 15 m high) by felling and girdling. The additional treatment is the removal and the retention of the lower-storey vegetation of saplings and shrubs. The study uses two species of *Dipterocapus* and two species of *Shorea*.

CONCLUSION

In line planting, different line directions have been recommended (Appanah & Weinland 1993, Adjers *et al*. 1996). The question is whether a particular direction is suited to the many species used for this project, coupled with the highly heterogeneous forest conditions. For operational efficiency, it is best to lay the lines perpendicular to the main access for easier distribution of the plants during planting and also it would be easier to relocate during maintenance.

Deciding on the widths of the planting lines and gaps to optimize plant growth has always pestered the manager's mind. In general wider openings are better (Adjers *et al*. 1996) but more costly. Also there is a risk of promoting weed growth, for example, small trees, shrubs and herbaceous plants, causing more shading to the planted seedlings. There is a need to strike a balance between operational considerations and plant growth. In the case where so many species are planted, a conservative opening initially is probably better overall. The subsequent maintenance and shade adjustment rounds will gradually open up the canopy after the plants are safely established.

The procedures, whether in line or gap planting are made simple enough to be implemented in the field. In general there is a preference for gap planting mainly because it requires half less lines to cut. Furthermore, the lines in gap planting are access lines and need not be very wide compared to line planting where the lines are for planting. Hence the 2-m width requirement. The lining can therefore be easier and faster for gap planting.

The cluster arrangement in gap planting also has another advantage. A gap can be considered a planting point. If eventually one out of three plants survives, the point is considered filled. The need for refilling which could be costly is avoided.

Recognizing the high cost associated with forest rehabilitation, especially during site preparation and planting and the hassle for legalized workers, a conscious decision was made at the start to keep the operations cost to a minimum at less than RM1 000 per hectare. This is possible by avoiding using contractors and to simplify most of the field operations so that the field crew are able to understand rapidly with some training and are able to effectively and accordingly implement these operations. Their basic tools are parangs, compasses, clinometers and tapes. Their crucial skills are tree species identification, and the ability to use the compasses and clinometers.

To date 3 500 ha have been planted for the project and another 90 ha silviculturally treated. The nursery has substantially expanded and has grown out of its dependence to buy planting stock towards self sufficiency.

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17 Using native tree species to restore degraded hillsides in Hong Kong, China

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ABSTRACT

The interest in restoring forest on degraded hillsides in Hong Kong for biodiversity conservation has been growing since the beginning of the last decade. This paper reviews the results of 8 planting trials conducted by different researchers on various scales in the last ten years using a total of 57 native tree and shrub[1] species with respect to early survival and growth. The performances of these seedlings were evaluated under the criteria of the framework species method of reforestation that was developed in North Queensland's wet tropics. Seedling performances were highly variable between species and sites. In general, a higher number of the native tree species showing early successional characters performed better on the exposed and eroded hillsides, such as Schefflera octophylla, Mallotus paniculatus and Zanthoxylum avicennae, while other early successional species performed badly, such as Sapium discolor. However, some late successional species also performed very well on the exposed hillsides, e.g. Cyclobalanopsis neglecta, C. edithiae and Syzygium hancei. Other late successional species performed very badly, such as Pygeum topengii. Only one of the 8 planting trials, also the latest one, used native shrub species. The preliminary results indicated that shrubs were doing very well even in very poor soil and on 55 degree cut slope surfaces. This suggests that the focus on planting tree seedlings for afforestation may have been misplaced in Hong Kong. The succession pathway from shrubland[1] to forest should be given more consideration and the first step of forest restoration projects may start with shrubs, followed by reinforcement with trees at a later stage. A list of potential framework species for restoring native, species-rich forest is prepared on the basis of this review.

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[1] Shrub is woody species that seldom exceeds 3 m in height in Hong Kong and vegetation formed by shrub species is referred to as shrubland.

INTRODUCTION

Tropical deforestation has been a major conservation issue for many years. Many efforts have been put to stop further deforestation on one hand and restore degraded forest land on the other. Exotic tree species are often used for plantation as well as environmental forestry. It is because exotic species have been tested, and seed sources selected and genetically improved to produce stocks of very high productive potential after many years of research (Haggar *et al.* 1998). In many cases, exotic species are also preferred because they grow faster than native species (Richardson 1998). They are also often better suited to planting on degraded land, where most afforestation is required. However, Butterfield (1993) points out that exotic tree species are rarely tested against local species that may be better adapted. With the rising concern for biodiversity conservation, habitat restoration is regarded a complementary measure to preserving existing habitats for native species (Jordan 1997). Reforestation aiming at restoring biodiversity has become a new trend and the planting of more native tree species is inevitable.

Currently, the problems with the wider use of native tree species in commercial and environmental forestry are yet to be overcome. There is a general lack of reliable knowledge of basic biology and nursery operations for native tree species in the tropics because of the large number of species and contradictory information from different areas (Richardson 1998). Information on seed collection, storage, germination and seedling growth conditions for many native tree species is not yet available (Blakesley *et al.* 2002). Native species are thus more difficult to manage silviculturally than the exotics. This makes the production of native seedlings more expensive (Elliott *et al.* 1995, Richardson 1998). Research on the use of native species, both in nursery production and planting method has already started throughout the tropics (Goosem & Tucker 1995, Forest Restoration Research Unit 1998, Hau 2000, Carnevale & Montagnini 2002). Some studies have already shown that certain native species are promising (Holl 1998, Blakesley *et al.* 2002).

Grasses and shrubs cover over 50% of the land area of Hong Kong, mostly on degraded hillside sites that formerly supported forest (ERM 2002). Forestry in Hong Kong has always been for environmental reasons, such as soil erosion control, watershed protection, landscape repair and more recently biodiversity conservation, rather than timber production (Corlett 1999). Despite the fact that the most commonly planted tree species in the early afforestation history of Hong Kong (1871–1965) was a native pine, *Pinus massoniana* (it lost its importance due to pest problems and its susceptibility to fire), Hong Kong has relied heavily on a limited number of exotic species in the 1970s and 1980s. Between 1871 and 1990, a total of 150 tree species were named in Hong Kong forestry reports, and only 33 were native species (Corlett 1999). After the Earth Summit in 1992, Hong Kong has declared its intention to follow the Convention on Biological Diversity. Since then, an increasing number of native species has been tried though a higher percentage of exotic trees are still used in reclamation projects on barren lands (Chong 1999, Lay *et al.* 1999). The percentage number of native trees planted in Country Parks, which cover the land area of Hong Kong, has increased from 38% (total 276 334) in 1994 to 59% (total 500 500) in 2001. However, most of these native tree species have been planted, albeit in the same way the exotics were, with little attempt to allow for the particular ecological characteristics of the species used. Most of these planting trials using native tree species have so far gained little success and are not well documented.

The aim of this paper is to review the performances of native tree species in eight planting trials in Hong Kong in which survival and growth data in the first two years are available. The performances and ecological characteristics of these native species were evaluated against the features of the framework species method of forest restoration, which was first developed in North Queensland’s Wet Tropics (Goosem & Tucker 1995).

METHOD

The Hong Kong Special Administrative Region of the People's Republic of China (hereafter, Hong Kong) (22°N, 114°E), consists of a section of the Chinese mainland (Kowloon and the New Territories) and numerous islands, with a total land area of 1 100 km^2. The topography is mostly rugged, with the highest point at Tai Mo Shan (957 m above sea level) in the New Territories. The climate is subtropical monsoon, with a hot, wet summer and cool, dry winter. This climate would support tall, evergreen, fire-excluding forest, but this has been largely cleared within the last 1 000 years (Dudgeon & Corlett 1994). Today all flatland is urbanized, cultivated or abandoned cultivation. The remaining 80% of the land area is mostly steep hillsides covered in secondary grasslands and shrublands, maintained by anthropogenic fires, with an increasing area of secondary forest that has largely developed since 1945 (Zhuang & Corlett 1997). Some sites at high altitude may have escaped complete deforestation, although all forest patches have been disturbed.

The eight planting trials were conducted in various parts of Hong Kong ranging from 70 to 550 m above sea level by different institutions (Table 1). All except the Tai Lam site were typical degraded hillside sites covered with either or both common shrubs (e.g. *Rhodomyrtus tomentosa*, *Melastoma sanguineum*, *Baeckae frustescens* and *Litsea rotundifolia*) and grasses (e.g. *Arundinella*, *Ischaemum*, *Eulalia*, *Eragrostis*, *Cymbopogon* and *Miscanthus* species). Container-grown seedlings of 30–50 cm in height were planted in these seven sites. Grass was cut in advance and grass leaves were left on site as mulching. The Tai Lam site was man-made cut slopes where loosened topsoil was scraped off after landslip by engineering means. The soil condition was thus the worst amongst all sites. Commercial Bermuda grass seeds were applied on the slope by hydro-seeding prior to planting. After the grass cover was well developed (in a month), container grown tree and shrub seedlings were planted. Only small trees and shrubs were planted on these slopes because of safety concern. The total number of seedlings planted range from 300 in Tai Mo Shan 2 to over 1 000 in Hung Lung Hang and Tai Lam.

The raw data of these eight planting trials were extracted and only the first two-year growth and survival data were used in this review. However, only 18-month data were available in the Tai Lam cut slope site. The relative height increment per year (RHI) was calculated using RHI = [ln (H_2) – ln (H_1)] / time in years, where H_1 and H_2 were the initial and final seedling heights respectively (Coomes & Grubb 1998). The growth and survival of the seedling species were summarized and compared. Based on the already existing ecological information on the tree species planted, they were evaluated against the principles of the framework species method (Goosem & Tucker 1995).

RESULTS

A total of 51 native trees and 5 native shrubs were used in these 8 planting trials (Table 2). Most of them bear fleshy fruits that are dispersed by birds in the winter dry season. The tree species used have most of the ecological characteristics of the tree flora in Hong Kong including early pioneers, common secondary forest dominant species and remnant forest species. Thirty species were used only in 1 site; 12 in 2 sites and 14 in 3 or more than 3 sites (Table 3).

Of the 14 species that were planted in 3 or more sites, 5 species had consistently high survival (50–100%) across all the sites they were planted. They were *Schefflera octophylla* (5 sites), *Machilus breviflora* (5 sites), *Choerospondias axillaris* (4 sites), *Cinnamomum camphora* (4 sites) and *Schima superba* (4 sites). The rest of the 14 species

Table 1. Characteristics of the eight study sites in chronological order

Year	Site	Vegetation cover	District	Altitude (m)	Steepness	Slope orientation	Data source
89–91	Kwun Yam Shan 1	Scrubland	Central New Territories	200	Gentle	N facing	Zhuang & Corlett, 2000
95–98	Tai Mo Shan 1	Grassland	Central New Territories	550	Steep	NW facing	Hau, 1999
95–98	Ho Sheung Heung	Grassland	Northern New Territories	20	Gentle	SE facing	Hau, 1999
95–98	Kwun Yam Shan 2	Scrubland	Central New Territories	200	Gentle	NW facing	Hau, 1999
98–00	Nam Shan	Grassland	South Lantau	250	Gentle	NW facing	Unpublished data, KGBG[1]
00–02	Tai Mo Shan 2	Grassland	Central New Territories	550	Steep	N facing	Unpublished data, KGBG
00–02	Hung Lung Hang	Grassland	Northern New Territories	70	Very gentle	S facing	Unpublished data, KGBG
01–02	Tai Lam	Cut slope	Northwest New Territories	200	Very steep	NE facing	Unpublished data, KGBG & CED[2]

Note: [1] KFBG is Kadoorie Farm and Botanic Garden; [2] CED is Civil Engineering Department, Hong Kong SAR Government.

Table 2. Ecological characteristics of the native tree and shrub species used in the eight planting trials

Species	Growth form	Dry/wet season fruiting	Fruit type	Seed dispersal agent in Hong Kong	Ecological status in Hong Kong
Antirhea chinensis	Small tree	Dry	Drupe	Bird	Common in secondary forest and scrubland
Aporosa dioica	Small tree	Wet	Drupe	Bird	Common in secondary forest and scrubland
Aquilaria sinensis	Large tree	Wet	Capsule	Bird	Common in lowland forest
Archidendron lucidum	Shrub	Dry	Capsule	Bird	Common in scrubland & forest edges
Ardisia crenata	Shrub	Dry	Drupe	Bird	Common forest floor species
Bischofia javanica	Large tree	Dry	Drupe	Bird	Common in secondary forest
Bridelia tomentosa	Small tree	Dry	Drupe	Bird	Common in secondary forest and scrubland
Castanopsis fissa	Large tree	Dry	Acorn	Bird	Common in secondary forest
Celtis tetrandra	Large tree	Wet	Drupe	Bird	Common in secondary forest
Choerospondias axillaris	Large tree	Dry	Drupe	Bird & civet	Common in secondary forest
Cinnamomum camphora	Large tree	Dry	Drupe	Bird	Common in secondary forest
Cleistocalyx operculata	Medium tree	Wet	Drupe	Bird	Riparian species
Cordia dichotoma	Large tree	Wet	Drupe	Bird	Remnant forest species
Cratoxylum cochinchinense	Small tree	Dry	Capsule	Wind	Common in secondary forest and scrubland
Cryptocarya concinna	Large tree	Dry	Berry	Bird	Remnant forest species
Cyclobalanopsis edithiae	Large tree	Wet	Acorn	None	Remnant forest species
Cyclobalanopsis myrisinifolia	Small tree	Dry	Acorn	None	Localized distribution
Cyclobalanopsis neglecta	Large tree	Dry	Acorn	None	Remnant forest species
Cyclobalanopsis championii	Small tree	Dry	Acorn	None	Localized distribution
Daphniphyllum calycinum	Small tree	Dry	Drupe	Bird	Common in scrubland and forest edges

Species	Growth form	Dry/wet season fruiting	Fruit type	Seed dispersal agent in Hong Kong	Ecological status in Hong Kong
Diospyros morrisiana	Small tree	Dry	Berry	Bird	Common in secondary forest
Elaeocarpus chinensis	Large tree	Dry	Drupe	Bird & civet	Common in secondary forest
Gordonia axillaris	Small tree	Dry	Capsule	Wind	Common in secondary forest and scrubland
Ilex rotunda	Small tree	Dry	Berry	Bird	Common in secondary forest and scrubland
Liquidambar formosana	Large tree	Dry	Capsule	Wind	Common in secondary forest
Lithocarpus glaber	Medium tree	Dry	Acorn	None	Common in secondary forest
Lithocarpus harlandii	Large tree	Dry	Acorn	None	Remnant forest species
Litsea rotundifolia var. *oblongifolia*	Shrub	Dry	Drupe	Bird	Common in scrubland and forest edges
Machilus breviflora	Medium tree	Dry	Drupe	Bird	Common in secondary forest
Machilus chekiangensis	Medium tree	Dry	Drupe	Bird	Common in secondary forest
Machilus chinensis	Large tree	Dry	Drupe	Bird	Remnant forest species
Machilus oreophila	Large tree	Dry	Drupe	Bird	Remnant forest species
Machilus velutina	Medium tree	Dry	Drupe	Bird	Common in secondary forest
Mallotus paniculatus	Small tree	Dry	Capsule	Bird	Common in secondary forest and scrubland
Melicope pteleifolia	Small tree	Dry	Capsule	Bird	Common in scrubland
Myrsine seguinii	Small tree	Dry	Drupe	Bird	Common forest floor species
Ormosia emarginata	Small tree	Dry	Capsule	Bird	Common in secondary forest
Pinus massoniana	Large tree	Dry	Cone	Wind	Common in secondary forest
Psychotria asiatica	Shrub	Dry	Drupe	Bird	Common in scrubland and secondary forest
Pygeum topengii	Medium tree	Wet	Drupe	Bird	Common in secondary forest
Rauvolfia verticillata	Small tree	Dry	Drupe	Bird	Common in secondary forest

Species	Growth form	Dry/wet season fruiting	Fruit type	Seed dispersal agent in Hong Kong	Ecological status in Hong Kong
Reevesia thyrsoidea	Small tree	Dry	Capsule	Wind	Common in scrubland and forest edges
Rhaphiolepis indica	Shrub	Dry	Drupe	Bird	Common in scrubland
Sapindus mukorossi	Medium tree	Wet	Drupe	Bird	Common in secondary forest
Sapium discolor	Medium tree	Dry	Capsule	Bird	Common in scrubland and forest edges
Schefflera octophylla	Large tree	Dry	Berry	Bird	Common in secondary forest and scrubland
Schima superba	Large tree	Dry	Capsule	Wind	Common in secondary forest
Sterculia lanceolata	Medium tree	Wet	Capsule	Bird	Common in secondary forest
Styrax suberifolius	Medium tree	Dry	Capsule	Unknown	Common in secondary forest
Syzygium cuminii	Medium tree	Dry	Drupe	Bird	Common in secondary forest
Syzygium hancei	Medium tree	Dry	Drupe	Bird	Common in secondary forest
Trema tomentosa	Small tree	Dry	Capsule	Bird	Common in scrubland and forest edges
Tutcheria championii	Large tree	Dry	Capsule	Unknown	Remnant forest species
Viburnum odoratissimum	Medium tree	Dry	Drupe	Bird	Common in secondary forest and scrubland
Xylosma longifolium	Medium tree	Dry	Drupe	Bird	Remnant forest species
Zanthoxylum avicennae	Small tree	Dry	Capsule	Bird	Common in secondary forest and scrubland

Table 3. Percentage survival (% S) and relative height increment (RHI) of each species at each site. N is the sample size

Species	Kwun Yam Shan 1			Tai Mo Shan 1			Ho Sheung Heung			Kwun Yam Shan 2			Nam Shan			Tai Mo Shan 2			Hung Lung Hang			Tai Lam		
	N	RHI	% S	N	RHI	% S	N	RHI	% S	N	RHI	% S	N	RHI	% S	N	RHI	% S	N	RHI	% S	N	RHI	% S
Cyclobalanopsis neglecta	20	0.66	43.00	150	0.64	97.50	40	0.65	90.00	40	0.67	80.00	25	0.52	15.39	18	0.58	90.00	82	0.27	48.78			
Mallotus paniculatus	20	0.39	100.00	40	0.30	100.00	40	0.26	87.50	40	0.29	42.50	202	0.45	73.40				220	0.48	80.45			
Castanopsis fissa	20	0.27	10.00	150	0.26	82.00	50	0.42	74.00	100	0.39	26.00	174	0.27	22.29									
Cinnamomum camphora	19	0.82	100.00	40	0.13	95.00	40	0.12	97.50	40	0.19	100.00	30	0.18	69.70									
Machilus breviflora	19	0.85	85.00	40	0.68	87.50	40	0.63	95.00	40	0.50	70.00	142	1.07	64.42									
Schefflera octophylla	10	0.84	65.00	150	0.44	82.00	50	0.83	70.00	100	0.52	59.00										112	0.62	71.32
Sterculia lanceolata	20	0.30	100.00	440	0.38	92.50	40	0.44	87.50	40	0.34	20.00	65	0.57	19.69									
Choerospondias axillaris				40	0.38	97.50	40	0.29	100.00	40	0.41	97.50							140	0.40	100.00			
Cyclobalanopsis edithiae	10	0.40	82.00										6	0.27	14.29	20	0.77	85.00	200	0.23	47.50			
Sapium discolor	20	0.35	55.00	150	N.A.	24.00	50	N.A.	0.00	100	N.A.	0.00												
Schima superba				150	0.15	96.00	50	0.23	86.00	100	0.19	78.00	3	0.47	83.33									
Cyclonalanopsis championii	10	0.47	80.00										34	1.14	40.00	23	0.69	47.82						
Gordonia axillaria	19	0.69	45.00										18	0.65	73.68							226	0.59	84.84
Pyguem topengii	23	0.63	60.00													11	0.45	1.00	100	0.18	35.00			
Bischofia javanica	20	0.83	100.00										9	0.81	22.22									
Cleistocalyx operculata	20	0.62	100.00										36	0.57	97.22									
Cordia dichotoma																14	0.07	57.14	25	0.31	76.00			
Cratoxylum cochinchinense	10	0.93	100.00										16	0.21	21.21									
Cyclobalanopsis myrisinifolia	20	0.66	27.00										16	0.36	29.41									
Daphniphyllum calycinum	20	1.27	80.00																5	0.16	20.00			
Diospyros morrisiana	20	1.17	95.00																80	0.25	22.50			
Liquidambar formosana	20	0.44	95.00										15	0.02	6.25									
Lithocarpus glaber	20	0.55	18.00										62	0.39	28.57									
Myrsine seguinii													7	0.50	62.50				15	0.16	73.30			
Reevesia thyrsoidea	20	0.42	100.00																30	0.21	60.00			
Tutcheria championii																109	0.59	94.00	20	0.21	35.00			
Antirhea chinensis																			6	0.08	16.67			

