Risks of species introductions in tropical forestry

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SUMMARY

Tropical tree seed has been moved around the globe on an unprecedented scale over the last three decades. The benefits and risks associated with introductions of tropical trees are reviewed. The current approach to species introductions in forestry is summarized and the marked lack of procedures covering movement of tropical tree germplasm discussed in relation to policies covering biocontrol agents and transgenic plants. General principles and specific guidelines that might be used to formulate a more rational approach to forestry introductions are presented and the problems involved in the assessment of risks associated with introductions pointed out. A more cautious approach to species introductions is advocated and the importance of species choice and the advantages and limitations of native and exotic species and seedless varieties are discussed.

Keywords: tropical trees, species introductions, invasive species, weediness, choice of species, exotics

The only indiscretion he is known to have committed was his endeavour to add variety to the flora of Ireland by scattering seeds of exotic plants around Dublin, which earned him the disapproval of local botanists.
Introduction to Burbridges's 'The Gardens of the Sun' by Francis Ng, 1989

INTRODUCTION

There is increasing concern among foresters, ecologists, botanists and conservationists about the threat of invasion of natural and semi-natural ecosystems posed by the continued, uncontrolled introduction of aggressive tree species as part of tropical forestry programmes. Although the main threat to biodiversity continues to be the direct destruction of habitats by people, invasion of natural and semi-natural habitats by alien organisms is widely recognized to be a serious and underestimated world-wide problem (Heywood, 1989; Coblentz, 1990; Soulé, 1990; Fuller and Cronk, in press). A significant proportion of invasive species is woody, and although most are the result of horticultural introductions, some are the direct result of use in forestry. These concerns have resulted in greater attention being focused on biological invasions and their control by national and international organisations over the last decade (e.g. the Species Survival Commission of IUCN (IUCN, 1987) and WWF (Fuller and Cronk, in press)). Global movement of tropical tree germplasm has increased dramatically in terms of numbers of species, levels of intraspecific variation and geographic spread over the same period, and continues largely unabated and uncontrolled at present. Large numbers of tree species have been introduced in the past; most do not naturalize, and most of those that naturalize do not become important invasives. Estimates broadly agree that an introduced plant species has about a 1% chance of becoming an invasive pest (Groves, 1986; Williamson and Brown, 1986). However, this may be an underestimate for tropical tree species introductions given that trees and shrubs make more impact as invasives than other plants (Richardson *et al.*, 1992), and that foresters deliberately seek aggressive species (see below) such as the woody legumes that currently dominate much non-industrial tree planting (e.g. Felker, 1994; Brewbaker and Sorensson, 1994). At any rate, if woody plants are translocated in large numbers, problems of invasion will continue to arise sooner or later. A relatively small invasive fraction can cause enormous conservation problems. The realization that the current scale of translocation of organisms is too great is not confined to trees or plants; the same dilemmas are being confronted in relation to translocation of other organisms with similar calls for greater control to reduce the current rampant worldwide movement of for example freshwater fish (Horowitz, 1990).

The controversy surrounding species introductions cuts to the heart of development and conservation issues and has generated a trail of often conflicting and sometimes extreme views. Two opinions by leading exponents illustrate the degree of divergence of opinion:

> ... in woody plant introduction programs, is it generally assumed that we have written off Nature in any original sense, and we are now simply biologically engineering the vegetative cover to give some desired set of creature comforts to *n* people? ...one does wonder at what point the sergeants, privates and lieutenants in this great army of

development are going to lay down their weapons and raise up a great chorus chorus of 'this is stupid' ... (Dan Janzen, Costa Rica, pers. comm. 1984).

I do have one philosophy, to be sure, that is that Leucaenas grow so well and so rapidly that they can often provide data on aspects of domestication (and all its nuances) long before philosophers could agree about anything. Thus the best thing is to grow them and try them out. Reforestation in the tropics is so vastly behind deforestation that we cannot wait to fully appraise all the potentially negative elements of domestication. Weediness is of consequence perhaps in Honolulu, but not in Addis or Delhi. Thus I would encourage extensive and intensive testing of almost any of the *Leucaena* species and hybrids throughout the tropics as possible domesticates (Jim Brewbaker, Hawaii, pers. comm. 1992).

