4. Vegetative propagation and preliminary field performance of sixteen rainforest tree species in north Queensland

D. Garth Nikles and Ken J. Robson

Abstract

This study assessed sixteen rainforest tree species, from nine taxonomic families, for amenability to vegetative propagation (VP) via rooted cuttings, as a possible means for overcoming constraints on seedling deployment of these species that were considered to have potential for plantings of various kinds. Elaeocarpus grandis *and* Cedrela odorata *(the latter being the only exotic species included) were found to be highly amenable to VP. Several other species (*Acacia aulacocarpa*,* Agathis robusta*,* Alloxylon flammeum*,* Araucaria cunninghamii *and* Gmelina fasciculiflora*) exhibited sufficient potential such that, if improvement in key propagation traits could be achieved in the future, then VP may become a viable deployment strategy for these species as well. In contrast,* Blephocarya involucrigea*,* Cardwellia sublimus*,* Castanospermum australe*, five* Flindersia *species and* Musgravea heterophylla *were much less promising for VP under the conditions employed.*

For a subset of three species, highly significant differences among clone means were demonstrated for two key VP traits (rootability and number of roots per rooted cutting). Differences were also observed in other species and in the propensity of hedged seedlings of all sixteen species to produce coppice shoots.

Rooted cuttings of seven species were included in one or two field trials for preliminary assessment of the potential of these species for deployment as clones. The more promising species for growth as rooted cuttings on at least one site were E. grandis *(outstanding),* C. odorata, A. cunninghamii *and* A. robusta*. Rooted cuttings of* A. aulacocarpa *grew moderately well, but apparently less well than seedlings at both sites. Those of* A. flammeum *and* G. fasciculiflora *were not promising for growth at either site, nor for survival at one site. Differences between clones in survival and growth were observed in some species.*

Based on the results of this preliminary study and other work, prospects for VP, clone selection and deployment as individual clones or clone mixtures using rooted cuttings, seem good for a few of the species. Further work would be required to achieve realisation of the potential of the promising species.

Introduction

A report was prepared in 1994 by the then Queensland Forestry Research Institute (QFRI) identifying tree domestication needs for the main species being planted under the Community Rainforest Reforestation Program (CRRP). It also defined the appropriate tree domestication strategies for these species (Nikles *et al.* 1994). It was recognised that some of the species of interest were characterised by constraints on regular production of large numbers of seedlings due to one or more of the following features: produce viable seed infrequently; have fruits, cones or seeds severely attacked by pests; have fleshy-fruited or other types of seed that do not store well; and/or have seeds that are difficult or slow to germinate.

Producing planting stock vegetatively (as rooted cuttings from limited seedling supplies) may avoid these problems and potentially allow more rapid genetic development of some species through deployment of superior families or clones (Evans and Turnbull 2004). Consequently, research on the amenability of such species to vegetative propagation (VP) was identified as worthy of attention within the program.

QFRI had been developing methodology for the VP of coniferous species for several years (Walker *et al.* 1996a). It was intended to apply this methodology, with modifications, to the propagation of several rainforest hardwood species. Evans and Turnbull (2004) reviewed the history of development and the present status of clonal plantations of forest trees and showed that many species are being deployed as rooted cuttings, including several rainforest species. In Vietnam, selected clones of the interspecific hybrid between the rainforest *Acacia* species *A. mangium* and *A. auriculiformis* are planted operationally (Kha 2001). It was reported by Arnold *et al.* (1998) that *A. aulacocarpa* was being considered for large scale deployment as rooted cuttings in the Philippines.

Table 1 details the fifteen native and one introduced species (*Cedrela odorata*), across a range of nine taxonomic families, that had been recommended by experienced foresters in the area as candidates for domestication and use in the CRRP. Information on these (and other species) covering natural distribution and conservation status, wood quality, biology, genetic variation and breeding activities with them is given by Nikles *et al.* (1994). These species were chosen for an exploratory study of their amenability to VP and potential for deployment to plantings in the form of rooted cuttings as mixed, identified clones.

Table 1 List of the 16 rainforest tree species tested [14 hardwoods and two conifers (c)] – all native except *Cedrela odorata*. [1]

Species' scientific name	Species' common name	Family
Acacia aulacocarpa Cunn. Ex Benth.	brown salwood	Mimosaceae
Agathis robusta C. Moore es F. Muell (c)	kauri pine	Araucariaceae
Alloxylon flammeum (W. Hill & F. Muell.) P. Weston & Crisp	satin silky oak	Proteaceae
Araucaria cunninghamii Aiton ex D. Don (c)	hoop pine	Araucariaceae
Blepharocarya involucrigera F. Muell.	rose butternut	Anacardiaceae
Cardwellia sublimis F. Muell.	northern silky oak	Proteaceae
Castanospernum australe A. Cunn.& A. Fraser ex Hook	black bean	Fabaceae
Cedrela odorata L.	West Indian cedar	Meliaceae
Elaeocarpus grandis F. Muell.	silver quandong	Elaeocarpaceae
Flindersia bourjotiana F. Muell.	Queensland silver ash	Rutaceae
Flindersia brayleyana F. Muell.	Queensland maple	Rutaceae
Flindersia iffliana F. Muell.	hickory ash	Rutaceae
Flindersia pimentaliana F. Muell.	maple silkwood	Rutaceae
Flindersia schottiana F. Muell.	northern silver ash	Rutaceae
Gmelina fasciculiflora Benth.	white beech	Verbenaceae
Musgravea heterophylla L. S. Sm.	briar silky oak	Proteaceae