Species	Kwun Yam Shan 1			Tai Mo Shan 1			Ho Sheung Heung			Kwun Yam Shan 2			Nam Shan			Tai Mo Shan 2			Hung Lung Hang			Tai Lam		
	N	RHI	% S	N	RHI	% S	N	RHI	% S	N	RHI	% S	N	RHI	% S	N	RHI	% S	N	RHI	% S	N	RHI	% S
Aporosa dioica																			100	0.18	73.00			
Aquilaria sinensis																			10	0.10	50.00			
Archidendron lucidum	20	0.79	89.00																					
Ardisia crenata																						98	0.40	79.39
Bridelia tomentosa	10	0.71	90.00																					
Celtis tetrandra	20	0.69	95.00																					
Cryptocarya concinna																			100	0.11	58.00			
Elaeocarpus chinensis																			100	0.30	31.00			
Ilex rotunda																10	0.06	60.00						
Lithocarpus harlandii																			50	0.21	70.00			
Litsea rotundifolia																						229	0.53	89.74
Machilus chekiangensis																			80	0.33	67.50			
Machilus chinensis	20	0.61	65.00																					
Machilus oreophila	20	0.31	80.00																					
Machilus velutina	20	0.92	65.00																					
Melicope pteleifolia																						145	0.64	86.41
Ormosia emarginata	20	0.45	28.00																					
Pinus massoniana	20	0.77	58.00																					
Psychotria asiatica																						114	0.46	91.58
Rauvolfia verticillata													3	0.26	75.00									
Rhaphiolepis indica																						140	0.38	56.49
Sapindus mukorossi	20	0.82	86.00																					
Styrax suberifolius																			50	0.13	42.00			
Syzygium cuminii													65	0.56	40.00									
Syzygium hancei																101	0.50	97.00						
Trema tomentosa	20	0.44	100.00																					
Viburnum odoratissimum																			24	0.30	79.16			
Xylosma longifolium																			70	0.19	78.57			
Zanthoxylum avicennae																						113	0.59	94.67

had variable survival in the sites planted. On the other hand, 4 species had consistently high growth (RHI > 0.4) in all sites they were planted. They were *S. octophylla* (5 sites), *M. breviflora* (5 sites), *Cyclobalanopsis championii* (3 sites) and *Gordonia axillaris* (3 sites). *Mallotus paniculatus* was planted in 6 sites and had consistently high survival in 5 sites. The rest of the 14 species had variable growth in the sites planted.

Seedling performances were variable at all sites except in the Tai Lam cut slope where the growth and survival were consistently high (RHI = 0.38–0.64; % S = 56.49–94.67).

A list of native tree species with high survival and growth in all sites planted, even if it is just one site, is selected according to the framework species criteria (Table 4).

Table 4. Selected Hong Kong native tree species according to the framework species criteria

Framework species criterion	Species
Toughness	*Schefflera octophylla, Machilus breviflora, Cyclobalanopsis championii, Gordonia axillaris, Schima superba*
Attractiveness to wildlife/ early production of wildlife resources	*Schefflera octophylla*, *Machilus breviflora, Ardisia crenata, Melicope pteleifolia, Zanthoxylum avicennae*
Regenerative ability/ease of germination	*Schefflera octophylla*, *Microcos paniculata, Choerospondias axillaris, Machilus breviflora*
Keystone species	*Schefflera octophylla, Ilex rotunda*
Architecture	*Choerospondias axillaris, Mallotus paniculatus*
Vigour	*Schefflera octophylla*, *Machilus breviflora, Gordonia axillaris*, *Cyclobalanopsis championii*
Species with limited dispersal mechanism	*Cyclobalanopsis championii*, *C. neglecta*

DISCUSSION

The results of the review show that most tree species performed differently at different sites. Nevertheless, two species, *S. octophylla* and *M. breviflora*, were found having consistently high survival and growth at all sites planted. Both species are common in secondary forests and *S. octophylla* is also common as seedlings in shrubland. It is thus considered an early pioneer species. They both bear fleshy fruits in the winter dry season that are dispersed by many bird species. *Schefflera octophylla* is particularly important in this respect because its fruit will last until the end of the dry season where fruit resources are scarce. However, not all early pioneer species performed well when planted in degraded sites. For example, *Sapium discolor* is very common in young secondary forests and shrubland in Hong Kong but its growth and survival in these planting trials were appalling. On the other hand, some remnant forest species, which are expected to be shade tolerant, performed unexpectedly well in at least some sites, for example, *Pygeum topengii*, *Tutcheria championii* and *Machilus chinensis*. Clearly, the results suggest that more screening trials are needed and future trials have to be further refined to match species with sites as well as microhabitats. Factors such as altitude, slope orientation, slope gradient, planting positions (i.e. ridges, gullies or slopes), degree of exposure to wind, existing vegetation cover (whether it is grass, shrub, fern or a mixture of these), and soil condition have to be tested.

The good performances of the species used in the Tai Lam cut slopes suggest that shrubs and small trees may play a significant role in very degraded sites. This fits in with the forest succession pathway whereby shrubs will establish prior to forest. Early studies in Hong Kong have already shown that in the absence of fire, degraded forest land with nearby seed sources will develop from grassland to shrubland in 5 to 10 years and to forest in another 20 to 30 years (Zhuang & Corlett 1997). The role of shrubs and small trees should be further studied in Hong Kong.

A list of framework tree species for Hong Kong, though short, is generated based on this review. A long-term demonstration plot, which is currently lacking, should be established in Hong Kong starting with this list of species and more species should be added pending the results of other planting trials.

This review also suggests that using native tree species to restore degraded hillsides in Hong Kong is possible. It is a matter of choosing the right species or the right mix of species for each site. Pending the results of more planting trials, this technical difficulty can be overcome. The experience in Hong Kong so far shows that the availability of tree seed is the limiting factor to wider use of native tree species. Seed collection is also time consuming and requires a certain degree of expertise. The silvicultural difficulties in the nursery propagation of native tree species are, however, low. For the 400 or so native tree species in Hong Kong, over 160 species have been successfully propagated in the Native Tree Nursery of the Kadoorie Farm and Botanic Garden in Hong Kong. Only a handful of species had germination problems in the nursery. A cost-effective approach from the nursery point of view is to concentrate on the production of ten or so framework species which have stable and abundant supply of seeds and to only produce other species in smaller quantities to enrich the diversity. In addition, high quality seedlings, good post-nursery care, good planting treatment and post-planting maintenance are all crucial to the success of any planting project.

Finally, the planting trials in Hong Kong so far are too small in scale. It is due to the high costs of planting in Hong Kong. Larger-scale planting trials should nevertheless be conducted and long-term monitoring is needed.

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18 Forest rehabilitation case study: rehabilitation after bauxite mining in the jarrah (*Eucalyptus marginata*) forest of southwestern Australia

John Gardner* and Carl Grant**

ABSTRACT

Alcoa World Alumina Australia currently operates two bauxite mines in the jarrah (Eucalyptus marginata) forest of Western Australia. The jarrah forest is a multiple land-use system and Alcoa's rehabilitation objective is to return a self-sustaining jarrah forest ecosystem that fulfils all of the pre-mining land uses. The current rehabilitation procedure has evolved over the last 35 years with continual improvement in site preparation techniques following extensive research and monitoring projects. Today's programme is based on a sound knowledge of jarrah forest ecology and land rehabilitation fundamentals, and years of operational experience. Significant advances have been made in topsoil handling, ripping, breaking seed dormancy and planting of species that are difficult to establish. These practices are successful in establishing vegetation that reinstates floral diversity and ecosystem processes such as litter accumulation, redevelopment of nutrient pools and the successional development. The established forest ecosystem is also highly productive in terms of timber quantity and quality. Many of the techniques utilized in bauxite mine rehabilitation in Western Australia are applicable to the re-establishment of forest ecosystems in other parts of the world, and after other transient land uses besides mining.

INTRODUCTION

Logging, mining, shifting cultivation and frequent burning cause disturbance of forests in many parts of the world. Without appropriate management to restore ecological values and productivity, these forests can degrade, resulting in loss of future benefits. The

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degraded and often eroding areas can also contribute to off-site impacts to adjacent land and water resources. The science and technology of land rehabilitation and restoration ecology has advanced to a high level in some sectors, such as the mining industry, allowing disturbed lands to be rehabilitated to meet complex and multiple objectives (Gardner 2001).

This paper presents the case of Alcoa World Alumina Australia's mine rehabilitation programme in the jarrah (*Eucalyptus marginata*) forest of southwestern Australia. The paper briefly outlines the advanced techniques for land preparation, soil handling, seed treatment and plant propagation that are used to re-establish the native forest ecosystem and restore the multiple land-use objectives of the forest. These techniques reinstate the primary ecosystem processes that progress towards those of the unmined forest over time and re-establish a very productive forest community.

BAUXITE MINING IN THE JARRAH FOREST

The jarrah forest covers some 1.8 million hectares, most of which is publicly owned and managed as state forest. The vegetation community is tall open forest dominated by jarrah (*Eucalyptus marginata*) and marri (*Corymbia calophylla*). This community is botanically diverse with an estimated 780 plant species occurring in the forest region. Less than 15 percent of the forest remains in an old-growth condition. Under a current proposal, about 34 percent of the forest is to be placed in conservation reserves that sample the range of forest ecosystems and protect remaining old-growth areas (Conservation Commission of WA 2002). The forest is close to Perth, the capital of Western Australia, which has a population of over 1.5 million people.

Alcoa operates two bauxite mines at Huntly and Willowdale, approximately 90km and 135 km southeast of Perth respectively. A third mine at Jarrahdale ceased production in 1998 and has now been decommissioned and fully rehabilitated. Currently, about 550 ha are mined and rehabilitated annually. Since the commencement of mining, 13 400 ha have been cleared and 11 100 ha have been rehabilitated. Bauxite mining occurs in isolated pods of 1 to 100 ha in area, averaging 10 to 20 ha. Mining is shallow open cut that removes a layer of bauxite approximately 4 m thick.

REHABILITATION PROCESS

Site preparation

The first step in the current rehabilitation process is to batter down the pit walls (2–5 m high) and recontour the mines to blend into the surrounding forest areas, with maximum slope angles of 20 percent. Recontouring of the mined-out pits aims to mimic the original, natural landscape. The gravelly sand surface covering the bauxite is stripped before mining and used for rehabilitation. Usually it is removed in two layers (known as double stripping): the upper 10–15 cm is referred to as topsoil, and the remainder, usually about 40 cm, is known as overburden. Double stripping maintains the concentration of seeds and organic matter at the surface of the rehabilitated soil profile. The overburden is stockpiled alongside the pit. Ideally, the topsoil, which contains much of the soil organic matter, nutrients, micro-organisms and seeds, is used immediately after stripping to rehabilitate a nearby pit (known as direct return). Directly returned topsoil may contain over 50 percent of the original unmined forest topsoil seed reserve, compared to 15 percent when topsoil is stockpiled (Koch *et al.* 1996). Where logistics or forest disease considerations dictate, the topsoil is stockpiled. In rehabilitated bauxite pits, over 70 percent of plant species originate from the topsoil (Koch & Ward 1994).

The overburden and topsoil are returned in the correct sequence and the pit is then contour ripped to a depth of approximately 1.5 m using a winged ripping tine. Ripping with the winged tine relieves soil compaction that could restrict root growth, encourages water infiltration, and reduces the risk of erosion. Ripping is carried out in summer and autumn to maximize shatter of the compacted clayey subsoil. Contour lines at 3–5 m vertical intervals are surveyed and marked in the field and ripping accurately follows the contours. The ripping creates furrows approximately 0.4 m in height and 1.5 m wide. The contour furrows are critical for preventing rainfall runoff and soil erosion. Following ripping, a few tree stumps, logs and rocks are returned to the mined areas to provide habitat for fauna.

Following the earthworks but prior to the onset of winter rains, the areas are seeded with a seed mix that contains 70 to 100 local plant species. Seeding immediately after ripping maximizes plant establishment from the applied seed (Ward *et al.* 1996). Seed is either broadcast by hand or applied directly on to the freshly ripped ground by a seeding machine attached to the ripping bulldozer. The seed mix is applied at about 2 kg per hectare. Seed of the dominant tree species, jarrah and marri, are included in the mix. Only indigenous species are included in the seed mix, and all the seed are sourced from within 20 km of each mine to retain local genetic material in the rehabilitated areas. Plant species that cannot be established from topsoil or applied seed (known as recalcitrant species) are propagated at Alcoa’s nursery and planted in rehabilitated areas in the first winter. Nursery plants are produced from treated seed, cuttings or tissue culture. In 2002, over 240 000 recalcitrant plants were planted at a rate of over 400 per hectare. Kangaroos graze some of the recalcitrant species and these plants are protected with tree guards. Finally, 500 kg ha^{-1} of a fertilizer mix based on di-ammonium phosphate with added potassium and micronutrients (16 percent P, 14 percent N, 5 percent K plus Cu, Zn, Mn and Mo) are applied by helicopter in spring.

Monitoring and research

To ensure that rehabilitated areas develop towards the identified rehabilitation objective, monitoring is conducted at an early stage and any unsatisfactory sites are remediated quickly. All rehabilitated pits are assessed at nine months for eucalypt, legume and weed density. Completion criteria specify that rehabilitation should contain 1 300 stems per hectare of eucalypts and one legume plant per square metre. Sites that contain less than 500 stems per hectare of eucalypts and less than 0.5 legume plants per square metre may need to be reseeded. Quality control during rehabilitation operations and reliable winter rainfall result in over 95 percent of rehabilitated areas meeting establishment standards. Occasional infestations of weed species are noted and sprayed.

When sites are 15 months old, plant species richness is measured. Completion criteria require that sites have greater than 50 percent of the understorey species richness of the unmined forest, but the company’s internal objective is to average 100 percent across all sites. The average for all areas rehabilitated in 2000 at the two active mine sites achieved this target, and all individual sites exceeded 60 percent of the understorey species richness of the unmined forest.

The successional development of the plants and animals over time is assessed through long-term vegetation and fauna monitoring programmes (e.g. Nichols & Gardner 1998). Fauna monitoring has found that all jarrah forest mammal species, 95 percent of bird species and 87 percent of reptile species have recolonized the rehabilitated areas by the time they are 10 years old (Nichols 1998). Numerous other issues relating to the development of rehabilitated areas have been studied over the last 25 years including nutrient cycling, water use, timber quality, invertebrate recolonization and the reintroduction of various vertebrate species. Research projects have underpinned many of the advances in rehabilitation procedures that have been made over the last 35 years.

Ecosystem development

The rehabilitation procedure employed by Alcoa provides the building blocks of a sustainable ecosystem. However, many important processes take time to develop as the established vegetation matures, and other plants and animals recolonize over time. Some of the critical ecosystem processes include the accumulation of litter, redevelopment of nutrient pools and the successional development of the established vegetation. The contour furrowing that results from soil ripping aids these processes by ensuring that resources such as water, leaf litter and nutrients are captured and used *in situ* or recycled The furrows also concentrate the litter, allowing decomposition processes to commence earlier.

Litter reaccumulates rapidly in rehabilitated sites, sourced mainly from seeded eucalypt and legume species. Within 3 to 5 years, rehabilitated areas have accumulated the same amount of litter as unmined forest sites contain after the same period of time following burning (Ward 2000). Rehabilitated sites rapidly redevelop nutrient pools in the soil, litter and under-storey vegetation, but the pool contained within trees takes longer to develop (Ward & Koch 1996). High densities of legume species are established in rehabilitated areas to provide nitrogen fixation, water use and soil stabilization. These species are generally short-lived and their senescence leads to accumulation of highly flammable material that increases the risk of fire. Unmined jarrah forest is periodically burnt and a number of research projects have now investigated prescription burning in rehabilitated areas (Grant & Loneragan 1999, Smith 2001). Disturbance associated with fire is a critical stage in the development of the rehabilitated ecosystem, as it provides further opportunity for plant recolonization, regeneration and multiplication and for cycling of nutrients. Fire also modifies the structure of the young forests, leading to the development of a more clearly stratified, two-tiered structure of canopy and understorey, more similar to the natural forest.

Rehabilitated forest productivity

One of the identified land uses for the rehabilitated forests in southwestern Australia is timber production. A considerable amount of research and monitoring has been undertaken over the last 15 years investigating the growth and form of jarrah trees in rehabilitated areas compared to the unmined forest (e.g. Ward & Koch 1995). In 10- to 13-year-old rehabilitated sites with an average density of 1 750 stems ha^{-1}, the mean annual increment of basal area under bark (BAUB MAI) averaged 1.81 $m^2ha^{-1}\ y^{-1}$ compared to the unmined forest with 0.19 $m^2ha^{-1}\ y^{-1}$ at a lower tree density (Abbott & Loneragan 1986). However, even if the growth estimate figure is adjusted to include only 400 stems ha^{-1}, which is the crop tree density specified in the completion criteria (0.39 $m^2ha^{-1}\ y^{-1}$), the productivity of the rehabilitation is still much higher than the unmined forest, at least for the first 15 years after rehabilitation. Early assessment of small diameter timber from these areas has indicated that quality is also generally high. Rehabilitation operations in the jarrah forest have therefore been successful in re-establishing ecosystem processes and a productive forest environment.

CONCLUSION

Large mining operations, such as Alcoa's bauxite mines in Western Australia, are intensive and well resourced, and have the opportunity to develop advanced forest rehabilitation programmes based on scientific investigation, monitoring and adaptive management. Alcoa's rehabilitation programme has been recognized as being amongst the best in the world through the receipt of many awards, including a listing in 1990 on the UNEP Global 500 Roll of Honour. Each year, many scientists and land managers from the mining, agriculture and forestry sectors visit our operations, where we openly share our knowledge. Alcoa is currently working to transfer best practice rehabilitation expertise from Western Australia to its mining operations throughout the world and to implement the same rehabilitation principles and standards worldwide. There is much opportunity for large international companies to help with the improvement of environmental standards for mining and forestry around the globe and to promote capacity building in the regulatory, technical and academic communities in developing countries.