The main objective of this paper is to explore such middle ground as may exist between these two extremes and to work towards guidelines and procedures for the regulation of species introductions that are both effective and realistic, and compatible with both conservation objectives and those of forestry development. Improved dialogue between foresters, ecologists and conservationists is needed to establish rigorous and realistic procedures which will minimize the risks associated with introduction of species in forestry.

BENEFITS AND RISKS OF INTRODUCTIONS

Benefits

One part of the forester's remit has been to increase the productivity of non-arable lands through plantations of various kinds to create abuse-resistant ecosystems (Armstrong, 1992) that give first priority to provision of human needs (fuel, timber, fodder, environmental stabilization). This remains the main objective of many forestry programmes today in the belief that, in the end, it will be most effective to preserve intensively small, manageable reserves of natural ecosystems and accept that extensive areas will be colonized by ecosystems resistant to abuse to provide for human needs. Successful plantation technologies have been developed in many countries (Evans, 1992; Kanowski and Savill, 1992).

Light-demanding, colonizing exotic species have been the most successful in monocultures under plantation management. Over the last 40 years, tropical and subtropical plantation forestry has focused on a small number of fast growing, colonizing species (most notably in the genera *Acacia, Eucalyptus, Gmelina, Pinus, Populus, Tectona*) (Evans, 1987). Choice of species for planting for non-industrial uses in social and farm forestry, often in agroforestry combinations, has largely continued along similar lines with heavy reliance on a small number of exotic species (Hughes, 1988), although Burley (1983) recorded more than 2000 species in use somewhere. These species have the ability to capture the site rapidly and tolerate harsh soil and climatic conditions and abuse from animals, humans and fire, traits that are a pre-requisite for success on the often highly degraded sites where tree planting is needed. Large yield advantages of exotics over indigenous species have been attributed to their greater tolerance of degraded sites and their escape from specialized pests and diseases, although these may arrive later, reducing this advantage (e.g. the psyllid defoliator *Heteropsylla cubana* on *Leucaena leucocephala*; Napompeth and MacDicken, 1990). Using such species, forestry is able to rehabilitate degraded lands, of which there are large unoccupied areas in the tropics, creating robust new ecosystems that are tolerant of a high degree of use and abuse. In the quest for suitable species, 'send us anything that will grow' has emerged as a frequent plea in the face of adverse site conditions. With large planting targets and short project time horizons, seed availability itself has become and continues to be a major deciding factor in choice of species for tree planting programmes (Turnbull, 1983; Tietema*et al.*, 1992). Precocious and prolific seed production is often another pre-requisite for species to be successfully adopted.

Movement of tropical tree seed

Over the last three decades, the search for useful tropical tree species and intraspecific genetic variation for tree improvement has intensified, with systematic exploration and seed collection programmes looking at a wider range of genera and species in many different regions. This has led to a period of unprecedented movement of tropical tree germplasm around the globe. Whereas historical spread of tropical trees was unsystematic, often casual or accidental and operated on a limited scale, recent programmes have embarked on a different scale of operation in three ways: (i) numbers of species that are being moved internationally have increased as whole woody floras are scoured for potentially valuable trees for planting (e.g. Turnbull, 1986 for the Australian flora; Hughes and Styles, 1984 in Central America), and close relatives of the few well-known species are investigated (e.g. Hughes, 1993 for *Leucaena*; Macqueen, 1992 for *Calliandra*); (ii) intensive sampling of intraspecific variation with range-wide provenance collections of more species results in wide distribution of complete packages of genetic diversity (e.g. Barnes and Keiding, 1989 for*Pinus kesiya*) compared to the narrow genetic base of most historical introductions; the benefits of provenance evaluation are well known (Turnbull and Griffin, 1986), but may also increase the risks of invasion; (iii) whereas in the past species were introduced to a few locations in a small number of countries, with more efficient communications and transport, seed can now be distributed simultaneously to virtually every country in the tropics with relative ease (e.g. the Oxford Forestry Institute, OFI distribution of*Gliricidia sepium* seed as reported in Simons and Dunsdon, 1992). The Commonwealth Scientific and Industrial Research Organisation, CSIRO, Tree Seed Centre in Australia provides a good example; it maintains seed of over 1000 Australian/Australasian tree species and distributes 15,000 seedlots of over 600 species to researchers in 100 countries per year (Vercoe and Midgeley, 1993; Booth and Turnbull, 1994;).

