Forestry Department

Food and Agriculture Organization of the United Nations

Forest Health & Biosecurity Working Papers

The status of invasiveness of forest tree species outside their natural habitat: a global review and discussion paper

by

K.A. Haysom and S.T. Murphy

CABI Bioscience

December 2003

Forest Resources Development Service

Forest Resources Division

Forestry Department

Working Paper FBS/3E

FAO, Rome, Italy

Disclaimer

The FAO Forestry Department Working Papers report on issues and activities related to the assessment, protection and sustainable management of forest resources. The purpose of these papers is to provide early information on on-going activities and programmes, and to stimulate discussion.

This paper is one of a series of FAO documents on forest-related health and biosecurity issues. The study was carried out in March 2003, and was financially supported by the FAO-Netherlands Partnership Programme on Agro-Biodiversity.

The authors would like to thank the organizers and members of the international Aliens-L list server; individuals and organizations listed in Appendix 2; and Paul Kirk, Craig Tarft, Louise Fulham, Gretel White, Jo Bunner, Rebecca Murphy and Tom Ings, for their contribution to this study.

Quantitative information has been compiled according to sources, methodologies and protocols identified and selected by the authors. For standardized forest inventory methodologies and assessments on forest resources, please refer to FAO, 2003. *State of the World's Forests 2003*; and to FAO, 2001. *Global Forest Resources Assessment 2000 (FRA 2000)*. FAO Forestry Paper No 140.

Official information can also be found at the FAO Internet site http://www.fao.org/forestry/forestry.asp.

Comments and feedback are welcome.

For further information please contact:

Pierre Sigaud, Forestry Officer (Forest Genetic Resources)
Forest Resources Division
Forestry Department
FAO, Viale delle Terme di Caracalla
00100 Rome, Italy
Fax: + 39 06 570 55 137
Email: pierre.sigaud@fao.org

Gillian Allard, Forestry Officer (Forest Health)
Forest Resources Division
Forestry Department
FAO, Viale delle Terme di Caracalla
00100 Rome, Italy
Fax: + 39 06 570 55 137
Email: gillian.allard@fao.org

For citation:

Haysom, K.A. and Murphy, S.T. 2003. *The status of invasiveness of forest tree species outside their natural habitat: a global review and discussion paper*. Forest Health and Biosecurity Working Paper FBS/3E. Forestry Department. FAO, Rome (unpublished).

CONTENTS

LIST OF TABLES AND BOXES

LIST OF FIGURES

EXECUTIVE SUMMARY

This discussion paper presents a global review of the status of the invasiveness of forest tree species outside their natural habitat. The review covers trees and woody shrubs commonly used in commercial forestry and agroforestry. Information for the review has been collated from published databases and papers, unpublished reports and personal communications.

A number of definitions of "invasive species" have been suggested in the literature, some specifically for invasive plants or woody plants. It is recommended here that, in the context of forestry, a common definition be developed that focuses on parameters of population expansion only, because in some common definitions of invasive species impacts are preconceived to be negative.

On a global basis, available information on the status of forestry trees that have become invasive is patchy. The terminology used by authors is also very variable and there is frequent overlap in the terms "invasive" and "naturalized". The evaluation of the extent of invasions by forest trees is most often very qualitative and subjective which makes overall assessments of the magnitude of the problem difficult.

With these caveats in mind, the following summarizes the global situation:
The number of species of trees or woody shrubs that were classed as invasive, including some listed by Binggeli (1996) as possible or potential invaders (based on literature where the extent of invasion was limited or unknown), was 443. A further 74 were reported as naturalized. Some 282 species used in forestry were among those listed as invasive, and a further 40 were reported as naturalized but not invasive. The majority of the species encountered in the review were used for more than one purpose (i.e. the same species may be used in forestry, agroforestry and/or for amenity plantings). Hence, among those species identified as invasive, 203 species were listed as being used in agroforestry and 292 in amenity plantings.

Fifty-eight families included at least one invasive forest tree species, and 34 families contained more than one invasive species. The latter represents half the total number of families with members used for forestry that are known to be grown outside their native range. Thirteen families contained no invasive forestry tree species. There were examples of both angiosperm and gymnosperm invasive species. In decreasing order, the majority of invasive forestry trees occurred in the families Leguminosae, Pinaceae, Myrtaceae, Rosaceae and Salicaceae.

Invasive species were reported in all seven geographic regions (Europe, Africa, Australasia, North America, South America, Pacific, Asia). Most invasive trees were reported from Africa (87 species) and fewest from Europe (12) and Asia (14). However, the majority of species were invasive in only one of the seven regions, and even among the most "invasive" species the number of countries where they were reported as invasive was generally much smaller than the number of countries where they had been introduced. Most invasive species had a native range that included Asia, and the fewest a range that included the Pacific.

During the examination of these data it was notable that most accounts gave little information on the use of the trees, details of their management (forestry, agroforestry, amenity, etc.), the history of their introduction or on the scale of planting and of invasion (land area). This lack of information limited discussion to the number of invasive species encountered in different situations and restricted interpretation. Geographically, it was notable that most invasive species were reported from countries and regions where investment in cataloguing or researching the number and impact of species had been high, e.g. South Africa, Puerto Rico and North America. There were distinct gaps in knowledge of the occurrence of invasive species in some other areas, namely Africa (outside South Africa, Zimbabwe, Botswana and the oceanic islands), Asia and parts of South America. It is therefore highly likely that the list of species known to behave invasively would expand, given further work in such locations.

Few studies have been conducted on the positive and negative aspects of the impacts of invasive forest trees. Positive impacts include providing fuel and other resources for resource-poor communities. The trees may also contribute to soil stabilization in over-exploited natural forest areas such as in India. Although hybridization between introduced species can potentially produce new invasive species, only a few instances have been reported in forestry: that of *Leucaena* and *Prosopis* hybrids and these are only locally important. Invasive forest trees have been reported as major problems in grassland pastures throughout the world, but there are fewer instances where trees invade other agricultural systems or forest plantations. Most reports of invasiveness relate to natural or semi-natural habitats, e.g. riparian and wetland systems. One of the most quantitative studies conducted on the impact of invasive trees in a natural habitat was undertaken in the fynbos biome in South Africa. Here trees cause substantial losses in local biodiversity and prevent natural run-off of water from catchment zones. This is reported to affect South Africa's water supply, especially in the dry seasons.

Over time there has been a growing national and international awareness of the possible risks of invasiveness of forestry trees, but it is likely that some stakeholders in plantation forestry remain ignorant of the risks. Awareness has been highest in environmental sectors but some of the risks have been highlighted by those in agricultural sectors. This has led to conflicts of interest in some parts of the world that are partly fuelled by the general lack of quantitative information on the ecological and economic impacts of invasive forestry trees. A compounding factor is the lack of information and tools (methodologies, etc.) to make such assessments. In the light of the above, it is recommended that a number of case studies be conducted in collaboration with countries that have a high dependence on planted forests. Such case studies should cover a range of plantation forestry situations (commercial, development, environmental) and include the development and promotion of tools for ecological and economic assessments. Particular attention should be paid to those regions of the world where little information exists concerning the invasiveness of exotic forestry trees (e.g. tropical and temperate Asia).

Many biological attributes (e.g. life history, taxonomic status, genetic constitution) are poor indicators of invasiveness if considered alone. However, some of these characteristics (in combination with other factors such as the extent of invasiveness expressed) are being used in risk assessments (see below). For those species that have already been recorded as highly invasive in at least one area, it would be of more practical significance to examine whether or not some form of control or management by local communities contributes to noninvasiveness in other areas.

Globally, the development and implementation of prevention, control and management tools for invasive forestry trees has been cautious and patchy because of the basic economic and developmental benefits of the trees concerned. Some countries, sometimes in collaboration with international partners, have made large investments in exotic trees and are therefore reluctant, given the general lack of quantitative information on the negative impacts, to take action against those species that have become invasive. An additional constraint that prevents many countries from implementing risk assessments, control and management schemes, is the general lack of both the necessary tools and relevant information concerning their use.

Work on prevention has included the development of risk assessment and risk management models. There are a number of discussions and suggested schemes in the scientific literature, some of which cover environmental aspects. All of these schemes are aimed at exotic plant introductions in general rather than forestry trees *per se*. Overall, the development of risk assessments poses some problems – such as factoring in the time lags that can occur before a tree becomes invasive as well as the problem of unpredictable hybridization with other tree species.

Practical risk assessments, based on information such as whether the plant is invasive elsewhere and various biological attributes, are now in use in Australia, New Zealand and the USA. A few other countries/territories have schemes under development. The most common assessment method to date is based on assigning numerical scores to various attributes. There is an urgent need for such risk assessments to be further evaluated for use in forestry and for them to be more widely promoted if they are considered appropriate.

Some research groups are developing alternative approaches to risk management, including the production of seedless clones of pines and near sterile hybrids of *Leucaena* species; however, propagation methods still need to be developed for the latter.

Risk assessment and management of alien plants (i.e. introduced plants that are not yet invasive) has also been considered in some cases. New Zealand, for example, already has a qualitative system in place. Many researchers in this field have called for monitoring schemes to be set up once a plant has been introduced. For forestry trees this would entail planting trials and would have to be continued for many years. Practical guidelines on monitoring aimed at forestry programmes are not readily available and this is an area where further work is required.

In some countries large-scale eradication programmes employing mechanical and chemical methods have been undertaken against woody legumes, such as *Prosopis*, that are invasive in pastoral systems. However, these methods are costly and it has generally not been possible to eradicate the trees concerned. In some cases, therefore, methods are now focused on control and use rather than eradication. Nevertheless, eradication methods (with sponsorship from the government) are being used effectively in South Africa to clear water catchment zones. Eradication methods have also been successful in clearing alien forest trees in areas of conservation value in Mauritius and Florida. Biological control and integrated control (biological with mechanical and chemical methods) have been used for the control of woody legumes in Australia, Southeast Asia and South Africa. These programmes are still largely ongoing and experience suggests that a complex of complementary natural enemies will be required to effect full control.

Some efforts are now being made to resolve conflicts of interest by developing management schemes rather than control programmes for invasive trees. In South Africa, on the basis of economic models, seed-feeding bruchids have been introduced to control the seed output of several leguminous trees that have become invasive (e.g. *Acacia mearnsii*) and these efforts are reported as being successful. These programmes are now supported by new legislation that restricts the planting of trees that have invasive tendencies. At more of a research level, work on pasturelands in other countries has shown that, under some management regimes, invasive woody legumes can complement pasture grasses for livestock feed. All these experiences can serve as models for other countries trying to resolve problems associated with invasive forestry trees.

1. INTRODUCTION

1.1. Background and objectives

Over the last century, plantation forestry using exotic trees has developed as an integral and crucial part of many national economies and environmental programmes. Planted trees and woody shrubs have also proved vital in improving the livelihoods of many of the world's poor. As a result, countries, international organizations, programmes and industries have been exchanging forest reproductive material on an ever-increasing scale. Given the current global agendas on trade, combating desertification and climate change, this trend is likely to continue.

In contrast, a separate global agenda is now focused on invasive alien species (IAS), which are currently considered second only to habitat destruction in terms of loss of biodiversity (Sandlund *et al.* 1999). This concern is reflected in Article 8(h) of the Convention on Biological Diversity (CBD), which calls on its members to "prevent the introduction of, control or eradicate those alien species which threaten ecosystems, habitats or species". Likewise, several international and national bodies such as the IUCN Species Survival Commission are focusing more attention on the issue of invasive alien species. Although large numbers of tree species have been introduced from one region to another in the past, most of these species do not naturalize and, of those that do, not all become invasive. However, there are now several well-documented studies that show the hazards that can result from an introduced tree or woody shrub becoming invasive (see Section 4). Some of these introductions are the result of horticultural activities but some are the result of plantation forestry and agroforestry programmes. This report is concerned only with the latter.

Various studies and reviews have been published regarding the "weediness" of introduced trees and woody shrubs, but little attempt has been made to evaluate information on the global status of these species and their impacts. This report attempts to fill this gap.

The aims of this study were to:

- conduct a global review of the status of invasiveness of introduced trees and woody shrubs;
- identify the possible link between planted forest development and the occurrence/risk of invasiveness;
- review the positive and negative impacts associated with invasiveness of the tree species;
- identify the planning, monitoring and management options in a forestry or agroforestry context; and
- highlight priority areas (geographic, thematic or species specific) for future in-depth studies.

In the remainder of this section the global status of forestry is considered, as well as some definitions of invasiveness in the context of trees and woody shrubs.

1.2. Forestry and agroforestry in a global context

Although there were introductions of trees such as teak (*Tectona grandis*), *Eucalyptus* and *Acacia* outside their natural range throughout the eighteenth and nineteenth centuries (Evans 1982), the planting of exotic trees for forestry and agroforestry in reforestation and afforestation programmes did not become a large-scale global activity until the second half of the twentieth century. At first, the extensive scale-up of use of these species was for industrial forestry, trees being grown for sawn timber and pulp. Plantations were first expanded in the Southern Hemisphere, for example in Chile and Australasia, but other regions (such as East Africa and northern South America) soon followed. The focus of these plantations has always been on the use of a small number of fast-growing species, mostly in the genera *Acacia, Eucalyptus, Gmelina, Pinus, Populus* and *Tectona*. Evans (1982) estimates that three genera, *Eucalyptus, Pinus* and *Tectona* account for 85 percent of all plantations in the tropics.

In the 1970s and 1980s tropical and subtropical regions experienced increasing shortages of fuelwood and other timber in rural communities, coupled with increasing environmental degradation, soil erosion and desertification. As part of national and international efforts to address these issues, exotic woody shrubs and, in particular, woody legumes were promoted for use in agricultural systems and to revegetate degraded lands (Hughes and Styles 1989). The woody legumes were particularly favoured because of their ability to grow rapidly under harsh conditions. As with industrial plantations, there has been heavy reliance on a small number of species, especially of *Acacia* and *Leucaena*.

With large areas of degraded land in tropical and subtropical regions, planting targets have always been ambitious. The availability of seed, together with basic information on how to collect, handle and grow different species in both nursery and plantation situations, have been major factors in determining the species chosen for planting programmes. As a result of the importance of seed availability, those species producing seed which can be stored for long periods have often been preferred.

1.3. Definitions

There are currently no widely agreed published definitions that cover the concept of an “invasive tree” or “invasive woody shrub”. This is partly because the term “invasive” is relatively new and its current wide usage to describe pest and disease problems, particularly those that affect the environment, seems to stem from the use of the term “alien invasive species” by CBD. The CBD defines this as “an alien species which threatens ecosystems, habitats or species” (Article 2). However, IUFRO’s *Silva Voc* are considering some working definitions which will be made available later this year. To date, the term “woody weed” is perhaps the most commonly used term in the scientific and pest management literature that can be equated with “invasive tree/woody shrub” (CABI Publishing Division, personal communication, 2002) but as yet this term has no formal definition. Unfortunately, published information on invasive trees/woody shrubs is very subjective and thus difficult to compare with other studies (see later).

However, a few authors who have published reviews or databases on "invasive trees/woody shrubs" have proposed some definitions, including the following:

1. Invasive woody plant – "[characterized by] the establishment of self-generating, usually expanding, populations of an introduced species in a free-living state in nature" (Binggeli 1996).
2. Invasive plant – "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" (Cronk and Fuller 1995).
3. Invasive plants – "naturalized plants that produce reproductive offspring, often in very large numbers, at considerable distances from parent plants (approximate scales being more than 100m in less than 50 years for taxa spreading by seeds and other propagules; more than 6m in 3 years for taxa spreading by roots, rhizomes, stolons or creeping stems) and thus have the potential to spread over considerable areas" (Richardson *et al.* 2000)

Definition 2 differs in two main ways from the others: the first is the inclusion of the word "alien" and the second is the inclusion of the expected impact of the invasive plant. These impacts could be considered detrimental or beneficial depending on who "uses" the ecosystem.

For comparison, two more general definitions of invasive species have been suggested:

4. Invasive species – "an alien species that becomes established in natural or semi-natural ecosystems or habitat, is an agent of change and threatens native biological diversity" (Shine *et al.* 2000).
5. Invasive alien species – "species introduced deliberately or unintentionally outside their natural habitats, where they have the ability to establish themselves, invade, out-compete natives and take over the new environment" (CBD 2001).

In these definitions, alien invasive species are considered to be a subset of alien species as a whole. The emphasis is on the threat to native biodiversity and hence the overall impact of invasive species is considered to be negative. For the purposes of those working in forestry or agroforestry, the first three definitions are of more practical use because the impact of an invasive species is not preconceived. The second definition is of particular relevance for this report because of the inclusion of the term "alien". These definitions will be discussed further in the last section of the report.

There are a few other terms that are commonly used in the literature on invasion biology. Again, these have been open to interpretation by authors but, nonetheless, useful working definitions do exist. Some of these terms, with their definitions, are as follows:

- Introduction – "the movement, by human agency, of a species, subspecies or lower taxon (including any part, gametes or propagule that might survive and subsequently reproduce) outside its natural range (past or present). This movement can be either within a country or between countries" (Shine *et al.* 2000).
- Alien species (= nonnative, nonindigenous, foreign, exotic) – "a species, subspecies, or lower taxon occurring outside of its natural range (past or present) and dispersal potential (i.e. outside the range it occupies naturally or could not occupy without direct or indirect introduction or care by humans), including any part, gamete or propagule of such a species that might survive and subsequently reproduce" (Shine *et al*. 2000).

- Naturalized – “alien species that have become completely established ferally and are breeding and holding their own in competition with the native flora and fauna” (Fitter and Fitter 1967).

This last definition is taken from British literature: more global definitions are not available.

2. METHODOLOGY

2.1. Data collection and management

In order to evaluate the extent to which the phenomenon of “invasiveness” is shown by introduced forest tree species it was necessary to gather data on the global use of introduced species within the forestry industry. In an attempt to reduce potential biases (i.e. over- or underestimation of the proportion of forestry tree species classed as “invasive” as opposed to “noninvasive”), two approaches to data collation were adopted.

In the first approach, two major online databases, Ecocrop (FAO, 1999) and the ICRAF Agroforestree database (World Agroforestry Centre, 2002) were used to compile a comprehensive list of tree species used in world forestry. This list included species known to occur only within their native range as well as those known to have been introduced to other countries. The trees with an exotic distribution included species not known to behave invasively, as well as those reported to be naturalized or invasive in at least one location.

In the second approach, online invasive species databases were used to identify trees or shrub-trees that were categorized as “invasive” by one or more authors. Key electronic data sources included the web-based database on invasive woody plants prepared by Pierre Binggeli (Binggeli 1999) and web pages prepared by various state agencies, e.g. the Government of Western Australia Department of Agriculture (2002), California Exotic Pest Plant Council (CalEPPC) (2002), Florida Exotic Pest Plant Council (2001), Southeast Exotic Pest Plant Council (2002), the Institute of Pacific Islands Forestry (2002), USGS (2002) and the Invaders Database System (University of Montana 1997).

To reduce biases towards electronic material, or to particular regions, these data were supplemented by a traditional literature review, further details of which are given in Appendix 1. Appendix 2 details all those who contributed unpublished information and ideas.

For those species analysed in more detail and used in case studies (species from the genera *Acacia* and *Prosopis*), the dataset was expanded to include information on biological characteristics, environmental factors across species ranges, silvicultural characteristics, the social, economic and biological impacts of invasion, habitats invaded and factors reputed to drive invasiveness.

2.2. Working definitions

2.2.1. Use of the terms "naturalized" and "invasive"

This review considers only naturalized or invasive *alien* species, i.e. it does not catalogue species that behave invasively within their native range. The wide variety of definitions used by different sources in connection with terms such as "invasive", "naturalized", "exotic", etc. has already been acknowledged (Section 1.3). This variety of terms presents a problem for any study seeking to provide a broad summary of the global status of invasive species. The policy of this review was, wherever possible, to accept the terms used by authors and correspondents, because in most cases it would not have been possible to verify or redefine the terms they used without further information. Where standard terminology such as "naturalized", "invasive", etc. was not used in the original source, the term *naturalized* was applied to any species that was reported to occur in the wild, but was not reported as spreading. The term *invasive* was applied to any species that was mentioned in the context of unassisted spread or described as an alien species that was thought to be in need of a control strategy. Ranked terms of invasiveness used by various authors were ignored, although species listed as "possibly/potentially invasive" by Binggeli (1999) were included on the grounds that they were classified according to a local event (Binggeli 1996).

2.2.2. Classification of native and exotic ranges

Countries included in the native range were taken directly from author and database sources (e.g. (International Legume Database & Information Service (ILDIS) 2002; World Agroforestry Centre 2002). For many species, native and exotic ranges were extracted from the Forestry Compendium Global Module (CAB International 2000). Range information from this source was interpreted cautiously because the term used ("natural forest"), while often referring to a species within its native range, was defined as late successional forest or "old-growth" forest. Such forests could also arise from introduction and naturalization processes and could potentially have been misclassified in the data summary. The contrasting term "planted forest" was also used in the context of species planted within their native range. The term "exotic range" comprised countries in which a species was planted but which were outside the "natural forest" region. Special care was taken with species that occurred in large land masses, for example North America, Australia, etc., where it was possible for a country to be listed both in a species' native and exotic range. Wherever possible, more detailed information on occurrence was collected (e.g. from a state or governmental unit) to clarify a species' native or exotic status (particularly in large countries).

2.2.3. Regional classification of native, exotic, naturalized and invasive ranges

Countries that were part of native, exotic, naturalized or invasive ranges were allocated to one of seven geographical regions (Europe, Africa, Australasia, North America, South America, Pacific or Asia) following the widely used International Working Group on Taxonomic Databases World Geographical Scheme for Recording Plant Distributions (TDWG (International Working Group on Taxonomic Databases) 1992). Brummitt (2001) gives full details of the countries included in these regions.