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19 Economic value of skid-track rehabilitation: a case study in Sabah, Malaysia

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ABSTRACT

Often soil rehabilitation research ends without considering if the increased timber production motivates the investments needed, with the result that the research is not practically applied. Therefore, in the context of Sabah Forest Industries Sdn Bhd plantation programme, this paper estimated the net present value (NPV) from a skid-track rehabilitation case study. Eight different management alternatives were considered, consisting of all combinations of 1) tracks rehabilitated or not rehabilitated, 2) areas outside tracks fertilized or not fertilized, and 3) tracks covering 10 or 30%. At 30% track cover without track rehabilitation or fertilization, the NPV outside tracks was negative at all relevant interest rates. Rehabilitation of tracks alone made this unprofitable plantation profitable to an interest rate of about 3.7%. Fertilization of areas outside tracks made the plantation profitable up to an interest rate of 16%, while additional track rehabilitation further increased this reference interest rate to 19%. At 10% track cover the increased benefits from tracks rehabilitation barely compensated for the costs. Fertilization of areas outside tracks, however, was now profitable to 20% interest rate. Most of the SFI concession area is within the studied growth range. Therefore, management should look into the need for rehabilitation, since all wood used for pulp production is going to be harvested from the plantations. This evaluation simplified the issue about soil degradation. In reality the values of goods and services from a system will consist of more values, e.g. risk reduction, recreational and different ecosystem values such as watershed protection and soil quality. One of the future challenges of resource management will be to develop assessment methods that can be used by policy-makers to apply such multi-dimensional value system.

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INTRODUCTION

The uniformity of raw material, reliability of supply, competitive pricing and relative proximity to centres of industry are factors that will increasingly favour industrial forest plantations as natural tropical forest resources become depleted owing to slow or no regeneration (e.g. Sayer *et al*. 1997). In the FAO Forest Resources Assessment, areas in Asia reported by country experts as forest plantations increased exponentially from 11 million ha in 1980 to 115 million ha in 2000 and there is not yet any sign of weakening in the trend (FAO 2001). In contrast, the 'Pan-tropical survey of forest cover changes', which is an independent and less subjective inventory based on LANDSAT images, estimated the area of plantations to be only 23.2 million ha in the total tropics compared to 187 million ha as reported by country experts (FAO 2001). This discrepancy may be explained by one or more of the following: 1) difficulty to detect plantations on LANDSAT images, 2) differences between official statistics and actual planting, and 3) conversion of planted areas into other land classes (e.g. fragmented forest, shrubland, fallows or other land uses).

Because of such uncertainties, wood production from tropical forests rests on a comparatively shallow scientific base. Despite high productivity in some well-maintained, often fertilized experimental plots, the long-term nutritional sustainability of short-rotation plantations is under debate (e.g. Sanchez *et al.* 1985, Nambiar & Brown 1997). It is also well documented that poor adaptation of logging systems like timber extraction with heavy machinery on humid tropical soils causes long-term degradation of soil physical properties and is detrimental to plant growth (e.g. Nussbaum *et al*. 1995, Woodward 1996). With these systems, skid tracks commonly cover up to 40% of the operation area (42%, Fox 1969; 24%, Malmer & Grip 1990; 30%, Nussbaum *et al*. 1995; 17%, Pinard *et al*. 2000). Because of the extent of selectively logged forests and forest plantations, rehabilitation of skid tracks has been assigned top priority for development research (Whitmore 1996).

However, despite the importance and extent of tractor disturbance, there have been few reported attempts to accelerate rehabilitation in humid tropical climates. In Sabah, Malaysia, there was a study, by Nussbaum *et al.* (1995), which found fertilization to significantly improve tree performance on timber landing sites, in contrast to mulching and loosening of soil, which had no effect. Woodward (1996) noted that fertilization, but not topsoil addition, increased plant growth in Amazonian Ecuador. In contrast to tree growth and soil physical properties, the effect of skid-tracks on soil chemical and biological properties has received little attention. This is despite that these factors could be equally responsible for the slow plant growth as the soil physical properties. Therefore, in the context of Sabah Forest Industries Sdn Bhd (SFI) plantation programme, an experiment was initiated to test if biological, chemical and physical properties of the soil could be improved on skid-tracks with additions of different combinations of commercial NPK-fertilizer, ash, and organic material (Ilstedt 2002). The organic material used was extracted from growing vegetation on the sides of the tracks and the ash was available from the SFI pulp-mill where it has been deposited and considered as waste. The main tree-growth related results so far from this study (Ilstedt 2002) showed that the total basal area of *Acacia mangium* at 24 months after planting increased from 2 to 14 m^2 ha^{-1} if tracks were tilled and fertilized. However, no effect on plant growth was found when either organic material or ash was added. Basal area outside tracks was 62% higher compared to untreated tracks.

It might seem like such result could be adopted into practical management. However, a large problem with management research at SFI and elsewhere has been that even though the increase in timber production can be quite marked, research often ends without properly considering if the increase is enough to justify the investments needed. Indeed, economic evaluations of rehabilitation studies are difficult to find in the literature. In their absence, an unmotivated fear for early investments might be a large contributor to why rehabilitation research is so seldom put into operational management. Furthermore, where the value of a new method actually has been assessed it has often been done without considering the effect of interest rate. Because two management options can both be the 'best' option depending on the interest rate, a better approach is to calculate the net present value (NPV) at a range of relevant interest rates (Duerr 1993). The higher the interest rate, the lower is the investor (or society) value future benefits. Thus, in forestry, a high interest rate favours short rotation times and small early investments. An increased expectancy of interest rate might also render a management option that was profitable at lower interest rates to be unprofitable. Since the choice of interest rate might differ with time and application, a range from 1% to the interest rate just above where the NPVs for all studied options are negative can be used. The interest rate when NPV is zero is often referred to as the 'internal rate of return' (IRR) (e.g. Duerr 1993). IRR can be seen as the interest rate that would be needed for an alternative investment (e.g. bank interest rate) or management option to be an economically competitive alternative. IRR and NPV have different advantages and shortcomings, and can therefore be seen as complementary ways to rank management options. IRR has an intuitive appeal, but if the objective of management is not to maximize the return of investments, the ranking might by misleading in some situations. Recent accounts on environmental and forestry investment analysis include those of Pearce (1990), Duerr (1993) and Klemperer (1996).

It might be tempting to evaluate the value of skid track rehabilitation by only comparing treated and untreated tracks. However, economic analysis of skid track rehabilitation should not be done in isolation from the management on areas outside tracks. For example, if skid track rehabilitation is profitable at high track cover, it is unlikely to be equally so if skid track cover is low. The lowest relevant skid track cover was considered here to be 10%, while 30% was considered normal. Furthermore, on tracks, tilling and fertilization were needed to achieve good rehabilitation of plant growth (Ilstedt 2002). Especially at high interest rates it can be asked whether a more economic option is to manage for a higher production by fertilizing just areas outside tracks, since this can be done without the extra cost of tilling.

Therefore, the objective of this paper, taking the results of a skid track rehabilitation experiment (Ilstedt 2002), was to estimate the NPV at a range of interest rates and at all combinations of,

1) tracks being rehabilitated or not rehabilitated;
2) areas outside tracks being fertilized or not fertilized;
3) 10 or 30% track cover.

METHODS

Study area

The project described in this paper was carried out in the Sabah Forest Industries Sdn. Bhd. (SFI) plantation concession. The concession consists of 289 000 ha of forest, including 17 990 ha of protected water catchment (SFI 2002). The SFI currently operates a pulp and paper mill as well as an integrated timber complex including a plywood mill and sawmill. The main objectives of forest management here are to provide the SFI mills with 750 000 m^3 y^{-1} of pulpwood and 339 000 m^3 y^{-1} of commercial wood. Today, most extracted pulpwood comes from the natural forests, but in the future, the raw materials should come entirely from the SFI plantations. The company started planting in 1985 and the present plantation comprises about 37 000 ha (SFI 2002), dominated mainly by acacia (mostly *Acacia mangium*) and eucalypts (above 800 m.a.s.l). However, on deep fine textured soils in the lowland, *Gmelina arborea* is planted. In 1998, large parts of the plantations were burned, and since then intensive efforts have been made to replant the affected areas. In addition to wood from the concession, villagers close to the concession area have been encouraged to establish smallholder plantations through agroforestry projects (Nykvist 1993) in which an area of about 1 699 ha has been established (SFI 2002). These villagers have been selling the wood to SFI since 1992.

The Mendolong research area and laboratory are run under a joint programme between SFI and the Department of Forest Ecology at the Swedish University of Agriculture Sciences. The skid track study is situated close to the Mendolong research area at an altitude of 580–620 m at the foothills of Mt. Lumaku, 35 km southeast of the coastal town of Sipitang (115.5°E, 5.0°N), Sabah, Malaysia (northern Borneo). In young plantations the monthly minimum temperatures generally vary between 20 and 22°C and maximum temperatures between 27 and 31°C (Malmer 1993). During the time of this study the annual precipitations were 1 840 and 3 290 mm in 1997 and 1998 respectively. The end of 1997 and the beginning of 1998 were unusual in that there were prolonged dry periods of several months in connection with the strong ENSO-event (El-Niño Southern Oscillations) of 1997/98.

The vegetation at the study site was formerly hill dipterocarp forest (Whitmore 1984), which was logged in 1988 and planted with *Acacia mangium*. The plantation was logged and residues were burned before the second generation planting in early 1998 (Figure 1). For this study an area with Haplic Acrisols (FAO 1988) developed on sandstones and shales was chosen because this soil type dominates large parts of Southeast Asia. Topsoil (0–5 cm) textures in Acrisols of the research area ranged from sandy loam to clay loam. Porosity in nearby undisturbed forest soil was high, up to 60–70% (Malmer & Grip 1990), bulk density was 0.83 (standard deviation, SD, 0.09) g cm^{-3} in the uppermost 5 cm of the soil (Malmer & Grip 1990) and the loss on ignition (LOI, %w/w) was in the range 5 to 15% (Malmer *et al*. 1998). Below this topsoil a 5 to 20 cm deep A/E horizon is generally found with lower organic matter content and bulk densities between 1.0 and 1.2 g cm^{-3} (Ohta & Syarif 1996). Below the A/E horizon there is a massive argillic Bt horizon with its lower boundary on about 1 to 2 m depth. Bulk densities in the Bt horizon are in the range 1.2 to 1.5 g cm^{-3} (Ohta & Syarif 1996). This profile development with depth is accompanied with increased exchangeable aluminum, and decreased nitrogen and phosphorous availability (Ohta & Syarif 1996). Crawler tractors used for skidding in the experimental area expose this Bt-horizon by moving the A/E horizon and parts of the B horizon to the side of the tracks.

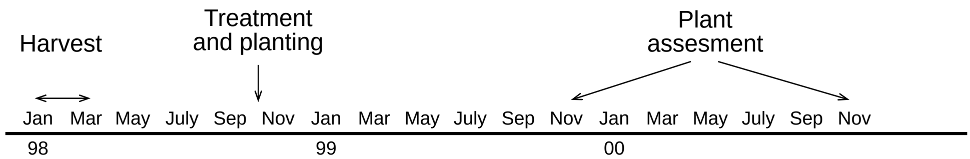

Figure 1. The timing for the treatments and assessments

Net present value analysis

The net present value (NPV) was calculated for an infinite number of rotations (1). The NPV in this case is often called 'land value', site value or 'soil value' and corresponds, in forest economics, to the well-known "Faustmann formula" (Faustmann 1995),

$$NPV = \sum_{t=1}^{n} [(B_t - C_t)\ (1+0.01*r)^{-t}] * (1+0.01*r)\ ((1+0.01*r) - 1)^{-1} \qquad (1)$$

B_t and C_t are the benefits and costs at t years respectively, and r the reference interest rate (%). The timing of benefits or costs even during one year can be important at high interest rates. To minimize this bias, all costs and benefits during one year were assigned to the middle of the year. Interest rates of 1, 3, 6, 9, 12, 15, 18, 21 and 24% rate were used to compare these alternatives and to estimate the internal rate of return (IRR; i.e. the interest rate when NPV is zero).

Management alternatives

Eight different management alternatives were studied (Table 1) consisting of all combinations of 1) tracks being rehabilitated (fertilized and tilled) or not rehabilitated, 2) areas outside tracks being fertilized or not fertilized, and 3) tracks covering 10 or 30%.

Table 1. The study alternatives and their mean annual volume increments

	Track cover (%)	**Tracks rehab.**	**Fertilized outside tracks**	**MAI ($m^3 ha^{-1} y^{-1}$)**
Rehab+fertil	30	yes	yes	23
Rehabilitated	30	yes	no	9
Fertilized	30	no	yes	18
Actual	30	no	no	4
Rehab+fertil	10	yes	yes	24
Rehabilitated	10	yes	no	6
Fertilized	10	no	yes	23
Actual	10	no	no	5

Table 2. The timing, costs and benefits used for the net present value calculations

Track cover	Management	Year	Cost / revenue (RM) [b]			
			Rehab+fertil	Rehabilitated	Fertilized	Actual
30%	Tilling	0.5	–173	–173	0	0
	Site preparation and planting	0.5	–1054	–1054	–1054	–1054
	Fertilization	0.5	–493	–148	–493	0
	Weeding and maintenance	0.5	–600	–600	–600	–600
	Weeding and maintenance	1.5	–340	–340	–340	–340
	Track maintenance	1.5	–50	–50	–50	–50
	Felling and extraction [a]	8	–7820	–3060	–6120	–1360
	Management overhead [c]	8	–300	–300	–300	–300
	Wood value (at mill gate)	8	17480	6840	13680	3040
10%	Tilling	0.5	–58	–58	0	0
	Site preparation and planting	0.5	–1054	–1054	–1054	–1054
	Fertilization	0.5	–493	–49	–493	0
	Weeding and maintenance	0.5	–600	–600	–600	–600
	Weeding and maintenance	1.5	–340	–340	–340	–340
	Track maintenance	1.5	–50	–50	–50	–50
	Felling and extraction [a]	8	–8160	–2040	–7820	–1700
	Management overhead [c]	8	–300	–300	–300	–300
	Wood value (at mill gate)	8	18240	4560	17480	3800

[a] Including transport within 50 km.

[b] US$1=RM3.80.

[c] Management overhead @ RM37.50 $ha^{-1}y^{-1}$ = RM300 ha^{-1} for 8 years.

In the NPV analysis the differences between the management alternatives were between the mean annual increment (MAI) and an additional cost for fertilization and tilling where applicable (Table 2). MAI (m^3 ha^{-1} y^{-1}) was calculated as BA*H *F, where BA was average yearly basal area increment, H was the average yearly height increment (Ilstedt 2002) and F a form factor of 0.4 (Nykvist *et al*. 1996).

Actual costs paid to contractors during all phases of plantation management (Table 2) were used. Work costs for plantation and maintenance were calculated assuming 1 111 trees ha^{-1}, which is the most common spacing at the SFI. The revenue of wood was calculated by multiplication of the MAI, the rotation age (8 years), and the market value of acacia wood at the mill gate (RM95 m^{-3}; US$1 = RM3.8). In the same way the SFI cost per hectare of harvesting and extraction was assumed at RM42.5 m^{-3} (within 50 km from the mill).

Rehabilitation treatments

The growth data for the study alternatives were taken from Ilstedt (2002). In October 1998 (Figure 1), the experimental plots (10 x 4 m) were laid out in the plantation on the tracks caused by skidding with crawler tractors (class D6). The amendments were additions (singly and in combination) of fertilizer, ash and green organic material (Table 3). There were 10 replicates of each combination resulting in 80 plots. The green organic material was extracted from slashed ground vegetation on the side of the plots. The added materials were mixed into the top 20-cm soil with a power tiller. The treatment combinations were randomly assigned to plots in order to test hypothesis about interaction effects of ash, fertilizer, and organic material. As an additional reference, 10 plots were put out at random positions outside the tracks.

Table 3. The amount of nutrients in the amendments

	C	N	P	K	Ca
	(kg ha^{-1})				
Fertilizer[a]	0.0	100	50	450	450
Ash[b]	n.d.	1	5	450	450
Organic[b]	940	26	1.0	24	4.0

[a] 0.4, 0.2, 1.8 and 1.8 kg per plot of urea, Christmas Island rock phosphate, K_2O and $CaCO_3$ respectively.

[b] 11 kg per plot.

[c] 25 kg fresh weght per plot.

Because only fertilization and tilling significantly affected growth on tracks, only untreated tracks, fertilized and tilled tracks (for the rehabilitated management option), as well as plots outside tracks were used for the net present value analysis in this paper. No data on growth outside tracks after fertilization were available for the study site. However, earlier experience from fertilization experiments in the SFI concession area (SFI 1991) suggests that for *A. mangium* a MAI of 25 m^3 $ha^{-1}y^{-1}$ can be expected on soil that is not disturbed by crawler tractors. Therefore this value was used to represent growth after fertilization outside tracks. This is also well within the range of 10–40 m^3 $ha^{-1}y^{-1}$ that is commonly reported for this species in the literature (e.g. Otsamo *et al*. 1995, Vichnevetskaia 1997, FAO 2001).

Assessment of plant growth

Plant growth was assessed by the average height and total basal area (at 1.3 m above the ground) per plot for five *A. mangium* seedlings, planted in October–November 1998. Height was measured 12 and 24 month after planting while basal area was measured at 24 month. According to routine nursery practices, seedlings were raised in seedling trays and were planted three months later (when 25–30 cm tall). In the nursery, 5 g Agroblen (NPK, 10:26:10) per seedling was mixed into the mineral soil used as potting medium. Agroblen is a fertilizer that is slowly released over about seven months. In the field, planting was carried out only during consecutive rainy days. On untilled tracks a spade was used to dig the planting holes (8 cm in diameter and 10 cm deep). Planted seedlings were inventoried two weeks after planting and dead seedlings were replaced. On each plot, five trees were planted with a spacing of 2 m. Plots were manually weeded using 'parangs' (machetes) at three-month intervals during the full study period. All plots were fenced to avoid human disturbance. Plots outside tracks were planted one month after the plots on the tracks.

RESULTS AND DISCUSSION

Profitability of the management alternatives

The 'actual' management resulted in negative NPV at all interest rates if track cover was assumed to be 30% (Figure 2). Since this is the management presently performed around the study site, the area should be regarded as economic impediment if it is not rehabilitated. However, not all areas in the concession perform as equally poorly as the 4 m^3 $ha^{-1}y^{-1}$ that was the average at the study site. During the first rotation in nearby experimental catchments, the MAI was 6.9 m^3 $ha^{-1}y^{-1}$ in tractor-logged and burned areas (Nykvist *et al*. 1996). As a comparison, in an unburned area that was logged without tractors, the MAI was 12.4 m^3 $ha^{-1}y^{-1}$ (Nykvist *et al.* 1996). If a MAI of 6.9 m^3 $ha^{-1}y^{-1}$ was used instead of 4 m^3 $ha^{-1}y^{-1}$ in the 'actual 30% track cover' alternative, the IRR increased from below zero to about 3.5%, and if the MAI was 12.4 m^3 $ha^{-1}y^{-1}$ the corresponding IRR was about 12% (data not shown). Small variations in track cover could make a substantial difference to the total MAI. However, it appears possible that the nutrient removal from harvest and burning, which were repeated for the second-generation plantation, has further depleted the already low nutrient capital, and therefore is responsible for at least a part of the lower growth at the study site. The area was also severely weed infested, which is a common phenomenon after shifting cultivation with repeated burnings at short intervals (Garrity *et al.* 1996, Goldammer 1997) as well as in plantations (Nykvist *et al*. 1996). Increased competition of weeds might therefore also be partly responsible for the lower growth.

