SPECIAL ARTICLE

FOREST RESTORATION—THE THIRD BIG SILVICULTURAL CHALLENGE

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The recent conference on 'Reclamation, Rehabilitation and Restoration: Towards a Greener Asia' held in Kuala Lumpur in July 2012 revealed a vigorous programme of research is under way across the region that seeks to restore forests cover to degraded lands. The conference illustrated several things. One was that this work is taking place in a large variety of field situations. These include marginal agricultural lands, heavily logged forests, old mine sites, and deforested and eroding coastal areas. The second theme emerging from the conference was that much of this work aims to restore forest cover in order to improve the delivery of ecosystem services rather than to simply produce timber. This means using multispecies plantings rather than conventional monocultures. I review here some of the main issues emerging at the conference and some of the outstanding questions still needing to be resolved. But before doing this, it is useful to put the subject of the conference within a broader historical context.

Previous tropical forest silvicultural research

Until recently the main research focus of most tropical silviculturalists was to develop methods of managing natural forests in ways that were ecologically sustainable. This work was initially concerned with developing silvicultural systems that reflected the underlying ecological attributes of the species and forests across the region. As these systems were developed, attention then moved to monitoring the ecological impact of this logging using systems of Criteria and Indicators. This task continues although the main silvicultural elements have been resolved for most forests. This is not to imply that sustainable logging is now widespread. On the contrary, reports from the International Tropical Timbers Organisation suggest it is not (ITTO 2006). However, the remaining problems are largely due to the inability of managers to apply this knowledge rather than a lack of any silvicultural understanding.

A new challenge arose with the realisation that the supposed permanent forest estate was shrinking and that timber yields from the second cutting cycle were going to be much lower than those from the first cutting cycle. The question was how could timber be grown plantations? In Malaysia these prospective new plantations were sometimes referred to as 'compensatory' plantations because they were to compensate for the reduced productivity of natural forests within the permanent (production) forest estate. Although some initial effort was made to grow high-value native tree species in plantations the focus quickly changed to exploring the use of fast-growing exotic species capable of producing large volumes of lower-value commodity timbers. Considerable effort was spent in evaluating various species. Those tested included species of *Pinus, Eucalyptus, Paraserianthese, Gmelina* and *Acacia.* Despite early successes, each one of these proved to have flaws including foxtailing (of pines), inability to regularly produce seed, heartrots and sensitivity to particular site requirements (Ng 1996). The forlorn hope that a single 'miracle' tree would be found that was able to grow well in all sites was dashed and it became clear that successful plantations would require careful matching of species to sites and also to markets. Some large timber plantations have been developed since that time although the majority of these have been created using a handful of non-native species grown on short (< 10 years) rotations. In some cases remarkably high levels of productivity have been achieved, for example, with eucalypts grown in plantations in Brazil.

In recent years a third problem has emerged to confront silviculturalists. This has been the development of large areas of degraded land that are marginal for food production. Most of these are former agricultural lands but some are former mine sites. These lands are often occupied by grasses or shrubs and are frequently sources of sedimentation, landslides and hydrological disruption. Some of the former mine sites are also sources of heavy metals or acidity that contaminates rivers. Estimates of the areas involved are difficult to make because 'degradation' is such a subjective term; what is 'degraded' land to a wildlife conservationist may be seen as still useful agricultural land by a farmer. However, one estimate suggests there may be 2 billion ha of 'degraded' land that is potentially available for reforestation (Laestadius et al. 2012).

Some of these lands may be reforested using the techniques developed to establish the industrial plantations referred to above. However, there is increasing interest in undertaking reforestation to generate ecosystem services as well as just goods such as timber. These services include stabilising hillslopes, providing clean water, creating habitats for wildlife or sequestering carbon. Besides the landholders themselves, those interested in these services include neighbouring farmers, downstream water users, wildlife conservationists as well as the broader community. The third new task for silviculturalists, therefore, is to develop ways of reforesting these lands to supply ecosystem services as well as traditional goods such as timber (Lamb 2011). This will be difficult to achieve. Unlike the earlier timber plantations, it is not just a matter of restoring forest cover using one or two tree species but of restoring the ecological processes and functioning of the original forests using a variety of species including many of the original native species. In a sense we are going back to where we started and reversing the trend to landscape simplification started when natural forests were cleared for agriculture and large monospecific timber plantations were established to supply pulpwood.

Methods of overcoming degradation

There are a variety of forms of reforestation that may be used to overcome degradation. Conventional timber plantations can be useful in some situations. They provide a continuous tree cover and, depending on the amount of understorey vegetation present, some soil protection. They can also be effective at producing large amounts of biomass thereby sequestering considerable carbon in a relatively short time. On the other hand, they may be less effective in conserving biodiversity and any carbon storage capacity they provide depends on the length of the rotation. Whether this will be acceptable to those buying credits in the carbon market remains to be settled.