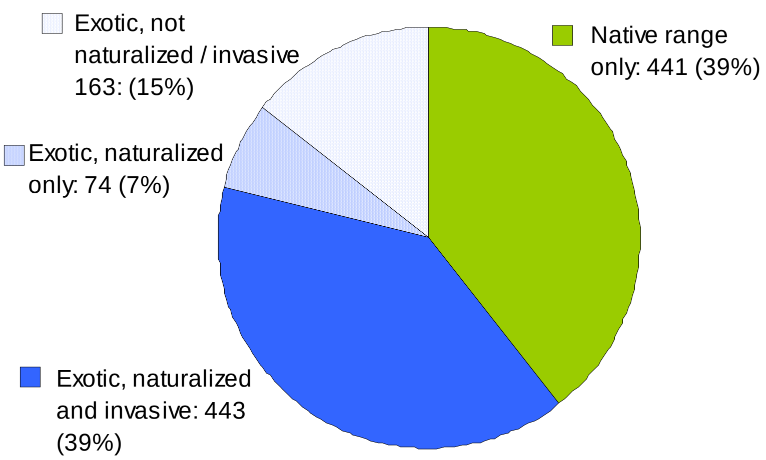
In brief, Europe was delimited by Portugal in the west and by Kamchatka in the east, by Svalbard in the north and by Crete in the south. Africa included mainland Africa and the Macronesian, Middle Atlantic Ocean and Western Indian Ocean islands. Asia extended from Turkey and the East Aegean Islands in the west to Papua New Guinea and the Solomon Islands in the east and from Mongolia in the north to Malaysia and the Cocos islands in the south. Australasia comprised Australia, New Zealand and their islands. The Pacific group extended from the Caroline Islands in the west to Easter Island in the east and from the Hawaiian islands in the north to Tonga and Niue in the south. The USA, Canada and Mexico were grouped as North America. The Caribbean islands and mainland American countries south of Mexico were classed as South America.

3. STATUS OF INVASIVENESS OF EXOTIC TREE SPECIES IN FORESTRY

3.1. General characterization of the dataset

Data were compiled for 1121 tree species known to occur outside of, or to be restricted to, their native range. Among species introduced outside their native range, the dataset incorporated both species reported to be naturalized (or naturalized and invasive) in at least one country and those not known to be naturalized or invasive. Figure 1 summarizes the contribution of the different groups in the dataset.

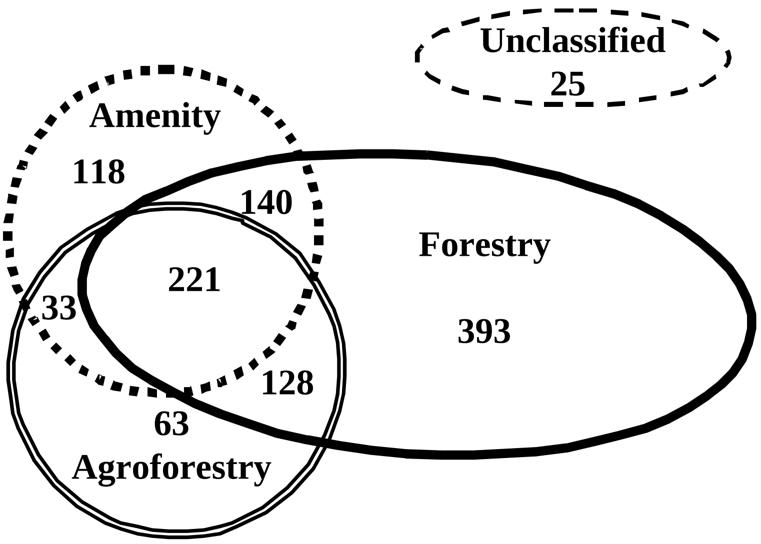
FIGURE 1. A SUMMARY OF THE DISTRIBUTION OF THE 1121 TREES IN THE DATASET ACCORDING TO GEOGRAPHICAL DISTRIBUTION AND INVASION BEHAVIOUR



Definitions: Native range only: species occurring only within their native range or not known to have been introduced into other countries. Exotic, not naturalized/invasive: species known to occur outside their native range but not reported to be naturalized or invasive. Exotic, naturalized only: species known to occur outside their native range, known to have naturalized in at least one location but not reported to be invasive. Exotic, naturalized and invasive: species known to occur outside their native range and to be invasive in at least one location.

The 1121 species in the dataset were drawn from 114 families and 451 genera. There were examples of both angiosperms (1026 species) and gymnosperms (95 species) and, among the angiosperms, both monocotyledons (31 species) and dicotyledons (995 species). Data sources ascribed several different growth forms (shrub/small tree/large tree) to the species in the dataset, with many species, e.g. *Acacia karroo* (CAB International 2000) exhibiting varied growth forms across their range, or according to their provenance.
Of the 1096 species that could be ascribed to a use category, 882 species (80 percent of the dataset) were used in forestry, 445 (41 percent) in agroforestry and 512 (47 percent) were amenity species. Almost half the species (522) were allocated to more than one category of use and 221 general-purpose species (20 percent) were allocated to all three classes. Figure 2 illustrates the distribution of species among the different usage categories.

FIGURE 2. THE USES OF THE 1121 TREE SPECIES INCLUDED IN THE LITERATURE REVIEW
Numbers in the diagram refer to the number of species ascribed to each category. The uses of 25 species could not be determined.



3.2. Invasive trees according to category of economic use

Sixty-one percent of species (680) occurred outside their native geographical range, while the remaining 441 species were either not believed to occur outside their native area, or insufficient information was available to allow them to be categorized.
Overall, 517 species (76 percent of those trees known to occur outside their native range) were classed as naturalized or invasive in at least one country or region. The number of species reported to be invasive was 443 (65 percent of those known to occur outside their native range). Table 1 summarizes data on the invasiveness of species according to the various economic use categories.

TABLE 1. NUMBER OF TREE SPECIES THAT WERE REPORTED AS NATURALIZED OR INVASIVE OUTSIDE THEIR NATURAL RANGE, GROUPED ACCORDING TO ECONOMIC USE.

Data are expressed both as a species count and as a percentage of the total number of species in each category known to occur outside their native range.

	Forestry	Agroforestry	Amenity	All purpose	Unclassified
Not reported invasive or naturalized	136 (30%)	104 (29%)	98 (22%)	57 (29%)	3 (13%)
Naturalized and invasive	282 (61%)	203 (58%)	292 (67%)	114 (58%)	15 (65%)
Naturalized only	40 (9%)	46 (13%)	49 (11%)	25 (13%)	5 (22%)
Total	**458**	**353**	**439**	**196**	**23**

3.3. Taxonomic characterization of the dataset

Further analyses excluded agroforestry or amenity trees not known to be used in forestry, and all species not known to be planted outside their native range. The remaining data (forestry species known to occur outside their native range) comprised 458 species and 215 genera drawn from 71 families. The distribution of species among families was highly skewed, with the top 10 families making up 64 percent of the dataset (295 species). In descending order of species number these families were the Leguminosae, Pinaceae, Myrtaceae, Rosaceae, Cupressaceae, Meliaceae, Salicaceae, Palmae, Fagaceae and Moraceae. The family with most species, the Leguminosae, comprised four tribes and 133 species – 29 percent of the forestry tree list. Twenty-seven families were represented by a single species each.

Fifty-eight families (82 percent of forestry families found to occur outside their native range) included at least one invasive species of forest tree. Thirty-four families contained more than one invasive species. More species in the genus *Acacia* (Leguminosae-Mimosoidae) were reported as invasive or weedy than in any other group (a total of 26 invasive species). In this family, however, there was also a similar number of species that were not reported as being invasive. For the majority of the 10 largest families represented in the dataset, the number of species termed invasive was proportionally higher than the number that were not reported invasive (see Table 2). Thirteen families (18 percent of the forest families introduced outside their native range) were not found to contain invasive forestry species.

There was no difference in the ratio of angiosperms to gymnosperms in the invasive/noninvasive classes. Approximately 87 percent of each category were angiosperm species and 13 percent were gymnosperm species.

TABLE 2. OCCURRENCE OF INVASIVENESS IN THE 10 LARGEST FAMILIES IN THE DATASET

Family	Not inv. /nat.	Not inv./ nat. %	Nat. only	Nat. only %	Nat. & inv.	Nat. & inv. %	Total species
Leguminosae	56	42%	19	14%	58	44%	133
Pinaceae	9	22%	0	0%	32	78%	41
Myrtaceae	4	15%	1	4%	21	81%	26
Rosaceae	0	0%	1	5%	19	95%	20
Cupressaceae	7	44%	0	0%	9	56%	16
Meliaceae	4	31%	2	15%	7	54%	13
Salicaceae	2	17%	0	0%	10	83%	12
Palmae	4	33%	1	8%	7	58%	12
Fagaceae	3	27%	0	0%	8	73%	11
Moraceae	1	9%	1	9%	9	82%	11

Not inv./nat: Not invasive or naturalized
Nat. only: Naturalized only
Nat. & inv.: Naturalized and invasive

3.4. Geographic characterization of the dataset

3.4.1. Location of introductions

The location of introduction was identified, in full or in part, for 388 of the 458 forestry tree species known to occur outside their native range (85 percent). Figure 3 shows the number of forestry species that were recorded as introduced, intentionally or by accident, into each of seven geographic regions (Europe, Africa, Australasia, North America, South America, Pacific and Asia). Introductions of forestry species were recorded for all regions, but the largest number of reports was for introductions to Africa (219 species). The dataset contained fewest records of forestry species introduced into Europe (95 species) and the Pacific (97 species). A large proportion of the species encountered had been introduced to many countries, across several geographic regions. For example, among the genus *Acacia*, 18 of the 46 species in the database for which the destinations of introductions were known, had been introduced into 20 or more countries. *Acacia holosericea*, *A. auriculformis* and *A. farnesiana* were reported to be exotic in 69, 58 and 57 countries, respectively. In contrast, approximately one-third of the *Acacia* species were listed as occurring in less than five countries outside their native range. On average, *Acacia* species were introduced into 19 countries. Seven tree species used in forestry (*Artocarpus altilis*, *Albizia lebbeck*, *Acacia decurrens*, *Acacia melanoxylon*, *Salix babylonica*, *Acacia farnesiana* and *Acacia holosericea*) had been introduced into countries outside their native range in all seven geographic regions.

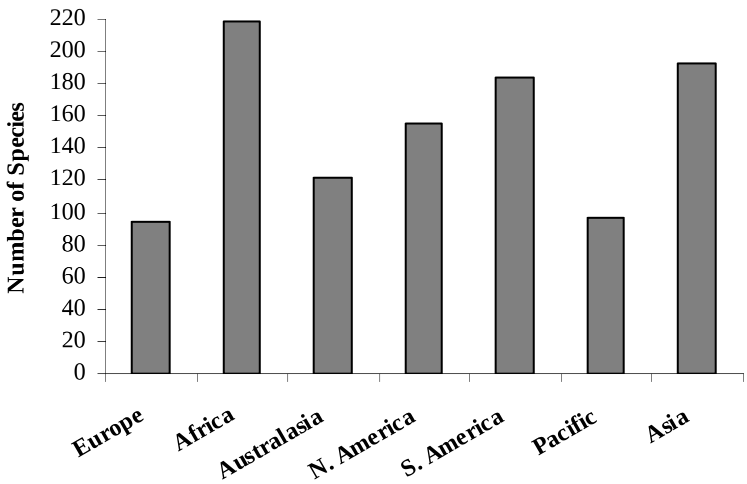


FIGURE 3. NUMBER OF FORESTRY SPECIES ENCOUNTERED IN THE REVIEW THAT WERE RECORDED AS HAVING BEEN INTRODUCED INTO EACH OF SEVEN GEOGRAPHIC REGIONS.

In the majority of cases, there was a lack of information on the mode of introduction (deliberate or accidental) and the country of origin of the introduced material. There were few reports of tree species (from any of the economic use categories) having been introduced accidentally, and several reports expressed uncertainty concerning the nature of the introduction event. Among those introductions thought to be accidental, Ghate (1991) described the introduction to India of *Senna occidentalis*, an agroforestry/amenity species, "along with foreign goods in a very early period" before the eighteenth century, and the more recent introduction of a forestry species *Senna uniflora* in 1980. In the absence of conflicting information, and taking account of the economic value of many of the species concerned, it was presumed that the vast majority of introductions of forestry species were deliberate events.

3.4.2. Location of naturalization and invasion events

Of the 322 forestry tree species in the dataset reported to be exotic and naturalized or invasive in at least one country, the locations of naturalization/invasion were identified, at least in part, for 246 species (76 percent). Figure 4 summarizes the number of species recorded as invasive (and naturalized), or naturalized (but not invasive) in each of the seven geographic regions. Appendix 3 lists in full the species reported as naturalized and/or invasive in each geographic region.

The region with the highest reported number of invasive forestry tree species was Africa, with 87 invasive species and a further 11 naturalized species. The lowest number of invasions was reported in Europe (12 forestry trees reported as invasive and a further 12 reported as naturalized). The large number of forestry species reported as naturalized or invasive in South America (114) was dominated by reports of naturalized or invasive species in Puerto Rico, where 23 forestry trees were known to be invasive and a further 59 were naturalized. A single source (Francis and Liogier 1991) contributed the majority of Puerto Rican data. The 14 species reported invasive in Asia (with a further 15 species reported naturalized) could be divided into those occurring in temperate or tropical regions. Two species (*Casuarina equisetifolia* and *Acacia longifolia*) were reported to be naturalized and invasive in temperate Asia. Twelve invasive and thirteen naturalized species were reported in tropical Asia. None of the species was reported to be invasive in both temperate and tropical parts of Asia, although *Ziziphus mauritiana* was reported to be naturalized in both climatic zones.

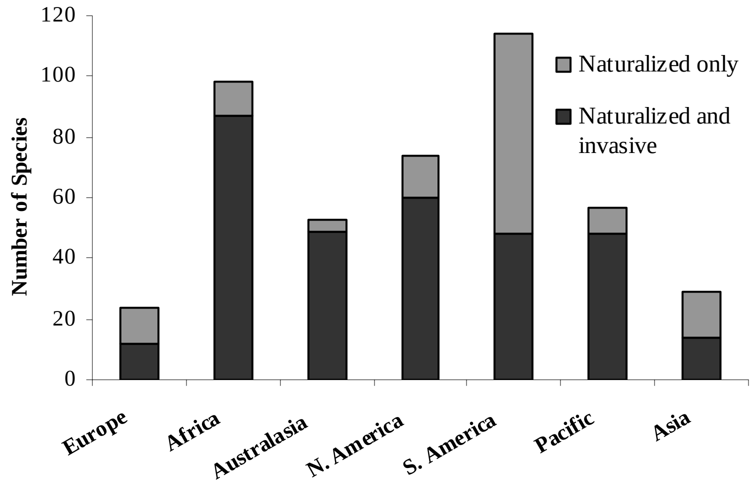
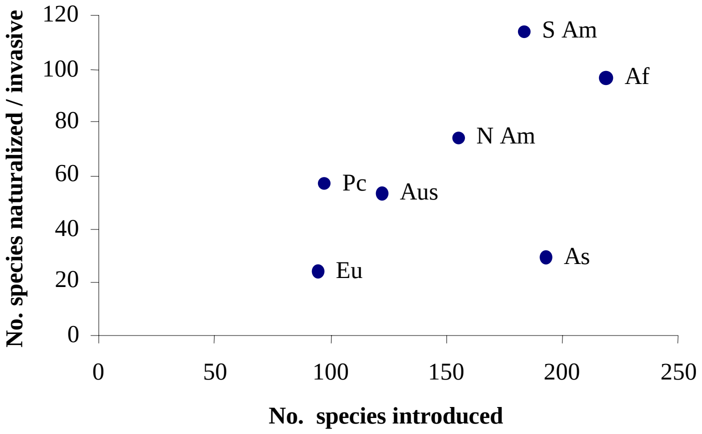
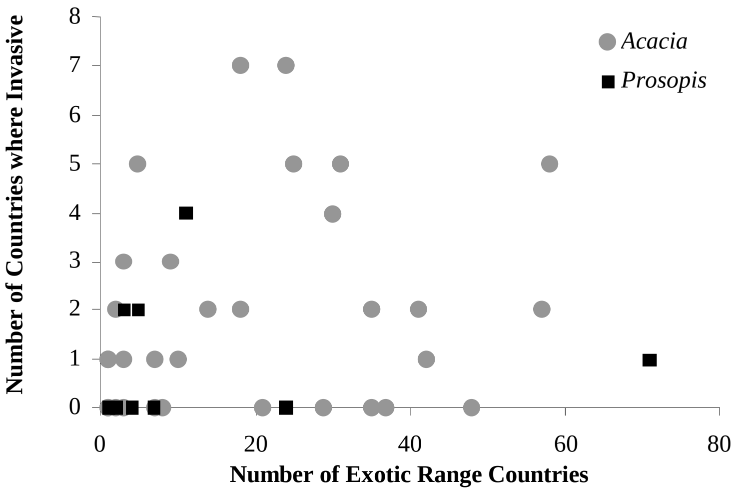


FIGURE 4. NUMBER OF SPECIES REPORTED AS NATURALIZED OR INVASIVE IN EACH OF SEVEN GEOGRAPHIC REGIONS.



<u>FIGURE 5.</u> NUMBER OF SPECIES REPORTED TO BE NATURALIZED OR INVASIVE IN EACH GEOGRAPHIC REGION PLOTTED IN RELATION TO THE NUMBER OF SPECIES REPORTED INTRODUCED IN EACH REGION.
Region codes: Eu, Europe; Pc, Pacific; Aus, Australasia; N Am, North America; As, Asia; S Am, South America; Af, Africa.

A general observation was that, for many of the species recorded as "invasive", the number of countries in which they had become invasive or naturalized was relatively small compared to the number of countries in which they had been introduced (Figure 5). For example, although *Prosopis* occurred exotically in over 70 countries (*Prosopis juliflora* alone was recorded as an exotic in 71 countries), and *Acacia* in over 60 countries (*Acacia holosericea* in 69 countries), the highest number of countries in which an individual species was reported as invasive was seven (*A. melanoxylon* and *A. nilotica*). A scatter plot showing the number of countries in which *Acacia* and *Prosopis* were introduced, and the number of countries in which they were reported as invasive, is shown in Figure 6.



<u>FIGURE 6.</u> NUMBER OF COUNTRIES IN WHICH 46 SPECIES OF *ACACIA* AND 9 SPECIES OF *PROSOPIS* WERE INTRODUCED, VERSUS THE NUMBER OF COUNTRIES IN WHICH THESE SPECIES WERE REPORTED AS INVASIVE.

The majority of forestry species for which the location of invasion/naturalization events were known were invasive in only one geographic region (Figure 7). The highest number of regions in which a forestry species was recorded as naturalized or invasive was six. Eleven forestry species were naturalized or invasive in five regions. This mirrored the pattern observed in the complete dataset from all categories of tree use (Figure 8). Across the whole dataset (all categories of tree use) the species with the widest geographical pattern of naturalization and invasion were *Robinia pseudoacacia* (six regions), and in five regions *Azadirachta indica*, *Casuarina equisetifolia*, *Pithecellobium dulce*, *Prosopis juliflora*, *Psidium guajava*, *Ailanthus altissima*, *Acacia dealbata*, *Acacia melanoxylon*, *Acacia mangium*, *Leucaena leucocephala*, *Schinus terebinthifolius*, *Broussonetia papyrifera* and *Lantana camara*.

3.4.3. Origin of invasive species

Figure 9 shows the native regions of forestry species that were reported to be naturalized or invasive in at least one country. Those forest trees with a native range that included the Pacific produced the fewest records of naturalized or invasive species (11 species), while Asia produced a total of 79 invasive species, including 55 from temperate areas and 47 from tropical areas.

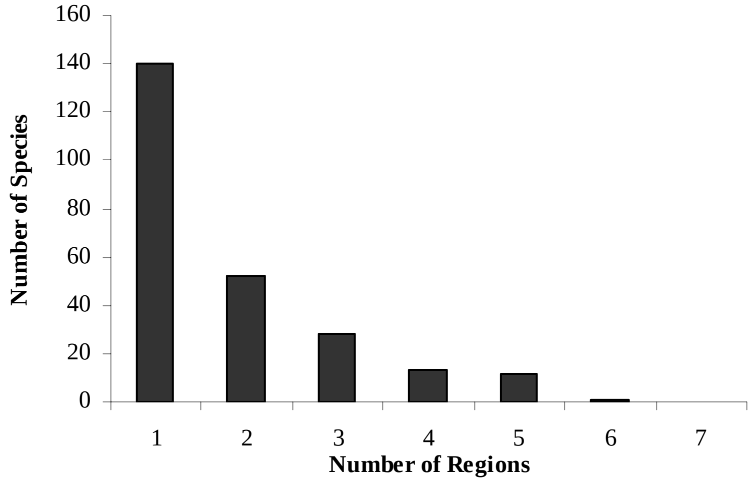


FIGURE 7. NUMBER OF FORESTRY TREE SPECIES RECORDED AS NATURALIZED OR INVASIVE IN ONE OR MORE OF THE SEVEN GEOGRAPHIC REGIONS.
Data summarize the results of 246 forestry species for which the locations of naturalization or invasion events were known. None of the species was recorded as exotic and invasive or naturalized in all seven geographic regions.