The OFI seed distribution programme has operated on a similar scale; between 1968 and 1993, 11,000 seedlots, including 233 taxa, were distributed to 128 countries (Pottinger, 1993 and pers. comm.). While the benefits of such introductions may be substantial (Barnes, 1988), if, as estimates suggest, 1% of introductions become invasives, these programmes alone have introduced at least six and two invasive pests respectively to several or potentially many countries. New and comprehensive seed collections of particular genera, such as *Leucaena* (Hughes, 1993) or *Calliandra* (Macqueen, 1992), that include a wide range of lesser-known species are now available and in great demand. Many organisations have been distributing tree seed on a similar scale over the last two decades. Notable examples in addition to CSIRO and OFI, include the Henry Doubleday Research Association (Harris, 1993), Food and Agriculture Organisation (FAO/IBPGR, 1980), Centre Technique Forestier Tropical (e.g. Corbasson *et al.*, 1987) and the Central America and Mexico Coniferous Resources Cooperative, CAMCORE (Dvorak and Donahue, 1992).

The marked lack of procedures covering movement of tropical tree germplasm, where whole genomes are translocated between continents without regulation, stands in stark contrast to the strict policies covering movement of biocontrol agents or genetically-engineered organisms. These are treated cautiously with a case-by-case approach to risk assessment despite general agreement that genetically-engineered organisms, with their relatively minor genetic modifications, pose significantly lower risks of invasion than introduced species (Shorrocks and Coates, 1993; Raybould and Gray, 1994). It is extremely easy to move seed of little-known tree species from one continent to another. Even within those organisations that operate large scale deliberate introduction programmes, the present process is characterized by a low level of concern about the hazards of invasives. In a few cases, warnings are provided by seed suppliers (e.g. Hughes, 1993), but these, at best, shift responsibility from the supplier (often a development organisation) to the seed recipient (usually in a developing country), who is often poorly placed to judge the advisability of introductions. In most cases both seed suppliers and recipients are unaware of the hazards; complete information on species characteristics is usually lacking, and legislation covering plant introductions is non-existent or severely lacking in most tropical countries.

Risks

As a result of the frequent need to employ aggressive trees, often those that seed heavily, many of the species used by foresters have the capacity to spread outside the area where they are being planted and are potentially invasive. Forestry is thus often working with 'conflict' species. Forestry species are particularly problematic as invasives in open forest types, savannas, fire-dominated ecosystems and numerous semi-natural habitats (Richardson *et al.*, 1992; Usher, 1988), rather than in closed moist tropical forest ecosystems which are generally resistant to invasion except by highly shade-tolerant species or in species-poor island forests (Whitmore, 1991). Disturbance, whether natural or induced by man, is a key factor permitting invasion (Whitmore, 1991).

The relatively small invasive fraction of introduced trees poses huge conservation problems, with the risk of diverse natural vegetation being replaced by exotic species. An invasive plant species may be defined as 'an alien plant spreading naturally (without the direct assistance of people) in natural or semi-natural habitats, to produce a significant change in terms of composition, structure or ecosystem processes' (modified from Fuller and Cronk, in press). Invasion may cause major loss of biodiversity and species extinction either due to direct replacement by exotics or indirect effects on the ecosystem. For example, in Mauritius and Hawaii, *Psidium cattleianum* has spread and dominates areas of wet evergreen forest, replacing much of the native vegetation (Lorence and Sussman, 1986). Similarly introduced *Acacia* and *Pinus* species have spread over large areas of fynbos vegetation in South Africa forming monospecific stands that now dominate thousands of hectares with severe impacts to the natural vegetation, leading to a reduction in biodiversity and threatening as many as 750 of the endangered species listed in the IUCN Red Data Book (Richardson *et al.*, 1992).