Forest rehabilitation and ecological restoration represent more complex forms of reforestation. For the purposes of this paper, I shall use the former to mean planting a mixture of species but not necessarily including all of the original flora. This may be because some of the original species are now unable to tolerate the present environmental conditions. Rehabilitated forests may also include some exotic species since these may be able to tolerate site conditions rather better than native species or because they are needed for commercial reasons. By contrast, ecological restoration seeks to restore all of the native species and thus the original ecosystem. This is necessarily a long-term task and so the more immediate objective is to establish a successional trajectory that will eventually lead to that point.

There has been considerable debate about whether ecological restoration will ever be possible. Some argue that invasive species, local extinctions and the impact of climate change will all make it difficult to achieve, especially at more heavily degraded sites. This has given rise to a discussion about the likely future importance of 'novel ecosystems' composed of species assemblages unlike those previously present at a particular site (Hobbs et al. 2006). Unlike simple plantation monocultures, both these forms of reforestation (i.e. rehabilitation and ecological restoration) are structurally complex and are eventually composed of a variety of tree age classes. These attributes, together with the diversity of species present, mean they are more likely to have re-established the functional properties of the original forests.

Issues emerged from the conference presentations

The conference presentations covered a variety of topics and issues. These included:

(1) There are multiple reasons for undertaking forest restoration

Some of those seeking to develop methods of overcoming degradation are primarily interested in forms of reforestation that will produce commercially attractive timber plantations (e.g. Mongolia, Thailand, Vietnam, Myanmar). Timber trees were also being used to reforest degraded peat swamp forests although in this case the objectives were to also prevent further carbon releases from the exposed peat (Malaysia) as well as to sequester carbon in the new forest. However, forest restoration is also being undertaken for a variety of other reasons. These include providing habitats for species threatened by a new water reservoir that was flooding their present habitat (Sarawak, Malaysia), developing new mangrove forests to protect coastal areas (Malaysia, China) or *Casuarina* shelterbelt forests to protect sandy coastal areas (southern China) and to rehabilitate former mine sites in order to stabilise the sites and limit the escape of acidic drainage water containing high levels of heavy metals (New Caledonia, India, Malaysia, Vietnam, Philippines). There were also reports of attempts to develop new urban forests for aesthetic and recreational purposes (South Korea, Thailand) including forests on land newly reclaimed from the sea (South Korea).

Of course motives and objectives can change over time as circumstances change. A striking example of this occurred in South Korea. The original objective of undertaking reforestation of degraded lands in South Korea was to provide people with building timber and firewood. However, over time, the objective has changed from being entirely concerned with the production of goods to, instead, being also concerned with the generation of ecosystem services including providing recreational opportunities and a pleasing aesthetic environment. This pattern of change is likely to be repeated more widely as populations grow, additional people move into the more affluent middle classes and as global climate change begins to affect ecosystems. Many newly reforested sites will be expected to provide multiple benefits and be able to withstand economic and ecological changes. Multispecies plantings are likely to be able to generate such outcomes rather better than simple plantation monocultures.

(2) There are a variety of planting models

New forests can be established including using seedlings as well as using direct sowing of seed. However, there is a large variety of ways these can be applied and new forests can be assembled. Conventional plantations have been established using just one species but a number of presentations reported on the use of multispecies plantings. Several involve mixtures of timber and fruit trees in order to make tree planting attractive to households (a design referred to as 'rainforestation' in the Philippines). Most tree plantings are established at densities of around 1100 stems per ha which strike a compromise between achieving rapid canopy closure and minimising planting costs. However, some trials have used extraordinarily high planting densities of up to 30,000 trees per ha (e.g. the Universiti Pertanian Malaysia–Mitsubishi trials at Bintulu, Sarawak). These have generated impressive species-rich forests but the costs are probably too high for the method to be widely applied. Several presentations reported investigations into the value of inoculating seedlings with particular mycorrhiza. Although some statistically significant initial benefits were sometimes found at the early seedling stage, it appeared that these have little practical benefit over the longer term as most seedlings were eventually inoculated by naturally occurring mycorrhiza.

(3) The role of exotic species

A widely debated question concerns the role of exotic species. There seems to be little doubt that certain exotic species, especially *Acacia* sp., have an important role to play in the restoration of badly degraded sites with infertile soils. They can also act as facilitators and assist the establishment of native species not tolerant of open-planting or infertile soils. Presentations reported examples from Malaysia and the Philippines. Further studies are necessary to establish the degree of cover needed and how this should be manipulated once the preferred species have been successfully established beneath the nurse tree crown (raising the question of whether it is necessary to thin the *Acacia* once the under-planted trees are established or whether these should these be left on the assumption that they will be eventually over-topped?). However, it is important to note that exotic species can sometimes be invasive and become weeds. Examples were given of how *Leucaena leucocephala* had been introduced to Taiwan and had invaded natural forest areas. In this case a variety of native 'framework species' had to be used to over-top and out-compete the shade intolerant exotic species.