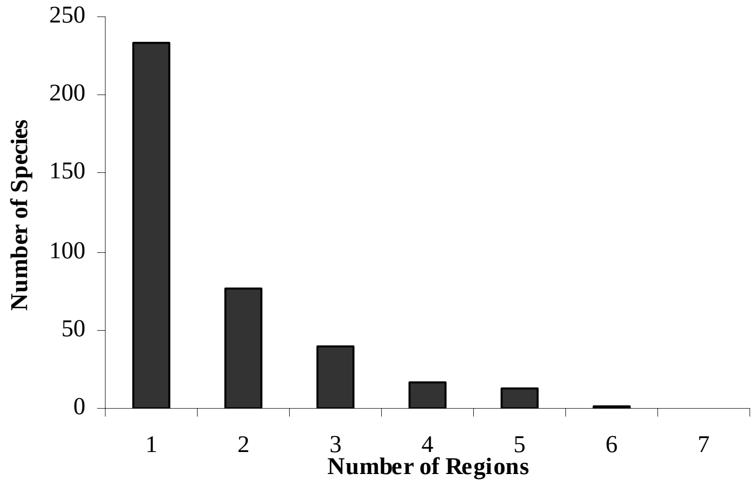


FIGURE 8. NUMBER OF TREE SPECIES RECORDED AS NATURALIZED OR INVASIVE IN ONE OR MORE OF THE SEVEN GEOGRAPHIC REGIONS.

Data summarize the results of 380 forestry, agroforestry, amenity and unclassified trees. None of the species was recorded as exotic and invasive or naturalized in all seven geographic regions.

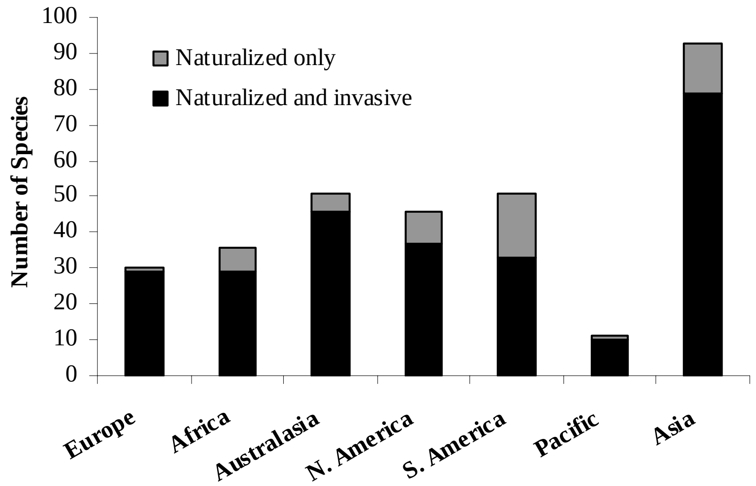


FIGURE 9. NATIVE RANGES OF FORESTRY SPECIES REPORTED TO BEHAVE INVASIVELY IN AT LEAST ONE COUNTRY.

The number of naturalized or invasive species originating in each of seven regions is shown. Note that the native range of several species included more than one geographic region.

3.5. Invasiveness in relation to time since introduction

Information on date of introduction was lacking for many species. In the case of forestry species, information on date of introduction was obtained for 51 (approximately 13 percent) of the 388 tree species where location of introduction was known. Information for species in other usage categories was similarly poor: of 158 tree species used for agroforestry, amenity or unclassified purposes (for which the location of introduction was known), the date of introduction was obtained for only 16 (10 percent). Almost universally, dates of introduction were found for only a fraction of the countries into which a species had been introduced, i.e. for any one species, information on introduction date was readily available for generally no more than 17 percent of the countries in which it had been introduced. Furthermore, where dates of introduction were known, it was usually impossible to separate small-scale or individual introductions from large-scale planting programmes. Hence, because of the lack of consistent, wide-scale, reliable data sources, no attempt was made to investigate the relationship between time since introduction and the occurrence of an invasion event.

3.6. Invasiveness in relation to scale of planting

Species level information on scale of planting was scarce, as were global data on plantation statistics that could be used to evaluate any potential relationship between scale of planting and scale of invasion. Country plantation statistics in the comprehensive *Global Forest Resources Assessment 2000* (FAO 2001) were summarized by total plantation area and by the plantation area of eight major categories: *Acacia*, *Eucalyptus*, *Hevea*, *Tectona*, “other broadleaved”, *Pinus*, “other coniferous” and “unspecified”. Even at this broad level, information on the distribution of plantations among the eight categories was not available for every country. For some countries, more detailed information on genera used in plantation forestry was given in the country profiles at the FAO website (http://www.fao.org/forestry/fo/country/nav_world.jsp); however, for many countries, this more detailed information was unavailable. The lack of data at species level prevented further analysis because no distinction could be made between plantations comprising native or exotic species. Similarly, no distinction could be made between plantations of forest trees known to behave invasively and those comprising species not known to spread beyond the plantation.

3.7. Invasiveness in relation to biological characteristics

An attempt was made to evaluate data on invasiveness in relation to biological characteristics such as “pioneer” (i.e. a plant occurring early in a vegetation succession), versus “climax” (i.e. a plant occurring in the latest stage of succession). Although these terms are useful and widely applied in the description of specific succession processes, it was considered that the tendency to behave as an “*r*- or *K*-strategist” (MacArthur and Wilson 1967; Pianka 1970) falls along a gradient. Typical *r*-strategist plants have a high rate of increase in uncrowded or otherwise favourable environments (i.e. the early stages of succession), manifested by rapid growth and the production of large quantities of easily dispersed seeds, rapid germination, etc. (Allaby 1994). Typical *K*-strategist plants live in a constant or predictable environment and experience density-dependent regulation. *K*-strategists often exhibit a smaller and delayed reproductive effort (Begon and Mortimer 1986). For many tree species represented in the dataset there was insufficient information to categorize them as “pioneer” or “climax” species on anything other than a highly subjective basis. It was also considered likely that species that occurred naturally in a range of ecosystems might occupy different stages in the successional process in different habitats, and that this could pose further problems in allocating them to a particular category. In this report, therefore, there has been no attempt to present data on the invasive behaviour of forestry trees in relation to their successional status in their native range.

Attempts were made to collate data on other biological characteristics (e.g. deciduous or evergreen, and breeding system (monoecious, dioecious, polygamodioecious, etc.)). Key reference sources such as Mabberley (1993) and the *Forestry Compendium Global Module* (CAB International 2000), did not, however, provide data for every species. The breeding strategies of some species varied in different regions, perhaps according to provenance or subspecies. The available data were considered to be too inconsistent to evaluate invasive or naturalization events in relation to biological characteristics, although analyses of this type conducted by other authors on smaller datasets were taken into account.

3.8. Discussion

3.8.1. Critique of data sources and approaches

The aim of incorporating material from both standard lists of forest species (i.e. Ecocrop (FAO 1999) and Agroforestree (World Agroforestry Centre, 2002)), and sources of information on invasives (e.g. Binggeli 1999), was to present a more balanced summary of the status of invasiveness of forest trees, by ensuring that both invasive and noninvasive species were considered. The data should be interpreted cautiously, however, because both types of sources have various gaps and biases. For example, the number of species regarded as noninvasive may have been underestimated because for many of the species on the Ecocrop forest or wood list, no further data were obtained on whether introduction outside their native range had occurred. In this particular case, a negative response to the question of whether a species occurs outside its native range should be understood to mean either that the species definitely does not occur outside its native range, or is *not known* to occur outside that range. Similarly, because species listed as “alien and invasive” may automatically be classed as occurring outside their native range, a bias could have been introduced whereby the number of species occurring outside their native range was skewed by information from species regarded as invasive. It should be emphasized that all references to *percentages* and *proportions* of species refer to the proportion of species *encountered in the review* and not to a finite and comprehensive world list.

In many cases, the process of collating information on both forestry and invasiveness characteristics was made more difficult by the fact that information derived from forestry sources (on introduction, silvicultural characteristics, etc.) did not generally provide much information on invasive tendencies. On the other hand, references to a species behaving invasively tended to be set within a very local context, frequently without information on the mode, source or history of introduction, or on the distance from a site of introduction or the extent of forestry planting.

The broad approach taken to incorporating information from different types of sources (published papers, electronic databases and personal communications) allowed new information to be included, particularly from regions where there were few written accounts. However, such an approach is vulnerable to the incorporation of errors, such as misidentification of a species. Several correspondents sent incorrect species identifications, which were later corrected. A review of this type relies heavily on the accuracy of original sources, because it is difficult to verify observer or even published records.

The "species based" approach was chosen to allow evaluation of the extent to which individual species were invasive in relation to their exotic range. Sometimes authors or correspondents reported invasiveness at genus level, e.g. *Eucalyptus* in Brazil (S. Ziller, personal communication, 2002). To avoid conferring invasive status on whole genera, such reports were omitted from the main summary, possibly leading to an underestimate of the occurrence of invasiveness for certain groups or localities where exact identifications have not been made or recorded.

Finally, the acceptance of authors' own terms (naturalized, invasive, etc.) conveys author perception, but it must be emphasized that variation in the use of these terms among authors places a caveat on the extent to which "naturalized" and "invasive" species can be distinguished in this summary. Some authors, for example, routinely spoke of "naturalized and spreading species" which other authors may have termed invasive. In tables listing invasive species for a region, it was not always clear whether a species was present merely as an exotic or as an invasive, and some sources combined both invasive alien and native species. In regions where there have been few studies to evaluate the presence and impact of invasive species, there was a tendency to describe the introduction or occurrence of "invasive alien species" such as *Lantana camara*. In these circumstances, it was not always clear whether a source was referring to the introduction of a species known to be invasive in another country (in the absence of local information) or to a species that was actually behaving invasively at that location. However, there were relatively few records of this type, so that instances of invasiveness are unlikely to have been substantially overestimated in this review. In a global context, it is more likely that invasiveness has been underestimated, due to the unequal recording of invasive species in different countries. A further complication was the large number of approaches used by authors to rank the "invasiveness" of species. So many methods were applied to ranking that it was not felt appropriate to use ranking in this review, other than providing information on those species known to be invasive in many geographical regions.

3.8.2. Conclusions

Estimation of the scale of naturalization and invasion events. The lack of readily available data at species-level, both on area of planting and on area occupied by species that have spread beyond the cultivation zone, restricts discussion of scale of invasion to a single currency, i.e. species number. However, the number of invasive species can only be a very crude summary of the phenomenon, because it makes no distinction between those species that have become only locally invasive (and make little impact on a country's economics and biodiversity), and those that cause major changes across countries and regions. Even with this caveat, the evidence obtained for this review suggests that alien invasive trees are a major phenomenon, with at least 443 species known to be invasive, including an estimated 282 forestry trees. Although these figures include 68 tree species listed as "possibly naturalized/some degree of invasiveness" in Binggeli (1996), where the extent of spread was either limited or unknown, this is in general agreement with analyses by another author (Richardson 1996, 1998) whose conclusion was that "of all the dominant tree genera used for commercial forestry, all except *Abies*, *Fagus*, *Gmelina* and *Swietenia* are noted as alien invaders". Binggeli (1999) subsequently classed *Abies alba*, *A. nilotica*, *A. nordmanniana* and *A. grandis* as potential invaders, *A. sibirica* and *Fagus sylvatica* as moderate invaders and *Gmelina arborea* as a moderate invader that was naturalized in the Pacific region. Furthermore, *Swietenia mahogoni* is invasive in Hawaii (University of Hawaii Botany Department 1998) and *S. macrophylla* has been classified as invasive in Sri Lanka (Cronk and Fuller 1995).

Richardson (1996) focused on the invasiveness of so-called "wonder trees", multi-purpose trees that could be grown in a variety of extreme conditions. In that review, all-purpose trees (those with applications in forestry, agroforestry and amenity), made up approximately 29 percent of the species encountered that were known to occur outside their native range. The proportion of this group that were rated as invasive or naturalized (71%) was in agreement with trees in other categories such as forestry (70 percent) or agroforestry (71 percent). Yet it should be noted that these categories were not exclusive: most species belonged to at least two usage categories, and the proportion of trees with a single use was relatively small. Similarly, the inherent bias of the information collecting process towards the more widely used or widely distributed species is likely to have ensured that many of these species could, at one time or another, have been regarded by foresters as "wonder trees".

Where species have different applications (plantation forestry, amenity, agroforestry) it is likely that their establishment, management and spatial/landscape placement conditions are likely to vary, and could potentially influence their likelihood of becoming invasive. For example, compare the case of a single street tree – separated from any neighbours and isolated in an urban environment away from potential areas to colonize – to that of a large stand of a commercial forest species situated upwind of a suitable area for seed establishment.

Rouget *et al.* (2001) recommended the careful siting of potentially invasive species at landscape level, particularly in relation to neighbouring areas of high wildlife value. However, in general, few papers were found in which a species invasion was considered in relation to the scale of a planting or its position in the landscape. Evidence that some species have become naturalized following introduction in relatively small trial plots (Hughes 1994) suggests that the threshold planting area required to precipitate invasion is likely to vary among species. Similarly, species that are harvested before they reach sexual maturity and set seed may not express an otherwise invasive character.

This may account for the apparent difference in the behaviour of *Pinus contorta* var. *latifolia* in the UK and Scandinavia (David Wainhouse, personal communication, 2002). In Scandinavia, where it is harvested after sexual maturity, it is regarded as potentially invasive (Andersson *et al.* 1999). In Britain, where it is harvested at a younger age, fewer problems are encountered, although Richardson and Higgins (1998) (cited by Andersson *et al.* (1999)), noted that this species spreads in Scottish forests that are disturbed by sheep grazing. The fact that this species is prone to insect defoliation in Britain may help to limit its invasive tendencies (Heritage 1997).

In general, more accurate data are required on the scale of planting, the scale of invasion events and variations in management practice, before species invasion can be understood and, potentially, managed.

Taxonomic characteristics of invasive species. In this review, the families that included the largest number of invasive species were, in decreasing order: Leguminosae, Pinaceae, Myrtaceae, Rosaceae and Salicaceae. This is broadly in agreement with those named in Binggeli (1996)(although this is not surprising as many of the trees included in this review were drawn from the latter publication). This does not lead conclusively, or automatically, to the view that some families are inherently more invasive than others. Testing this hypothesis would require the separation of scale of planting from reproductive and growth biology, since species in these families are among the most widely introduced of forest trees.

Location of naturalization and invasion events. Although the data used in this review documented the large-scale introduction of forestry species across many countries and continents, there were many cases in which the source or history of an introduction was either unknown or unidentified. Without information on the location, scale and history of an introduction it is impossible to calculate the rate of spread, or to estimate any “time lag” between introduction and invasion. It is possible that certain provenances or subspecies have the capacity to become invasive more frequently that others, yet it is difficult to predict where problems may arise when knowledge of local provenances and their behaviour is so fragmented.

The overwhelming conclusion from the distribution of invasive events was that the invasion and naturalization of forestry, and other commercially used trees and woody shrubs, is a global phenomenon. Invasive species were reported in all seven regions (Europe, Africa, Australasia, North America, South America, Pacific, Asia), although the relative number of invasive species in each region is likely to reflect, in part, the availability of reliable data sources. Investment in cataloguing the invasive species “problem” has been particularly high in South Africa and North America and the availability of data sources such as Henderson (2001), the INVADERS Database System (Rice 2002) and the lists produced by the various North American Exotic Pest Plant Councils make it unsurprising that Africa and North America are among the regions with the highest numbers of reported invasive species. Figure 3 may infer as much about the scale of *reporting* as about the scale of *invasion* in the different regions.

The case of Puerto Rico demonstrates the sensitivity of this type of data to the contributions of individual research groups. Of 114 forestry trees reported as naturalized or invasive in the region, 68 were listed in Francis and Liogier (1991) as naturalized or invasive in Puerto Rico. Excluding all the species for which the only South American record was from Puerto Rico would have reduced the South American list by 61 species (54 percent). Of these 61 species, 53 (87 percent) were reported by Francis and Liogier (1991), underlining the large contribution to the South American list that was made by a single scientific paper. Similarly, it is interesting to note that the African region is dominated by reports of invasions in South Africa, Botswana and Zimbabwe, countries that have been the focus of intensive research on invasion ecology (e.g. Richardson *et al.* 1994; Richardson 1996; Henderson 2001) or the subject of recent reviews (e.g. Buss 2002; Nyoka 2001). A disproportionately low number of species were recorded in Africa outside these countries, particularly in central and northern Africa. The only exception to this distinct bias was a group of reports for African islands, e.g. Mauritius, Reunion, St Helena, etc., where again there has been considerable investment in the cataloguing of exotic species. It seems likely that further research in other parts of Africa will uncover previously undocumented cases of invasive species.

Binggeli (1996) reported the distribution of invasions in the temperate zone “from most regions with the exception of southern America and Asia and in the tropical zone from Pacific and Indian Ocean islands without any records from South America”. Correspondence conducted for this study resulted in the reporting of numbers of invasive species from South America which were similar to those reported from the known centres of invasive species research, i.e. Australasia and the Pacific. If naturalized species were included, South America became the region with the largest number of naturalized or invasive species. The more limited number of reports from Asia (see Figures 4 and 5) would appear to be due to the fact that, although many countries are aware of the potential problem, detailed inventories of invasive species or studies of their impact have not been conducted.

At a recent workshop on the prevention and management of invasive alien species in South and Southeast Asia, many country delegates commented that research on invasive species and their impact was required in the region (e.g. Paudel and Kaini 2002; Sinohin and Cuaterno 2002). There appears to be an additional information gap in temperate Asia: for example, a Chinese website on invasive species (Chinese Biodiversity Information Centre 2002) lists no invasive forest trees. Furthermore, Wang (2001) stated that although some species “had naturalized” there were no accounts of invasive species from China. This is despite the fact that China has the largest area of plantation forestry in Asia (nearly 40 000 ha) (FAO 2001).

The low number of species recorded as invasive in Europe is likely to reflect the comparatively low number of commercial tree species planted in the region.

Invasiveness as a species trait. Although many species have been introduced into 20 or more countries, most species were reported as invasive in only a fraction of their exotic range (see Figure 4). Several factors may account for this disparity, including a lack of reporting (as discussed above). In other cases it is possible that there has been insufficient time since introduction for invasion to be expressed. A third possibility is that invasiveness is not purely a species trait, but a complex interaction between a species’ reproductive biology, the local habitat, management, landscape characteristics and the established local flora. Further research and monitoring are needed to understand the extent to which a species may be classed as invasive across its exotic range and what factors are involved in the occurrence of local invasions (Section 5).

It is also desirable for the impact of invasive species to be monitored over longer time scales. For example, Walters and Savill (1992) reported the alternation of regeneration between invasive sycamore (*Acer pseudoplatanus*) and native ash (*Fraxinus excelsior*), and questioned the extent to which *A. pseudoplatanus* threatens British woodland in the face of such an interaction.

4. EFFECTS OF INVASIVE FOREST TREES

This paper reviews both the positive and negative effects of invasive exotic trees and woody shrubs from a global perspective. However, it should be noted that definitive reports on impacts are rare and on a global scale information is very patchy. This paper does not cover the basic benefits of forestry and agroforestry *per se* as these have already been reviewed by Mather (1993) and Evans (1982) for forestry trees and by Hughes and Styles (1989), Nair (1990) and Hughes (1994) for agroforestry.

In several of the situations discussed in Sections 4.1 and 4.2, a conflict of interest has arisen (when a tree becomes invasive) between the value that results from the introduction (including values that might arise out of invasiveness) and the perceived negative impacts; this is discussed further at the end of this chapter.

4.1. Positive effects resulting from the invasiveness of exotic trees

In agroforestry, there are several reports of positive effects of trees and woody shrubs that have become invasive. As noted previously, most species introduced for agroforestry have been selected for a number of traits, including their suitability for fodder and fuelwood. In many areas of the developing world, the very high demand for forest products has meant that local communities have exhausted their natural supplies. In some cases, though, the aggressive, spreading nature of introduced trees has resulted in reforestation, albeit with an introduced species. This in turn has provided rural communities with a “free” and continuous supply of forest products.

For example, *Prosopis juliflora* was introduced into India from Central America. It is now invasive in most of India where it grows on waste ground, along roadsides and in pastures. The rural poor in India now exploit these trees for vital supplies of fuel and pods (Muthana and Arora 1983; Pasiecznik *et al.* 2001). Some of the American *Prosopis* species also exhibit similar behaviour *within their native range*. Ranchers dislike these natural successional invasions of native *Prosopis* species in grasslands because they occur in dense stands and reduce the amount of available fodder. Comparable situations are likely to exist for other introduced agroforestry trees in other parts of the world, but have not been widely reported.

In a similar vein, many invasive alien trees are reported by some Forest Departments as providing important soil stabilization in areas where natural forests have been over-exploited (e.g. Karnataka Forest Department, India, personal communication, 2002). Both of these impacts need further study.

4.2. Negative effects resulting from the invasiveness of exotic trees

Reports of effects that can be classed as "negative" can be divided into the following categories:

- hybridization of tree species,
- economic and social impacts, and
- environmental impacts.

4.2.1. Hybridization between tree species

Hybridization can occur between different species introduced into the same area or between an introduced and a native species. There are few recorded instances of negative impacts of hybridization in trees. However, some examples do exist, as documented by Hughes (1998) in the case of *Leucaena*, a genus known to hybridize readily and of which several hybrids already exist. One hybrid, *L. leucocephala* × *L. diversifolia*, which occurs naturally in central America, Papua New Guinea and the Philippines, is self-fertile and has become weedy in at least one location (Veracruz, Mexico). Similar problems have arisen from hybrids of *Prosopis* species in South Africa (Pasiecznik *et al.* 2001). Given that an increasing number of species of *Leucaena* and other trees are being introduced, largely unchecked, in other parts of the world, the main concern is that other hybrids with weedy tendencies may also arise (see Section 4.3).

Hybridization coupled with backcrossing (introgression) can lead to contamination of natural gene pools. Again, few problems have been reported in the literature, but this situation is likely to occur in the case of the *Leucaena* complex in Mexico referred to above (see Hughes (1998)). *Quercus, Eucalyptus, Erythrina* and *Acacia* all have the ability to cross readily, but since it requires considerable effort to understand the genetic diversity of even a single species, studies of genetic diversity and the ability to form hybrids have been conducted for only a small group of taxa, including some species of *Salix*, *Populus* and *Erythrina* (C. Hughes, personal communication, 2002). It is therefore possible for invasive hybrids to be overlooked, particularly where invasions are discussed only at the generic level (as for *Tamarix* and *Eucalyptus*).