A summary list of genera that include species that are both important for forestry and the focus of eradication efforts following invasion (*Acacia, Acer, Ailanthus, Albizia, Cedrela, Dichrostachys, Eucalyptus, Leucaena, Maesopsis, Melaleuca, Melia, Parkinsonia, Pinus, Pittosporum, Prosopis, Prunus, Psidium, Robinia, Schinus, Sesbania, Swietenia, Tamarix* and *Toona*; largely from Fuller and Cronk, in press) is indicative of the scale of the problem and the degree of overlap between species that are used in forestry and those that are invasive. Several species are the focus both of germplasm collection and distribution efforts in tree improvement *and* of biocontrol or eradication programmes (e.g. *Acacia nilotica* promoted in Africa and India and eradicated in Australia and Indonesia).

Concern about weediness hazards associated with continued introductions has been growing over the last decade. Many conservationists are strongly opposed to further introductions, and movement of forestry and agroforestry germplasm has been the target of specific criticism (Janzen 1987a; Stirton, 1978). Conservation agencies faced with large bills for the control of invasive plants are seeking greater accountability from individuals and agencies involved in species introductions. It seems likely that the 'polluter pays' principle may be applied where invasion occurs in the future.

GUIDELINES FOR SPECIES INTRODUCTIONS

The challenge facing foresters and conservationists is to reduce risks of introducing new invasives without hindering valuable reforestation efforts. This will demand species that have the ability to survive, grow well under harsh conditions and provide high quality products, but that do not invade remnant natural ecosystems or interfere with wider conservation efforts.

Choice of species

As a starting point in any tree planting programme, alternative *native* species that might be used to provide similar benefits to the well-known exotics should first be considered. Introductions should only be contemplated if no native species are suitable for the purpose for which the introduction is being made (IUCN, 1987). In the majority of situations this simple recommendation is consistently ignored and only rarely is a thorough assessment of native alternatives undertaken.

In industrial plantation forestry, cogent arguments in terms of yield gains, economics, marginal returns and uniformity of product can be made to support widespread use of a small number of exotic species that have generally outperformed native alternatives in terms of survival, yield and product quality. These species have dominated industrial plantations to the exclusion of the majority of native alternatives. Indeed, Evans (1992) suggests that 85% of industrial plantations in the tropics are established with species from three genera; *Eucalyptus, Pinus* and *Tectona.* However, even for industrial plantations, there are many examples of successful use of native species (Kanowski and Savill, 1992). It has been argued that many valuable species have been excluded from consideration and that the growth potential of most tropical species remains unknown with only limited investment in the development of native species for plantation use. The information gap in itself favours continued use of well-known exotics (e.g. Butterfield and Fisher, 1994); 'new' species with potential for plantation establishment continue to be 'discovered' (e.g. Nichols, 1994, Butterfield and Fisher, 1994) and in the last few years proposals for 'complex' plantation forestry with use of a wider range of species have been made (discussed in Kanowski and Savill, 1992).

For non-industrial tree planting, the arguments in favour of choosing from only a handful of globally promoted exotic species appear to be less compelling. In small scale agroforestry planting, in addition to simple evaluation of species in terms of yield (the main criterion usually employed in species elimination trials), there are wider considerations of stability, security and risk reduction, sustainability, micro-site matching, product quality and timing of production in relation to seasons, compatibility with crops and livestock, market participation, and self-sufficiency and autonomy. These considerations demand use of highly diverse material that matches the diversity of products that have been traditionally harvested, in some areas, from natural forest. In general, the more diverse the forest in terms of species, the more secure the services and the wider the range of available products (Sargent, 1992). Such planting must incorporate a wide diversity of species in any one area (Marten, 1988; Sinclair *et al.*, 1994). The 'multipurpose' tree concept in itself has mitigated against use and conservation of a wider range of species (Barnes, 1990) as a way of obtaining multiple products and reducing risks. There has also been some discussion about risk reduction through careful maintenance of a broad genetic base within multipurpose species (e.g. Simons, 1992); a much simpler and more effective way to reduce risks is simply to use a wider range of species; the arrival of the psyllid defoliator *Heterospylla cubana* in Asia was devastating not because of the narrow genetic base in *Leucaena leucocephala*, but because certain communities had become heavily dependent on *L. leucocephala*, which was planted to the exclusion of all other species in some areas.