Behind the collective term 'site preparation and planting', there are activities like track construction, culvert maintenance, burning, under-brushing, boundary maintenance, and planting. Therefore the cost of tilling and fertilization was only a small fraction of the total cost that is needed for site preparation, planting and maintenance (Table 2). This resulted in a small interaction between interest rate and management option (i.e. the differences in slope for the alternatives in Figures 1 and 2 were similar). Therefore the relative ranking of the options was the same at interest rates when the NPVs were positive, which means that the following discussion regarding the ranking of the

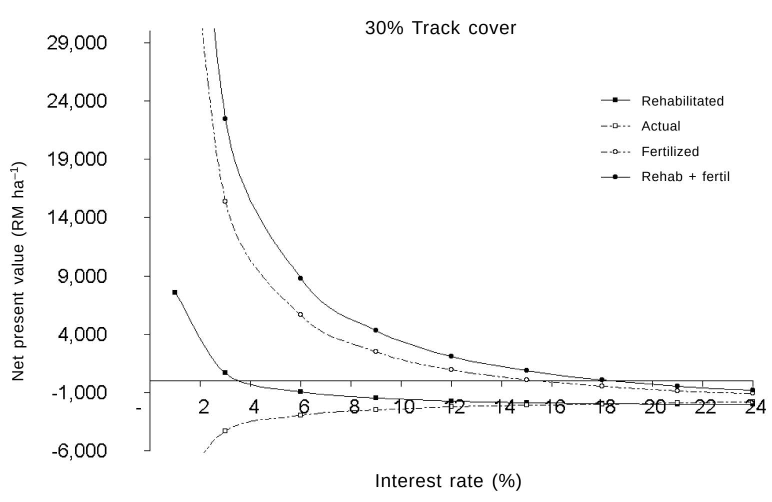

Figure 2. The net present value at 30% track cover as a function of interest rate (US$1 = RM3.8)

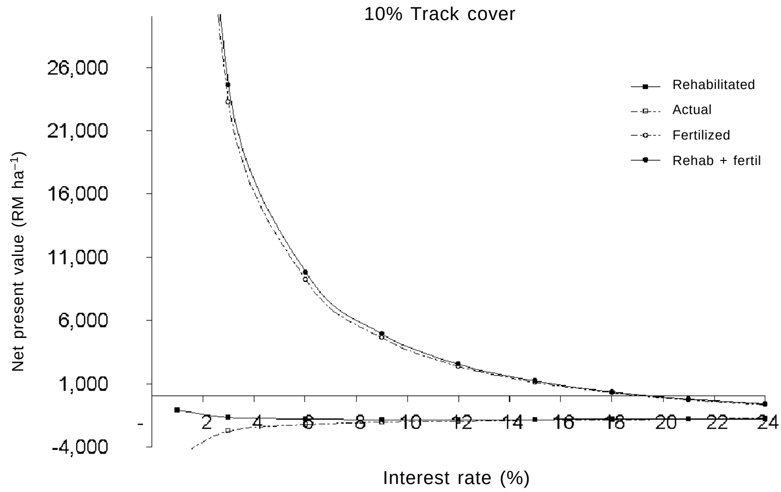

Figure 3. The net present value at 10% track cover as a function of interest rate (US$1 = RM3.8)

management options can be simplified to IRR. The IRR increased from below zero to about 18% in the best of the studied option, i.e. tilling of tracks and fertilization of the whole area (Figure 2). However, fertilization of just areas outside tracks increased the IRR to 16%, which might be a preferred alternative if there are constraints on workforce or cost. Given the sensitivity of the economic outcome to the MAI, more site-specific management should be considered. If there are constraints to costs or workforce, these might include avoiding low productivity sites. Otherwise improved stand and soil management should be the preferred options. This study showed that despite higher costs for fertilization and tilling of tracks, these were more than compensated for by increased benefits.

The cost for tilling was estimated during the end of establishment of the experiment when the workers were used to the machines and productivity had levelled to a constant length of tracks tilled per working day. However, other equipment and situations might result in higher or lower costs. It is therefore valuable to calculate the break-even cost for tilling. That is how much the cost of tilling could be for the alternatives with and without rehabilitation to have equal NPV. Assuming 30% track cover and areas outside tracks fertilized, the break-even was about RM690 ha^{-1} at 16% interest rate (i.e. IRR for fertilization only), RM2 500 ha^{-1} at 9% interest rate and about RM3 000 ha^{-1} at 6% interest rate. Therefore, since the cost for tilling was estimated to RM173 ha^{-1}, there seems to be a considerable marginal before track rehabilitation becomes unprofitable.

It appears that 10% track cover was very close to the limit for when rehabilitation no longer is worth the cost (Figure 3). However, 10% track cover is very low, and track cover lower than this might be associated with increased costs in equipment, planning, education and salaries, which have not been considered in this paper. For example, cable systems might reduce the need of track cover to about 10%. Since the NPVs for 10% track cover without tilling are very close to the NPVs with tilling at 30% track cover, the cost of, for example cable systems, could be compared to the break-even costs for tilling (see above). If the total cost for the cable system is lower than the break-even costs for tilling, the cable system should be preferred.

It should be recognized that the economic model is sensitive to changes in wood market value. If the wood price changes, the absolute NPV might change dramatically. However, the relative ranking between the alternatives should not change within reasonable market changes. The conclusions made about skid-track rehabilitation in this paper were based on results two years after treatment and planting. This represents ‘only’ 25% of a normal rotation. Therefore it can be asked whether the growth rates noted after fertilization in this study will be maintained during the rotation and if the growth on untreated tracks will be restored to the next generation. Furthermore, at present there are no published studies in the tropics following productivity from natural forest to second generation of plantation. Therefore extrapolations of economic costs and incomes in subsequent rotations as done here should be interpreted with care (cf. Sanchez *et al.* 1985, Nambiar & Brown 1997). However, the ranking of the management options does not change if one or several rotations are considered.

Research needs

The large variation of productivity in tropical plantations is coupled both to management and inherent soil fertility, but the knowledge of the interaction between site management and productivity is not very good for most tropical conditions (Binkley *et al*. 1997, Fölster & Khanna 1997). Obviously, the knowledge of the interaction between site management and economic profitability is then even less developed. This was exemplified in the present study, and if the study site of this thesis is representative of a larger area much work is presently done without sufficient economic return. Unbiased inventories of actual productivity at a larger scale would therefore be of high value. There is a need for accurate and easily used site-indices to predict wood production as well as responses of the soil to management. Examples of applications where good indicators could improve management are site selection, choice of soil preparation, fertilizer optimization and site–species matching. The perfect setting for such a study would be comprehensive factorial fertilizer trails stratified for important site factors (including site history such as type and degree of disturbance). However, in line with the above reasoning research proposals should already from the start include a component making economic evaluation of the results possible.

Application of the research to society

The discussion of degradation has evolved from economical production to also cover ecosystem structure (e.g. diversity) and ecosystem function (biomass and nutrients) (Bradshaw 1990, Lamb 1994b) as well as other social services and goods (Sayer *et al*. 1997). Degradation is usually defined as a reduction in some or all of these values permanently (Lovejoy 1985) or temporally (Bradshaw 1990, Lamb 1994a, FAO 2001). However, for a farmer with limited recourses, an increase in the amount of inputs in the form of time, work or money is just as severe as a reduction in crop productivity. A deficiency of most definitions of degradation is therefore the neglect to take into account the input of energy and resources needed to get access to the values and services of a system. The concept of net present value does this partly, since an increase in cost will decrease the net present value. However, if there are no constraints on the amount of costs for a given management alternative, the 'best' NPV might be the one that the land user can not afford. In a more general assessment of the effects of degradation and rehabilitation, we therefore suggest that the different social values (including net present value) as well as the costs are analysed as separate 'sub-variables' of the total degradation. For each sub-variable the socially relevant range is then determined, and optimization can be restricted to this range.

This paper only analysed one of the many aspects of soil degradation. In reality the values of goods and services from a (management) system will consist of even more values, for example, risk reduction, recreational values as well as different ecosystem values such as watershed protection and soil quality. Each of these groups can consist of several more or less useful indicator variables. However, it is likely that many of these values (or variables) are related and therefore can be reduced to fewer components by available multivariate statistical methods. One of the future challenges of soil science and forestry is in our opinion to develop such indicator variables that can be used by social scientists and policy-makers to apply a multi-dimensional value system on regions and countries. The only way to achieve this is by close interaction between different groups of scientists and the stakeholders to which the model is applied.

CONCLUSION

For a 30% track cover, tilling and fertilization of skid tracks made this unprofitable humid tropical plantation profitable to a reference interest rate of about 3.4%. Fertilization of areas outside tracks made the plantation profitable up to a reference interest rate of 16%, while additional tilling and fertilization of skid tracks further increased the expected rate of return to 19%.

The general implication of this study is that the break-even between uneconomical and economically competitive plantations is very dependent on soil management, as manifested in the resulting effect on stand growth. Therefore, even seemingly large costs might be motivated by increased growth rates. Much of the SFI concession as well as other humid tropical forest plantations might have growth rates close to what is economically viable. Therefore, sound inventories are needed and the rehabilitation of skid tracks should be incorporated into the management if, as is often stated, most of the wood used for pulp and paper production is going to be harvested from the plantations in the future.

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SESSION V

20 Institutional financing of forestry programmes including afforestation of wastelands in India: some issues and options

Kulbhushan Balooni* and Katar Singh**

ABSTRACT

India has vast tracts of wastelands, which have been lying barren for ages. Most of such lands are suitable for growing trees and thus could be put to socially productive uses. Growing trees, or afforestation of wastelands, is also economically viable but requires massive investment of funds, which is beyond the means of most of the land owners. The budgetary allocations of the government for afforestation are also inadequate. Institutional credit is therefore needed. In recognition of this need, the National Bank for Agriculture and Rural Development (NABARD) of India provides refinance facilities to individuals and organisations for forestry activities under a number of different schemes. Although the number of forestry schemes refinanced by the NABARD was high in the past, they currently constitute only about 1% of the total number of loans sanctioned and account for only about 2% of the cumulative loan disbursements made by the NABARD so far. In fact, since 1992, their share has declined. Major constraints on the pace of expansion of forestry programmes include non-availability of degraded land, technical information not available to potential tree growers, delays in sanctioning and disbursement of bank credit, low prices for tree products, and policies of the Indian state forest departments unfavourable to tree growers. Unless these constraints are overcome, the NABARD cannot effectively speed up the refinancing of developmental programmes in the forestry sector. The authors believe that most of the constraints on institutional credit for wasteland afforestation can be removed/relaxed.

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INTRODUCTION

India has vast tracts of wastelands extending over 100 million ha. Tree plantation is considered both a socially optimal and an ecologically sound use of such lands. However, restoration and afforestation require huge investment (Kapoor 1992, World Bank 1993), beyond the means of local landowners and the government forest sector. Therefore access to external funds, preferably from institutional sources, is a prerequisite for afforestation of wastelands in India. The National Bank for Agriculture and Rural Development (NABARD) of India could play an important role in providing credit for the wasteland afforestation schemes.

Rural credit

The NABARD has, since its inception in 1982, emphasized the need for increasing the productivity of the forest sector. Prior to the establishment of the NABARD, the policy, planning and operational aspects of rural credit came under the Agricultural Refinance and Development Corporation (ARDC) and the Rural Credit Planning Division of the Reserve Bank of India. In the late 1980s, from providing support to activities leading to commercial exploitation of forest resources the NABARD's lending priority in the forestry sector shifted to schemes of tree plantation on private and community lands. In fact, during its very first year (1982–83) of operation, the NABARD decided to consider refinancing farm forestry development schemes for private lands and the planting of trees on degraded lands belonging to the government and leased to farmers, either individually or in groups (NABARD 1983).

This article first examines the role played by the NABARD and other financial institutions under its aegis in financing forestry programmes, including wasteland afforestation in India. The article then identifies various constraints on wasteland afforestation through institutional financing and related issues involved. Options and alternatives to resolve these constraints are briefly outlined.

THE ROLE OF THE NABARD IN REFINANCING OF WASTELAND AFFORESTATION PROJECTS

The NABARD provides refinancing assistance to financial institutions like scheduled commercial banks, state cooperative banks, state land development banks and regional rural banks with respect to loans advanced by them to individuals and groups of individuals for undertaking afforestation of private wastelands. Projects for the development of wastelands can also be formulated by forest-based industries, corporations and non-governmental organisations (NGOs) engaged in the promotion of wasteland development. The NABARD also provides funds, on a selective basis, for capacity building of NGOs (NABARD 2000). In its first years of operation, the NABARD placed more emphasis on refinancing afforestation of private wastelands undertaken by individual landowners than on supporting corporations or other organisations. However, after the promulgation of the National Forest Policy of 1988, its priority focus has shifted to forest-based industries, corporations and organizations such as state forest development corporations and NGOs undertaking wasteland development at the grassroots level.

In order to boost the development of forestry and wasteland afforestation programmes in the country, the NABARD identified six activities as main thrust areas (Sharma 1993). Most of these activities were directed towards development of wastelands, both degraded forests and non-forested lands. Many innovative schemes were sanctioned by the NABARD for refinancing of plantation programmes. One of them is the Margin Money Assistance Scheme/Investment Promotion Scheme, sponsored by the Department of Land Resources of the Ministry of Rural Development and refinanced by the NABARD. The main objective of this scheme is to encourage the flow of low-cost institutional funds to socially beneficial afforestation and wasteland development projects in non-forest areas; the Ministry of Environment and Forests, Government of India, is responsible for the rehabilitation of degraded forests in India. This is sought to be achieved by extending the central assistance so that such schemes could meet the economic viability criteria of the NABARD. Under this scheme, the central promotional grant/subsidy to individuals/ groups is limited to Indian rupees (INR) 2.5 million or 25 percent of the project cost, whichever is less subject to the condition that the promoters' contribution in the project shall not be less than 25% of the project cost (Government of India 2002a). Similar schemes providing subsidy for the social forestry sector are also promoted in other countries. For example, in Colombia, the Government promotes reforestation through subsidies financed with loans from the Inter-American Development Bank (IDB), the German Reconstruction Credit Institution (KfW) and the World Bank (Gaviria 1997).

The NABARD is somewhat similar to BANRURAL (National Bank for Rural Credit), which is the largest agricultural bank in Mexico owned by the government, with an extensive presence in the country through its regional offices. In Mexico, the Bank of Mexico is the trustee for agricultural funds administered by the Trust Fund for Agriculture (FIRA). The other trust funds and banks engaged in financing the forestry sector are FICART (Trust Fund for Credit in Rainfed and Irrigated Area), FODEF (Trust Fund for Forestry Development) and BANRURAL. Even the disbursement of funds from the World Bank forestry development loans are routed through these trust funds and banks to private and commercial banks for on-lending to the ultimate beneficiaries (*ejidos* [public land], *comunidades* [communities]) and small producers (Weaver 1996). Of late, the NABARD has also been involved in implementing externally aided innovative projects with the objective of poverty alleviation through resource development and people's participation in management of common property resources (NABARD 1999). For example, a rubber development project assisted by the World Bank has been under implementation with assistance of SDR14.59 million. The money is routed through the Government of India and the NABARD and is used for providing loans to rubber growers to create on-farm and off-farm employment opportunities (NABARD 2000).

THE NABARD'S REFINANCING OF FORESTRY SCHEMES

During the period 1983/1984 to 1991/1992, the number of forestry schemes, including wasteland afforestation, refinanced by the NABARD grew at an annual compound rate of 21.66 percent (Table 1). This compares well with the overall average growth rate of 4.09 percent for all the categories of schemes refinanced by the NABARD over the same period of time. However, the average proportion of forestry sector schemes is only 0.61 percent of the total number of schemes sanctioned by the NABARD in the same time period; the highest yearly percentage being 1.22 percent in 1986–1987 (Figure 1). At the national level, theNABARD's cumulative disbursement of funds[1] under schematic lending[2] to the forestry sector at the end of March 1992 amounted to INR1 343.9 million, which is 0.82 percent of the total cumulative disbursement of INR163 640 million under all the categories of schemes. Though the annual compound growth rates of forestry schemes (21.66 percent) and of disbursement (21.95 percent) in various years have been higher as compared with those of all the schemes taken together, the share of forestry schemes in the total schemes refinanced by the NABARD is still less than 2 percent. In view of the fact that the entire amount of funds disbursed to the forestry sector does not go to afforestation of wastelands, the NABARD's contribution to this important activity in India has been paltry. This is also reflected by the fact that the Government of India's contribution to afforestation of wastelands in the Seventh Five-Year Plan, 1985–90, was INR24 266.3 million (Indian Council of Forestry Research and Education 2000). As against this, the disbursements by the NABARD to the forestry sector during the same period of time amounted to only INR661.3 million, which is only 2.73 percent of the former (Table 1).

Table 1. Forestry schemes refinanced by the NABARD from 1982–83 to 1992–93[a,b]

Year	Number of schemes		Disbursement (INR million)	
	Forestry	Total including forestry	Forestry	Total including forestry
1982–83[c]	5	24 410	98.8	34 921.2
1983–84	15	4 866	45.8	8 841.1
1984–85	22	5 446	23.5	10 512
1985–86	49	7 835	96.6	11 916.5
1986–87	123	10 068	91.8	13 342
1987–88	73	9 995	191.3	14 819.1
1988–89[d]	48	7 037	110.5	12 701.5
1989–90	64	9 211	171.1	17 021.3
1990–91	62	10 650	290.5	19 021.7
1991–92	72	6 706	224	20 543.6
Total	583	96 219	1 343.9	163 640
Annual compound growth rate (%) (1983–84 to 1991–92)	21.66	4.09	21.95	11.11

[a] Source: Annual Reports of the NABARD for the respective years.

[b] All the figures refer to the NABARD's schematic lending.

[c] Figures for 1982–83 are cumulative up to the year including ARDC sanctions.

[d] For the year 1988–89, the figures relate to 9 months period (July–March).

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[1] This includes disbursement of funds by erstwhile Agricultural Refinance and Development Corporation.

[2] The NABARD has stipulated certain guidelines for preparing applications by banks for loans refinanced by them. The loan applications are verified by the NABARD officials for financial viability and other aspects. Such loans with project duration of more than three years refinanced by the NABARD come under the category of schematic lending. The appraisal of such projects is done by the NABARD according to pre-determined parameters.

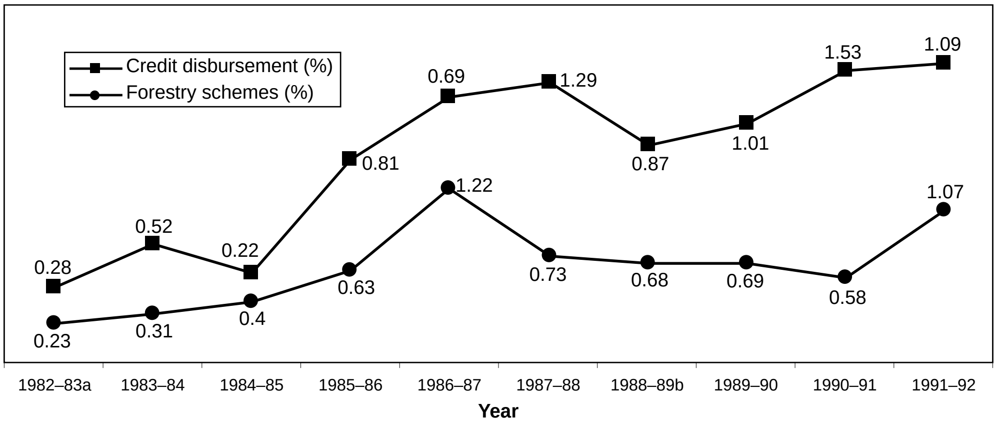

Figure 1. Proportions of schemes sanctioned and credit disbursed in the forestry sector under schematic lending to total schemes sanctioned and credit disbursed by the NABARD respectively from 1982–83 to 1991–92 (Based on Annual Reports of the NABARD)

[a] Figures for 1982–83 are cumulative up to the year including sanctions of erstwhile Agricultural Refinance and Development Corporation.