4.2.2. Economic, social and environmental impacts

Economic, social and environmental impacts are considered together since some of the issues are interlinked. In many cases invasive forestry species invade natural or semi-natural ecosystems in developing countries and have an impact on the services that those ecosystems provide to local communities. However, despite the large number of invasive species that have been recorded, little economic data exists on the impact of these species and few studies have quantified environmental impacts.

Invasive trees and woody legumes can be conveniently classified according to the following types (Holzner, 1982; Hughes and Styles, 1989):

- ruderal – weeds of waste ground and disturbed habitats;
- agrestal – weeds of crops, orchards and gardens;
- pastoral – weeds of grasslands;
- silvicultural – weeds of forestry plantations;

- floral/environmental – weeds that compete with native flora (or are harmful to specific ecosystems);
- aquatic – weeds of wetlands and water bodies;
- health related – weeds that harbour pests and diseases or act as alternative hosts for such species.

As seen in Section 3, there are examples of invasive trees and woody shrubs in each of the first six categories; whilst the final category is an important one it is not considered in this report. Following the approach of Hughes and Styles (1989) the impacts of invasive trees and woody shrubs are considered under each of these categories.

Ruderal weeds. Globally, the highest proportion of invasive tree and woody shrub species is found in wasteland and disturbed habitats. As discussed above, it is likely that in these situations the species concerned are providing benefits such as soil stabilization or fuelwood for local communities.

Agrestal weeds. In general there are few reports of trees and woody legumes in these situations, since such systems tend to be intensively managed. Nevertheless, the woody legume *Mimosa pigra* has been reported as an important weed in rice fields and sugar plantations in Asia, and *Leucaena leucocephala* as a weed of cocoa in Hawaii, where it is planted as a shade tree (see Hughes and Styles 1989). Impacts in terms of yield loss and increased labour costs are not available. Other examples probably exist but are unlikely to be significant.

Pastoral weeds. World wide, there are many records of the invasion of grassland pastures by exotic woody legumes, especially species such as *Acacia farnesiana*, *Mimosa pigra*, *Prosopis glandulosa* and *P. velutina*. These legumes reduce the amount of grass fodder available for grazing and also create dense thickets through which livestock cannot move. The principal countries affected include Australia, South Africa and Zimbabwe. Large-scale eradication and control programmes have been undertaken in most of the affected countries, but have been costly and generally ineffective (see Section 4.3).

Silvicultural weeds. Many of the trees used in commercial forestry are known to be highly invasive, especially species of *Acacia* and *Pinus* (Richardson, 1998). In Sweden, the lodgepole pine (*Pinus contorta* var. *latifolia*) has been reported as invasive, regenerating spontaneously even within plantations. This phenomenon is more common in older stands. In Scotland, this species also affects forest plantations of other species (Andersson *et al.* 1999). The costs involved in managing these self-sown trees within plantations are not readily available. In the more tropical parts of Australia, *Acacia* species commonly invade *Pinus radiata* plantations.

Floral/environmental and aquatic weeds. Globally, most reports of invasions of trees and woody shrubs relate to semi-natural or natural habitats. These reports include species from a wide range of genera and in general, most of the affected habitats are either semi-natural or natural with some degree of disturbance, e.g. the invasion of shrublands in Hawaii and California by *Eucalyptus globulus* and of semi-natural pine–oak woodlands in South and Central Europe by *Robinia pseudoacacia*.

In most cases, reported impacts are qualitative assessments, including, for example, the replacement of native flora and the disturbance of feeding and breeding grounds for invertebrates and vertebrates. Interestingly, the likely impact of invasive forestry trees on nutrient cycles and soil biodiversity has received very little attention, although in New Zealand, *Pinus radiata* has been shown to alter the hydrology and nutrient levels of plantation areas (Richardson *et al.* 1994). Another study in northern India has shown that *Lantana camara* (which is not used for forestry) can significantly reduce soil nitrogen and phosphorous levels in oak–pine woodlands (Bhatt *et al.* 1994).

Some studies have been made of invasions of pristine habitats. Most cases relate to invasions of open forest, grasslands and fir-dominated ecosystems, but other cases have been reported. For example, the Australian pine (*Casuarina equisetifolia*) has invaded the Florida everglades and shorelines, where it is reported to negatively affect crocodile and turtle nesting grounds (Randall *et al.* 1997); *Mimosa pigra* is also a major invasive species in the wetland areas of Thailand and Australia (Lonsdale *et al.* 1995).

Some of the best examples come from South Africa, where several pines and woody legumes (particularly *Acacias*) have invaded the fynbos biome in the south and the veld biome in the Transvaal (Richardson 1998). A number of economic and ecological studies (e.g. Geldenhuys 1986) have been conducted on the benefits of the trees versus their associated risks. For example, in the fynbos biome, the run-off from watersheds cloaked in invasive trees (mostly pines and *Hakea sericea*) is 30–70 percent lower than in pristine areas. Since fynbos catchments supply about two-thirds of the region's water needs, and large areas of these catchments have been invaded (Higgins *et al.* 1997; Richardson 1998), such invasions are of major concern. Furthermore, Richardson *et al.* (1989) reported that the species richness of fynbos ecosystems could be reduced by almost half when invaded by alien trees and shrubs.

4.3. Awareness and conflicts of interest

Over the past 10 years or so, there has been a growing national and international awareness of the possible risks of invasive forestry trees (see Hughes and Styles 1989; Richardson 1998). However, as mentioned above, apart from the basic benefits of forestry and agroforestry, some communities have derived additional benefits from invasive trees (e.g. an example from North Africa showing that some degree of invasion of grasslands by woody legumes can be beneficial for livestock grazing, particularly in time of drought (Hughes and Styles 1989)). In a number of cases, therefore, conflicts have arisen over the positive and the negative impacts of invasive tree species. Such conflicts include, for example, those between economic development and conservation, which have become increasingly common as conservation agencies have become more aware of the risks to biodiversity that can result from biological invasions.

The available literature includes few case studies with quantitative ecological and economic data that would help to resolve such conflicts. This lack of information has hindered the ability of national governments to understand the issues and to develop policies on further introductions. In many countries, an additional compounding factor is likely to be a lack of information and training in the use of environmental impact assessment. This has been identified as an important constraint in relation to the development and implementation of management schemes for existing invasive species (see Section 6).

In summary, more case studies are required in representative countries to examine the benefits and invasion risks of introduced forestry trees. This would increase awareness of the issues and help national governments to make balanced assessments of proposed tree introductions and expansions of plantations.

5. TREE INVASIONS: A SPECIES OR LANDSCAPE PHENOMENON?

At present, it is unclear whether environmental factors or species-specific characteristics are more important in determining the tendency of a species to become invasive. This problem has led to substantial research efforts over the past 15 years to try to identify those factors that might result in a tree becoming invasive (e.g. see Richardson 1998). This has been part of a wider effort to understand the general basis of invasiveness in plants (Rejmanek 2001). For example, one characteristic that has been frequently used to select trees used in forestry and agroforestry is growth rate, particularly in relation to poor soils. This has often resulted in trees being used that seed heavily and that can survive under a wide range of environmental conditions. Unfortunately, these very qualities can lead to a tree becoming invasive. If more such traits can be identified, it would both help to guide future searches for new forestry species and aid weed risk assessments for new and recently introduced species.

Richardson *et al.* (1994) were among the first to draw attention to the fact that, of the many pines introduced for forestry, some naturalize but remain largely under their own canopy, while others naturalize and then spread widely. In this review, 68 forestry species were listed in Binggeli (1996) as “possibly naturalized/some degree of invasiveness” but the extent of spread was either limited or unknown. Corroborating evidence that these trees were invasive was obtained for approximately one-third of these species.

There are many cases in which a species known to be highly invasive in at least one country has not shown the same trait when introduced elsewhere (or at least has not been reported as such), e.g. *Acacia melanoxylon*, *A. nilotica* and *Prosopis juliflora* (see Figure 4). It is well known that most invasive tree species have taken something like 50 years or more to attain that state (Hughes 1995). Time is thus a very important variable that needs to be taken into account when recording whether or not a species is invasive.

For those species classed as “naturalized” but not invasive, is it then just a matter of time before they become invasive, or will they remain naturalized? Richardson *et al.* (1994) cited some examples of naturalized pines that have subsequently become invasive whereas others have remained merely naturalized. If “invasiveness” is independent of time, then invasiveness could be linked to some species characteristic. If, on the other hand, the occurrence of invasiveness is strongly linked to time, then the start of an invasion might indicate some change in dispersal ability or colonization opportunities in the area of introduction. These aspects have received much attention from invasion ecologists and there is now a substantial body of scientific literature on the subject (see below). However, because of the absence of information on the time element in the dataset, identifying those tree species that are truly invasive versus those that are not is fraught with difficulties. This problem is compounded by the incomplete information available for so many of the records and the subjectivity of much of the information.

It would be of more practical significance to examine those species that have been recorded as highly invasive in at least one area, in order to determine whether or not some form of control or management by local communities is contributing to noninvasiveness in other areas.

In the following section, the results of previous studies on the "basis" of invasiveness are summarized in order to provide some background on the subject. Some aspects of the reported invasiveness of the genera *Acacia* and *Prosopis* are then evaluated to illustrate the importance of understanding the available data on invasiveness.

5.1. Previous studies on the "basis" of invasiveness

Trees have been identified as the most successful group of plant invaders (compared to other plant growth forms) in natural or semi-natural habitats (Cronk and Fuller 1995). Broadly speaking, biological factors that have been suggested as contributing to invasiveness fall into the following categories:

1. Species characteristics. Here, factors such as breeding systems and seed ecology may be important. Most plants are outbreeders with some capacity for self-fertilization and this seems to be the case for invasive plants (Cronk and Fuller 1995). For introduced trees, outbreeding may not be a constraint as many species have been introduced in large numbers, e.g. *Pinus radiata.* Furthermore, many of the introduced trees produce large quantities of seed (e.g. pines, eucalypts, woody legumes) and Richardson *et al.* (1994), through their work on pines, have suggested that propagule pressure is an important factor contributing to invasiveness.

2. Seed dispersal mechanisms. Cronk and Fuller (1995) collated information that showed that the dispersal of many invasive plants is facilitated by vertebrates. In New Zealand, over half of the woody invaders have fruits that are adapted for dispersal by birds. Similarly, in South Africa, the most successful *Acacia* species are those dispersed by birds.

3. Absence of herbivores/competitors/pests. There are many studies that show that trees in their native ranges are attacked by a wide variety of coevolved micro-organisms and herbivores (both insects and vertebrates). However, when trees are introduced they are often relieved of this pressure, as the herbivores etc. in the area of introduction are not coevolved and are usually less diverse. Such observations underpin the concept of "classical" biological control for weeds.

4. Ecosystem disturbance. Most invasions by forestry trees occur in semi-natural ecosystems (see Section 4) and "disturbance" has frequently been identified as an essential prerequisite for invasion by an introduced species. Further support for this idea comes from Hughes and Styles (1989) who cited examples from South America of introduced trees that were unable to invade natural ecosystems.

5.2. Case study: evaluation of Acacia and Prosopis

Acacia and *Prosopis* are two genera in the family Leguminosae, tribe Mimosoidae. Among other characteristics described more fully in CAB International (2000), many species in these genera have bisexual flowers, fix nitrogen through rhizobia, have the ability to regenerate rapidly following the loss of plant parts and can exist in a range of growth forms (e.g. shrub, small tree, large tree etc.), depending on their environment. Within both genera, there are species that can survive extremes of temperature, aridity, shade, frost, weeds, fire, salt, waterlogging and browsing. Their main pollinators are insects and birds. The ability of these trees to tolerate difficult environments and to provide useful products (e.g. fuelwood, timber and nutritious pods that can feed cattle and sheep in savannah-type grazing systems), makes them attractive not only for forestry and agroforestry, but also for soil improvement or stabilization. As a result, they have been introduced to a large number of countries (see Figure 4). However, several species (e.g. *Acacia nilotica*, *A. melanoxylon* and *P. juliflora*) have subsequently become invasive.

Many of the positive attributes listed above could also contribute to invasiveness. For example, vigorous growth, though useful for coppicing systems, can be detrimental if the bushes form unmanageable thickets, particularly if the species concerned are also thorny. However, even the most notoriously invasive *Acacia* and *Prosopis* species have only been reported as invasive in a fraction of the areas in which they have been introduced (see Figure 4 and Section 3.4.2).

A correspondence analysis (based on data extracted from CAB International (2000)) was performed on the ability of various *Acacia* and *Prosopis* species to tolerate climatic factors (drought, rainfall, maximum temperature etc.) and to regenerate rapidly. The summarized tolerance scores for axes 1 (drought tolerance/rapid regeneration) and axes 2 (frost tolerance) were then used in a principal components analysis (PCA) along with the latitudinal, altitudinal and climatic range of these species. The hypothesis being tested was that "invasive" species would be more tolerant of various extremes, or could be separated from "noninvasives" by some other characteristic. Figure 10 shows the result of this analysis.

According to the PCA, there was considerable overlap in the characteristics and environmental tolerance ranges of both invasive and noninvasive *Acacia* and *Prosopis* species. The distribution of the points summarizing the characteristics of invasive and noninvasive species also broadly overlapped. A more comprehensive dataset that included more biological characters (e.g. seed size, seed dispersal, reproductive system, age at first reproduction, etc.) would have allowed a more detailed analysis to be conducted (similar to that undertaken for the genus *Pinus* by Richardson *et al.* 1994). The two groups might have appeared more distinct if a broader range of characteristics could have been considered.

The basis on which such an analysis could be performed, however, may be questionable. For example, at what point should a species be defined as "invasive", considering that it may have been introduced into 20 countries but become invasive in only one? Rather than using average data on a species' biological characteristics, it may be more appropriate to use local data drawn specifically from sites of invasion versus noninvasion. However, at present, such data appear to be largely unavailable. Furthermore, for such an analysis to be valid, reporting of invasion must be equally reliable for all species. If such data could be provided, then this type of analysis might be a viable tool for better understanding invasiveness, and even for performing risk assessments on the introduction of new species. It is important to remember, however, that management approaches may differ in different areas, and that they, too may affect the status of a species (not invasive, naturalized, invasive, etc.) in different parts of its exotic range.

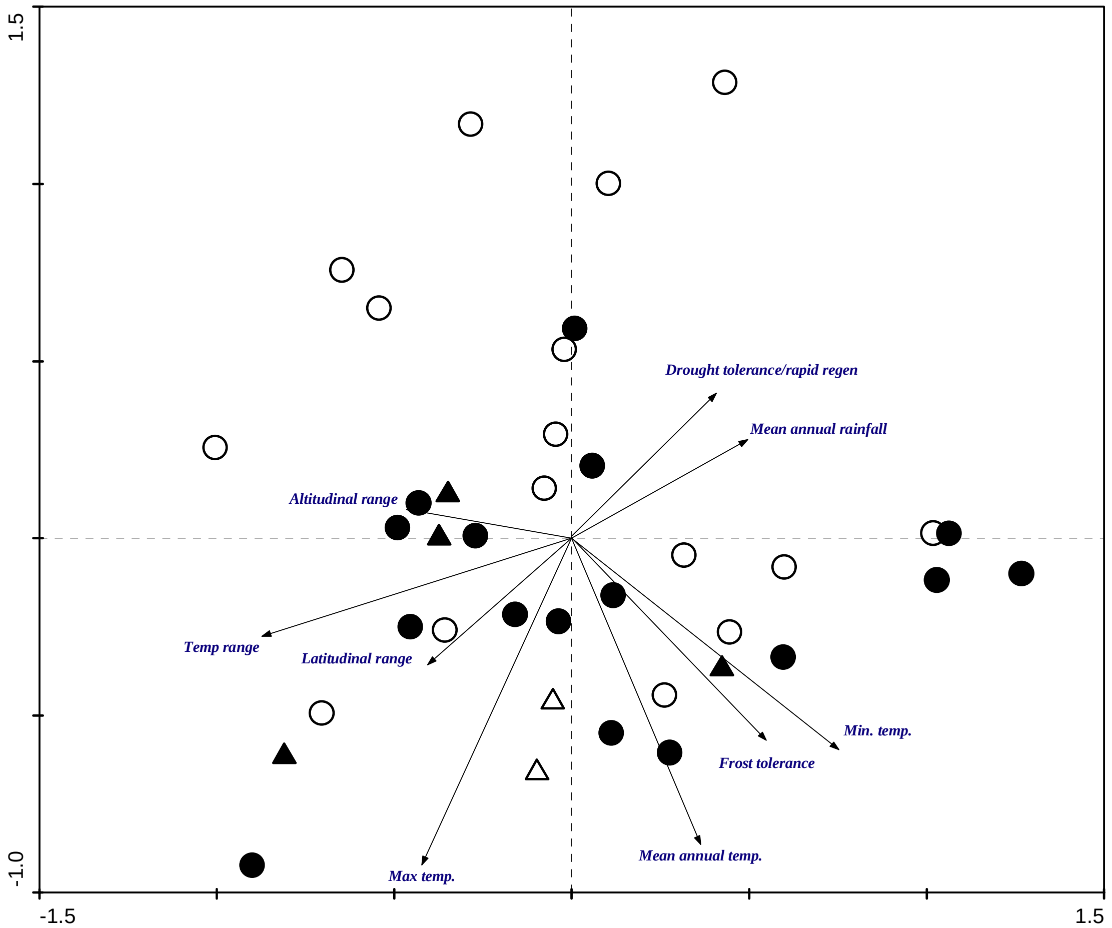


FIGURE 10. PCA ORDINATION PLOT OF 32 *ACACIA* AND SIX *PROSOPIS* SPECIES KNOWN TO OCCUR OUTSIDE THEIR NATIVE RANGE.

Acacia species are represented by circles and *Prosopis* by triangles. Invasive species are represented by open symbols and noninvasives by closed symbols. Eigenvalue axis 1 = 0.297. Eigenvalue axis 2 = 0.250. The first two axes explained 54.7 percent of the variance of the data on species attributes.

How can information from invasiveness studies be used? Results from the international program on the assessment of invasives by the Scientific Committee for Problems of the Environment (SCOPE) showed that many biological attributes (e.g. life history, taxonomic status and genetic constitution) were poor indicators of invasiveness. Nevertheless, some of these characters (in combination with other factors) are being used in risk assessments (see Section 6).

6. PREVENTION, CONTROL AND MANAGEMENT: A BIOSECURITY PERSPECTIVE

Hughes and Styles (1989) drew attention to the fact that, at that time, the process of species introduction was characterized by (i) little knowledge of the real needs of those whom introduced trees were intended to benefit, (ii) uncontrolled distribution of germplasm around the world and (iii) a low level of concern regarding potential problems of weediness (invasiveness). Whilst tremendous progress has been made in relation to the first two points, many countries are still not addressing the issue of weediness, despite pressure from international conventions such as the CBD. Although there is now a greater awareness among stakeholders of the issue of invasiveness, the general lack of quantitative information on the benefits versus the risks and impacts of invasiveness has prevented many countries from taking action. The lack of appropriate tools for assessing and managing the risks associated with plant introductions (or for managing existing invasive tree species) are additional constraining factors. Furthermore, in many cases, there has been little study of the biology of the trees and woody shrubs used in agroforestry prior to introduction. With respect to biosecurity (the policy and regulatory framework for managing all risks associated with food, agriculture, fisheries and forestry), the forestry sector is not as advanced as some of the others (FAO 2002). However, attempts have been made to address this issue and some progress has been made over the last decade.

Some of the measures taken to address the real or potential negative effects of introduced trees are discussed below.

6.1. Preventative measures and monitoring

Preventative methods have focused on the development of management models and techniques for risk assessment. In general, trees and woody shrubs have formed just one part of a larger consideration of risk assessment for all alien plants. This is a relatively new and dynamic area of research, but some countries have already implemented assessment and management schemes in combination with their national quarantine services. Two situations are considered here: risk assessment and management of plants not yet introduced and risk assessment and management of alien plants already present. The attention of most countries has been focused on the former.

6.1.1. Risk assessment models for plants not yet introduced

Hughes and Styles (1989), Cronk and Fuller (1995), Hughes (1994, 1995), Lonsdale (1994) and Panetta (1993) were among the first to call for and suggest improved methods for the introduction of exotic species of trees and woody shrubs. Hughes (1994, 1995) suggested that protocols for introductions should be based on an assessment of benefits and risks prior to seed distribution and should include some assessment of site adaptation and acceptability versus the risk of becoming invasive. Hughes (1995) also suggested some protocols (Box 1) for introductions in forestry based on IUCN (1987) guidelines on the translocation of living organisms.

In accordance with the principles suggested by the IUCN (1987), Hughes (1995) stressed the point that native species should always be assessed before exotics are considered for any new tree-planting programme. In agroforestry, there is now a range of criteria that are used to select species (e.g. yield, stability, microsite matching, product quality, compatibility with livestock, etc.) and there is thus a need to employ a diversity of planting material. This runs counter to the “multipurpose” tree concept and provides the opportunity of using many native species in agroforesty. It also has the advantage of reducing the risks associated with relying on a few exotic species in any one area.

The use of native species in commercial forestry seems to be a more complex and contentious issue. With pines, for example, the most productive species are known to be invasive (Richardson and Higgins 1998) and forestry companies often wield considerable economic and political influence locally (Richardson 1998), so that economic considerations may outweigh ecological concerns. Nonetheless, there are good examples of cases in which native species have been employed, or where less aggressive exotic species have been used. Part of the problem seems to be that in many countries, few native species have been adequately studied, especially in relation to their growth potential. For those countries with only a few native species suitable for forestry, the use of exotics is likely to continue to be the most viable option for their forestry industry.