Outstanding issues arising at the conference that deserve further study

This third silvicultural phase investigating ways of establishing multispecies plantings at degraded sites has barely started and there is a variety of questions deserving study. Some of these involve biophysical problems while others are concerned with economic and social matters. Amongst the many interesting questions arising from the conference are:

(1) How can more indigenous species be included in multispecies rehabilitation and restoration programmes?

There is general agreement that greater use should be made of indigenous species, especially when the objective is to generate ecosystem services. Many conference presentations gave examples of this being done. However, a great deal remains to be known about these species in most countries. In some cases such species will colonise restoration plantings from nearby patches of residual forest and there was clear evidence of this occurring at the Tin Tailings Afforestation Centre at Bidor that was visited by conference participants on the post-conference field day. However, many species are poorly dispersed and ways need to be found of ensuring they are included in restored forests.

(2) How many species are needed to generate a full range of ecosystem services?

Simple plantation monocultures can provide some ecosystem services but not others. Just how many tree species are needed (for watershed protection? for wildlife conservation?) and how can these mixtures be assembled? What would it take to reassemble the full range of species (i.e. to achieve ecological restoration)?

(3) How to make the transition from even-aged to uneven-aged forests?

Many restoration plantings are created by establishing seedlings at a single time. Unlike conventional timber plantations these plantings are not clear-felled. Instead they should eventually begin to contain naturally regenerated seedlings of the constituent species on the forest floor. How can this transition from an even-aged plantation to an uneven-aged forest be managed? Can it be left to nature or should some form of careful thinning be carried out that creates canopy gaps and assists natural regeneration? Alternatively, should the original plantings include some short-lived species that will die and create such canopy gaps? What is the role for under-planting? Should it only involve poorly-dispersed species or should a wider range of species be used?

(4) How to reduce costs and undertake reforestation on a larger scale?

Any form of reforestation is expensive and multispecies plantings are especially costly. How can these costs be reduced thereby making it easier to restore forests on a large scale?

(5) Which are the areas with the highest priority for forest rehabilitation or restoration?

The large areas of degraded land (and forest) now present mean that choices have to be made about restoration priorities. How should these priorities be set? Should the highest priority be given to the most degraded sites (e.g. mine sites) or to areas more easily treated where restoration costs are lower? Or should it be based on the numbers of stakeholders likely to be affected by restoration (or the absence of restoration)?

(6) How to make reforestation attractive to landholders?

Many degraded lands are owned by the state but some very large areas are also owned by communities and households. All forms of reforestation including restoration can have high opportunity costs. What is needed to make one or other of these forms of reforestation attractive to private landholders? Some degree of long-term land tenure is obviously important. However, will the current multispecies planting models be sufficiently attractive to landholders for them to undertake reforestation without the need for additional support? If incentives are needed then what types of incentives are best—financial or non-financial incentives?

(7) What things should be measured during a monitoring programme?

Unexpected developments can occur during restoration programmes and some form of monitoring is needed so that, if necessary, managers can adapt their practices to suit the new situations. However, what things need to be monitored? Monitoring of conventional monocultural plantations usually involves measurements of attributes such as tree survival and growth. However, monitoring of restoration plantings is likely to require assessment of a much broader range of attributes such as species richness, the amount of self-regeneration of the planted species and the extent of species colonisation from outside. If the primary purpose of restoration is to provide certain ecosystem services, then monitoring should also measure whether these are being delivered. Ideally monitoring programmes should be designed around a series of explicit questions (e.g. Is species richness increasing or decreasing? Is natural seedling regeneration present on the forest floor? Is stream sedimentation increasing or decreasing? Are wildlife beginning to use the planted areas?).

(8) How to reduce the cost and improve the effectiveness of mine site rehabilitation?

Mining can cause severe environmental damage if it is not regulated. In too many cases, rehabilitation is not considered until the mining operation is complete and the environmental damage is complete. A much preferable situation would be to begin planning rehabilitation when the mine is being designed. In this way arrangements can be made to ensure tailings containing high levels of heavy metals or likely to generate acidic drainage are safely buried at low cost when heavy machinery is still at the site. Likewise topsoils (containing organic matter, seeds and mycorrhiza) can be removed and stockpiled so it can be respread over the site prior to rehabilitation. There appears to be large numbers of old abandoned mine sites across the region where these things have not been done making rehabilitation far more expensive than it could have been. More mines are being planned meaning a better policy framework is needed.

CONCLUSIONS

A very large area of degraded forest and land has now accumulated across the world's tropics but there is rising interest in doing something about this. A number of reforestation techniques have been developed over the last few decades enabling the establishment of very productive timber plantations. Such simple plantations provide a good starting point but will not be sufficient to address the variety of problems arising from degradation. Instead, the task facing ecologists and silvicultural researchers is to devise a variety of new options to suit the range of ecological and socio-economic situations needing to be addressed. The task is not one that ecologists and silviculturalists can tackle alone. Rather, partnerships need to be developed with economists and rural sociologists to ensure any proposed solutions meet the needs of landholders and other stakeholders. This third silvicultural challenge will provide a rich field of enquiry for many years to come.

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