The prevalent idea of the 1970-80s that a few 'multipurpose' species could adequately meet the complex needs of resource-poor farmers, is now being overtaken by new strategies for choice of species that concentrate on a wider range of local trees (Carter and Gronow, 1992 in Nepal; Kiambi and Opole, 1992 in Kenya; Tietema *et al.*, 1992 in Botswana). Local species have the advantages of being non-invasive, well adapted to the environment, accepted by local people, of having a wide range of existing uses supported by existing local knowledge and may be important in the local culture. Additional benefits of genetic conservation through use in agroforestry (Cooper *et al.*, 1992; Pimental *et al.*, 1992; Gajaseni and Jordan, 1992) also argue for wider use of native species. Conversely, wide use of exotic trees in farm and agroforestry may greatly hasten the demise of native trees that are used in traditional agroforestry systems (e.g. Hellin and Hughes, 1993 for Honduras). Indeed promotion of exotic agroforestry trees over indigenous alternatives strongly parallels the loss of traditional crop varieties following promotion of green revolution improved varieties (e.g. Altieri and Merrick, 1987; Cooper *et al.*, 1992). In many cases, foresters are handicapped by their limited knowledge of local floras and, under pressure to plant *x* trees or *y* hectares per year, fall back on the limited set of well-known exotics with which they are familiar and for which seed is often more readily available. Rarely is time taken to investigate the potential of lesser-known local species for which seed may not be readily available and for which reliable propagation methods and silvicultural regimes are only poorly known. In Central America, detailed field exploration over several years was needed to 'discover' some of the species with greatest potential for agroforestry, which were little known to science and often geographically restricted, although locally highly preferred and offering considerable potential for tree planting (e.g. Leucaena salvadorensis in Honduras; Hellin and Hughes, 1993). Greater attention to propagation methods for indigenous species can often yield rapid results (Tietema *et al.*, 1992).

While native species are not risk free, and can alter seed flows into neighbouring natural vegetation when extensively planted in surrounding areas, they do not have the same potential for catastrophic invasion. A switch of philosophy from promoting species as exotics across the tropics (e.g. NAS, 1984), the common exercises of recent years of setting species priorities across regions, and reliance on standardized trial networks, to promoting greater use of and research on local tree diversity, could ameliorate the problems associated with introductions, arguably improve the sustainability and value of agroforestry planting, and make a significant contribution to *in-situ* conservation of biological diversity.

Procedures for introductions

If introduction of new species or provenances is contemplated, careful procedures need to be followed to assess risks and benefits. Draft guidelines for species introductions have been provided by IUCN (1987), and discussed by Fuller and Cronk (in press). These guidelines are presented (see box) and discussed here in relation to tropical forestry species introductions.

Fundamental to an improved approach is adequate assessment of benefits and risks *prior* to seed distribution. A 'guilty until proven innocent' approach, where potential introductions are considered first as potential weeds until evidence suggests otherwise, has been suggested as an alternative to the current experimental approach where species are introduced first and assessed as invasives later (Fuller and Cronk, in press). At present, species are assessed only *after* they have become invasive, when it is usually already too late to prevent wider spread through control or eradication. It will clearly be impossible to certify a species as 100% safe; introduction will always carry some element of risk. Assessment should proceed essentially as a cost-benefit exercise. What is important is assessment not only of risk but also of what degree of risk is acceptable in relation to likely benefits. Although a 'guilty until proven innocent' approach is unacceptably dictatorial and would undoubtedly prove impractical if strictly applied, it appears to offer the only viable framework to ensure that prior assessment of risks and benefits is undertaken in a thorough and serious way. To be effective, prior assessment needs to be supported by a permit system whereby introductions are authorized by the appropriate government agency with adequate administrative, scientific and technical support to accept responsibility for decision-making. In the absence of official authorization, agreement of liability to bear the costs of control should the introduced plant become invasive is an alternative. Assessment of introductions in this way would undoubtedly lead to a dramatic reduction in the flow of new forestry species around the globe.