The assessment protocols detailed in Box 1 still need to address certain issues. For example, there is frequently a time lag between the introduction of a species and it becoming invasive; for trees this can be 50 or more years. Thus longer-term factors that may lead to a species becoming invasive need to be incorporated into assessment protocols. There is also the problem referred to earlier that introduced species may hybridize unpredictably with native species and produce highly aggressive crosses. This risk also needs to be assessed.
As mentioned earlier, many biological characteristics are poor indicators of a species' potential to become invasive. In view of this and the other factors mentioned above, some aspects of risk assessment may be problematic, at least for some tree species. This could be counterbalanced by placing more emphasis on assessing the benefits of a species introduction (Hughes 1995).

BOX 1. PROTOCOL FOR SPECIES INTRODUCTIONS

- 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 are 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.
- The taxonomic identification of the proposed introduction needs to be confirmed.

Only if these first four conditions are met should further assessment be undertaken.

- Reports of weediness from other areas should be assessed. If the proposed introduction is a reported weed, in most cases this is grounds for rejection, unless overriding benefits can be demonstrated that outweigh likely costs. A full Environmental Impact Assessment is justified in such cases.
- Introductions should not be made until the risks of weediness or invasion of surrounding areas have been assessed as far as possible, taking into account essential data on:
  (i) The autecology of the species (seed dispersal, reproductive ecology, factors limiting its distribution and abundance in its native habitat).
  (ii) Conditions in the area of introduction (including likely effects of rare climatic or other events such as flood, drought and fire).
  (iii) Information on weediness from other areas and for closely related species.
  (iv) Likelihood of interspecific hybridization with closely related native or other introduced species, and risk of contamination of native gene pools through introgression or evolution of new and potentially aggressive polyploid species.
- Preliminary surveys for natural enemies/control methods should be carried out to assess potential for control and ensure eradication if needed.
- Introductions should be made initially in small, closely monitored field trials under quarantine conditions. Monitoring should include assessment of seed production and dispersal and natural regeneration into surrounding areas. Collection of seed from trials by station workers or visitors should be prevented by harvesting all seed before it ripens. When assessment is complete, trials should be completely destroyed, including any soil seed bank that has developed.
- The case for proposed introduction, including data on benefits and risks as outlined above, should then be put before the relevant national and/or state quarantine authorities for final decision. Costs should be borne by the intending importer.

Source: Hughes (1995) (modified from IUCN (1987) and amalgamating points from Panetta (1993), Hughes (1994) and Lonsdale (1994)).

Despite these drawbacks, information such as whether the plant is invasive elsewhere can be used as the basis of a risk assessment for proposed introductions (Panetta 1993). Practical risk assessments based on this and other information (mostly biological characters – see Section 5) are now in use in Australia, New Zealand and the USA. A few other initiatives are either under discussion or development (e.g. in Hawaii) but are not yet operational; these are discussed by Groves *et al.* (2001). Other, more ecologically based risk assessments, such as habitat models (e.g. Zalba *et al.* 2000) are not considered here since they are currently only proposals in the scientific literature.

One method of risk assessment in current use is that based on some form of numerical scoring system. Perhaps the most advanced of these is that developed by the Australian Quarantine and Inspection Service (AQIS). The AQIS model, known as the Weed Risk Assessment (WRA) system, forms the second tier of the Australian protocols for plant introductions. The three tiers (Walton 2001)are:

1. Identification of the species with reference to current lists of prohibited and permitted species and determination of its Australian distribution.
2. If the species is not listed and is not established in Australia, a pre-entry assessment procedure is applied to determine the risk of the species becoming a weed in Australia (the WRA system); possible recommendations are "accept", "reject" and "further evaluate". Rejected or accepted species are added to the prohibited or permitted lists.
3. If a recommendation for acceptance or rejection cannot be obtained from the second tier, and the importer wishes to proceed, then the species in question is subjected to post-entry evaluation either in the field or in glasshouse trials in order to examine its weed potential more directly (and/or to verify potential uses) so that, eventually, the species can be placed on a prohibited or permitted list.

The WRA system was developed by P.C. Pheloung (see Pheloung 2001). Plants are scored using 49 criteria, including life history characteristics and evidence of weediness elsewhere; the latter in particular is heavily weighted in the analysis. The system was initially calibrated using 370 known plant introductions to Australia. Hughes (1998) reported a "test" of the system using the legume *Leucaena leucocephala* subsp. *leucocephala.* This species fell within the "evaluate further" category – an appropriate result for such a species, which has many benefits but which is also known to be highly invasive. The WRA model is practical and was formally adopted by AQIS in 1997; it is currently being used to evaluate 600 plants of potential value to Australia, including some new tree species for forestry (Walton 2001). It has also been modified for use in New Zealand (Williams *et al.* 2001).

Tucker and Richardson (1995) suggested a model for risk assessment that was developed with a specific purpose in mind, namely the screening of plants for potential invasiveness in the South African fynbos biome. In the USA, the Animal and Plant Health Inspection Service (APHIS) has adopted another risk assessment model based on the FAO's International Standards for Phytosanitary Measures Part 1 – Guidelines for Pest Risk Analysis. The FAO guidelines identify three stages in pest risk analysis (FAO 1996):

1. Identifying species that may qualify as quarantine pests, and/or pathways that may allow the introduction or spread of such pests.
2. Assessing pest risk (determining which species are quarantine pests, based on the likelihood of their entry, establishment, spread and economic importance).
3. Managing pest risk (developing, evaluating, comparing and selecting options for dealing with the risk).

APHIS adapted stages one and two to produce a qualitative assessment. In conducting the evaluation, APHIS makes considerable use of available databases and other published sources of information. After assessment, plants are classified in terms such as “high” or “low” risk.
There is an urgent need for these risk assessment models to be evaluated further for use in forestry and agroforestry. If validated, they could then be built into decision support systems that include socio-economic and other factors as well as biological risk. However, suitable ways still need to be found of assessing plants for which there is little or no information concerning their invasive tendencies elsewhere.

6.1.2. Risk management for plants not yet introduced

Some research groups have been working on a different approach to reducing the potential invasiveness of economically important trees and woody shrubs. Much of this work has been devoted to the production of either sterile hybrids or varieties with low levels of seed production. For example, in South Africa, work has started on the production of seedless clones of *Pinus elliottii, P. patula* and *P. radiata* by irradiating seed. Germination trials of such treated seed are now under way (Richardson 1998).

Research on *Leucaena* has been focused on producing sterile or near-sterile hybrids (Hughes 1998). The first such hybrid was a triploid produced from *L. leucoephala* × *L. pulverulenta.* This arose spontaneously in the tea- and coffee-growing areas of Indonesia where *L. leucocephala* is grown as a shade tree. The hybrid was propagated artificially by grafting and sold commercially but proved to be very susceptible to damage by the Leucaena psyllid (*Heterosylla cubana*). Widespread planting has therefore stopped except in areas where there is no pressure from the pysllid. Another triploid hybrid has been produced in Hawaii by crossing *L. leucocephala* with *L. esculenta.* This hybrid is very resistant to psyllid attack and has good properties as a tree for reforestation. However, the problem remains of how to propagate such hybrids in large numbers.

6.1.3. Risk assessment and risk management for alien plants

The New Zealand Department of Conservation has implemented a model for plants that are already present in the country but have not yet become invasive (Tye 2001). This model includes assessment of the following:

- types of community potentially at risk;
- potential effects on the ecosystem;
- biological success rating;
- additional information (e.g. fire risk, competitive ability and resistance to management).

Other information is also taken into account (e.g. the year of naturalization and the bioclimatic zones in which the species might be a pest in other countries).
More generally, several authors (Hughes 1995; Richardson 1998; Reichard 2000) have emphasized the need for monitoring schemes to be set up once a plant species is introduced, both at the site of planting trials and in the surrounding area (Hughes 1995). At present, however, there are no practical guidelines on monitoring forestry species and this is an area where further work is urgently needed.

6.2. Control and management measures

Diverse control methods have been used for forestry trees that have already become invasive, although implementation of these measures on a global scale has been patchy. Early attempts to eradicate woody legumes in grassland were largely unsuccessful, although similar campaigns in other ecosystems were more promising. Taking into consideration both these experiences and changing perspectives on the risks posed by invasive species compared to their potential benefits, more emphasis is now being placed on more appropriate types of control. These are discussed in more detail below. Methods for the control of invasive plants in general have been reviewed by Cronk and Fuller (1995).

6.2.1. Eradication

Various attempts have been made to eradicate species from a number of genera, mostly those used in agroforestry, including *Acacia, Albizia, Cedrela, Leucaena, Maesopsis, Melia, Parkinsonia, Prosopis, Psidium, Sesbania, Swietenia* and *Toona* (T. Simons, personal communication, 2002). Some of the most intensive efforts have been directed against *Prosopis* and *Leucaena*. In the case of the former, attempts have been made to eradicate species in Argentina, Australia, Pakistan, South Africa, Sudan and the USA (Pasiecznik *et al.* 2001). In the USA, control of the invasive native *P. glandulosa* was initially based on hand clearance and was followed by mechanical site clearance with tractors. However, these methods proved too labour intensive, and current control approaches rely heavily on chemical methods. At present, the most effective herbicides are clopyralid, dicamba, picloram and triclopyr, either alone or in combination (Pasiecznik *et al.* 2001). The most effective approach is a combination of mechanical and chemical control techniques. Fire was traditionally used as a control tool in American grasslands, but is no longer used to any great extent. Overall, experience has shown that *Prosopis* can be controlled but not eradicated.

More effective attempts at eradication have been made in South Africa against a range of exotic trees that invade watersheds. A detailed cost–benefit analysis showed that clearance of the trees was justified because the cost of clearance was much less than the value of benefits from the improved water supply (van Wilgen *et al.* 1996). This led to the Government of South Africa funding a large and successful invasive tree programme that engaged large numbers of unemployed and unskilled people. This has become known as the “Working for Water” programme.

On a smaller scale, *Casuarina equisetifolia* (Australian pine) and other plants have been removed from a nature reserve in Florida by volunteers (Randall *et al.* 1997). There has also been a successful project in Mauritius to eradicate guava and other invasive plants from plots in natural forest areas by hand weeding. These plots are also fenced to keep out invasive mammals such as deer (Cronk and Fuller 1995).

6.2.2. Biological control

Biological control of weeds through the importation of natural enemies from the area of origin has a long history and a good success rate (McFadyen 1998). Some attempts have been made against invasive forestry trees, mostly in Australia, Southeast Asia and South Africa. A long-running programme of biological control of *Mimosa pigra* in Australia and Southeast Asia has been undertaken by CSIRO (Commonwealth Scientific and Industrial Research Organization) along with other Australian partners and the government of Thailand (Lonsdale *et al.* 1995; Napompeth 1982). Several insect and fungal natural enemies from the neotropics have been assessed and released in Australia and Thailand; the results are still being evaluated but it is predicted that a larger complex of natural enemies will be needed to exert full control. Similarly, efforts are being made in South Africa to control *Acacia saligna* through the use of a gall-forming rust fungus, *Uromycladium tepperianum*, which kills saplings and some older trees and reduces seed production in others (Morris 1995). Again, however, further efforts will be needed if complete control is to be achieved.

Researchers in South Africa have also pioneered a novel approach to the biological control of several economically important woody legumes by using introduced bruchid seed predators (Neser 1996; Zimmerman 1991). Seed predator communities can be quite diverse in the native ranges of some of these trees (e.g. see Hughes (1998) for the species that feed on *Leucaena* in Central America). The aim of this approach is to "control" the invasiveness of the trees by seed predation. Host-specific bruchids have now been successfully established for the control of *Acacia melanoxylon* and various *Prosopis* species, and the same approach is being used for an ongoing programme to control black wattle (*Acacia mearnsii*) in South Africa (Adair 2002) and *Prosopis juliflora* in Ascension Island (S.V. Fowler, personal communication, 1998). Another bruchid species has also been introduced into South Africa for the control of *Leucaena*. This species was also accidentally released in Australia, where its impact is currently being assessed (Hughes 1998).

6.2.3. Integrated control

There are relatively few case studies of fully integrated control. An important exception is the successful management of *Hakea sericea* in South African rangelands by combining mechanical, chemical and biological control methods (Kluge *et al.* 1986).

6.3. Management in the context of conflicts of interest

In South Africa, management methods have been developed for some invasive forestry trees that are based on the biological control of seed production and/or eradication of the plant in watershed catchment areas. This approach was developed on the basis of economic and environmental models that were intended to facilitate the resolution of conflicts over the benefits and negative impacts of invasive forestry trees (Geldenhuys 1986; Higgins *et al.* 1997). This example demonstrates the value of these assessments and models. More recently, new legislation in South Africa requires land users who plant crop species, including forestry trees, to be responsible for the control of water and seed pollution; the species have to be planted within designated areas and any invasions outside these areas have to be controlled (Klein 2002).

In some grassland areas (such as the southern USA and northern Africa), research has been conducted on the ways in which invasive woody legumes can complement pasture grass. Woody legumes can be a valuable resource in times of drought and, in some circumstances, can even improve grass production. Thus, some foresters have called for “bush management” rather than control (Hughes and Styles 1989; Pasiecznik *et al.* 2001).

7. CONCLUSIONS AND RECOMMENDATIONS

Trees have now been identified as one of the most significant groups of invasive plants (e.g. Richardson 1998). However, even though there are several well-documented cases of invasions by exotic forestry trees, these cases form only a small proportion of all the records in the literature. It should also be emphasized that not all of the effects recorded for invasive trees are detrimental: some human communities derive benefits from the invasive character of some species.

The main conclusions of this review and some recommendations are summarized below. The latter are shown in bold type.

1. A number of definitions of “invasive species” have been suggested in the literature, including some specifically for invasive trees or woody plants. However, none has been universally adopted by scientists or those working in applied fields such as agriculture and forestry. Some of the definitions distinguish between *all* invasive species and *alien* invasive species (the definition of “alien” is provided in Section 1). In terms of forestry and agroforestry, it may be more practical to confine the issues of invasiveness to introduced (i.e. alien) species as it is the scale of species introductions as a whole that is causing most concern on a global basis. Also, some communities associate invasive species with benefits, so invasiveness should be defined only as a biological character.

Recommendation 1. In the context of forestry, a common definition should be developed that focuses only on parameters of population expansion, since some definitions of invasive species imply only negative impacts, which is not always the case.

It is suggested that the definition provided by Cronk and Fuller (1995) has the most practical application in forestry:

Invasive plant – an alien plant spreading naturally (without direct assistance from people) in natural or semi-natural habitats, to produce a significant change in terms of community composition, structure or ecosystem processes.

2. On a global basis, only patchy information is available on the status of exotic forestry trees that have become invasive. The terminology used by authors is also very variable and there is frequent overlap in the terms “invasive” and “naturalized”. The evaluation of the extent of invasions by forest trees is generally very qualitative and subjective, making it difficult to assess the overall magnitude of the problem.

With these caveats in mind, the following summarizes the global situation. A total of 443 species, including 282 trees and woody shrubs used in forestry, 203 used in agroforestry and 292 amenity species, have been described as invasive (bearing in mind that some of these species are included in more than one usage category). However, there is little documentation that sets invasions within a wider context, despite the fact that, for each species, the scale of planting, the method and time span of introduction, establishment and management are all likely to vary according to their use, with consequent effects on their potential to become invasive.

Invasive species occur in many forestry genera, and are recorded in all parts of the world. However, there are certain regions where a potential information gap has been identified, e.g. Asia, northern and central Africa and parts of South America. Many species were reported as invasive in only a fraction of the countries in which they have been introduced, but the underlying reasons for this are not yet fully understood.

Recommendation 2. There is a need for further research and monitoring that will provide information on the management processes in planted systems and take account of the scale (i.e. land area) of plantings and of the area occupied by invasive species. Identification and monitoring of invasive species should be particularly supported in those areas where there is currently little documentation. Studies that focus on species which are invasive in some areas, but not in others, would be of particular value.

3. Few studies have been conducted on the positive and negative impacts of invasive forest trees. Positive impacts include fuel and other resources for resource-poor communities, as well as soil stabilization in overexploited natural forest areas. On the other hand, problems could potentially arise if introduced species hybridized to produce new invasive species; however, only a few such cases have been reported in forestry species (i.e. hybrids of *Leucaena* and *Prosopis*) and these are only locally important. Invasive forest trees have been reported as major problems in grassland pastures throughout the world but there are few instances where trees have invaded agricultural systems or forest plantations. Most reports of invasiveness relate to natural or semi-natural habitats. The latter include open forest systems, grasslands, riparian areas, wetlands and fire-dominated ecosystems. Some countries have quantified impacts on local species diversity and available ground water, but overall there is a severe paucity of information.

Although there has been a growing national and international awareness of the possible risks of invasive forestry trees, it is likely that some stakeholders in forestry remain ignorant of these risks. Awareness is highest in environmental sectors, but some of the risks have been highlighted by those in agricultural sectors. In some parts of the world, this has led to conflicts of interest that are fuelled partly by the general lack of quantitative information on the ecological and economic impacts of forestry trees. Such conflicts are compounded by a general lack of information on suitable tools (methodologies etc.) for making such assessments.

Recommendation 3. In light of the above, a number of case studies should be conducted in collaboration with countries that have a high degree of dependence on forestry. Such case studies should cover a range of forestry situations (commercial, developmental and environmental) and include the development and promotion of tools for ecological and economic impact assessments. Particular attention should be paid to those regions of the world where there is little information on the invasiveness of exotic forestry trees (e.g. tropical and temperate Asia).

4. Taken alone, many biological attributes (e.g. life history, taxonomic status and genetic constitution) are poor indicators of invasiveness. However, some of these characters (in combination with other factors such as the extent of invasiveness expressed), are being used in risk assessments (see below).

Recommendation 4. Rather than focusing on biological attributes, it would be of more practical value to examine those species that have been recorded as highly invasive in at least one area, in order to determine whether or not some form of control or management by local communities contributes to noninvasiveness in other areas. This approach could be combined with the studies suggested in Recommendations 2 and 3.

5. Globally, the development and implementation of prevention, control and management tools for invasive forestry trees has been cautious and patchy because of the various economic and developmental benefits of the trees concerned. Some countries, sometimes in collaboration with international partners, have made large investments in exotic trees. Thus, given the general lack of quantitative information on negative impacts, little action has been taken by many countries. The general lack of management tools (or information concerning existing tools) is an additional constraint that prevents many countries from implementing risk assessments, control and management schemes.

Work on prevention has included the development of risk assessment and risk management models. Practical risk assessments, based on information such as whether the plant is invasive elsewhere, are now in use in Australia, New Zealand and the USA. A few other countries/territories have schemes under development. The most common assessment methods to date are based on numerical scores (see Pheloung 2001).

Recommendation 5. There is an urgent need for methods of risk assessment to be evaluated further for use in forestry and, if found to be effective, promoted. These could also be incorporated into more general decision support systems that include socio-economic factors as well as biological risk.

6. Risk assessment and management of alien plants has also been considered in some cases. Many researchers in this field have called for monitoring schemes to be set up once a plant has been introduced. For forestry trees, this would involve planting trials and would need to be continued for many years.

Recommendation 6. Further work is required to develop practical guidelines specifically for monitoring forestry species, since no such guidelines are currently available.

7. In some countries, large eradication programmes employing mechanical and chemical methods have been undertaken against woody legumes (such as *Prosopis*) that are invasive in pastoral systems. However, experience has shown that these methods are costly and usually have not eradicated the trees concerned (although some success has been achieved in conservation areas in several countries (e.g. Mauritius and South Africa).

Recommendation 7. The small scale eradication project in Mauritius could usefully be used as a model for other areas.

8. Biological control and integrated control (biological with mechanical and chemical methods) have been used for the control of woody legumes in Australia, Southeast Asia and South Africa. These programmes are still largely ongoing and the results to date suggest that a combination of complementary natural enemies will be required to effect full control.

Some efforts are now being made to resolve conflicts of interest through the development of management (rather than control) programmes for invasive trees. In South Africa, on the basis of economic models, seed feeding bruchids have been introduced to control the seed output of several legume trees that have become invasive (e.g. *Acacia mearnsii*) and these efforts are reported as being successful. These programmes have been supported by new legislation that restricts the planting of trees that have invasive tendencies. At more of a research level, work in pasturelands in other countries has shown how, under some management regimes, invasive woody legumes can complement pasture grasses for livestock feeds.

Recommendation 8. All these various experiences in management should be used as models for other countries trying to resolve issues associated with invasive forestry trees.

REFERENCES

Adair, R. 2002. Black Wattle: South Africa manages conflict of interest. *Biocontrol News & Inform.*, *23*(1): 5–7.

Allaby, M. (Ed.). 1994. *The concise Oxford dictionary of ecology*. Oxford, UK, Oxford University Press.

Andersson, B., Engelmark, O., Rosvall, O. & Sjöberg, K. 1999. *Environmental impact analysis (EIA) concerning lodgepole-pine forestry in Sweden*. Oskarshamn, Sweden, SkogForsk (The Forestry Research Institute of Sweden).

Begon, M. & Mortimer, M. 1986. *Population ecology. A unified study of animals and plants*. Oxford, UK, Blackwell Scientific Publications.

Bhatt, Y.D., Rawat, Y.S., & Singh, S.P. 1994. Changes in ecosystem functioning after replacement of forest by *Lantana* shrubland in Kumaun Himalaya. *J. Vegetation Sci.*, *5*: 67–70.

Binggeli, P. 1996. A taxonomic, biogeographical and ecological overview of invasive woody plants. *J. Vegetation Sci.*, *7*: 121–124.

Binggeli, P. 1999. *Invasive woody plants* (available at http://members.lycos.co.uk/WoodyPlantEcology/invasive/index.html).

Brummitt, R.K. 1992. *Vascular plant families and genera*. London, Royal Botanic Gardens, Kew.