[b] For the year 1988–89, the figures relate to 9 months period (July–March).

Moreover, in recent years also, the amount refinanced by the NABARD to financial institutions and disbursed by financial institutions to wasteland schemes has declined considerably; it was INR290.5 million in 1990–91 (Table 1) as compared with INR90 million in 1998–99 (Table 2). The share of the forestry sector in the total disbursement by the NABARD was 1.53 percent in 1990–91 as compared with 0.2 percent in 1998–99. During 1992–96, under the *Investment Promotion Scheme* promoted by the Government of India and the NABARD, only four projects were sanctioned in the country. And during 1998–1999, three projects were sanctioned and an amount of only INR0.22 million was released as subsidy (Government of India 2002a). The main reason for the decline in the demand of credit and/or disbursement of credit by financial institutions for forestry schemes seems to be the dilution of focus of the government on farm forestry since 1991, as observed by the Planning Commission of India (Government of India 2002b). Besides, the macro-indicators also corroborate the decline in investments in the forestry sector. For example, in the Eighth Five-Year Plan, 1992–97, the proportion of forestry sector's outlay to total public sector outlay was 1.13percent, which has been reduced to 0.84 percent in the Ninth Five-Year Plan, 1997–2002.

Table 2. The NABARD's disbursement to forestry schemes during 1997–98 and 1998–99[a] (INR million)

	Forestry	Total including forestry	% of forestry to total
1997–98	110	39 220	0.30
1998–99	90	45 210	0.20

[a] Source: Annual Report of the NABARD for 1998–99.

THE NABARD'S REFINANCING OF FORESTRY SCHEMES BY AGENCY

Of all the financial institutions, which were provided refinance facility by the NABARD, the share of scheduled commercial banks in the total number of forestry schemes sanctioned (70.67%) and the total disbursement of funds (93.20%) until March 1992 (including the share of the ARDC) was highest (Table 3). The state land development banks together ranked second with their shares in the forestry schemes sanctioned and the total credit disbursed being 25.04% and 6.28% respectively. The state cooperative banks and the regional rural banks played a less significant role in the financing of forestry schemes. To involve them more effectively, a specific target amount for financing afforestation programmes should be assigned to each bank for each year. There are 32 232 rural and semi-urban branches of scheduled commercial banks and 196 regional rural banks with their 14 539 branches in India (NABARD 1993). Besides, there are 97 122 cooperative credit societies including state cooperative banks (Central Statistical Organisation 1998). With this kind of widespread network of bank branches and adoption of the *service area approach*, banks could and should play an important role in the development of forestry by financing afforestation programmes with funds provided by the NABARD. *Service area approach* is an effort towards decentralization of credit planning for the rural sector in India. Under this approach, the entire responsibility of assessing and meeting the credit needs of all the approximately 600 000 villages in India has been assigned to the branches of commercial banks and cooperative banks (a cluster of 15–20 villages served by one branch).

Table 3. Forestry schemes refinanced by the NABARD in India from 1982–83 to 1992–93 by agency[a,b]

Agency	Number of schemes		Disbursement (INR million)	
	Forestry	% of forestry to total	Forestry	% of forestry to total
State land development banks	146 (25.04)[c]	0.46	84.4 (6.28)	0.15
Scheduled commercial banks	412 (70.67)	0.73	1 252.5 (93.20)	1.58
State cooperative banks	6 (1.03)	0.21	28 (0.01)	0.04
Regional rural banks	19 (3.26)	0.40	42 (0.01)	0.02
Total	583	0.61	1 343.9	0.82

[a] Source: Annual Reports of the NABARD for the respective years.
[b] The figures are inclusive of the cumulative sanctions of ARDC till 1982 and refer to schematic lending.
[c] Figures in parentheses are the percentages of the respective column totals.

CREDIT DISBURSEMENTS BY THE NABARD FOR AFFORESTATION BY REGION

The NABARD has divided its area of operation into six regions (Table 4). Among all the regions, the share of the Central Region was highest in terms of both the number of forestry schemes sanctioned (35.42%) and the disbursement of funds (34.33%) under schematic lending (Table 4 and Figure 2). The Southern Region ranked second with its share in the number of schemes sanctioned being 34.17% and in the disbursement of funds being 23.36%. When we compare regionwise forestry schemes with regionwise total forest degraded land and non-forest degraded land (Figure 2), we find that, by and large, the NABARD's allocation of forestry schemes to different regions is positively correlated with the extent of total degraded lands available for afforestation in the regions. But when we compare the NABARD's regionwise disbursement of credit for forestry schemes with the regionwise availability of total forest degraded land and non-forest degraded land, we find that the former is not commensurate with the latter except for the Central Region, which has the highest disbursement of credit and the highest degraded land in the country. In all the regions, the number of schemes under forestry (accounting for 0.20 to 2.32%) and disbursement of credit for forestry schemes (accounting for 0.06 to 1.70%) are abysmally low as compared with the total number of schemes refinanced and total disbursements made by the NABARD during the period 1987–92.

Table 4. Extent of wastelands and the NABARD's refinancing of forestry schemes in India from 1987–88 to 1991–92 by region[a,b]

Region	Forest degraded land and non-forest degraded land[c] (Million hectares)	Number of schemes		Disbursement (INR million)	
		Forestry	% of forestry to total	Forestry	% of forestry to total
Northern	27.17	38	0.71	176.8	1.30
North-eastern	7.45	4	0.82	1.2	0.06
Eastern	14.66	26	1.04	11.3	0.11
Central	28.2	113	2.32	339	1.69
Western	22.24	29	0.20	228.4	1.70
Southern	26.26	109	0.69	230.7	0.92
Total	125.98[d]	319	0.73	987.4	1.17

[a] Source: Annual Reports of the NABARD for the respective years.
[b] All the figures refer to the NABARD's schematic lending.
[c] Source: Society for Promotion of Wasteland Development, New Delhi.
[d] The total figure for Column 2 excludes the degraded forest area and non-forest degraded area in the Union Territories.

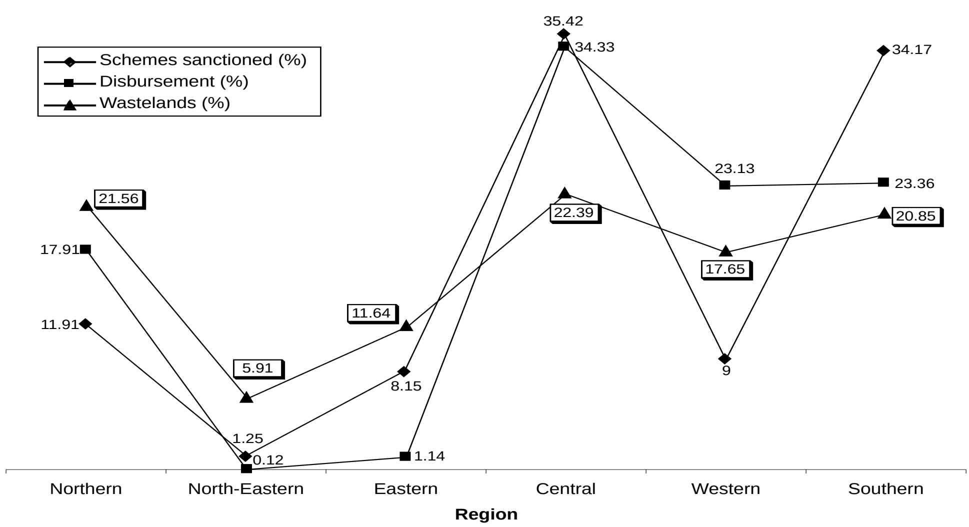

Figure 2. The NABARD's disbursement to forestry schemes in India from 1987–88 to 1991–92 *vis-à-vis* extent of wastelands in India[a]

[a] Source: Annual Reports of the NABARD for the respective years.

CONSTRAINTS ON INSTITUTIONAL FINANCING OF WASTELAND AFFORESTATION PROGRAMMES

There are quite a few physical, technical, financial, and institutional/organizational constraints on promoting wasteland afforestation in India. A brief description of each of them follows.

Problems in availability of degraded land for tree plantation

The information needed for assessing the potential of non-forest and cultivated lands, like ownership, extent and type of degradation, and present and future uses, has never been collected on a systematic basis for the entire country (Romm 1981a,b). This lack of ground-level data/information has dampened the progress of formulation and implementation of bankable plantation programmes. However, some initiatives have been taken to improve the availability of grassroots level data for this purpose. Now there are many NGOs and tree growers' cooperative societies involved in providing institutional finance for afforestation of wastelands in India. But most of them face the problem of non-availability of degraded forest lands for afforestation programmes due to a variety of procedural and legal complications. Such complications need to be removed.

The financial institutions also face difficulty in identification of compact blocks of wasteland for sanctioning the credit in the case of private landowners (Sreenivasan 1992). The scattered landholdings make the tasks of project formulation and close supervision by the field staff of financing institutions difficult. There is a need to consolidate the scattered landholdings in rural India. This can be done by implementing the already existing land reform laws to facilitate tree plantation with the help of institutional credit in the regions where there exists vast potential for tree cultivation.

Moreover, most of the revenue wastelands and degraded forests are in remote rural areas, far away from the area of the operation of rural branches of commercial banks and Regional Rural Banks. This makes it difficult for bank personnel to access the tree growers and the tree plantations.

Lack of information and technical support to tree growers

Most of the tree growers in India are poor, small-scale operators, unorganized and illiterate. They do not have access to the latest technical information about farm forestry nor can they afford fertilizers and pesticides. A large volume of information about the latest developments in technical aspects of growing trees is now available in India with various organizations. But the typical potential tree grower in India is still ignorant about fast-growing species and techniques of cultivating them. There is a need to make tree growers aware of those new species which are most likely to thrive in local conditions and generate higher profit than the existing crops. This information needs to be disseminated to potential tree growers using appropriate mass media tools and techniques. Provision of information will need to be supplemented by training tree growers in the latest techniques of tree plantation. Many institutions, both at the national and state levels, have been established within the last decade to overcome the technical constraints in tree growing and to disseminate the latest information to farmers under various social forestry programmes. These need to play a greater role in the future.

Unless the tree growers are aware of the various aspects of tree growing, the NABARD and the financial institutions refinanced by it cannot increase institutional financing for wasteland afforestation programmes.

Delays in sanctioning and disbursing credit and long gestation

The lack of adequate expertise in forestry and of infrastructure with financial institutions dissuades the banks from taking up afforestation projects. There is also a long time lag between the date of submission of application by the beneficiary and the final sanction of loan. This dampens the interest of potential beneficiaries (Pethiya 1993, Sharma 1993). The interest rates charged by the NABARD for various categories of tree growers and for various types of forestry projects are the same. There is a need for financing the forestry projects at differential rates of interest by the NABARD based on classification of farmers into small, medium and large farmers, and on the potential of their land (Kant & Saxena 1993, Pethiya 1993). Financial institutions should also work towards rationalizing credit delivery and recovery systems for afforestation of wastelands, particularly in view of the fact that trees mature slowly, and consequently investors have to wait for many years for the returns on their capital invested. Moreover, some institutional arrangements need to be made to provide adequate and assured income earning opportunities to tree growers during the long gestation period.

Institutional, organizational and legal constraints

The state governments in India need to take some concrete steps for the benefit of tree growers like modifying legal provisions so that tree growers can freely harvest trees grown on their own farms. In several states, provisions of the Forest Law discourage farm forestry by imposing restrictions on felling, and transportation and sale of timber standing on private lands. For example, in Gujarat, there are restrictions on felling of twenty-six tree species including teak (Professional Assistance for Development Action 1990). Further, the farmers have to seek permission for felling trees from the Revenue Department before harvesting trees on their private lands. It could take a year or two before the farmer gets the requisite permission (National Tree Growers' Co-operative Federation 1998). The Andhra Pradesh Forest Produce Transit Rules of 1970 regulate the transit of forest produce into or from or within any area in the State of Andhra Pradesh. According to Balaji (1997), "at policy level (in the State of Tamilnadu) the cultivation of trees is inhibited by a number of *archaic acts* and rules that restrict felling and transport of timber."These restrictions erode the value of produce for the farmers and dissuade them from taking up plantations. This ultimately dampens tree grower's interest in approaching commercial banks for credit.

According to Guha (1994), even the proposed new forest act, which is to be called the 'Conservation of Forests and Natural Ecosystems Act' and is to replace the Indian Forest Act of 1927, stipulates unnecessary and irksome interference by the state in the affairs of the tree growers. It claims that it will facilitate tree farming, but at the same time it places numerous hurdles in the path of farmers who might actually want to plant trees on their own lands. It also requires that every tree grower registers with the local state forest department, and informs it when trees planted and nurtured by him are to be felled or sold. This would be a great deterrent to farmers who might otherwise like to plant trees on their land. This draft act, which generated a lot of debate, is still to be presented in the Indian Parliament. In the mean while, the old Indian Forest Act of 1927 with subsequent amendments continues to be in operation (Kulkarni 2000).

To substantiate the above-mentioned facts, we reproduce a part of a recent notification by the Ministry of Environment and Forests (Government of India 2001): *"Trees: There shall be no felling of trees whether on Forest, Government, Revenue or* *private land within the Eco-Sensitive Zone, without the prior permission of the State Government in the case of forest land, and the respective District Collector in the case of Government, Revenue and private land, as per procedure which shall be prescribed by the State Government, provided that the District Collector shall not delegate this power to any subordinate officer below the rank of Sub-Divisional Officer".*

There are many other constraints, which impede the development of afforestation of wastelands, and which need to be resolved. For example, the present policy of the Government of India that forest lands should not be leased out to private entrepreneurs for raising plantations to meet their raw material needs is a big hurdle in attracting private investment in tree plantations. Also, the preference of some of the state governments for community forestry schemes over farm forestry schemes reduces the number of financially viable farm forestry schemes being referred to the NABARD.

Given the above-mentioned context, there is a need for the government and financial institutions to encourage NGOs and tree growers' cooperative societies through financial, technical, and legal support to take up afforestation activities.

Non-remunerative prices and lack of marketing facilities

Poor infrastructure and the lackadaisical approach to marketing of farm forestry products followed in the past have led to tree growers receiving unrewarding prices for their products. This has dampened the interest of present tree growers as well as potential tree growers in planting trees and approaching financial institutions for loans even when many schemes for tree plantation are available (Chambers *et al.* 1989, Saxena 1992, Singh 1993). This situation has been more or less the same for decades now. In many places where transport and communication facilities are lacking, middlemen and local entrepreneurs who come over to villages to procure trees and pay very low prices for them often cheat the tree growers. This can be attributed to the lack of knowledge on the part of tree growers regarding prevailing market prices and their inability to go to the distant markets. There is a need for the state governments' intervention to provide the requisite information about markets and prices and to purchase the harvested produce at a reasonable price, if necessary.

A CASE STUDY

To complement the discussion presented in the preceding sections, a case study was undertaken to find out the constraints in financing afforestation programmes by financial institutions at the grassroots level. The present case study evaluates the performance of some representative banks in Gujarat State, in financing afforestation of wastelands, namely the regional office of the NABARD in Ahmedabad, the zonal office of the State Bank of India (SBI) in Ahmedabad; and the Agricultural Banking Division of the Mehmedabad Branch of SBI. These financial institutions are mentioned in descending order in terms of quantum of refinanced credit sanctioned by the regional office of the NABARD to a financial institution disbursing credit to beneficiaries at the grassroots level.

It has been shown that financial institutions in India have disbursed a rather small quantum of credit for afforestation programmes. The case study on institutional financing revealed that the same scenario prevailed in the State of Gujarat, despite the fact that the state was a pioneer in India in implementing social forestry programme. The pattern of refinance allocation of forestry schemes by the regional office of the NABARD, Ahmedabad, to financial institutions in Gujarat, and disbursement of credit by these financial institutions for the years 1991–92 and 1992–93 is presented in Table 5. This table shows that among all the financial institutions, which were offered refinance by the NABARD, only a few scheduled commercial banks had disbursed credit for forestry schemes, amounting to only 1.67% of the total credit disbursed by them during 1991–93. Even after the sanction of credit by financial institutions for afforestation schemes in Gujarat, many of the schemes were abandoned. During 1989–92, six major wasteland development schemes were sanctioned by the NABARD for refinance in Gujarat, but by March 1992, loans had been disbursed to only three of them. These six schemes are profiled in Table 6. One of the reasons behind the failure of three plantation schemes to take off as revealed by the officials of the NABARD was the long gestation period.

Table 5. The NABARD's refinance allocation to forestry schemes and actual disbursement of credit in Gujarat State during 1991–92 and 1992–93[a] (INR million)

Financial institution		Refinance allocation by NABARD		Disbursement	
		Forestry	Total including forestry	Forestry	Total including forestry
Scheduled commercial banks[b]	1991–92	11.80	521.34	8.64	518.12
	1992–93	11.05	599.66	5.29	522.77
Regional rural banks[c]	1991–92		81.53		77.55
	1992–93		96.91		95.85
State land development bank[d]	1991–92	15	295		321.46
	1992–93	20	550		525.02
State cooperative bank[e]	1991–92		101.02		88.85
	1992–93		100		124.55

[a] Source: The NABARD, regional office, Ahmedabad.

[b] Includes nineteen scheduled commercial banks.

[c] Includes nine regional rural banks.

[d] Gujarat State Cooperative Agriculture and Rural Development Bank Ltd.

[e] Gujarat State Cooperative Bank.

Now, we shall discuss one such scheme, which could not take off. A major scheme for the cultivation of *Salvadora persica* on private marginal lands in 275 villages in the Bhal region of Gujarat, involving a refinance of INR46.27 million by the NABARD, was abandoned (Table 6). This scheme was sponsored by the Mumbai-based Lauric Oilseed Company, engaged in the extraction of lauric and myristic fatty acids from the seeds of *Salvadora* for industrial use. These fatty acids are used particularly in pharmaceutical and chemical industries. *Salvadora* is considered suitable for arid and semi-arid zones and is also drought resistant and salt tolerant. Farmers of the region were to raise these trees in collaboration with the industry. The scheme was to be financed by a consortium of nine scheduled commercial banks and was approved in 1991. However, the farmers did not show any interest in raising the *Salvadora* trees as they were also not convinced about the projected benefits from the plantation. The company tried in vain to motivate the farmers and promised to provide quality planting material. On the other hand, the bankers were also hesitant in providing loans to farmers, despite the NABARD's willingness to refinance such loans.

Table 6. Wasteland development schemes sanctioned and refinanced by the NABARD for Gujarat State from 1989–90 to 1991–92[a] (INR million)

Wasteland development scheme	Financing agency	Refinance sanctioned	Disbursement up till March 1992
Salvadora persica plantation in Ahmedabad district	Bank of Baroda[b]	1.1	0.006
Wasteland development through afforestation of 324 ha in Valsad and Bharuch districts	Gujarat State Cooperative Agricultural and Rural Development Bank Ltd. (GSCARDB)	3.14	0.18
Wasteland development through social forestry plantation on 80 ha in Dabhoi in Baroda district	State Bank of India[b]	0.66	
Schemes for plantation of fuel trees in Bhavnagar district	GSCARDB	0.51	
Scheme for cultivation of *Salvadora persica* in 275 villages in Bhal region comprising the districts of Ahmedabad, Surendranagar, Bhavnagar and Kheda.	Consortium of nine scheduled commercial banks	46.27	
Scheme for *Zizyphus* sp. cultivation on wastelands	Dena Bank[b]	0.39	0.31

[a] Source: The NABARD, Regional Office, Ahmedabad.