Problems with assessment of benefits and risks

Assessment of benefits must first consider whether clear and well-defined benefits to man or natural communities can be foreseen and whether similar benefits or products could be derived from alternative native species. There would appear to be little justification for introductions of species that provide only basic products such as firewood, poles or green manure that are produced by a wide range of species. Over time, land use and production goals may change and species perceptions may be radically altered. A species that is highly preferred now may become obsolete and be perceived as a weed; for example, gorse (*Ulex europaeus*) has changed from a widely cultivated winter feed bush (Elly, 1846) to a pasture weed during the last century in the UK; correspondingly, a decline in demand for tannin has reduced the value of *Acacia mearnsii* in southern Africa. Market and technology changes may be hard to predict; a long-term perspective, although difficult to achieve, is required.

Assessment of risks relies on the ability to predict the outcome of an introduction through consideration of species characteristics, conditions (in the broadest sense) in the destination country, adequate dialogue between suppliers and seed recipients, and the use of accumulated information on invasive species from other areas and closely related species. The long-term behaviour of introduced species is complex and may be very difficult to predict.

An 'incubation' period (a few years to many decades) following introduction before species start to spread invasively, is a common phenomenon. Introduced species often only start to show invasive tendencies 50 or more years after introduction. *Acacia nilotica* in Queensland, Australia provides one example; introduced in the late 1890s, spread was not reported until the 1950s, and the species was declared a noxious weed in 1957 (Carter, 1994) and is currently the focus of a costly biocontrol programme. In some cases this lag may be more perceived than real, reflecting a gradual initial spread which is only noticed much later as invasion progresses. In other cases, invasion may be triggered by unusual events such as storms, flooding, fire, or mis-management of livestock that create 'transient invasion windows' (Richardson *et al.*, 1992), leading to massive regeneration or seed dispersal. In the case of *Acacia nilotica*, a series of years with above-average rainfall in the 1950s coupled with a switch from sheep to cattle grazing, appears to have precipitated dispersal and regeneration on a large scale (Carter, 1994). Many recently introduced species may be poised to spread given the 'right' combination of conditions. This pattern of invasion is important given that most legislation and assessment of plant introductions relies on schedules that prohibit import of plants that are known weeds in other regions. Current invasive problems provide a poor guide to the future. Again, assessment needs to adopt a long-term perspective, examine long-term climatic cycles, the likely effects of grazing or fire and the possible outcomes of chance events. Assessment will always depend on thorough knowledge of the autecology of the species in question; very often this is not available at the time an introduction is contemplated but is only sought much later when invasion occurs and control measures are needed (e.g. Glendenning and Paulsen, 1955 for *Prosopis velutina*).

Species may spread widely from the initial point of introduction. A plant introduced anywhere in Africa, for example, can over time, quite readily spread itself into most habitats it can tolerate throughout the African continent. The assumption that an introduction may be a permanent addition to the flora should examine more distant localities and their conditions. Certain areas are particularly vulnerable to introductions and invasion. These include islands, including isolated biological systems, because their ecosystems offer refugia for species that are not aggressive competitors (Vitousek, 1988). Island floras are often rich in endemic species and on many islands costly battles are now being fought against invasive plants that threaten the last remnants of these floras (e.g. Strahm, 1990 in Mauritius). Protected areas and their buffer zones are another case deserving special protection. Small reserves are particularly susceptible to invasion, although easier to monitor and patrol against invasives (Janzen, 1983; 1987b) and new introductions must be considered inappropriate in such areas.

In addition to direct invasion, interspecific hybridization and the evolution of new taxa following introductions is of concern and its likelihood should also be assessed. Introductions may bring previously isolated species into artificial sympathy with either closely related native species, or other species that are also being introduced into cultivation. New hybrid taxa may present additional unpredictable threats of weediness or invasion, and introductions may 'pollute' native species through hybridization and introgression (see review by Abbott, 1992). There are several examples of spontaneous hybridization resulting from tropical forestry activities: e.g. *Leucaena* in Mexico (Hughes and Harris, in press), *Acacia* in S.E. Asia (Sedgeley *et al.*, 1992), and *Prosopis* in South Africa (Poynton, 1990). In the case of *Prosopis*, Poynton (1990) documents the introduction of six species to southern Africa from the New World. Spontaneous hybrids between *P. glandulosa* var. *torreyana* and both *P. velutina* and *P. chilensis* have been found to be extremely invasive, with the ability to colonize a wider range of habitats than either of the parent species. Intercontinental movement of species in a large pantropical genus such as *Acacia* (as promoted by FAO/IBPGR, 1980) presents many opportunities for production of novel hybrids and pollution of native species.