Brummitt, R.K. 2001. *World geographic scheme for recording plant distributions* (2nd edition). Pittsburgh, International Working Group on Taxonomic Databases For Plant Sciences (TDWG), Hunt Institute for Botanical Documentation, Carnegie Mellon University.

Buss, C.M. 2002. *The potential threat of invasive tree species in Botswana*. Department of Crop Production and Forestry, Ministry of Agriculture, Government of Botswana.

CAB International. 2000. *Forestry compendium global module*. Wallingford, UK, CAB International.

California Exotic Pest Plant Council (CalEPPC). 2002. (available at http://www.caleppc.org/).

Chinese Biodiversity Information Centre. 2002. *Invasive species in China* (available at http://monkey.ioz.ac.cn/bwg-cciced/english/cesis/invasive.htm).

Convention on Biological Diversity (CBD). 2001. *Alien species* (available at http://www.biodiv.org/programmes/cross-cutting/alien/).

Cronk, Q.C.B. & Fuller, J.L. 1995. *Plant invaders*. London, Chapman & Hall.

Di Castri, F., Hansen, A.J. & Debussche, M. (eds.). 1990. *Biological invasions in Europe and the Mediterranean Basin*. Vol. 65. Dordrecht, The Netherlands, Kluwer Academic Publishers.

Evans, J. 1982. *Plantation forestry in the tropics*. Oxford, UK, Clarendon Press.

FAO. 1996. *International standards for phytosanitary measures: guidelines for pest risk analysis.* Publication No. 2. Rome, Italy, Secretariat of the International Plant Protection Convention.

FAO. 1999. *Ecocrop.* No. 3. Plant Production and Protection Division of FAO (available at http://ecocrop.fao.org/).

FAO. 2001. *FRA 2000 global tables* (available at http://www.fao.org/forestry/fo/fra/index_tables.jsp).

FAO. 2002. *Technical consultation on biological risk management in food and agriculture* (available at ftp://ftp.fao.org/es/esn/food/tc_bangkok/tc_brm_03_2en.doc).

Fitter, R. & Fitter, M. 1967. *The Penguin dictionary of British natural history*. London, Penguin.

Florida Exotic Pest Plant Council. 2001. *Exotic pest plant database*. Florida Exotic Pest Plant Council (available at http://www.fleppc.org/database/data_intro.htm)

Francis, J.K. & Liogier, H.A. 1991. *Naturalized exotic tree species in Puerto Rico*. New Orleans, USA, United States Department of Agriculture, Forest Service.

Geldenhuys, C.J. 1986. Costs and benefits of the Australian blackwood *Acacia melanoxylon* in South African forestry. *In* I.A.W. Macdonald, F.J. Kruger, & A.A. Ferrar, eds. *The ecology and management of biological invasions in southern Africa*, pp. 275–284. Cape Town, South Africa, Oxford University Press.

Ghate, V.S. 1991. Noteworthy plant invasions in the flora of Western Ghats of Maharashtra. *J. Bombay Natural History Soc.*, 88: 390–394.

Government of Western Australia Department of Agriculture. 2002. *Weed science – the big weed list* (available at http://www.agric.wa.gov.au/progserv/plants/weeds/weeds/weedlist.htm).

Groves, R.H. & Di Castri, F. (eds.). 1991. *Biogeography of Mediterranean invasions*. Cambridge, UK, Cambridge University Press.

Groves, R.H., Panetta, F.D. & Virtue, J.G. (eds.). 2001. *Weed risk assessment*. Collingwood, Australia, CSIRO Publishing.

Henderson, L. 2001. *Alien weeds and invasive plants*. Vol. 12. Cape Town, South Africa, Plant Protection Research Institute, Agricultural Research Council.

Heritage, S. 1997. *Pine beauty moth: its biology, monitoring and control.* Research Information Note 290. Farnham, UK, Forestry Commission.

Higgins, S.I., Azorin, E.J., Cowling, R.M. & Morris, M.J. 1997. A dynamic ecological–economic model as a tool for conflict resolution in an invasive alien plant, biological control and native plant scenario. *Ecol. Econ.,* 22: 141–154.

Holzner, W. 1982. Concepts, categories and characteristics of weeds. In W. Holzner & M. Numata, eds. *Biology and ecology of weeds,* pp. 3–20. The Hague, The Netherlands, Junk.

Hughes, C.E. 1994. Risks of species introductions in tropical forestry. *Commonwealth Forestry Rev.,* 73: 243–252.

Hughes, C.E. 1995. Protocols for plant introductions with particular reference to forestry: changing perspectives on risks to biodiversity and economic development. *In* C.H. Stirton, ed. *Weeds in a changing world. British Crop Protection Council Symposium Proceedings No. 64,* pp. 15–32. Farnham, UK, BCPC.

Hughes, C.E. 1998. *Leucaena. A genetic resources handbook.* Vol. 37. Oxford, UK, Oxford University Press.

Hughes, C.E. & Styles, B.T. 1989. The benefits and risks of woody legume introductions. *Adv. Legume Biol.,* 29: 505–531.

Institute of Pacific Islands Forestry. 2002. *Pacific Island Ecosystems at Risk (PIER)* (3.3) (available at http://www.hear.org/pier/index.html).

International Legume Database & Information Service (ILDIS). 2002. *ILDIS world database of legumes* (6.05) (available at http://www.ildis.org/LegumeWeb/).

IUCN. 1987. *The IUCN position statement on translocation of living organisms*. Gland, Switzerland, IUCN.

Klein, H. 2002. New legislation benefits weed biocontrol in South Africa. *Biocontrol News & Inform.,* 23(1): 11–13.

Kluge, R.L., Zimmerman, H.G., Cilliers, C.J. & Harding, G.B. 1986. Integrated control of invasive alien weeds. *In* I.A.W. Macdonald, F.J. Kruger & A.A. Ferrar, eds. *Ecology and management of biological invasions in southern Africa,* pp. 294–302. Cape Town, South Africa, Oxford University Press.

Lonsdale, W.M. 1994. Inviting trouble: introduced pasture species in northern Australia. *Australian J. Ecol.,* 19: 345–354.

Lonsdale, W.M., Miller, I.L. & Forno, I.W. 1995. *Mimosa pigra*. *In* R.H. Groves, R.C.H. Shepherd & R.G. Richardson, eds. *The biology of Australian weeds*, pp. 69–188. Melbourne, Australia, Richardson & Richardson.

Mabberley, D.J. 1993. *The plant-book, a portable dictionary of the higher plants*. Cambridge, UK, Cambridge University Press.

MacArthur, R.H. & Wilson, E.O. 1967. *The theory of island biogeography*. Princeton, NJ, USA, Princeton University Press.

Macdonald, I.A.W., Kruger, F.J. & Ferrar, A.A. (eds.). 1986. The ecology and management of biological invasions in southern Africa. In *Proc. of the National Synthesis Symposium on the ecology of biological invasions*. Cape Town, South Africa, Oxford University Press.

Mather, A. (ed.). 1993. *Afforestation. Policies, planning and progress*. London, Belhaven Press.

McFadyen, R.E.C. 1998. Biological control of weeds. *Ann. Rev. Entomol.*, 43: 369–393.

Morris, M.J. 1995. Can a gall-forming rust fungus control an invasive tree? *In* E.S. Delfosse & R.R. Scott, eds. *Proc. of the Eighth International Symposium on Biological Control of Weeds,* 2–7 February 1992, Lincoln University, Canterbury, New Zealand, p. 509. Melbourne, Australia, DSIR/CSIRO.

Muthana, K.D. & Arora, G.D. 1983. *Prosopis juliflora* (Swatz) DC., a fast growing tree to bloom in the desert. *CAZRI Monogr.*, 22: 1–21.

Nair, P.K.R. 1990. *The prospects for agroforestry in the tropics*. Washington, DC, World Bank.

Napompeth, B. 1982. Biological control research and development in Thailand. *In* K.L. Heong, B.S. Lee, T.M. Lim, C.H. Teoh, & Y. Ibrahim, eds. *Proc. of the International Conference on Plant Protection in the Tropics,* pp. 301–323. Kuala Lumpur, Malaysia, The Malaysian Plant Protection Society.

Neser, S. 1996. *Acanthoscelides* of *Leucaena* in South Africa. *LEUCNET News*, 3: 16–18.

Panetta, D. 1993. A system of assessing proposed plant introductions for weed potential. *Plant Protec. Quart*., 8: 10–14.

Pasiecznik, N.M., Felker, P., Harris, P.J.C., Harsh, L.N., Cruz, G., Tewari, J.C., Cadoret, K. & Maldonaldo, L.J. 2001. *The Prosopis juliflora–Prosopis pallida complex: a monograph*. Coventry, UK, HDRA.

Paudel, K.C. & Kaini, B.R. 2002). Status of invasive alien species in Nepal: sharing experience in agricultural and forestry sectors. Paper presented at *The Prevention and Management of Invasive Alien Species: Forging Cooperation throughout South and Southeast Asia*, 14–16 August 2002, Bangkok, Thailand.

Pheloung, P.C. 2001. Weed risk assessment for plant introductions to Australia. *In* R.H. Groves, F.D. Panetta & J.G. Virtue, eds. *Weed risk assessment,* pp. 83–92. Collingwood, Australia, CSIRO Publishing.

Pianka, E.R. 1970. On *r*- and *k*- selection. *Amer. Naturalist,* 104: 592–597.

Randall, J.M., Lewis, R.R. & Jensen, D.B. 1997. Ecological restoration. *In* D. Simberloff, D. C. Schmitz & T.C. Brown, eds. *Strangers in paradise,* pp. 205–219. Washington, DC, Island Press.

Reichard, S. 2000. Using plant traits to guide detection efforts. In *Detecting and Monitoring of Invasive Species. Plant Health Conference,* 24–25 October 2000, Raleigh, North Carolina, USA, pp. 27–26. Technical Bulletin, USDA Animal and Plant Health Inspection Service.

Rejmanek, M. 2001. What tools do we have to detect invasive plant species? *In* R.H. Groves, F.D. Panetta & J.G. Virtue, eds. *Weed risk assessment,* pp. 3–9. Collingwood, Australia: CSIRO.

Rice, P.M. 2002. *INVADERS database system*. University of Montana Division of Biological Sciences (available at http://invader.dbs.umt.edu).

Richardson, D.M. 1996. Forestry trees as alien invaders: the current situation and prospects for the future. *In* O.T. Sandlund, P.J. Schei & Å. Viken, eds. *Proceedings of the Norway/UN Conference on Alien Species,* 1–5 July 1996, Trondheim, pp. 127–135. Trondheim, Norway, Directorate for Nature Management, Norwegian Institute for Nature Research.

Richardson, D.M. 1998. Forestry trees as invasive aliens. *Conservation Biol.,*12(1): 18–26.

Richardson, D.M. & Higgins, S.I. 1998. Pines as invaders in the southern hemisphere. *In* D.M. Richardson, ed. *Ecology and biogeography of Pinus,* pp. 450–473. Cambridge, UK, Cambridge University Press.

Richardson, D.M., Macdonald, I. A.W. & Forsyth, G.G. 1989. Reductions in plant species richness under stands of alien trees and shrubs in the fynbos biome. *South African Forestry J.,* 149: 1–8.

Richardson, D.M., Pysek, P., Rejmánek, M., Barbour, M.G., Panetta, F.D. & West, C.J. 2000. Naturalization and invasion of alien plants: concepts and definitions. *Diversity and Distributions,* 6(2): 93–107.

Richardson, D.M., Williams, P.A. & Hobbs, R.J. 1994. Pine invasions in the Southern Hemisphere: determinants of spread and invadability. *J. Biogeogr.,* 21: 511–527.

Rouget, M., Richardson, D.M., Milton, S.J. & Polakow, D. 2001. Predicting invasion dynamics of four alien *Pinus* species in a highly fragmented semi-arid shrubland in South Africa. *Plant Ecol.,* 152: 79–92.

Sandlund, O.T., Schei, P.J. & Viken, Å. (eds.). 1999. *Invasive species and biodiversity management*. Vol. 24. Dordrecht, The Netherlands, Kluwer Academic Publishers.

Shine, C., Williams, N. & Gundling, L. 2000. *A guide to designing legal and institutional frameworks on alien invasive species*. Vol. 40. IUCN Switzerland and UK.

Sinohin, V.O. & Cuaterno, W.R. 2002. Invasive alien species resource directory for the Phillipines. Paper presented at *The Prevention and Management of Invasive Alien Species: Forging Cooperation throughout South and Southeast Asia*, 14–16 August 2002, Bangkok, Thailand.

Southeast Exotic Pest Plant Council. 2002. *SE-EPPC* (available at http://www.se-eppc.org/).

TDWG (International Working Group on Taxonomic Databases). 1992. *World geographic scheme for recording plant distributions.* Plant taxonomic database standards No. 2. Version 1.0. Hunt Institute for Botanical Documentation (available at http://www.bgbm.fu-berlin.de/TDWG/geo/default.htm).

The Plant Names Project. 1999. *International plant names index* (available at http://www.ipni.org).

Tucker, K. & Richardson, D.M. 1995. An expert system for screening potentially invasive alien plants in fynbos. *J. Environ. Mgmnt.,* 44: 309–338.

Tye, A. 2001. Invasive plant problems and requirements of weed risk assessment in the Galapagos Islands. *In* R.H. Groves, F.D. Panetta & J.G. Virtue, eds. *Weed risk assessment,* pp. 153–175. Collingwood, Australia, CSIRO Publishing.

University of Hawaii Botany Department. 1998. *Hawaiian alien plant studies* (available at http://www.botany.hawaii.edu/faculty/cw_smith/aliens.htm).

University of Montana. 1997. *Invaders database system* (available at http://invader.dbs.umt.edu/).

USGS. 2002. *Hawaiian Ecosystems at Risk Project (HEAR)* (available at http://www.hear.org/).

van Wilgen, B.W., Cowling, R.M. & Burgers, C.J. 1996. Valuation of ecosystem services. *Bioscience,* 46: 184–189.

Walters, T.L. & Savill, P.S. 1992. Ash and sycamore regeneration and the phenomenon of their alternation. *Forestry,* 65: 417–433.

Walton, C. S. 2001. Implementation of a permitted list approach to plant introductions to Australia. *In* R.H. Groves, F.D. Panetta & J.G. Virtue, eds. *Weed risk assessment,* pp. 93–99. Collingwood, Australia, CSIRO Publishing.

Wang, H. 2001. On invasion of exotic trees. *In* H. Wang, Y. Zheng & R. Wei, eds. *Exotic trees and ecological environment*. Beijing, China Environment Science Press.

Williams, P.A., Nicol, E. & Newfield, M. 2001. Assessing the risk to indigenous biota of plant taxa new to New Zealand. *In* R.H. Groves, F.D. Panetta & J.G. Virtue, eds. *Weed risk assessment,* pp. 100–116. Collingwood, Australia, CSIRO Publishing.

World Agroforestry Centre. 2002. *Agroforestree database* (available at http://www.worldagroforestrycentre.org/Sites/TreeDBS/AFT/AFT.htm).

Zalba, S.M., Sonaglioni, M.I., Compagnoni, C.A. & Belenguer, C.J. 2000. Using a habitat model to assess the risk of invasion by an exotic plant. *Biol. Conservation,* 93: 203–208.

Zimmerman, H.G. 1991. Biological control of mesquite, *Prosopis* spp. (Fabaceae), in South Africa. *Agric., Ecosyst. Environ.,* 37: 175–186.

APPENDICES

Appendix 1. Notes on methodology

1. Literature review: sources and approach

Relevant papers and conference proceedings were identified using CAB Abstracts 1972–2002 and the search terms "invasions" and "trees" or "woody", "forestry", "agroforestry", "silviculture" or "plantations". This covered most articles describing "woody weed" entries. Key texts were Cronk and Fuller (1995), Henderson (2001) and the various SCOPE volumes, e.g. Macdonald *et al.* (1986), Di Castri *et al.* (1990) and Groves and Di Castri (1991). Articles describing the successional processes of trees in their native ranges were excluded. To include "grey" literature sources and unpublished information, contacts were established with representative national institutions and the private sector, via a request for information on invasive tree species that was published on the Aliens-L list server, an international mailing group for researchers and practitioners active in the study and control of invasive species. Additional information on the mode and history of introduction of species was obtained by searching CAB Abstracts using the search term "introductions" in combination with each of the major genus names listed in the database.

2. Verification of taxonomic information

Spelling and species names were checked using the International Plant Names Index (The Plant Names Project 1999). Genera were allocated to families using Brummitt (1992). As far as possible, data were checked to remove the duplicate appearance of a species under two or more synonyms. The International Legume Database and Information Service website (International Legume Database & Information Service (ILDIS) 2002) provided useful information on the latest taxonomy of leguminous species, but for other species it was more difficult to determine the most recent taxonomic classification. The original terms of reference requested that the common names of trees (in various languages) and synonyms be listed. This requirement was renegotiated as being beyond the timeframe of this short review, as alternative names of trees, including invasive species, are widely available (e.g Binggeli (1999); CAB International (2000); FAO (1999); International Legume Database & Information Service (ILDIS) (2002); World Agroforestry Centre (2002)).

3. Classification of species by economic use

Forestry species. A species was defined as a commercial forestry species if it met one of the following criteria:

(i) It was listed in the FAO Ecocrop (FAO 1999) list of 760 species that were returned using the search terms "life form: tree" and "category: forest or wood".

(ii) It appeared in the Forestry Compendium Global Module (CAB International 2000) species selection module as a species planted for fuelwood, round wood, sawn or hewn building timber, wood-based materials or pulp. The species selection module was queried systematically in connection with different regions (Europe, Americas, Asia, etc.) with the aim of focusing on planted species as opposed to those exploited from natural populations.

(iii) It was referred to as a forestry species by an author, correspondent or electronic source.

Agroforestry species. A tree/woody shrub was classified as an agroforestry species if it met one of the following criteria:

(i) It was listed in the ICRAF Agroforestree database (World Agroforestry Centre 2002).

(ii) It was listed in the Forestry Compendium Global Module (CAB International 2000) species selection module as a species used in agroforestry.

(iii) It was referred to by an author, correspondent or electronic source as an agroforestry species, or described as a commercially planted tree for the harvesting of a nonwood product.

Amenity species. The term amenity was used in connection with species that were grown as ornamentals, or species conferring a benefit (e.g. hedge, windbreak, soil improver, etc.) that was not a harvestable product. A tree was listed as an amenity species if:

(i) The ICRAF Agroforestree database (World Agroforestry Centre 2002) identified it as a species with amenity use.

(ii) It was identified in the Forestry Compendium Global Module species selection module (CAB International 2000) as a species with an amenity or ornamental function.

It was named as an amenity or ornamental species by an author, correspondent or electronic source.

Appendix 2. List of contributors

Name	Department	Organization	Country	WebPage
Laura Arriaga		CONABIO	Mexico	
Nick Brown	Department of Plant Sciences	University of Oxford	UK	http://www.plants.ox.ac.uk/
Chris Buddenhagen	Plantas Introducidas	Estacion Cientifica Charles Darwin	Galapagos, Ecuador	http://www.darwinfoundation.org/terrest/terrest.html
Chris Buss		Government of Botswana, Ngamiland region	Botswana	
Sean Carrington		University of the West Indies	Barbados	
Joana Castleton	Regional Environmental Office for South America	U.S. Embassy	Brazil	
Martin Cheek		Royal Botanic Gardens, Kew	Europe	
Colin Clubbe		Royal Botanic Gardens, Kew	UK	
Joseph Cobbinah		Forestry Research Institute of Ghana	Africa	
Mathew Cock		CABI Bioscience Switzerland Centre	Switzerland	
Mick Crawley	Department of Biological Sciences	Imperial College at Silwood Park	UK	
Sarah Darwin		Natural History Museum	UK	
Roger Day	Knowledge & Information Systems	CAB International Africa Regional Centre	Africa	http://www.cabi.org
Fern Duvall			Hawaii	
Julian Evans	T H Huxley School	Imperial College	UK	
Grant Flanagan		KI Natural Resources Board	Australia	
Anne Franklin	Invertebrates dept	Royal Belgian Institute of Natural Sciences	Belgium	http://www.naturalsciences.be/bch-cbd/homepage.htm
Kevin Frediani		The Crown Estate	UK	
Rachel Garthwaite	Biosecurity	Department of Conservation	Australia	
Jodi Graham		Pibara Mesquite management committee Inc.	Australia	
Alexis Guttierrez		John Hopkins University	USA	
Michael Hailu	Information Services Group	CIFOR	Indonesia	
Alan Hamilton		WWF International	UK	
John Hammerton		Bahamas Environment, Science and Technology Commission	Bahamas	

Name	Department	Organization	Country	WebPage
Juan Herrero	Direccion Forestal	Departmento Ordenacion Forestal	Cuba	
Colin Hughes	Department of Plant Sciences	University of Oxford	UK	http://www.plants.ox.ac.uk/
Heinke Jäger	Department of Botany	Charles Darwin Research Station	Galapagos	http://www.darwinfoundation.org/
Melanie Josefsson			Sweden	
Moses Kairo		CAB International Caribbean and Latin America Regional Centre	Trinidad & Tobago	
Ben Lawson	School of Natural and Rural Systems Management	University of Queensland	Australia	
Sandy Lloyd	State Weed Plan	Department of Agriculture	Australia	
Wai Hong Loke		CAB International South-East Asia Regional Centre	Malaysia	
Vyju Lopez		CAB International Caribbean and Latin America Regional Centre	Trinidad & Tobago	
Juan Jose May Montero		OIRSA	El Salvador	
Gwen Mayo		University of Adelaide;Co-operative Research Centre for Weed Management Systems, Australia	Australia	
Rodney Milner	Revive Our Wetlands	Conservation Volunteers Australia	Australia	http://www.reviveourwetlands.net
Robert Nasi		CIFOR	Indonesia	
Nick Pasiecznik		CABI Publishing	UK	
Tim Pearce	Seed Conservation Department	Royal Botanic Gardens, Kew	UK	
Vicente Quevedo Bonilla	Division de Patrimonio Natural	Estado Libre Asociado de Puerto Rico, Departmento de Recursos Naturales y Ambientales	Puerto Rico	
Marcela Ramirez	Regional Environmental Hub for Central America and the Caribbean	U.S. Embassy	Costa Rica	
Don Reilly	Department of Business, Industry and Research Development	Government of Australia	Australia	
Victor Sanchez-Cordero	Departmento de Zoologia	Instituto de Biologia, UNAM	Mexico	http://www.ibiologia.unam.mx
Peter Savill	Department of Plant Sciences	University of Oxford	UK	http://www.plants.ox.ac.uk/
Erich Schaitza		Embrapa Forestry	Brazil	
Douglas Sheil		CIFOR		

Name	Department	Organization	Country	WebPage
Paul Smith	Seed Conservation Department	Royal Botanic Gardens, Kew	UK	
Jim Space		Pacific Island Ecosystems at Risk (PIER)	South Pacific	http://www.hear.org/pier
Demel Teketay		Ethiopian Agricultural Research Organization	Africa	
Gerard van Buurt		Department of Agriculture	Curacao	
David Wainhouse	Forest Research	Forestry Commission	UK	
Oliver Whalley		Royal Botanic Gardens, Kew	UK	
Carmen Lucia Yurrita Obiols		OTECBIO-CONAP	Guatemala	
Sergio Zalba	GEKKO - Grupo de Estudios en Conservacion y Manejo, Departmento de Biologia, Bioquimica y Farmacia	Universidad Nacional del Sur	Argentina	
Zang Runguo		Chinese Academy of Forestry	People's Republic of China	
Silvia Renate Ziller		Institute for Development of Natural Energy and Sustainability	Brazil	

Appendix 3. Tables 3–9, species invasive in different regions

Table 3. The 24 alien forestry species found to be associated with naturalization or invasion events in Europe.
Locations of naturalization / invasion events are listed.