[b] Scheduled commercial bank.

Discussions with the officials of the Mehmedabad Branch of the Agricultural Banking Division, the State Bank of India, revealed that the lack of expertise of bank officials was one of the major constraints to the financing of forestry schemes. Such failures and constraints in delivering credit by financial institutions at the grassroots level are also reported in Latin American countries (Weaver 1996). Recently, the NABARD has tried to remove these constraints by commissioning selected NGOs to train its officials in forestry to process forestry loan applications. Uvin *et al*. (2000) reported that MYRADA, a reputed NGO from India, specializing in organizing self-help groups (SHGs) among small farmers to save money and help one another by advancing loans out of the savings credit, has trained hundreds of the NABARD officers in the use of their model.

A SYNTHESIS

The above discussion reveals that most of the constraints hampering the progress of disbursement of credit for wasteland development through afforestation can be traced to the state governments and their forest departments. The Government of India has stipulated an enhanced role for the NABARD in refinancing the wasteland development programmes. But it is quite evident from our study that its own rigid policies have thwarted such programmes and are likely to jeopardize various wasteland afforestation schemes unless some radical steps are taken by the government to simplify its own rules and regulations and make them tree-grower friendly. If the aforesaid constraints are not overcome, the NABARD would not be successful in achieving its mandated targets of disbursement of credit for wasteland development programmes.

On other hand, it has also been argued that subsidized credit is not a proper incentive mechanism as it leads to decapitalization of the financial institution advancing such loans. Moreover, directed credit is difficult to administer. Haltia and Keipi (1997) have analysed this situation with reference to Latin American countries. Besides, Weaver (1996) pointed out that in Mexico, the rural poor and Indian people could not make proper use of credit for productive purposes due to the lack of the requisite knowledge about banking and the banks were urban based and urban biased. A similar situation occurs in India wherein the NABARD is directing subsidized credit for forestry schemes through financial institutions to ultimate beneficiaries, a large majority of whom are illiterate and hence lack banking knowledge and aptitude. One solution for these two situations lies in the direct incentive administered by governments though co-financing of inputs such as seedlings and provision of extension services. The golden era of *Eucalyptus* plantations on private lands during the late 1970s and early 1980s under the auspices of social forestry programme in India was an outcome of this strategy. This strategy has also been successful in the ongoing joint forest management programmes to rehabilitate government-owned degraded forests (common lands) in India along with one more crucial input, the people's participation.

CONCLUSION

The restoration and afforestation of wastelands require huge investment, which is beyond the reach of owners of such lands and the budgetary resources of the government. Therefore, availability of external funds, preferably from institutional sources, is a pre-requisite for afforestation of wastelands in India. The NABARD can play an important role in refinancing the wasteland afforestation schemes. It has already accepted this role and provides refinance facility to state land development banks, scheduled commercial banks, state cooperative banks and regional rural banks for the purpose. Its contribution so far has, however, been meagre —less than 2 percent. There are many physical, technical, financial and institutional constraints on refinancing of wasteland afforestation schemes by the NABARD. But many of these constraints can be removed/relaxed and the NABARD could and should play a bigger role in future.

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21 Forest rehabilitation and forest genetic diversity—management implications and research needs

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ABSTRACT

There is increasing scientific evidence that forest rehabilitation and restoration are technically feasible through silvicultural interventions in degraded tropical forests and lands. In tropical Asia and the Pacific alone, there are several million hectares of degraded forests and land areas that can be restored for biodiversity conservation or rehabilitated for tree-based production systems, such as agroforestry or tree plantations. Traditionally, reforestation efforts have attempted to re-establish tree cover with any suitable species regardless of the original tree species composition at a given site. The term 'forest rehabilitation' is commonly used for reforestation and other related techniques like assisted natural regeneration when the goal is to re-establish the original forest cover with native tree species. After forest rehabilitation, the aim is often to manage and utilize the rehabilitated forests to fulfil various human needs. 'Forest restoration', on the other hand, attempts to re-establish the original forest ecosystems with complex interaction and it often emphasizes habitat and wildlife conservation instead of human utilization as a management target. While evaluating whether reforestation, rehabilitation and restoration efforts have been successful or not, the output is commonly measured in terms of hectares or number of reintroduced species while less attention is paid for analysing the long-term sustainability of these efforts. In this regard, forest genetic diversity has an important role to play in maintaining the rehabilitated forests under changing climate and against the potential risks this role will bring along. Already under the present environmental conditions, narrow genetic diversity makes the rehabilitated forests vulnerable to pest and disease outbreaks, for example. Very little information is available on the level of genetic variation in rehabilitated forests, i.e. how well various rehabilitation efforts have been able to restore forest genetic diversity. This information is not only relevant for sustainable forest management but also for future conservation efforts as natural

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production forests can significantly contribute to conservation of forest genetic resources if managed properly. In this paper, we provide an overview to the various forest rehabilitation efforts in the Asia Pacific region and discuss their sustainability from the forest genetic diversity point of view. Based on this and the likely effects of relevant genetic processes, we also highlight some management implications for future rehabilitation efforts and identify research needs.

INTRODUCTION

In the tropical Asia Pacific region alone, there are millions of hectares of degraded forests and unproductive land areas that could be rehabilitated or developed to tree-based production systems, such as agroforests, intensively managed natural forests or tree plantations. Similarly, large parts of these areas could also be turned back into original forest ecosystems through restoration efforts. Several scientific studies have indicated that forest rehabilitation and restoration are technically feasible through silvicultural interventions in degraded tropical forests and lands (e.g. Kuusipalo *et al*. 1995, Ashton *et al*. 1997, Oberhauser 1997, Chapman & Chapman 1999, R. Otsamo 2000a, Yirdaw 2001, Bebber *et al*. 2002). These efforts, if implemented together with revised policies on natural resources management, could significantly improve the livelihood of rural people and enhance conservation of biological diversity.

Biological diversity consists of variation in all species of plants and animals, their genetic material and the habitats in which they occur. Subsequently, diversity occurs at genetic level (variation in genes and genotypes), species level (species richness) and ecosystem level (communities of species) (e.g. Ramanatha Rao & Hodgkin 2002). Biological diversity and its sustainable use provide numerous benefits for human well-being and therefore the importance of conserving this diversity is well recognized. A lot of efforts have been put to conserve genetic diversity of domesticated crop species in particular whereas less attention is given to conserving forest genetic diversity. Unlike crop genetic resources, long-term conservation of tropical forest genetic resources in seed banks is problematic in many forest species as they have recalcitrant seed behaviour and therefore their long-term conservation is mostly dependent on conserving forest ecosystems.

Degraded forests and land areas are often results of human interventions. Mining activities often leave behind totally barren soils. Areas cleared for agriculture are commonly abandoned when they become unproductive and these may develop into grasslands or forest fallows. Selective logging leaves behind secondary forests, which still have adequate canopy cover (more than 10%) to be classified as forests but their biodiversity is often deteriorated considerably. In general, three broad approaches are used for overcoming forest and land degradation (Lamb 1994). Traditionally, reforestation efforts have attempted to re-establish forest cover with exotic tree species with no attempt to bring back the original, native tree species composition at a given site (*reclamation*). In *rehabilitation*, native tree species are used for reforesting a site with or without exotic species but the management goal is not to recreate the original and often complex forest ecosystem. After forest rehabilitation, the aim is to manage and utilize the rehabilitated forests to fulfil various human needs. The most ambitious approach is *restoration*, attempting to recreate the original ecosystem with complex interaction of plants and animals that once occupied the site. Thus the management objective in restoration emphasizes habitat and wildlife conservation prior to utilization for human needs.

The reclamation–rehabilitation–restoration sequence is a continuum of different approaches and techniques, ranging from simple to complex, from less expensive to more expensive and from necessity to 'luxury' (Lamb 1994). Social and economic conditions influence the selection of the management goal and the subsequent decision as to which part of this continuum is applied to a certain situation. Several countries in the Asia Pacific region have both practical experience and scientific knowledge on different parts of the continuum. However, many countries have chosen to emphasize the first step of the continuum, i.e. reclamation, which can rapidly provide social and economic return even if the available resources would be limited. On the other hand, the pressure of human populations does not often allow establishment and occupation of large areas solely for wood production purposes without the option to produce food and income-generating cash crops. It should be kept in mind that the reclamation–rehabilitation–restoration continuum is also a reflection of another continuum ranging from sole utilization of forest genetic resources to conservation of overall biological diversity in forest ecosystems.

In this paper, we provide a short overview of various forest rehabilitation efforts in selected countries in the Asia Pacific region and discuss their sustainability from the forest genetic diversity point of view. We also discuss how reforestation and rehabilitation efforts could increase the use of forest genetic diversity and the role of these efforts in conserving forest genetic resources. Based on this and the likely effects of relevant genetic processes, we also highlight some management implications for future rehabilitation efforts and identify research needs.

REHABILITATING AND RESTORING TROPICAL FORESTS IN THE ASIA PACIFIC REGION

Forest rehabilitation and restoration include a wide range of different conceptual frameworks and techniques, which aim at regenerating logged-over and secondary forests or establishing tree cover in degraded lands using native or exotic species. This range starts at planting with native or exotic species using high human input, and ends at 'pure', assisted natural regeneration without tree planting using low human input. The term 'assisted natural regeneration' often refers only to rehabilitation or restoration efforts on secondary forests or degraded lands with some trees, apart from various well-established silvicultural systems that aim to ensure forest regeneration immediately after logging in tropical forests.

The ratio of natural regeneration to tree planting varies from zero (intensive tree planting) to one (assisted natural regeneration) within the above-mentioned range of methods available (Hardwick *et al*. 2000). Between these two methods, there are several others that apply a mixture of enrichment planting and natural regeneration. Basically all conceptual frameworks and methods rely on assisting or manipulating the natural process of ecological succession. In the following chapters we shall shortly highlight some experiences and results from different methods in selected Southeast Asian countries before discussing the genetic implications of these methods in forest rehabilitation.

Malaysia

On average, some 235 000 and 175 000 ha of natural forests are harvested annually in Peninsular Malaysia and Sabah respectively, and about one-third of the area harvested is likely to become degraded (see Nik Mohd. & Mohd. Zaki 1995). In addition to this, there are large areas of ex-tin mining areas (tin tailings), about 205 000 ha in Peninsular Malaysia (Ang 1987, cited by Awang & Venkateswarlu 1992) and 250 000 ha in Sabah (Lim *et al*. 1981, cited by Nik Mohd. & Mohd. Zaki 1995). Rehabilitation efforts in Malaysia have focused mainly on planting indigenous tree species in logged-over or secondary forests (Tang & Chew 1980, Ang *et al*. 1992, Maswar *et al*. 2001, Mohamad Azani *et al*. 2001) and multipurpose exotic tree species in old tin mining areas (Awang & Venkateswarlu 1992). Planting of native species has also been tested under fast-growing exotic tree plantations (Ueda *et al*. 1995).

Rehabilitation in logged-over tropical rain forests has emphasized enrichment planting with commercially important indigenous tree species, mainly dipterocarps. The potential of several native species for tree plantations is also well known but these species have never been planted on a large scale. The major problem has been species selection for given site conditions as seedlings of most dipterocarp species are very specific to light conditions. In various planting experiments, dipterocarps have shown a wide rage of survival rates and generally seedlings planted under partial shade survive better than those planted in open areas (Abdul Rahman *et al*. 1992, Ang *et al*. 1992, Nik Mohd. & Mohd. Zaki 1995, Mohamad Azani *et al*. 2001). Both line planting and gap planting are suitable methods but it has been suggested that line planting provide less favourable light conditions for seedling growth as compared to gap planting (Bebber *et al*. 2002). Gap planting has also been found more efficient and effective than line planting in terms of costs and keeping the undergrowth suppressed (Maswari *et al*. 2001).

In the case of tin tailing areas, multipurpose tree species, such as *Acacia* and *Leucaena* spp., have been used for rehabilitation to improve site conditions and provide multiple products (Awang & Venkateswarlu 1992). The results of these efforts are very promising and have a potential to pave the way for developing more diverse production systems or accelerating recovery of native forest species. At a later phase, narrow strips or small gaps could be opened within the exotic plantations to promote further rehabilitation and even restoration through planting of carefully selected dipterocarp species (cf. Ueda *et al*. 1995).

Indonesia

Similarly to Malaysia, increasing efforts to rehabilitate logged-over rain forests have taken place in Indonesia (e.g. Mori 2001). The present logging practices have considerably reduced dipterocarp seed production and regeneration in and altered the responsiveness of these forests to the El-Niño Southern Oscillations (ENSO) by disrupting edaphic conditions or causing extended drought stress (Curran *et al*. 1999). Logged-over forests are expected to develop into the original primary forests through natural succession and post-logging silvicultural operations are often conducted to speed up this process. However, these techniques may not guarantee that this objective is achieved. For example, Kuusipalo *et al*. (1996) reported that liberation cutting of pioneer or secondary forest tree species to favour dipterocarp species did not enhance the succession in logged-over areas after a short (2 years) or long (12 years) period of time. Instead of large-scale liberation cuttings, Tuomela *et al*. (1996) reported that the fastest early growth of dipterocarps is achieved by opening up artificial gaps less than 500 m^2 in size in logged-over forests. The results can be further enhanced by opening the gaps in places where an abundant ephemeral seedling stock of dipterocarps is present (Tuomela *et al*. 1996).

In addition to logged-over rain forests, there are considerably large areas of degraded land in Indonesia. Degraded, low-volume (≤30 m^3 ha^{-1}) humid lowland rain forests covered about 16 million hectares in the country at the end of the 1980s (ITTO 1990) and presumably the figure is much higher today as deforestation has been continuing despite the increasing efforts to promote sustainable forest management (cf. FAO 2001). Mega-level *Imperata* grasslands cover 8.5 million hectares, equalling 4% of the total land area of Indonesia, and this figure does not include smaller grasslands (Garrity *et al*. 1997). Fast-growing tree plantations of *Acacia crassicarpa*, *A. mangium*, *Gmelina arborea* and *Paraserianthes falcataria*, for example, have been successfully used to shade out the *Imperata* grass while transferring the unproductive grasslands into industrial wood production (e.g. A. Otsamo *et al*. 1995, 1997). These plantations also enhance natural regeneration of native forest tree species in their understorey (Kuusipalo *et al*. 1995, R. Otsamo 2000a). As an additional management objective, tree plantations can be diversified with silvicultural interventions such as gap opening to facilitate rehabilitation or even restoration process (R. Otsamo 1998, 2000b).

Thailand

Thailand, like several other Southeast Asian countries, has struggled with large-scale deforestation during the past decades. Presently, the total forest area is about 14.7 million hectares, covering 28.9% of the total land area (FAO 2001). Traditionally, reforestation efforts have promoted establishment of tree plantations mainly with exotic tree species. As a result of these efforts, there are some 4.9 million hectares of tree plantations in Thailand (FAO 2001) but the establishment of tree plantations has not been able to stop deforestation or deterioration of biodiversity in the remaining natural forests. Simultaneously with reforestation efforts increasing research efforts have been carried out to gain better understanding on the natural forests and their regeneration processes, especially in seasonally dry northern Thailand (e.g. Elliott *et al*. 1989, Koskela *et al*. 1995, Maxwell *et al*. 1995, Hardwick *et al*. 1997, Oberhauser 1997).

The drawbacks and limitations of traditional reforestation methods have initiated the development of alternative methods in Thailand. Some tree plantations, like the ones established using native *Pinus kesiya*, have shown great potential to facilitate forest restoration. Oberhauser (1997) reported that native vegetation was regenerating better beneath the pine plantations than abandoned agricultural fields in northern Thailand. Although some plant species are able to regenerate in open clearings, in many cases seed dispersal and germination face serious obstacles even in relative small clearings (<1 ha) in the seasonally dry tropical forests of northern Thailand (Hardwick *et al*. 1997).

To increase ecological restoration, the framework species method, originally developed for restoring humid tropical rain forests in Queensland, Australia, was introduced to Thailand and experiments are underway to test its applicability in restoring seasonally dry tropical forests (e.g. Elliott *et al*. 2000). The concept involves planting of fast-growing, native tree species with a dense canopy so that these can shade out weeds and attract seed-dispersing wildlife to promote further regeneration of native species. Nearly 400 native tree species have been screened for their potential usefulness in forest restoration (Blakesley *et al*. 2000) and a total of 45 species have been recommended for forest restoration in northern Thailand (FORRU 2000). Seed germination and dormancy studies have also been conducted in 36 potential framework species (Blakesley *et al*. 2002). The preliminary results from field experiments indicate that selected framework species such as *Erythrina subumbrans*, *Melia toosendan* and *Prunus ceradoides*, for example, perform well in terms of early survival and growth (Elliott *et al*. 2000). Thus, the framework species method seem to have potential even for large-scale forest rehabilitation and restoration efforts, provided that some problems in seed and seedling supply can be solved.

Philippines

The conceptual framework of assisted natural regeneration (ANR) was specifically developed to restore vast areas of *Imperata* grasslands in the Philippines and it has also been successfully applied elsewhere. Basically ANR is based on the ecological principles of community succession (e.g. Sajise *et al*. 1976) and is most applicable if there are patches of natural forests or trees mixed within the grasslands. ANR relies on natural regeneration, either from natural seedlings or planted wildings, and prevention of fire in the grasslands. ANR can also include enrichment planting of tree species that match a given site. The subsequent successional development increases shading, which suppresses *Imperata* grass and facilitates invasion of other native tree and plant species into the rehabilitated areas.

Since ANR does not necessarily require nurseries, it is a cost-efficient way to carry out forest restoration. It also has a number of other advantages, such as maintaining the original vegetation and corresponding ecosystem function, promoting biodiversity conservation and the use of indigenous knowledge, and providing employment for local people (Sajise 1989). On the other hand, labour intensity can also become a constraint for ANR and similarly inadequate extension, insecure land and tree tenure, and poverty may prevent a proper use of ANR (Friday *et al*. 1999). ANR, like any other forest restoration frameworks, has technological, biophysical and socio-cultural dimensions, which need to be included in a complementary manner to ensure the successful outputs (Sajise 2002).

FOREST GENETIC DIVERSITY IN REHABILITATION PROCESS

Genetic diversity in degraded forests

Logging in tropical forests tends to reduce biodiversity in all its different levels and only very low-intensity timber harvesting has the potential to maintain biodiversity (see Putz *et al*. 2001). Logging not only reduces population size but also causes structural alterations that are likely to change the complex ecological interactions between trees and various animals necessary for maintaining the genetic processes (Bawa & Seidler 1998, Wickneswari & Boyle 2000). The way in which logging is implemented has major impact on regeneration potential of the remaining stand, i.e. how much physical damage is caused to remaining trees and seedlings. Similarly to timber harvesting, collection of non-timber forest products may also reduce species diversity and especially genetic diversity if the harvesting is focused on reproductive parts, e.g. flowers or fruits (Wickneswari & Boyle 2000).