Given these problems, accurate evaluation of risks may be extremely difficult and in some cases impossible, prior to an introduction. These difficulties place even more emphasis on thorough assessment of likely benefits which is usually easier; if large enough benefits can be demonstrated for a proposed introduction, including comparison with native alternatives, these are likely to outweigh any possible risks. By simply avoiding introductions that are not justified in terms of clear and substantial benefits, a considerable proportion of recent and current introductions would undoubtedly have been avoided. New research on methods to predict and understand the outcome of species introductions might help to reduce these difficulties.

Guidelines for Species Introductions (modified from IUCN (1987)).

- Introductions should only be considered if clear and well-defined benefits to man or natural communities can be foreseen and demonstrated.
- Introductions should only be considered if no native species is suitable for the purpose for which the introduction is being made.
- Introductions should not be made into pristine natural or semi-natural habitats, reserves of any kind or their buffer zones and, in most cases, oceanic islands.
- Introductions should not be made until risks of weediness or invasion of surrounding areas have been assessed as far as possible, taking into account essential data on:

  1. the autecology of the species (seed dispersal, reproductive ecology, factors limiting its distribution and abundance in its native habitat).
  2. conditions in the area of introduction (including the likely effects of rare climatic or other events such as flood, drought and fire).
  3. information on weediness form other areas and for closely related species.
  4. likelihood of interspecific hybridization with closely related native or other introduced species, and risk of contamination of native genepools through introgression or evolution of new and potentially aggressive polyploid species.

- Introductions should be made initially in small, closely monitored field trials. Monitoring needs to include assessment of seed production and dispersal and natural regeneration into surrounding areas. Collection of seed by station workers or visitors from trials needs to be controlled by harvesting all seed before it ripens. When assessment is complete, trials need to be completely destroyed, including any soil seed bank that has developed.

Monitoring in trials

Once assessment is complete and a species is approved as beneficial and unlikely to be invasive, introduction initially into small scale experimental trials that would permit eradication if cause for concern arose, is the recommended process (IUCN, 1987; Fuller and Cronk, in press). However, such trials, which are normal practice in forestry introduction programmes, will provide only limited information on invasive tendencies. To be effective in controlling invasives, trials would need to be heavily protected, isolated and closely monitored for several years and in some cases decades; these conditions are rarely met in practice. Trial assessments rarely look at reproductive ecology or dispersal and regeneration; there are many cases where a few trees surplus to trial requirements are distributed to farmers; often on-farm testing of species is recommended; often trials remain in a neglected state long after assessment is complete providing a long-term source of possible invasives (Sheil, 1994); often seed is collected from trials by experimental station workers or visitors to plant in other areas or back in their gardens and farms. Thus, although trials provide scope for monitoring and control, and should be pursued with improved monitoring procedures, it is a fallacy that movement of introduced species can be reliably controlled at the stage of initial field testing of new tree species following current practice; controlled introduction trials are not an adequate substitute for thorough prior assessment of benefits and risks. Development of explicit guidelines for monitoring trials that address these inadequacies would help.

Alongside specific guidelines and procedures covering species introductions, Fuller and Cronk (in press) point out that education, awareness raising, legislation, information and record keeping can contribute to limit unwise introductions. Education of foresters and others working with trees is needed to raise awareness of the difference between native and exotic species, the importance of native trees, the dangers of exotics and the hazards associated with apparently harmless forestry activities such as testing new species in trials. Improved plant quarantine legislation is also an urgent priority with introduction of permit systems to authorize introductions. Accurate recording of introductions, invasive species, rates of spread, impact and ecological behaviour is essential in prevention and control of invasions.

This paper is about minimizing risks and damage limitation rather than cure. Methods to control invasive species include physical, chemical and biological methods and environmental management, and are amply reviewed by Fuller and Cronk (in press).