Family	Species	Countries where naturalized	Countries where naturalized and invasive
ACERACEAE	*Acer platanoides*		UK
ACERACEAE	*Acer pseudoplatanus*	Denmark, Norway	UK, Ireland
ANACARDIACEAE	*Rhus typhina*	UK	
CUPRESSACEAE	*Chamaecyparis lawsoniana*	UK	
CUPRESSACEAE	*Thuja plicata*	UK	
ELAEAGNACEAE	*Hippophae rhamnoides*		UK, Netherlands
FAGACEAE	*Castanea sativa*	England	
FAGACEAE	*Quercus cerris*		UK
FAGACEAE	*Quercus ilex*		UK
HIPPOCASTANACEAE	*Aesculus hippocastanum*	UK	
LEGUMINOSAE-Mimosoideae	*Acacia dealbata*		Portugal
LEGUMINOSAE-Papilionoideae	*Robinia pseudoacacia*		Netherlands, France, Germany, UK, Switzerland, Hungary, Greece
PINACEAE	*Larix decidua*	UK	
PINACEAE	*Larix kaempferi*	UK	
PINACEAE	*Picea sitchensis*	UK	
PINACEAE	*Pinus contorta*		Sweden, UK
PINACEAE	*Pinus sylvestris*		England
PINACEAE	*Tsuga heterophylla*	UK	
ROSACEAE	*Malus domestica*		Poland, Byelorussia
ROSACEAE	*Prunus lusitanica*	England	
ROSACEAE	*Prunus serotina*		Belgium, UK, Netherlands
ROSACEAE	*Sorbus intermedia*	UK	
SIMAROUBACEAE	*Ailanthus altissima*		Europe
ULMACEAE	*Ulmus minor*	UK	

Table 4. The 98 alien forestry species found to be associated with naturalization or invasion events in Africa.
Locations of naturalization / invasion events are listed.

Family	Species	Countries where Naturalized	Countries where naturalized and Invasive
ACERACEAE	*Acer pseudoplatanus*		Madeira
ANACARDIACEAE	*Mangifera indica*		Mauritius
ANACARDIACEAE	*Schinus molle*		Botswana
ANACARDIACEAE	*Schinus terebinthifolius*		Botswana, St Helena
BIGNONIACEAE	*Jacaranda mimosifolia*		South Africa, Zimbabwe, Botswana
BIGNONIACEAE	*Spathodea campanulata*	Tanzania (East Usambara)	
BIGNONIACEAE	*Tabebuia heterophylla*		Diego Garcia
BIGNONIACEAE	*Tecoma stans*		Botswana
CASUARINACEAE	*Casuarina cunninghamiana*		South Africa, Botswana
CASUARINACEAE	*Casuarina equisetifolia*		Mauritius, South Africa, Botswana, Reunion
COMBRETACEAE	*Terminalia catappa*		Botswana
CUPRESSACEAE	*Callitris endlicheri*		Zimbabwe
CUPRESSACEAE	*Cupressus lusitanica*		Malawi, Zimbabwe, Botswana
EUPHORBIACEAE	*Hevea brasiliensis*	Tanzania	
FAGACEAE	*Quercus robur*	South Africa	
FLACOURTIACEAE	*Flacourtia indica*		Mauritius
LAURACEAE	*Cinnamomum camphora*		Reunion, Botswana, South Africa
LEGUMINOSAE-Caesalpinioideae	*Bauhinia variegata*		South Africa, Botswana
LEGUMINOSAE-Caesalpinioideae	*Delonix regia*		Botswana
LEGUMINOSAE-Caesalpinioideae	*Gleditsia triacanthos*		Botswana
LEGUMINOSAE-Caesalpinioideae	*Parkinsonia aculeata*		Botswana
LEGUMINOSAE-Caesalpinioideae	*Senna siamea*		Ghana
LEGUMINOSAE-Caesalpinioideae	*Senna spectabilis*	Uganda	
LEGUMINOSAE-Mimosoideae	*Acacia baileyana*		South Africa
LEGUMINOSAE-Mimosoideae	*Acacia cyclops*		South Africa
LEGUMINOSAE-Mimosoideae	*Acacia dealbata*		South Africa, Zimbabwe
LEGUMINOSAE-Mimosoideae	*Acacia decurrens*	South Africa, Zimbabwe	South Africa, Zimbabwe
LEGUMINOSAE-Mimosoideae	*Acacia elata*	Zimbabwe	South Africa, Zimbabwe

Family	Species	Countries where Naturalized	Countries where naturalized and Invasive
LEGUMINOSAE-Mimosoideae	*Acacia implexa*		South Africa
LEGUMINOSAE-Mimosoideae	*Acacia leptocarpa*		Tanzania
LEGUMINOSAE-Mimosoideae	*Acacia longifolia*		South Africa
LEGUMINOSAE-Mimosoideae	*Acacia mangium*		Africa
LEGUMINOSAE-Mimosoideae	*Acacia mearnsii*	Zimbabwe	South Africa, Zimbabwe
LEGUMINOSAE-Mimosoideae	*Acacia melanoxylon*	Zimbabwe	South Africa, Zimbabwe
LEGUMINOSAE-Mimosoideae	*Acacia nilotica*		Botswana
LEGUMINOSAE-Mimosoideae	*Acacia paradoxa*	South Africa	South Africa
LEGUMINOSAE-Mimosoideae	*Acacia pendula*	South Africa	
LEGUMINOSAE-Mimosoideae	*Acacia podalyriifolia*	Zimbabwe	South Africa, Zimbabwe
LEGUMINOSAE-Mimosoideae	*Acacia saligna*		South Africa, Botswana
LEGUMINOSAE-Mimosoideae	*Albizia chinensis*	Tanzania	
LEGUMINOSAE-Mimosoideae	*Albizia lebbeck*	Africa	South Africa, Botswana
LEGUMINOSAE-Mimosoideae	*Albizia procera*		South Africa, Zimbabwe
LEGUMINOSAE-Mimosoideae	*Falcataria moluccana*		Seychelles
LEGUMINOSAE-Mimosoideae	*Leucaena diversifolia*	Africa	
LEGUMINOSAE-Mimosoideae	*Leucaena leucocephala*		Reunion, Mauritius, Rodrigues, Botswana, Ghana, South Africa, Kenya, Tanzania, Cameroon
LEGUMINOSAE-Mimosoideae	*Pithecellobium dulce*	Tanzania	
LEGUMINOSAE-Mimosoideae	*Prosopis glandulosa*	Sudan	South Africa, Botswana, Namibia
LEGUMINOSAE-Mimosoideae	*Prosopis juliflora*		Ethiopia
LEGUMINOSAE-Mimosoideae	*Prosopis velutina*		Botswana, South Africa
LEGUMINOSAE-Papilionoideae	*Robinia pseudoacacia*		Botswana
LEGUMINOSAE-Papilionoideae	*Tipuana tipu*		South Africa, Botswana
MELIACEAE	*Azadirachta indica*	Mauritius, Egypt	Ghana, Botswana
MELIACEAE	*Cedrela odorata*	Tanzania	South Africa

Family	Species	Countries where Naturalized	Countries where naturalized and Invasive
MELIACEAE	*Melia azedarach*	Tanzania	South Africa, Zimbabwe, Botswana
MELIACEAE	*Toona ciliata*	Tanzania	South Africa, Zimbabwe
MORACEAE	*Artocarpus heterophyllus*	Tanzania (East Usambara)	
MORACEAE	*Broussonetia papyrifera*	Uganda	Ghana, Uganda
MORACEAE	*Morus alba*		South Africa
MORACEAE	*Morus nigra*	South Africa	
MYRTACEAE	*Eucalyptus camaldulensis*		South Africa, Zimbabwe, Botswana
MYRTACEAE	*Eucalyptus citriodora*		Zimbabwe
MYRTACEAE	*Eucalyptus cladocalyx*		South Africa
MYRTACEAE	*Eucalyptus diversicolor*		South Africa
MYRTACEAE	*Eucalyptus globulus*		Zimbabwe
MYRTACEAE	*Eucalyptus grandis*		South Africa, Zimbabwe, Botswana
MYRTACEAE	*Eucalyptus lehmannii*		South Africa
MYRTACEAE	*Eucalyptus microcorys*		Zimbabwe
MYRTACEAE	*Eucalyptus paniculata*		South Africa, Zimbabwe
MYRTACEAE	*Eucalyptus robusta*		Zimbabwe
MYRTACEAE	*Eucalyptus sideroxylon*		South Africa, Botswana
MYRTACEAE	*Eucalyptus tereticornis*		Zimbabwe, Botswana
MYRTACEAE	*Psidium guajava*	Uganda	Seychelles, Mauritius, South Africa, Zimbabwe, Botswana
OLEACEAE	*Ligustrum robustum*		Mauritius, Reunion, Rodrigues
PALMAE	*Phoenix dactylifera*		Botswana
PINACEAE	*Pinus canariensis*		South Africa
PINACEAE	*Pinus elliottii*		South Africa, Zimbabwe
PINACEAE	*Pinus halepensis*		South Africa
PINACEAE	*Pinus kesiya*		Zimbabwe
PINACEAE	*Pinus patula*		South Africa, Zimbabwe, Botswana, Malawi

Family	Species	Countries where Naturalized	Countries where naturalized and Invasive
PINACEAE	*Pinus pinaster*		South Africa
PINACEAE	*Pinus pinea*		South Africa
PINACEAE	*Pinus radiata*		South Africa, Zimbabwe, Kenya
PINACEAE	*Pinus taeda*		South Africa, Zimbabwe, Canary Islands, St Helena
PITTOSPORACEAE	*Pittosporum undulatum*	St. Helena, Canary Islands	Canary Islands, South Africa, Azores
PROTEACEAE	*Grevillea robusta*		South Africa, Zimbabwe, Botswana
RHAMNACEAE	*Maesopsis eminii*		Rwanda, Tanzania (East Usambaras), East Africa
RHAMNACEAE	*Ziziphus mauritiana*	Zimbabwe, Zambia	Zimbabwe, Zambia
RUBIACEAE	*Cinchona succirubra*		St Helena
RUBIACEAE	*Coffea arabica*	Tanzania	
SALICACEAE	*Populus canescens*		South Africa, Zimbabwe
SALICACEAE	*Populus alba*		South Africa
SALICACEAE	*Populus deltoides*		South Africa
SALICACEAE	*Populus nigra*		South Africa
SALICACEAE	*Salix babylonica*		Botswana, South Africa
SALICACEAE	*Salix fragilis*		Botswana, South Africa
SOLANACEAE	*Solanum mauritianum*		Reunion, South Africa, Uganda
STRELITZIACEAE	*Ravenala madagascariensis*		Mauritius
TAMARICACEAE	*Tamarix chinensis*		South Africa

Table 5. The 53 alien forestry species found to be associated with naturalization or invasion events in Australasia.
Locations of naturalization / invasion events are listed.

Family	Species	Countries where naturalized	Countries where naturalized and invasive
ACERACEAE	*Acer pseudoplatanus*	New Zealand	New Zealand
ANACARDIACEAE	*Schinus terebinthifolius*		New Zealand, Australia (Norfolk Island)
ASCLEPIADACEAE	*Calotropis procera*		Australia (Western Australia, Northern Territory)
BETULACEAE	*Alnus glutinosa*		New Zealand
CAPRIFOLIACEAE	*Sambucus nigra*		New Zealand
LAURACEAE	*Cinnamomum camphora*		Australia (New South Wales)
LEGUMINOSAE-Caesalpinioideae	*Parkinsonia aculeata*		Australia (New South Wales, South Australia, Western Australia, Tasmania, Queensland, Northern Territory)
LEGUMINOSAE-Mimosoideae	*Acacia catechu*		Australia (Western Australia, Queensland, Northern Territory)
LEGUMINOSAE-Mimosoideae	*Acacia dealbata*	Australia (South Queensland, South Australia), New Zealand	New Zealand
LEGUMINOSAE-Mimosoideae	*Acacia decurrens*	Australia (New South Wales, Australian Capital, Territory, Victoria, Tasmania, Queensland, South Australia), New Zealand	
LEGUMINOSAE-Mimosoideae	*Acacia farnesiana*		Australia
LEGUMINOSAE-Mimosoideae	*Acacia karroo*		Australia (Western Australia, New South Wales, Queensland)
LEGUMINOSAE-Mimosoideae	*Acacia laeta*		Australia (Western Australia)
LEGUMINOSAE-Mimosoideae	*Acacia longifolia*	New Zealand	New Zealand
LEGUMINOSAE-Mimosoideae	*Acacia mangium*		Australia (Western Australia)
LEGUMINOSAE-Mimosoideae	*Acacia mearnsii*		New Zealand
LEGUMINOSAE-Mimosoideae	*Acacia melanoxylon*		New Zealand, Australia (Western Australia)
LEGUMINOSAE-Mimosoideae	*Acacia nilotica*		Australia (Western Australia, New South Wales, South Australia, Queensland, Northern Territory)
LEGUMINOSAE-Mimosoideae	*Acacia paradoxa*		New Zealand, Australia (Western Australia, Queensland)
LEGUMINOSAE-	*Pithecellobium dulce*		Australia (Western Australia,

Family	Species	Countries where naturalized	Countries where naturalized and invasive
Mimosoideae			Queensland)
LEGUMINOSAE-Mimosoideae	*Prosopis glandulosa*		Australia (Queensland)
LEGUMINOSAE-Mimosoideae	*Prosopis pallida*		Australia (Victoria, New South Wales, South Australia, Western Australia, Tasmania, Queensland, Northern Territory)
LEGUMINOSAE-Papilionoideae	*Dalbergia sissoo*		Australia (Western Australia, Northern Territory)
LEGUMINOSAE-Papilionoideae	*Robinia pseudoacacia*		New Zealand, Australia
MELIACEAE	*Azadirachta indica*		Australia
MELIACEAE	*Khaya senegalensis*		Australia
MORACEAE	*Ficus carica*		New Zealand
MORACEAE	*Ficus macrophylla*		New Zealand
MYRTACEAE	*Acmena smithii*		New Zealand
MYRTACEAE	*Eucalyptus botryoides*		New Zealand
MYRTACEAE	*Eucalyptus globulus*		New Zealand
MYRTACEAE	*Eucalyptus saligna*		New Zealand
MYRTACEAE	*Psidium guajava*		New Zealand
PALMAE	*Trachycarpus fortunei*		New Zealand
PINACEAE	*Pinus caribaea*	Australia	
PINACEAE	*Pinus contorta*	New Zealand	New Zealand
PINACEAE	*Pinus elliottii*		Australia
PINACEAE	*Pinus halepensis*		Australia (South Australia)
PINACEAE	*Pinus mugo*	New Zealand	
PINACEAE	*Pinus nigra*		New Zealand
PINACEAE	*Pinus pinaster*	New Zealand	New Zealand
PINACEAE	*Pinus radiata*		Australia (Tasmania), New Zealand
PINACEAE	*Pinus rigida*	New Zealand	
PINACEAE	*Pseudotsuga menziesii*		New Zealand
PITTOSPORACEAE	*Pittosporum undulatum*	New Zealand	Australia (New South Wales, South Central Victoria, Norfolk

Family	Species	Countries where naturalized	Countries where naturalized and invasive
			I., Lord Howe I.)
RHAMNACEAE	*Ziziphus mauritiana*		Australia (South Australia, Northern Territory, Queensland)
ROSACEAE	*Eriobotrya japonica*		New Zealand
ROSACEAE	*Prunus lusitanica*		New Zealand
SALICACEAE	*Populus alba*		New Zealand
SALICACEAE	*Salix fragilis*		New Zealand
SIMAROUBACEAE	*Ailanthus altissima*		Australia (Victoria, New South Wales)
SOLANACEAE	*Solanum mauritianum*		New Zealand, Australia (Norfolk Island)
TAMARICACEAE	*Tamarix aphylla*		Australia (South Australia, Western Australia, Tasmania, Northern Territory)

Table 6. The 74 alien forestry species found to be associated with naturalization or invasion events in North America.
Locations of naturalization / invasion events are listed.

Family	Species	Countries where naturalized	Countries where naturalized and invasive
ACERACEAE	*Acer platanoides*	USA (Idaho, Montana, Washington)	USA (Oregon, Virginia), Canada
ANACARDIACEAE	*Schinus molle*	Mexico, USA	USA (California)
ANACARDIACEAE	*Schinus terebinthifolius*		USA (Florida)
APOCYNACEAE	*Alstonia macrophylla*		USA (Florida)
BETULACEAE	*Alnus glutinosa*	Canada (Nova Scotia, Newfoundland)	Canada (Ontario)
BETULACEAE	*Betula pendula*		Canada
BORAGINACEAE	*Cordia dichotoma*		USA (Florida)
CASUARINACEAE	*Casuarina cunninghamiana*		USA (Florida)
CASUARINACEAE	*Casuarina equisetifolia*		USA (Florida)
CASUARINACEAE	*Casuarina glauca*		USA (Hawaii, Florida)
COMBRETACEAE	*Terminalia catappa*		USA (Florida)
COMBRETACEAE	*Terminalia muelleri*		USA (Florida)
ELAEAGNACEAE	*Elaeagnus angustifolia*	USA (Idaho, Montana, Tennessee, Washington, Wyoming)	USA (California, Oregon)
EUPHORBIACEAE	*Aleurites fordii*		USA (Florida)
EUPHORBIACEAE	*Bischofia javanica*		USA (Florida)
EUPHORBIACEAE	*Sapium sebiferum*		USA (California, Florida, Georgia, gulf coast Texas to Florida, east coast Louisiana up to N. Carolina)
FAGACEAE	*Quercus acutissima*		USA (Virginia)
FAGACEAE	*Quercus robur*	USA (Idaho)	
FLACOURTIACEAE	*Flacourtia indica*		USA (Florida)
GUTTIFERAE	*Calophyllum inophyllum*		USA (Florida)
JUGLANDACEAE	*Juglans regia*	USA (Idaho)	
LAURACEAE	*Cinnamomum camphora*		USA (Florida)
LEGUMINOSAE-Caesalpinioideae	*Bauhinia variegata*		USA (Florida)
LEGUMINOSAE-Mimosoideae	*Acacia auriculformis*		USA (Florida)
LEGUMINOSAE-Mimosoideae	*Acacia cyclops*		USA (California)
LEGUMINOSAE-Mimosoideae	*Acacia longifolia*	USA (California)	
LEGUMINOSAE-Mimosoideae	*Acacia melanoxylon*		USA (California)
LEGUMINOSAE-Mimosoideae	*Acacia saligna*	USA (California)	

Family	Species	Countries where naturalized	Countries where naturalized and invasive
LEGUMINOSAE-Mimosoideae	*Adenanthera pavonina*		USA (Florida)
LEGUMINOSAE-Mimosoideae	*Albizia julibrissin*		USA (Florida, Georgia, Kentucky, Tennessee, Virginia)
LEGUMINOSAE-Mimosoideae	*Albizia lebbeck*		USA (Florida)
LEGUMINOSAE-Mimosoideae	*Leucaena leucocephala*	USA (Texas)	USA (Florida)
LEGUMINOSAE-Mimosoideae	*Prosopis alba*	USA (Idaho, Tennessee)	
LEGUMINOSAE-Mimosoideae	*Prosopis juliflora*	Mexico	
LEGUMINOSAE-Papilionoideae	*Dalbergia sissoo*		USA (Florida)
LEGUMINOSAE-Papilionoideae	*Gliricidia sepium*	Mexico	
LEGUMINOSAE-Papilionoideae	*Robinia pseudoacacia*	North America	North America (beyond northeast), Canada
MALVACEAE	*Thespesia populnea*		USA (Florida)
MELIACEAE	*Melia azedarach*		USA (Florida, Virginia)
MORACEAE	*Broussonetia papyrifera*		USA (Florida)
MORACEAE	*Ficus benghalensis*		USA (Florida)
MORACEAE	*Ficus carica*		USA (California)
MORACEAE	*Morus alba*		USA (Oregon, Virginia)
MYRTACEAE	*Eucalyptus globulus*		USA (California)
MYRTACEAE	*Melaleuca quinquenervia*		USA (Florida)
MYRTACEAE	*Psidium guajava*		USA (Florida)
MYRTACEAE	*Syzygium cumini*		USA (Hawaii, Florida)
PALMAE	*Phoenix reclinata*		USA (Florida)
PINACEAE	*Picea abies*	USA (Idaho)	
PINACEAE	*Pinus sylvestris*	USA (New England, Lake States)	Canada
PINACEAE	*Pinus thunbergii*		USA (Virginia, Oregon)
RHAMNACEAE	*Rhamnus cathartica*		USA
ROSACEAE	*Crataegus monogyna*		USA (Pacific Northwest)
ROSACEAE	*Prunus avium*	USA (Idaho, Washington)	USA (Oregon)
ROSACEAE	*Prunus cerasifera*	USA (Idaho, Montana, Washington)	USA (Oregon)
ROSACEAE	*Prunus cerasus*	USA (Montana, Washington)	
ROSACEAE	*Prunus lusitanica*		USA (Oregon)
ROSACEAE	*Prunus mahaleb*	USA (Idaho, Montana, Washington)	USA (Oregon)
ROSACEAE	*Prunus padus*	USA (Montana, Washington)	
ROSACEAE	*Prunus persica*	USA (Idaho)	
ROSACEAE	*Prunus spinosa*	USA (Idaho, Washington)	USA (Oregon)
ROSACEAE	*Prunus tomentosa*	USA (Idaho, Montana, Washington)	USA (Oregon)
ROSACEAE	*Pyrus communis*	USA (Idaho, Montana,	USA (Oregon)

Family	Species	Countries where naturalized	Countries where naturalized and invasive
		Washington)	
ROSACEAE	*Sorbus aucuparia*	USA (Idaho, Washington)	USA (Oregon)
ROSACEAE	*Sorbus hybrida*	USA (Idaho)	
SALICACEAE	*Populus alba*	USA (Montana, Washington, throughout North America)	USA (Oregon, Virginia), Canada
SALICACEAE	*Salix alba*	USA (Idaho, Montana)	
SALICACEAE	*Salix babylonica*		USA (Oregon)
SALICACEAE	*Salix fragilis*	USA(Idaho, Montana, Washington)	
SCROPHULARIACEAE	*Paulownia tomentosa*	USA (Washington, Mid-Atlantic, Southeast)	USA (Georgia, Kentucky, Oregon, Tennessee)
SIMAROUBACEAE	*Ailanthus altissima*	USA (Idaho)	USA (California, Kentucky, Oregon, Tennessee, Virginia)
TAMARICACEAE	*Tamarix chinensis*		USA (California, all western states except Washington and N. Dakota)
TAMARICACEAE	*Tamarix sp.*	USA (Idaho, Washington)	USA (Oregon, Wyoming)
ULMACEAE	*Ulmus pumila*	USA (Washington)	USA(Oregon, Virginia, Utah, Idaho and eastward)

Table 7. The 114 alien forestry species found to be associated with naturalization or invasion events in South America.
Locations of naturalization / invasion events are listed.