Lee *et al*. (2002) studied the effect of selective logging on the genetic diversity of *Scaphium macropodum* in Peninsular Malaysia. They found no negative immediate reduction in genetic diversity when logging reduced the density of the species from 10 to of 8 trees ha^{-1} (>20 cm in diameter). Similarly, Wickneswari and Boyle (2000) observed that a single low-intensity logging event did not cause adverse reduction in genetic diversity of *Parkia speciosa*, *Shorea leprosula*, *Garcinia malaccensis*, *Daemonorops verticillaris* and *Labisia pumila*. However, Lee *et al*. (2002) also reported that, as a result of logging in low-abundant *S. macropodum* stands (about 2 trees ha^{-1}), a significant loss in genetic diversity still prevailed 40–50 years after logging. Thus the effects of logging on forest genetic diversity depend not only on harvesting intensity but also on the density of harvested tree species and more importantly, the number of reproducing individuals in a stand.

Logging not only reduces the overall number of trees but it may also cause spatial isolation of the remaining tree populations and thus fragmentation. However, after logging activities have opened access to a given forest area, the subsequent development often leads to the conversion of the forest to other land uses such as agriculture or pasture and this is likely to cause more fragmentation than logging as such. As fragmentation proceeds, its genetic effects also become more obvious, including loss of genetic diversity, change in interpopulation structure and increased inbreeding (Young & Boyle 2000). In India, for example, genetic diversity of *Santalum album* (sandal) decreased in terms of heterozygosity along an extraction pressure gradient from the core zone of a protected area to buffer and periphery zones (see Nageswara Rao *et al.* 2001). Fragmentation also tends to reduce the activity of animal vectors contributing to gene flow among and between populations in tropical tree species, which are predominantly outcrossing. However, despite fragmentation, some fragments may still be linked by gene flow in case the distances between the fragments are short or if there are individual trees between facilitating the movement of pollinators (see Young & Boyle 2000).

Intensive selective logging, however, is not likely to maintain links in the form of individual trees between forest fragments. Condit *et al.* (2000) analysed spatial patterns in the distribution of tropical tree species from dry deciduous to humid evergreen forests in Asia and Central America. They found that most tree species were aggregated than random and that rare tree species were more aggregated than common ones. Thus intensive selective logging may remove entire clusters or leave behind unproductive individuals and cut off possible links between clusters or subpopulations. This will obviously lead to serious long-term genetic consequences in the remaining fragmented and often small tree populations.

Several plant species have low net seed or fruit production in small fragments, like on the mallee woodlands of Australia (Cunningham & Duncan 2001). In northern Thailand, Ghazoul (2001) also observed considerably lower fruit set in *Shorea siamensis* at logged sites as compared to unlogged sites. In Costa Rica, Rocha and Aguilar (2001) compared the reproductive biology of *Enterolobium cyclocarpum*, a predominantly outcrossing and insect pollinated dry forest species, between trees found in pastures and in continuous forests. They found that trees in continuous forests were more likely to set fruits and more seeds per fruit than trees in pastures. Rocha and Aguilar (2001) also reported that the vigour was higher in seedlings originating from continuous forests than in those from pastures.

These findings demonstrate that seed or fruit production will be reduced far before any long-term genetic consequences take place in fragmented forests. Inbreeding can also result in deleterious alleles, which further reduce survival and reproduction potential even in relatively large populations, depending on the level of inbreeding depression in a given species. However, small population size does not necessarily indicate low levels of genetic variability although species with narrow distributions have often less variability than widely distributed species (Savolainen & Kuittinen 2000). In forest fragments, genetic drift can considerably change allele frequency already over a few generations although usually the genetic effects take place slowly. For the management of forest fragments, the major genetic concern is to increase population sizes large enough so that mutation and recombination can generate enough variability within populations to respond to selection pressures (Savolainen & Kuittinen 2000).

Forest genetic diversity in rehabilitation process

As discussed above, there is increasing scientific evidence that forest rehabilitation and restoration are technically feasible through silvicultural interventions in degraded tropical forests and lands. However, what remains unclear is the effect of these interventions on forest genetic diversity, i.e. how well the diversity can be recovered and maintained in rehabilitated forests. To our knowledge, very few scientific studies have been carried out in the Asia Pacific region to find answers specifically for these questions and to provide management guidelines for practical work. Despite the very little specific information available, some conclusions for rehabilitation work can be drawn based on the above-mentioned genetic studies and guidelines developed for managed natural forests and protected areas (FAO, DFSC, IPGRI 2001) and seed handling (Schmidt 2000).

The way a rehabilitation process is initiated, i.e. how degraded forests are regenerated, has a crucial effect on long-term productivity and sustainability of rehabilitated forests. It also determines the later value of these forests in conserving genetic resources of selected priority species, if the forests are managed for production purposes or biodiversity conservation. From the genetic processes point of view, rehabilitation efforts can be classified into three broad categories, 1) silvicultural interventions after selective logging in well-stocked natural forests or in secondary forests, 2) assisted natural regeneration in landscape where only forest fragments and individual trees still exit, and 3) seriously degraded landscapes where only a few trees are left.

For the rehabilitation efforts in recently logged natural forests or secondary forests, the following general guidelines are applicable (FAO, DFSC, IPGRI 2001):

- Local seed sources should be used as a source for the next generation (applies for both natural regeneration and possible enrichment planting).
- To maintain (or enrich) genetic diversity, a sufficient number of seed trees should contribute to regeneration or, if direct seeding or planting is applied, seeds should be collected from a larger number of individuals and pooled.
- Silvicultural interventions should avoid creating neighbourhoods of related trees which might lead into inbreeding and growth depression in subsequent generations in species with mixed mating systems.

As we have discussed above, the effects of logging on forest genetic diversity are highly site and species specific; so it is difficult to define exactly what is a sufficient number of seed trees. If no detailed genetic studies have been carried out, as many seed trees as it is practically feasible should be left or used for collecting seeds after logging. For moist tropical forests, for example, it has been suggested that 6–10 seed trees per hectare and species would probably be sufficient and when genetic conservation is included as a management objective, the total number of individuals within a larger area should be kept relatively high (>150) (FAO, DFSC, IPGRI 2001).

In the case of secondary forests, rehabilitation efforts have to rely on what is left, and it is likely that genetic diversity has decreased considerably. To enhance the recovery of genetic diversity, seeds or wildings of a given species could be collected from several local stands and from as many individuals as possible and pooled to be used in the rehabilitation process within a limited local area. For highly endangered species, gene pools could be even pooled over larger geographical regions, as suggested within the concept of forest genebanks (Uma Shaanker & Ganeshaih 1997, Uma Shaanker *et al*. 2002). However, it should be kept in mind that this kind of pooling over large geographical regions may cause loss of rare alleles, disrupt adaptation to local conditions and prevent new genotypes from having desirable and valuable quantitative traits.

In fragmented landscapes where forests occur in isolated patches, maintaining and enriching genetic diversity during the rehabilitation process require special attention. Assisted natural regeneration can be used for creating links or ‘ecological corridors’ between fragments but the reduced capacity of fragments to produce viable seeds and vigorous seedlings is likely to hinder these efforts. In some species, long-distance gene flow may maintain genetic diversity even in small fragments, depending on their pollination vectors and seed dispersers. However, to facilitate the recovery of genetic diversity assisted natural regeneration efforts in fragments and surrounding degraded areas should include direct seeding or tree planting efforts using germplasm from other local sources.

In seriously degraded landscapes, assisted natural regeneration is not a feasible means for rehabilitation as it is likely that isolated trees are not producing viable seeds and vigorous seedlings. In degraded areas like *Imperata* grasslands, it is also difficult for many tree species to regenerate naturally and initiate the succession even if seed production would be adequate. Therefore rehabilitation efforts in seriously degraded sites commonly include artificial regeneration, which makes the efforts more costly than other methods relying on natural regeneration. When the management objective is to restore the original forest ecosystem, the framework species method seems to be highly applicable. If the management objective is to rehabilitate forest cover and simultaneously support rural livelihood or local industrial activities, establishment of tree plantations or agroforests would be desirable. In both cases, it is essential that potential tree species for these specific purposes have been identified and tested in various sites and environmental conditions before using them for rehabilitation.

When collecting seeds (or wildings) for rehabilitation of seriously degraded landscapes, germplasm should be obtained from several adjoining areas or forest fragments with similar environmental conditions, if possible. This will ensure that the material is adapted to local conditions. Seed collection efforts should also follow the following guidelines to ensure that genetic diversity is enriched or maintained in rehabilitated forests (Schmidt 2000, FAO, DFSC, IPGRI 2001):

- Collect seed or wildings from a large number of trees (preferably more than 50) with a minimum distance of 100 meters between seed trees.
- Collect an equal amount of seed from each tree and keep the seed separate by tree until sowing or propagate separately and mix prior to planting.
- Collect seed during years of mast flowering and fruiting to enhance the likelihood of high levels of outcrossing.
- Collect seed several times a year for species that flower and fruit sporadically throughout the year.

In addition to these guidelines, there are several points that need to be considered during the seed handling process to avoid loss of genetic diversity and these are presented in detail by Schmidt (2000).

In degraded landscapes with forest fragments, it is obvious that the requirements for the number of seed trees and the minimum distance between seed trees are difficult to follow due to small fragment size and low number of individuals per species left in the fragments. Therefore, these requirements need to be adjusted and applied according to species and local conditions to maximize the amount of genetic diversity among collected seed or wildings under the existing constraints. Most tropical tree species have aggregated spatial distribution (Condit *et al*. 2000) and neighbouring trees in natural stands are often related to each other (Griffin 1991); so the purpose is to avoid collecting seed and wildings from related individuals or inbred populations. When rehabilitation efforts aim at establishing forests for production rather than conservation purpose, seed can be collected from only 25 or even as low as 15 individual trees (see Schmidt 2000).

Well before a rehabilitation (or restoration) process and planning of seed or wildling supply are initiated, the ultimate management goal should be clearly identified. The long-term management goal can be to 1) restore a site for conservation of forest genetic resources or biodiversity in general, 2) rehabilitate a site for short-term production purposes with native or exotic species and after the first rotation period, shift the focus towards restoration taking a full advantage of the succession bringing in more native forest species, and 3) rehabilitate a site for long-term production purposes and manage native or exotic forest species to meet human needs while simultaneously providing environmental services. The identification of the management goal will not only facilitate decision-making during the rehabilitation process (e.g. how many seed trees should be used) but also determine the value of rehabilitated sites for genetic conservation and their usefulness to be used as seed sources in the future. Obviously, the selected management goal and subsequent activities during a rehabilitation process, including seed or wilding collection, should be well documented and records maintained properly. Documentation also enables later analyses on how much various man-made inputs attract natural recovery of species and genetic diversity.

Research needs

A lot of studies have been done to analyse various methods for reclamation, rehabilitation and restoration. While the existing information can already provide a rather sound basis for large-scale implementation of more ecological reforestation and rehabilitation, there are still gaps in our understanding, especially on how to manage forest genetic diversity during the rehabilitation process. Some research topics specifically relevant for rehabilitation include:

- selecting and testing native tree species for rehabilitation;
- assessing and locating genetic diversity of potential native tree species;
- genetic diversity of forests rehabilitated with various methods;
- gene flow between fragments and rehabilitated forests in degraded landscapes.

Although increasing efforts have been put on assessing usefulness of native tree species for rehabilitation, there is a need to test more species for different site and environmental conditions. This work should also include development of appropriate propagation methods and collection of indigenous knowledge. Information on genetic diversity of potential native tree species is needed to identify the most diverse populations of fragments for genetic conservation and to be used as seed sources. There is very little information available on how well various methods have been able to restore genetic diversity. Therefore, genetic studies are needed to analyse some successful methods and to provide guidelines for managing forest genetic diversity during the rehabilitation process. Tree plantations and the framework species method, for example, can significantly facilitate natural regeneration of native species but it is unclear how well the process can restore genetic diversity. Much of the additional geneflow into rehabilitated areas occurs in the form of seeds but in some cases, pollen movements may also have a significant role.

In addition to the above-listed topics, there are several broader research topics that are also relevant for managing forest genetic diversity during rehabilitation efforts (Ramanatha Rao & Koskela 2001):

- improving methods for surveying, sampling and assessing inter- and intraspecific diversity;
- ethnobotany and socio-economics to better understand the role of local communities in conservation;
- population genetics and conservation biology to better understand dynamics of forest genetic diversity;
- development of improved *ex situ* conservation methods;
- improving information and documentation methods;
- economic studies on the benefits from conservation and use of forest genetic resources.

SOCIO-ECONOMIC CONSIDERATIONS IN FOREST REHABILITATION

As mentioned earlier, any forest rehabilitation effort has technological, biophysical and socio-economic dimensions (Sajise 2002). More efforts are often put on understanding technological and biophysical aspects of a given rehabilitation intervention as compared to socio-economic aspects. However, the success or failure of any forest rehabilitation or biodiversity conservation project is strongly dependent on how the needs of local people are taken into account while planning and implementing the activities (e.g. Enters 2000). Thus forest rehabilitation process should not only promote biodiversity conservation but also bring benefits to rural communities and provide them a channel to participate in this process. Obviously, the socio-economic dimension has a strong influence on how the long-term management goal is identified for a given rehabilitation or restoration effort.

Many Asian countries have recognized the importance of involving local people in forest conservation and subsequently participatory approach is increasingly applied to forest conservation and management (e.g. Isager *et al*. 2002). However, there still is a need to enhance the creation of enabling environments for participatory process in the Asia Pacific region. These include appropriate institutional and regulatory framework, secure land tenure and various forms of capacity building (Isager *et al*. 2002). In general, policies for forest rehabilitation and conservation need to be based on a wider recognition of various interests and rights which makes the development of such policies a more demanding task than developing the technical parts of conservation and use policies (Kanowski 2000).

As we move into the new millennium, there is an increasing demand for wood and non-wood products in both industrial and local sectors. In forest rehabilitation point of view, this demand has to be taken into account and activities balanced between production of forest-based goods and biodiversity conservation. Therefore forest geneticists and others should not only conserve genetic diversity of indigenous forest species in rehabilitation process but also promote its increasing use.

CONCLUDING REMARKS

Forest rehabilitation and restoration in degraded tropical lands have great potential to enhance sustainable forest management, contribute to biodiversity conservation, increase food security and provide income for rural people. Several countries in the Asia Pacific region have both practical experience and research results on various methods for forest rehabilitation and restoration but it seems that their large-scale implementation is still waiting for its turn. Therefore, it is important that policy-makers in different countries support increasingly rehabilitation and restoration while formulating or updating national forest policies and offer appropriate incentives.

Conservation and wise use of forest genetic resources are a corner stone for truly sustainable forest management. In this paper, we have provided some guidelines for managing genetic resources in forest rehabilitation and restoration process but there are gaps in common understanding of how genetic processes operate in natural tropical forests, both in intact and degraded ecosystems. Also, national programmes on forest genetic resources are weak in many countries in the Asia Pacific region. Thus more research and management capacity on forest genetic resources needs to be built at national and regional levels to alleviate these problems and to enhance sustainable forest management.

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22 The rehabilitation of the poorly-stocked hill forests in Peninsular Malaysia: crucial for timber production

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ABSTRACT

Hill forests will continue to be an important source of the future timber supply in Peninsular Malaysia. This is true when most of the lowland forests have largely been converted for other land-based development. Hill forests occur on mountain terrain of the country that ranges from 300 to 800 m above mean sea level and are categorized into lower and upper dipterocarp forests. These forests are generally managed for productive and protective functions. A considerable portion of the production forests has been allocated for sustainable production of timbers, while the remaining is set aside as protection forest for the conservation of biodiversity, forest recreation, water catchment, Virgin Jungle Reserve (VJR), wildlife sanctuary, amenity, education and research. In the production forests, the distribution of timber trees, however, is generally scattered, richer on the ridge tops and lower slopes, but poorer on the steeper slopes. The forest stands are also dominated largely by tree species in the emergent and main storey but fewer trees in the understorey and in the lower part of the main storey. Intensive rehabilitation efforts through tree planting programmes are therefore necessary to increase the productive capacity of the hill forests as well as to ensure that the timber trees are well distributed in the stand. This paper highlights several issues and challenges encountered in the implementation of forest rehabilitation activities in the hill forests. It also attempts to outline important policies and strategies emphasizing the importance of hill forests under the Sustainable Forest Management practices in Peninsular Malaysia.

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INTRODUCTION

Peninsular Malaysia is fortunate to have a large tract of rich tropical rain forest. This forest has long been valued as a source of food, fuel, medicine and materials for shelter and livelihood. It continues to play an important role in the rural economy and influences significantly the socio-economic development, community welfare and the people's quality of life. In Peninsular Malaysia, the forestry sector continues to be one of the important sectors contributing to the national economy. In terms of timber production, for example, the forest industry has contributed significantly to the total value of export of the country. In 2002, the annual export earning of Peninsular Malaysia from processed timber and medium density fiberboard (MDF) was RM21.2 billion (USD5.5 billion).

Recognizing the crucial role of the forest and to ensure its sustainable contribution to the socio-economic development of the country, a Permanent Reserved Forest (PRF) has been gazetted under the National Forestry Act 1984 to be managed under the sustainable forest management practices. In terms of timber production, sustainable production from the PRF areas is essential to provide sufficient raw material for the domestic wood-based industries. In order to achieve this, the Selective Management System (SMS) has been introduced and practised for the timber harvesting in Peninsular Malaysia. Under this system, only selected timber trees within the prescribed cutting limit timber are tagged and harvested (for logging). The bulk of the future long-term timber production in Peninsular Malaysia, however, is largely dependent on the availability of the hill forests. The supply of timber from these forests has been very restricted by the availability of sufficient stand stocking as well as the extent of the said forests particularly for timber production.

Hill forests occur on mountain terrain that ranges from 300 to 800 m above sea level. These forests are generally managed for productive and protective functions. A considerable portion of the production forests has been allocated for sustainable production of timbers, while the remaining is set aside as protection forests for the conservation of biodiversity, forest recreation, water catchment, Virgin Jungle Reserve (VJR), wildlife sanctuary, amenity, education and research.

Floristically, hill forests are characterized by several unique timber tree species and differ from lowland forests in the floristic composition of the dominants in the upper and main tree storeys. Several large trees in the hill forests are generally slightly smaller and shorter than the tallest trees in the lowland forest, except for the big trees that grow on the ridge tops.

This paper, therefore, attempts to highlight several issues and challenges encountered in the implementation of forest rehabilitation activities in the hill forests in contributing to the effective implementation of Sustainable Forest Management, particularly for the purpose of continuous timber production through the implementation of enrichment planting programme. It also attempts to outline important policies and strategies emphasizing the importance of hill forests in Peninsular Malaysia.

FOREST COVERS

The total area of forests in Peninsular Malaysia as at the end of 2001 was estimated to be 5.97 million hectares or 45.4 percent of the total land area. The majority of these forests areas comprise the Dry Inland Forest (5.49 million hectares), Peat Swamp Forest (0.30 million hectares), Mangrove Forest (0.11 million hectares) and the planted forest

(0.07 million hectares). Out of these, a total of 4.84 million hectares or 36.8% of the total forested land in Peninsular Malaysia have been secured in their tenure and gazetted in accordance with the National Forestry Policy 1984 as PRF. For management purposes, the PRF has been classified into production and protection forests. Approximately 1.90 million hectares or 39.2 percent of the total PRF in 2001 are protection forest while the remaining 2.94 million hectares are production forest. The PRF forms the most important forest resource under the custodian of the Forestry Department of Peninsular Malaysia, through the respective State Forestry Departments and continues to be sustainably managed under the Sustainable Forest Management (SFM) system.