SEEDLESS VARIETIES

Varieties or hybrids that are sterile or weakly fertile provide an enticing option where there is particular concern about weediness. By using environmentally friendly, seedless versions of potentially invasive tree species, problems of invasion could be circumvented at a stroke, although some species could still spread vegetatively by root suckers. Despite the attraction, there appear to be few examples of use of seedless varieties in forestry. The only example known so far is use of spontaneous sterile or very weakly fertile triploid hybrids between *Leucaena leucocephala* and *L. pulverulenta* in tree planting for tea shade in Java, Indonesia, where weediness of *Leucaena* in tea plantations was a problem (Dijkman, 1950). Seedless *Leucaena* hybrids are in demand in other similar agroforestry situations, where the widely planted and heavy seeding *L. leucocephala* can become an agricultural weed. Lack of seed production in certain areas where species are introduced (e.g. for *Pinus tecunumanii* in some tropical areas; Dvorak and Lambeth, 1992), normally viewed as a problem in forestry, could provide some safeguard against invasion, but information on seed production capacity is generally unavailable prior to introduction.

The problems associated with production and use of sterile lines are obvious. First, effective, low technology vegetative propagation techniques are needed. As discussed above, tropical tree planting, particularly if community or farmer-based, relies on ease of propagation and ready access to planting material. This explains the widespread adoption of species that produce abundant seed. Considerable progress in low cost, low technology vegetative propagation techniques for some species has been made in recent years (Leakey *et al.*, 1992; Haines, 1994). Secondly, seedless varieties or hybrids must be available for propagation. Finally, there are well-known pitfalls associated with narrowing the genetic base through widespread planting of one or a few sterile clones (Burdon, 1989). Increased research on viable options for breeding low seeding varieties and hybrids is needed.

FUTURE PROSPECTS

Species introductions will continue to take place, either accidentally or intentionally. As one of the principal agents involved, foresters must accept their responsibility and adopt a more cautious approach, guided by rigorous procedures of assessment and local testing with strict monitoring. The current lack of awareness and complacency amongst foresters about the risks of species introductions may stem from the fact that only a relatively small number of tropical trees have so far become serious weeds; this complacency is unjustified given the recent scale of introductions and the prevalent 'incubation' period before invasion becomes apparent. What is proposed here is not a complete halt to introductions but a reduction in the scale of operations and imposition of a framework that demands a more considered approach. Similarly, it is accepted that ecosystems are dynamic and continue to evolve with introduced species as part of that process; again it is the present scale of introductions that is unacceptable in terms of wholesale movement of species and potential for catastrophic invasion that may jeopardize future evolutionary potential.

Increased attention to choice of species, particularly in non-industrial tree planting programmes where there appears to be ample scope to concentrate much more on native species, offers perhaps the greatest scope to reduce the current magnitude of forestry introductions and the associated problems of invasion. Choice of species in non-industrial forestry is in its infancy and previous successes and failures have been, in many cases, accidental, lacking the sound scientific research base that is needed. Nevertheless, for industrial plantation forestry, the reliance on exotics and further introductions are likely to continue. However, in the industrial sector, with its generally well-defined, documented, controlled and managed plantations, there is greater scope to predict and control spread (e.g. Ledgard, 1994 for introduced conifers in New Zealand) and greater opportunity to seek more accountability from agencies who continue to test or introduce species that are known or potential invasives, conditions that patently do not apply in the non-industrial forestry arena.

Unfortunately, only a handful of developed countries and states which have experienced severe problems of invasion, such as Australia, South Africa and the State of Hawaii, USA (Smith, 1985), are attempting to regulate in a serious way, with legislation and policing by government agencies, the flow of non-native species into their territories. For the vast majority of tropical developing countries regulation is currently minimal. Awareness of invasive plants is low. Conservation agencies are small, in many cases embryonic, and have limited resources that are fully stretched in the establishment and management of protected areas. In many countries, there are no complete species check lists for native plants, let alone introduced species or invasives. There is a strong case for development assistance to support the establishment of effective plant import regulations and authorities in many tropical countries. In the meantime, until seed recipients in these countries are in a better position to assess, regulate and monitor their own incoming introductions, it is the clear responsibility of the supplier of seed or other material being used to introduce new trees to undertake assessment on their behalf.

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