Family	Species	Countries where naturalized	Countries where naturalized and invasive
ACERACEAE	*Acer pseudoplatanus*		Chile
ANACARDIACEAE	*Mangifera indica*	Guatemala, Curacao	Antigua, Puerto Rico
ANACARDIACEAE	*Schinus terebinthifolius*	Puerto Rico	Bahamas, Puerto Rico
ANACARDIACEAE	*Spondias mombin*	Curacao	
ANNONACEAE	*Cananga odorata*	Puerto Rico	
APOCYNACEAE	*Funtumia elastica*	Puerto Rico	
ARAUCARIACEAE	*Agathis robusta*	Puerto Rico	
ASCLEPIADACEAE	*Calotropis procera*	Curacao	Puerto Rico
BALANITACEAE	*Balanites aegyptica*		Curacao, Caribbean
BIGNONIACEAE	*Jacaranda mimosifolia*	Guatemala	
BIGNONIACEAE	*Spathodea campanulata*	Guatemala	Puerto Rico
BIGNONIACEAE	*Tabebuia chrysantha*	Puerto Rico	
BIGNONIACEAE	*Tabebuia donnell-smithii*	Puerto Rico	
BIGNONIACEAE	*Tabebuia heterophylla*	Guadeloupe, Martinique, Anguilla, Antigua-Barbuda, Bahamas, British Virgin Islands, Cayman Islands, Cuba, Dominica, Dominican Republic, Grenada, Haiti, Jamaica, Monserrat, Netherlands Antilles	
BIGNONIACEAE	*Tecoma stans*		Brazil
BIXACEAE	*Bixa orellana*	Puerto Rico	
BORAGINACEAE	*Cordia alliodora*	Galapagos	
CASUARINACEAE	*Casuarina cunninghamiana*	Bahamas	
CASUARINACEAE	*Casuarina equisetifolia*	Bahamas, Puerto Rico	Bahamas, Puerto Rico, Brazil
CASUARINACEAE	*Casuarina glauca*	Bahamas	
CASUARINACEAE	*Casuarina jungimiana*	Bahamas	
COMBRETACEAE	*Terminalia catappa*		Barbados, Puerto Rico
COMBRETACEAE	*Terminalia ivorensis*	Puerto Rico	
COMBRETACEAE	*Terminalia myriocarpa*	Puerto Rico	
COMBRETACEAE	*Terminalia oblonga*	Puerto Rico	
CUPRESSACEAE	*Cupressus lusitanica*	Puerto Rico	
CUPRESSACEAE	*Cupressus sempervirens*		Argentina
EUPHORBIACEAE	*Aleurites fordii*	Puerto Rico	
EUPHORBIACEAE	*Aleurites moluccana*	Puerto Rico	
GRAMINEAE	*Bambusa vulgaris*	Puerto Rico	

Family	Species	Countries where naturalized	Countries where naturalized and invasive
GUTTIFERAE	*Calophyllum inophyllum*	Puerto Rico	
LAURACEAE	*Persea americana*	Galapagos, Puerto Rico	Galapagos
LEGUMINOSAE-Caesalpinioideae	*Bauhinia tomentosa*	Puerto Rico	
LEGUMINOSAE-Caesalpinioideae	*Bauhinia variegata*	Bahamas, Puerto Rico	
LEGUMINOSAE-Caesalpinioideae	*Delonix regia*		Barbados, Puerto Rico
LEGUMINOSAE-Caesalpinioideae	*Dialium guianense*	Puerto Rico	
LEGUMINOSAE-Caesalpinioideae	*Parkinsonia aculeata*	Puerto Rico	
LEGUMINOSAE-Caesalpinioideae	*Peltophorum pterocarpum*	Puerto Rico	
LEGUMINOSAE-Caesalpinioideae	*Schizolobium parahyba*	Puerto Rico	
LEGUMINOSAE-Caesalpinioideae	*Senna siamea*		Puerto Rico
LEGUMINOSAE-Caesalpinioideae	*Senna spectabilis*	Puerto Rico	
LEGUMINOSAE-Caesalpinioideae	*Tamarindus indica*	Curacao, Puerto Rico	Antigua
LEGUMINOSAE-Mimosoideae	*Acacia dealbata*	Chile	Argentina
LEGUMINOSAE-Mimosoideae	*Acacia farnesiana*		Puerto Rico
LEGUMINOSAE-Mimosoideae	*Acacia mangium*	Puerto Rico	
LEGUMINOSAE-Mimosoideae	*Acacia melanoxylon*		Argentina
LEGUMINOSAE-Mimosoideae	*Acacia nilotica*	Puerto Rico	Antigua-Barbuda, Anguilla, Ecuador
LEGUMINOSAE-Mimosoideae	*Adenanthera pavonina*	Puerto Rico	
LEGUMINOSAE-Mimosoideae	*Albizia lebbeck*	West Indies, Bahamas	Venezuela, Caribbean, Puerto Rico
LEGUMINOSAE-Mimosoideae	*Albizia procera*		Venezuela, Puerto Rico
LEGUMINOSAE-Mimosoideae	*Dichrostachys cinerea*		Cuba
LEGUMINOSAE-Mimosoideae	*Enterolobium cyclocapum*	Puerto Rico	
LEGUMINOSAE-Mimosoideae	*Leucaena diversifolia*	Caribbean	
LEGUMINOSAE-Mimosoideae	*Leucaena leucocephala*	Galapagos	West Indies, south of Mexico to Brazil, Brazil (Fernando de Noron) Puerto Rico, Bahamas
LEGUMINOSAE-Mimosoideae	*Lysiloma latisiliqua*	Puerto Rico	

Family	Species	Countries where naturalized	Countries where naturalized and invasive
LEGUMINOSAE-Mimosoideae	*Pithecellobium dulce*		Puerto Rico
LEGUMINOSAE-Mimosoideae	*Prosopis juliflora*	Brazil	Puerto Rico
LEGUMINOSAE-Mimosoideae	*Prosopis pallida*		Puerto Rico
LEGUMINOSAE-Mimosoideae	*Samanea saman*	Puerto Rico	
LEGUMINOSAE-Papilionoideae	*Dalbergia sissoo*	Puerto Rico	
LEGUMINOSAE-Papilionoideae	*Erythrina berteroana*	Puerto Rico	
LEGUMINOSAE-Papilionoideae	*Erythrina fusca*	Puerto Rico	
LEGUMINOSAE-Papilionoideae	*Erythrina poeppigiana*	Puerto Rico	
LEGUMINOSAE-Papilionoideae	*Gliricidia sepium*	Puerto Rico	
LEGUMINOSAE-Papilionoideae	*Myroxylon balsamum*	Puerto Rico	
LEGUMINOSAE-Papilionoideae	*Pterocarpus indicus*	Puerto Rico	
LEGUMINOSAE-Papilionoideae	*Pterocarpus macrocarpus*	Puerto Rico	
LEGUMINOSAE-Papilionoideae	*Robinia pseudoacacia*		Argentina
LEGUMINOSAE-Papilionoideae	*Sesbania grandiflora*	Puerto Rico	
MALVACEAE	*Thespesia populnea*	Bahamas	Puerto Rico
MELIACEAE	*Azadirachta indica*		Puerto Rico
MELIACEAE	*Carapa guianensis*	Puerto Rico	
MELIACEAE	*Cedrela odorata*	Galapagos	Galapagos
MELIACEAE	*Khaya nyasica*	Puerto Rico	
MELIACEAE	*Khaya senegalensis*	Puerto Rico	
MELIACEAE	*Melia azedarach*	Bahamas, Puerto Rico	Brazil
MELIACEAE	*Swietenia macrophylla*	Puerto Rico	
MELIACEAE	*Swietenia mahogoni*	Puerto Rico	
MORACEAE	*Artocarpus altilis*		Puerto Rico
MORACEAE	*Artocarpus heterophyllus*	Puerto Rico	
MORACEAE	*Broussonetia papyrifera*		Peru
MORACEAE	*Castilla elastica*	Puerto Rico	
MORACEAE	*Morus nigra*	Puerto Rico	
MORINGACEAE	*Moringa oleifera*	Puerto Rico	
MYRTACEAE	*Eucalyptus camaldulensis*		Argentina
MYRTACEAE	*Eucalyptus robusta*	Puerto Rico	Brazil

Family	Species	Countries where naturalized	Countries where naturalized and invasive
MYRTACEAE	*Melaleuca quinquenervia*	West Indies, Bahamas	Bahamas, Puerto Rico
MYRTACEAE	*Psidium guajava*	Galapagos, Bahamas	Galapagos, Puerto Rico, Brazil
MYRTACEAE	*Syzygium malaccense*	Puerto Rico	
OLEACEAE	*Fraxinus uhdei*	Puerto Rico	
PALMAE	*Cocos nucifera*	Puerto Rico	
PALMAE	*Hyphaene thebaica*	Curacao	
PALMAE	*Ptychosperma macarthurii*		Barbados, Panama
PINACEAE	*Pinus caribaea*	Puerto Rico	
PINACEAE	*Pinus elliottii*		Brazil
PINACEAE	*Pinus halepensis*		Argentina
PINACEAE	*Pinus radiata*		Argentina
PINACEAE	*Pinus taeda*		Brazil
PITTOSPORACEAE	*Pittosporum undulatum*	Bermuda	Jamaica
PROTEACEAE	*Grevillea robusta*		Jamaica
RHAMNACEAE	*Maesopsis eminii*	Puerto Rico	Puerto Rico
RHAMNACEAE	*Ziziphus mauritiana*	Barbados, Jamaica, Guadaloupe, Martinique, Puerto Rico	
ROSACEAE	*Eriobotrya japonica*	Guatemala	
RUBIACEAE	*Cinchona succirubra*		Galapagos
RUBIACEAE	*Coffea arabica*		Puerto Rico
RUBIACEAE	*Morinda citrifolia*	Puerto Rico	
RUBIACEAE	*Neolamarckia cadamba*	Puerto Rico	
SAPOTACEAE	*Chrysophyllum cainito*	Puerto Rico	
SIMAROUBACEAE	*Simarouba amara*	Puerto Rico	
STERCULIACEAE	*Sterculia foetida*	Puerto Rico	
TAMARICACEAE	*Tamarix sp.*		Peru
TILIACEAE	*Muntingia calabura*		Puerto Rico
ULMACEAE	*Ulmus minor*	Chile	
VERBENACEAE	*Tectona grandis*	Guatemala	

Table 8. The 57 alien forestry species found to be associated with naturalization or invasion events in the Pacific region.
Locations of naturalization / invasion events are listed.

Family	Species	Countries where naturalized	Countries where naturalized and invasive
ANACARDIACEAE	*Anacardium occidentale*		Niue
ANACARDIACEAE	*Schinus terebinthifolius*		Hawaii
ANNONACEAE	*Cananga odorata*		American Samoa, Chuuk, Niue
APOCYNACEAE	*Funtumia elastica*	Samoa (Upolu, Savai'i)	
BIGNONIACEAE	*Spathodea campanulata*		Hawaii
BIGNONIACEAE	*Tabebuia heterophylla*	Kwajalein, Guam	American Samoa, Chuuk, Hawaii, Diego Garcia
BIGNONIACEAE	*Tecoma stans*	Tonga, French Polynesia	
BOMBACACEAE	*Ceiba pentandra*	Samoa, Tonga	American Samoa, Chuuk, Tonga
BORAGINACEAE	*Cordia alliodora*	Samoa	Vanuatu, Tonga (Tongapatu, 'Eua, Vava'u)
CASUARINACEAE	*Casuarina equisetifolia*		Niue, French Polynesia, Hawaii
CASUARINACEAE	*Casuarina glauca*		Hawaii
EUPHORBIACEAE	*Aleurites moluccana*	Pacific	
LEGUMINOSAE-Caesalpinioideae	*Delonix regia*		American Samoa, Chuuk, Niue, Tonga
LEGUMINOSAE-Mimosoideae	*Acacia auriculformis*		American Samoa, Chuuk, Tonga
LEGUMINOSAE-Mimosoideae	*Acacia confusa*		Hawaii
LEGUMINOSAE-Mimosoideae	*Acacia decurrens*	Hawaii	
LEGUMINOSAE-Mimosoideae	*Acacia farnesiana*		Hawaii
LEGUMINOSAE-Mimosoideae	*Acacia glauca*		Cook Islands
LEGUMINOSAE-Mimosoideae	*Acacia mangium*		American Samoa, Chuuk
LEGUMINOSAE-Mimosoideae	*Acacia mearnsii*		Hawaii
LEGUMINOSAE-Mimosoideae	*Acacia melanoxylon*		Hawaii
LEGUMINOSAE-Mimosoideae	*Albizia lebbeck*		Chuuk
LEGUMINOSAE-Mimosoideae	*Falcataria moluccana*		Hawaii
LEGUMINOSAE-Mimosoideae	*Leucaena leucocephala*		Chuuk, Tonga, Guam, Vanuatu, Hawaii

Family	Species	Countries where naturalized	Countries where naturalized and invasive
LEGUMINOSAE-Mimosoideae	*Pithecellobium dulce*		Chuuk, Hawaii
LEGUMINOSAE-Mimosoideae	*Prosopis juliflora*	Hawaii	
LEGUMINOSAE-Mimosoideae	*Prosopis pallida*		Hawaii
LEGUMINOSAE-Mimosoideae	*Samanea saman*		American Samoa, Chuuk, Hawaii, Tonga
MELIACEAE	*Azadirachta indica*	Fiji	
MELIACEAE	*Cedrela odorata*		Tonga
MELIACEAE	*Melia azedarach*		Chuuk
MELIACEAE	*Swietenia mahogoni*		Hawaii
MELIACEAE	*Toona ciliata*		Hawaii, Tonga
MORACEAE	*Broussonetia papyrifera*	Pacific Islands	
MORACEAE	*Castilla elastica*	French Polynesia	Samoa, Hawaii
MORINGACEAE	*Moringa oleifera*		Chuuk, Niue
MYRTACEAE	*Eucalyptus globulus*		Hawaii
MYRTACEAE	*Melaleuca quinquenervia*		Hawaii
MYRTACEAE	*Psidium guajava*	Hawaii, the Marquesas, French Polynesia, New Caledonia, Fiji	American Samoa, Chuuk, Hawaii, Tonga
MYRTACEAE	*Syzygium cumini*	Niue	Hawaii
OLEACEAE	*Fraxinus uhdei*		Hawaii
PALMAE	*Elaeis guineensis*		Chuuk, Niue
PINACEAE	*Pinus caribaea*		French Polynesia, Hawaii
PINACEAE	*Pinus patula*		Hawaii
PINACEAE	*Pinus pinaster*		Hawaii
PITTOSPORACEAE	*Pittosporum undulatum*	Hawaii	
PROTEACEAE	*Grevillea robusta*	Hawaii	Niue, Hawaii
RHAMNACEAE	*Maesopsis eminii*	Fiji	
RHIZOPHORACEAE	*Rhizophora mangle*		Hawaii
RUBIACEAE	*Coffea arabica*	Guam, Samoa	

Family	Species	Countries where naturalized	Countries where naturalized and invasive
RUTACEAE	*Flindersia brayleyana*		Hawaii
SIMAROUBACEAE	*Ailanthus altissima*		Hawaii
SOLANACEAE	*Solanum mauritianum*	Hawaii, Fiji, New Caledonia, Solomon Islands, Tonga	Tonga, Cook Islands (Raratonga)
TAMARICACEAE	*Tamarix aphylla*		Hawaii
TILIACEAE	*Muntingia calabura*		Chuuk
ULMACEAE	*Trema orientalis*		Hawaii
VERBENACEAE	*Gmelina arborea*	Cook Islands, 'Atiu	

Table 9. The 29 alien forestry species found to be associated with naturalization or invasion events in Asia.
Locations of naturalization / invasion events are listed.

Family	Species	Countries where naturalized	Countries where naturalized and invasive
BIGNONIACEAE	*Spathodea campanulata*		Singapore
CASUARINACEAE	*Casuarina equisetifolia*	China	Japan
LEGUMINOSAE-Caesalpinioideae	*Parkinsonia aculeata*	India	
LEGUMINOSAE-Mimosoideae	*Acacia auriculformis*	Malaysia, western Malaysia	Borneo (Sabah, Brunei), Singapore, Bangladesh
EUPHORBIACEAE	*Aleurites moluccana*		Christmas Island
LEGUMINOSAE-Mimosoideae	*Acacia confusa*	Japan (Saipan, Okinawa)	
LEGUMINOSAE-Mimosoideae	*Acacia dealbata*	India	
LEGUMINOSAE-Mimosoideae	*Acacia longifolia*		Israel
LEGUMINOSAE-Mimosoideae	*Acacia mangium*		Malaysia (Sabah), Bangladesh
LEGUMINOSAE-Mimosoideae	*Acacia nilotica*		Indonesia
LEGUMINOSAE-Mimosoideae	*Adenanthera pavonina*		Malaysia
LEGUMINOSAE-Mimosoideae	*Falcataria moluccana*		Singapore
LEGUMINOSAE-Mimosoideae	*Leucaena diversifolia*	Southeast Asia	
LEGUMINOSAE-Mimosoideae	*Leucaena leucocephala*		Phillipines, Indonesia (Java), Papua New Guinea, Malaysia, New Britain, Pakistan
LEGUMINOSAE-Mimosoideae	*Pithecellobium dulce*	India, Philippines	
LEGUMINOSAE-Mimosoideae	*Prosopis juliflora*		Pakistan, India
LEGUMINOSAE-Papilionoideae	*Flemingia macrophylla*	Papua New Guinea	
LEGUMINOSAE-Papilionoideae	*Robinia pseudoacacia*	Pakistan	Turkey, Cyprus, Israel
LEGUMINOSAE-Papilionoideae	*Tephrosia candida*	Southeast Asia	
MELIACEAE	*Azadirachta indica*	Malaysia, Indonesia, Thailand	
MELIACEAE	*Swietenia macrophylla*		Sri Lanka
MORACEAE	*Broussonetia papyrifera*	Pakistan, Thailand	India, Pakistan
MYRTACEAE	*Eucalyptus camaldulensis*		Bangladesh, Pakistan

Family	Species	Countries where naturalized	Countries where naturalized and invasive
MYRTACEAE	*Melaleuca quinquenervia*	India, Philippines	
RHAMNACEAE	*Maesopsis eminii*		India
RHAMNACEAE	*Ziziphus mauritiana*	Myanmar, Iran, Sri Lanka, Syria	
SCROPHULARIACEAE	*Paulownia tomentosa*	Japan, North Korea, South Korea	
SIMAROUBACEAE	*Ailanthus altissima*		Pakistan
SOLANACEAE	*Solanum mauritianum*	Solomon Islands	