The long-term timber supply (production) under the sustainable forest management practices in Peninsular Malaysia will always be largely dependent on the availability of the productive Permanent Reserved Forest (PRF). Dipterocarps remain an important group of timber species extracted during timber harvesting (logging). The opening of the PRF for timber harvesting (logging) is largely governed by the annual coupe (or annual allowable cut) approved and endorsed by the National Forestry Council (NFC). Generally, the PRF covers the three major forest types, *vis-à-vis* the Dry Inland Forests, Peat Swamp Forests and Mangrove Forests. In terms of Dry Inland Forests, the proportion of PRF currently comprises about 10 percent lowland and 90 percent hill forests. While, there has been a gradual reduction of lowland forests (Lowland Dipterocarp Forests) in the Dry Inland Forests for the past many years, the future forest areas for timber harvesting (or logging), therefore, will be largely confined to the hill forest (Hill Dipterocarp Forests).

In terms of long-term forest resource security, the Government has formulated and implemented the Land Capability Classification (LCC) since in 1967 (Haron & Abdul Rahman 1991). The LCC serves as a guideline which indicates the purpose for which given areas of land should be used, in order to make the best use of the inherent resources (Anonymous 1967). This guideline thus facilitates the objective to maximize the benefits derived from any form of land use. Through the LCC, 1967, land has been classified into 5 classes, viz. Class I (land suitable for mining), Class II (land suitable for agriculture), Class III (land suitable for agriculture), Class IV (land suitable for forestry), and Class V (land suitable for forestry). In terms of forestry, Class IV land is to be used for productive forests and Class V land to be used for protective forests.

FOREST MANAGEMENT PRACTICES IN THE DRY INLAND FORESTS

The earliest forest management system was the “Departmental Improvement Felling or Regeneration Improvement Felling (RIF)”. Introduced and implemented in the early 1920, it aimed mainly at improving the existing stand stock through the removal of inferior species (tree-girdling) in stages. This system particularly promotes the establishment of improved existing stands of the preferred species having actual or potential market value, such as cengal (*Neobalanocarpus heimii*). RIF was actually designed to establish natural regeneration of mainly the naturally durable heavy hardwood species particularly in the lowland forests. At the same time, “Commercial Regeneration Felling” was also practised in areas having demands for firewood and poles by the mining industry. This involved a 5-year regeneration period coupled with several felling operations for the extraction of selective highly marketable timber species.

After the Second World War, the number and processing capacity of wood-based processing mills, such as sawmills, as well as the demand for timber as raw materials increased. More forest areas were opened for logging to support these demands. The RIF management system was found to be unsuitable to cope with the increasing demand for timber by these processing mills. This led to the discontinuation of the RIF management and the implementation of the Malayan Uniform System (MUS) from 1948 onwards. The MUS was then formulated and implemented for the purpose of converting the virgin tropical lowland forests to more or even-aged forests, while removing a reasonable volume of timber from the stand for the wood-based processing mills. The MUS was timely and crucial to ensure a sufficient number of residual stocking for the next harvesting.

By the end of 1970s, however, most of the lowland forests have generally been harvested and the hill forests then constituted the bulk of the productive forests for the subsequent harvesting operation. The MUS cannot be universally applicable to both the lowland forests and the hill forests. The Selective Management System (SMS) was then formulated and introduced in Peninsular Malaysia in 1978. Currently, the production forests are managed under this system. The SMS allows for more flexible timber harvesting regimes consistent with the need to safeguard the environment and at the same time to take advantage of the demands in the timber markets. The SMS is polycyclic in nature. Felling limits are determined from a pre-felling inventory, catering for the dipterocarp and non-dipterocarp components of the forests. This system seems to be well adapted to the hill forests.

For the purpose of timber management, the Selective Management System (SMS) is implemented. The SMS involves the following (Shaharuddin 1997):

(a) pre-harvesting (pre-F inventory and prescribing the minimum cutting limit);
(b) during harvesting (implementation of reduced impact logging, determination of felling direction, implementation of timber tagging); and
(c) post-harvesting (post-F inventory, prescribing suitable silvicultural treatments).

In practice, the SMS adopts a modest cutting cycle of 25–30 years after the first logging with an expected net economic outturn of 40–50 $m^3 ha^{-1}$ enriched with dipterocarp species. No clear felling is involved. The following prescriptions have been adopted for the implementation of the SMS in Peninsular Malaysia (Thang 1997):

- The cutting limit prescribed for the group of dipterocarp species should not be less than 50 cm dbh, except for chengal (*Neobalanorcarpus heimii*) where the cutting limit prescribed should not be less than 60 cm dbh.
- The cutting limit prescribed for the group of non-dipterocarp species should not be less than 45 cm dbh.
- The difference in the cutting limits prescribed between the dipterocarp species and the non-dipterocarp species should be at least 5 cm.
- The residual stocking should have at least 32 sound commercial trees per hectare in the dbh class from 30 to 45 cm or its equivalent. The adequacy of residual stocking for the next cutting cycle and the number of residual stems in the higher dbh classes are deemed to have an equivalent value to the proportion of stems required by the standards of the next lower dbh class, as illustrated in the following table.

Table 1. Minimum residual stocking standards

Class	Size	Number of trees per hectare at the next cut	Tree(s) equivalent to number of trees in the 30–45 cm dbh class
Exploitable	+45 cm dbh	25	2
Ingrowth	30–45 cm dbh	32	1
Small trees	15–30 cm dbh	96	(1/3) (trees below 30 cm dbh are not generally considered for the next cut)

- The percentage of the dipterocarp species in the residual stand for trees having dbh of 30 cm and larger should not be less than that in the stand prior to harvest (original stand).

FOREST REHABILITATION ACTIVITIES FOR SUSTAINABLE TIMBER PRODUCTION

The dipterocarps remain the important timber-producing trees in Malaysia (Saw & Sam 1999). They may comprise over 30% of the basal area of the trees in both the lowland and hill forests or close to or over 40% of the emergents (Manokaran & Swaine 1994). The composition of natural regenerations of dipterocarps in the hill forests, however, is not as abundant or widely distributed as in the lowland forests. While the topographical condition of the hill forest has also a significant effect on the distribution of commercial timber tree species, the importance to enrich the forests seems to be more critical particularly when the hill forests have been opened for logging. The damage to the residual stand after any harvesting operation (or logging) normally depends on the volume of timber removed which creates large crown gaps in the forest. For example, the more bigger trees are harvested, the greater is the damage to the stand. In addition, there is reason to believe that the potential for environmental damage to the residual stand may also increase as the slope increases. It is in this context that normally after harvesting (or logging), the composition of the residual stand for the subsequent cut in the next harvesting rotation is relatively poor in stocking for the next cut. Therefore, the forest stand needs to be artificially regenerated through vigorous planting operation with suitable selected timber tree species. Hence enrichment planting is very crucial particularly for the poorly-stocked hill forests.

Generally, a poorly-stocked stand may be attributed to the following:

- uncontrolled timber harvesting resulting in insufficient availability of commercial sized trees in the residual stand for the next cut; and
- degraded land resulting from the opening of forest areas for forest road (feeder roads and skid trails), logging camp (or matau) or log yard.

Poorly-stocked stands need to be enriched (or to increase its productivity) through tree planting programmes or 'artificial regeneration' or 'enrichment planting' of suitable/ selected indigenous timber species. Silvicultural treatments are therefore crucial to rehabilitate (or to increase stand productivity) poorly-stocked forests. Forest rehabilitation in the PRF may involve two major approaches. These may include 'natural regeneration' and ‘artificial regeneration’. Both of these approaches have been undertaken as an important rehabilitative measure to varying extents for poorly-stocked logged-over forests in Peninsular Malaysia. For an example, during the ‘gutta-percha era (1900–1922)’, silvicultural operations were only confined to the establishment of stands for selective commercial species, such as taban (*Palaquium gutta*), para rubber (*Hevea brasiliensis*) and chengal (*Neobalanocarpus heimii*). These forest resources were naturally abundant and easily available; hence natural regeneration approach seemed to be more suitable than artifical regeneration. Under this approach, sufficient mother trees were left in the residual stand for the purpose of liberation of seeds.

Enrichment planting or artificial regeneration, on the other hand, has been defined as the introduction of valuable selected timber species into degraded forest areas without eliminating the existing timber trees in any single forest stand. In other words, it is essentially a process of supplementing the natural regeneration where it is insufficient, with seedlings of commercial species (preferably indigenous) (Appanah & Weinland 1993). Enrichment planting activities were seriously introduced in the mid-1960s when more timber species were needed by the processing industries in tandem with the increasing demand for wood-based products. Species such as meranti tembaga (*Shorea leprosula*), meranti sarang punai (*S. parvifolia*), meranti bukit (*S. platyclados*), mersawa (*Anisoptera* spp.), kapur (*Dryobalanops aromatica*) and jelutong (*Dyera costulata*) were selected to be planted under encrichment planting activity, particularly for the logged-over forest areas with relatively low residual stocking.

In the current management sequence of the SMS, enrichment planting has been considered as an essential and important silvicultural component for the purpose to enrich poorly-stocked logged-over forest in Peninsular Malaysia (Singh 1970, Thang 1997). This is particularly crucial for the successful implementation of Sustainable Forest Management (SFM) in the hill forests. Some of the significant roles of enrichment planting are summarized as follows:

(i) introduction of selected and desired good quality timber species into the forest stand;
(ii) manipulation of stocking through specified planting distance;
(iii) enhancement of the rate of recovery of a poorly-stocked logged-over forest;
(iv) improving residual stocking of a poorly-stocked logged-over forest for the next cut.

The implementation of enrichment planting programmes under the MUS and SMS in the past many years has provided a lot of experience and knowledge as well as training ground for the foresters. Some of the information gained was in the areas related to selection of planting materials, proper planting techniques, handling of planting materials and tending of planted trees. Through years of experience and with the information and knowledge gained in the field, the Silviculture Unit at the Forestry Department Headquaters of Peninsular Malaysia has produced a practical guide to enrichment planting entitled ‘Handbook on enrichment planting’ in 1978 for the planning and execution of enrichment planting programmes in the country. This served as a first guide to enrichment planting practice by the Forestry Department, which has been continuously reviewed. This guideline was further revised and ‘Panduan aktiviti tanaman mengaya’ (*Guideline for the enrichment planting activity*) was produced on 1 March 1996 as the Circular of the Director-General of Forestry No: 2/96. This guideline serves as an important reference to many aspects related to the implementation of enrichment planting in Peninsular Malaysia, covering the key areas such as factors governing selection of species, areas to be planted, aspects of field operation to be addressed and tending of planted areas.

During the early implementation of the enrichment planting, the main focus was in the form of ‘taungya system’ practices, which form one of the models available under ‘agroforestry’ land-use practice. It is basically referred to as raising of forest tree species together with agriculture crops. This system focused on reforestation, especially small patches around forest fringes in the Permanent Reserved Forests (PRF) which had long been encroached into by illegal agricultural farmers. Under this system, participating farmers were given a special forest permit to allow them to cultivate the degraded land with agriculture crops such as banana and tapioca. In return the farmers planted tree seedlings supplied by the Forestry Department. Through this system large patches of degraded forests had been successfully rehabilitated with both exotic and indigenous timber species such as pine (predominantly *Pinus caribaea*), kapur, meranti tembaga, balau kumus (*S. laevis*), meranti seraya and mahogany (*Swietenia macrophylla*). The oldest of taungya planting was recorded in Perlis, in which a total of 133 ha of the degraded forests has been cultivated with teak (*Tectona grandis*) and mainly intercropped with hill paddy and tobacco.

Other than the planting approach under the ‘taungya system’, early enrichment planting project embarked on by the Forestry Department was the planting under ‘single cropping’ of indigenous timber species such as meranti sarang punai (*Shorea pavifolia*) through strip/line-planting technique in a poorly-stocked forest area at Bukit Tapah Forest Reserve, Perak. The result was very promising. The annual mortality rate was seen to be decreasing as the planted trees grew older. The annual mortality rate decreased from 10% at one year after planting to 5% in the following three years after planting. The mean annual height increment was generally between 1.2 and 1.5 m and mean annual diameter increment was between 1.3 and 1.5 cm (Tang & Chew 1980). These initial findings showed that enrichment planting under ‘single cropping’ could be extended on a larger scale. Subsequently, more enrichment planting activities were implemented on a relatively bigger scale in poorly-stocked forest areas of the PRF throughout Peninsular Malaysia. As at the end of year 2001, a total of 24 441 ha had been planted under the enrichment planting programme with dipterocarp and non-dipterocarp timber species throughout Peninsular Malaysia, as shown in the Table 2.

Large tracks of successfully established enrichment planting plots are available in the State of Perak, followed by Selangor, Kelantan, Pahang, Johor, Kedah, Melaka, Terengganu and Negeri Sembilan. Almost 79.3% of the species planted under the enrichment planting programmes throughout Peninsular Malaysia are mainly focussed on the dipterocarps especially the genera *Shorea* and *Dipterocarpus*, while about 17.4% are mixed dipterocarps and non-dipterocarps. The main timber species planted are commercially preferred species such as *Shorea leprosula, S. parvifolia, S. acuminata, Dryobalanops aromatica, Hopea odorata, S. pauciflora, S. ovalis, Dipterocarpus cornutus* and *Anisoptera* spp. Most of the species of interest are covered in the ‘Regeneration sampling (RS) list of 1974’, of the FDPM (Anonymous 1974) and ‘*Panduan aktiviti tanaman mengaya, 1996*’.

Table 2. Areas planted through enrichment planting in Peninsular Malaysia

State	Area planted (ha)			Total area planted (ha)	Planting spacing (line planting)
	Dipterocarps	Non-dipterocarps	Mixed		
Johor	1 804	–	–	1 804	3 × 3 m
					3 × 10 m
Kedah	1 030	23	553	1 606	3 × 10 m
Kelantan	3 505	66	190	3 761	6 × 10 m
					5 × 10 m
Melaka	399	–	–	399	3 × 3 m
Negeri Sembilan	832	–	126	958	5 × 4 m
					3.3 × 3.3 m
					3 × 5 m
					3 × 10 m
Pahang	4 733	10	220	4 963	3 × 10 m
					5 × 10 m
					7 × 11 m
Perak	4 426	489	435	5 350	3 × 10 m
					3 × 3 m
Selangor	3 636	25	–	3 661	3 × 10 m
Terengganu	1 779	–	–	1 779	3 × 10 m
Total	22 304	614	1 524	24 441	
%	91.3	2.5	6.2	100	

ISSUES AND CHALLENGES

Continuing to explore the complexity of the hill forests

The complexity of the hill forests remains a unique feature. Forest management in the hill forests particularly for timber production must therefore continue to take corrective measures in tandem with the availability of new research findings (Appanah *et al*. 1997). For an example, in relation to the poor regeneration capability in the hill forests, Thang (1987) has emphasized that the success of the SMS would depend on growth and mortality rates, logging damage to residual stand and adequacy of residual stock to ensure sustainability as well as ingrowth. Updated information is thus crucial to unsure successful implementation of the SMS while further refining various assumptions and theories that were outlined earlier (Abd. Rashid & Moktar 1997). Hence continuous research is necessary.

Overcoming the poor stocking of regeneration in the logged-over hill forest stand

Adequacy of the naturally residual stocking and its species composition after logging need to be further explored to ensure in particular adequate dipterocarp timber species for the next cut. The existing silvicultural prescriptions on the residual stand after logging give more emphasis on immediate trees (Abd. Rashid & Mokhtar *et al*. 1997). It is acknowledged that dipterocarp and non-dipterocarp timber species have different growth rates (Nussbaum *et al*. 1996, FDPM/PSFD/JICA 1999). Hence, if blanket prescriptions are applied for the whole forest stand, for both the dipterocarps as well as non-dipterocarps, they will have an unpleasant impact on the growth of both groups of species. Again, the silvicultural prescriptions given are to assist the growth of residual stands of higher diameter classes for the next cut. The effect on the rate of growth of residual stands of lower diameter class would be much affected. Rehabilitation effort through enrichment planting has a great potential to enrich or increase the residual stocking of the logged-over forest stand (Azahar 1997).

Exploring suitable species for planting programme

Rehabilitation of poorly-stocked forests is seen to be mandatory in order to ensure forest stand productivity regains for the next cut or at least a reversion to the original state. Enriching the poorly-stocked stand through artificial tree planting is thus necessary. In relation to the hill forests, however, selection of suitable indigenous species for effective rehabilitation would need, for example, to take cognizance of the following (Zuhaidi & Weinland 1993, Wan Yusof & Abdul Rahman 1997):

- easy handling of the species in the nursery;
- high rate of germination;
- regular flowering and fruiting;
- higher growth rate, particularly at the initial stage of planting;
- shade tolerance; able to withstand competition between trees on planting sites;
- good self pruning (if possible);
- low susceptibility to diseases, insect and fungal attacks.

Post-planting tending operations not properly implemented

Post-planting treatments are critical for the successful establishment of planted seeding (Raja Barizan & Shamsuddin 1997). Tending operations after planting as well as the maintenance of enrichment planting areas, however, are not properly implemented and are of very limited scope. Due to manpower and cost limitations, the tending operations are seen to be confined only to canopy manipulations at different levels after planting to ensure sufficient sunlight for planted seedlings to grow. It has been recommended that overhead shade should be removed within three to six months after planting, as delays would reduce height increments of planted seedling (Tang & Chew 1980). A prolonged treatment of removing overhead shade to 15 years after planting improved the percentage of survival and diameter increments of planted trees (Azman *et al*. 1991). Record keeping and mapping (if possible) are essential in order to facilitate the monitoring as well the implementation of rehabilitation programmes. This is crucial to attain the objective of the tree planting programme.

Requirement of comprehensive ‘site–species matching’ outputs

Comprehensive ‘site–species matching’ is necessary for effective implementation of enrichment planting. Site–species matching enables large-scale establishment of commercial tree plantations to be successfully achieved. At the moment, site–species matching is still limited to certain species and certain sites. Thus coordinated and aggressive R&D should be undertaken.

High cost of enrichment planting programme

Financial constraints for effective implementation of enrichment planting remain as it is costly to embark upon commercial tree planting (Awang Noor *et al*. 1997). This is a challenge for future enrichment planting activities in Peninsular Malaysia.

STRATEGIES FOR THE WAY FORWARD

The tropical rain forests of Peninsular Malaysia will continue to be managed sustainably. Thus more research, particularly for hill forests, is required to further appraise and unveil the complexity of the forests. This information is essential for effective timber production planning.

Planting should be done immediately after timber harvesting (or logging) with priority given to dipterocarp timber species where minimum canopy opening and line clearing are required. However, sufficient funds are needed for the effective implementation of enrichment planting, particularly in the poorly-stocked forests. In this regard, sufficient forest development funds, such as from the silvicultural cess, are very essential for forest rehabilitation in the poorly-stocked forests.

Artificial regeneration through enrichment planting will continue to be important in the silvicultural practices (or forest rehabilitation) of the poorly-stocked forest. In the past, it has often been shown that enrichment planting is an essential silvicultural treatment in order to enrich the stocking of the poorly-stocked logged-over forest stand, both in terms of quantity as well as quality of the timber trees produced. Although substantial funds are required for the implementation of such rehabilitation activities, past records clearly indicate that enrichment planting is economically viable. It will inevitably be incorporated into the SMS practices, particularly for the management of the hill forests in Peninsular Malaysia.

Finally, no 'silver bullet' or 'golden rule' can be applied universally to ensure sustainable timber harvesting in the hill forests. This remains the most important issue and poses a great challenge to forest managers. Coordinated and aggressive R&D amongst the forest related agencies is necessary. Successful R&D findings would ensure strengthening the effective implementation of SFM in the hill forests.

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