[1] *Available records of seed origins are given in Appendix 1.*

Toona ciliata M. Roemer (red cedar) (Meliaceae), an Australian "icon" among rainforest timbers, was not included in the study because of its well-known, extreme susceptibility to the shoot borer (*Hypsipyla robusta* Moore). Furthermore, the species was known already to be highly amenable to propagation by rooted cuttings from seedlings (Haley 1957; Collins and Walker 1998).

This chapter gives an overview of the establishment and initial management of seedling hedges planted in 1993 and 1994. It describes shoot production following first hedging, the rootability of cuttings from the shoots and the numbers of roots produced per rooted cutting. For a subset of species, the early field performance of rooted cuttings clones and seedlings in trials undertaken in north Queensland in the 1990s is outlined. The potential of the species for further planting in north Queensland is examined briefly in the light of results of this and other work. Also, recommendations are made on the support required to derive definitive conclusions from work of the kind that was undertaken in this preliminary study.

Materials and methods

Hedge establishment and management

The botanical and common names and the taxonomic families of the species chosen for the study are detailed in Table 1. Seedlings for the study were procured from stock at the Department of Primary Industries - Forestry's plant nursery at Walkamin near Atherton. Available information on seed sources is given in Appendix 1. An area within the nursery boundary was prepared with planting lines ripped and mounded at two-meter intervals. In October 1993, seedlings of eleven hardwood species (Table 2) were planted at intervals of one meter in the prepared rows along with weed matting (Figure 1), These seedlings were then managed as hedges to produce cuttings for use in screening trials of rootability and related aspects of VP.

Table 2 Rootability (percentage of cuttings set that rooted), average number of roots per rooted cutting and the average number of shoots produced per hedge plant in a three-month period for each of 11 rain forest hardwood tree species. Numbers of cuttings set per species ranged from 35-386, reflecting the prolificacy of coppicing.

Species' scientific name	Species' common name	Mean rootability (%)	Mean no. roots per rooted cutting	Mean no. shoots per hedge plant over a 3-mth period
Acacia aulacocarpa	brown salwood	59.0	13.8	4.5
Alloxylon flammeum	satin silky oak	71.8	6.2	6.6
Blepharocarya involucrigera	rose butternut	0.6	3.0	7.3
Castanospernum australe	black bean	26.8	2.0	4.6
Cedrela odorata	West Indian cedar	86.7	17.2	4.6
Elaeocarpus grandis	silver quandong	73.2	8.7	17.1
Flindersia bourjotiana	Queensland silver ash	8.8	3.2	2.4
Flindersia brayleyana	Queensland maple	5.7	1.0	2.0
Flindersia iffliana	hickory ash	3.0	1.0	2.0
Flindersia schottiana	northern silver ash	14.3	2.2	3.3
Gmelina fasciculiflora	white beech	52.3	4.0	13.7
	Overall mean	**36.6**	**5.7**	**6.2**

Figure 1 A section of a hedgerow showing the weed matting and plants of *Gmelina fasciculiflora* some three months after topping in January, 1994.

In March 1994, similar rows were established for the other five species – two conifers, *Agathis robusta* (kauri pine) and *Araucaria cunninghamii* (hoop pine), and three hardwood species *Cardwellia sublimus* (northern silky oak), *Flindersia pimentaliana* (maple silkwood) and *Musgravea heterophylla* (briar silky oak).

For each of the 16 species there were three replications of rows containing 22 plants of each species for propagation studies, and one 22-plant row for observations (results not reported here) on the coppicing ability of each species.

Hedge seedlings planted in October 1993 were topped at a height of 30 cm in January 1994, to stimulate production of coppice shoots (see Figure 1). The numbers of shoots produced in the following three months were counted in April 1994. Hedges planted a year later were similarly topped and observed for shoot production in 1995.

The data collected on shoot production of the hedges of the 11 species planted in 1993 are reported as species' means in Table 2.

Nursery trials of rootability

Following topping of the hedges in January 1994, juvenile coppice shoots were collected in April 1994 from a range of recorded positions and ages of each hedge for each of the 11 species. These were both single and multi-noded and in 5 cm and 10 cm sections. These were prepared by reducing the leaf area on the shoots to about half (Figures 2, 3).

Replicated trials were established to investigate the effects on propagation traits of:

- shoot length and position in hedge plant;
- cutting length, diameter and segment order (from apex to base);
- rooting medium (various mixtures of sterile peat, vermiculite and perlite);
- concentration of Indole 3 Butyric Acid (IBA); and
- clonal identity.

Figure 2 A rooted cutting of *Gmelina fasciculiflora* showing the reduced leaf area, extensive callus and root system developed nine weeks after setting and placement under mist.

Figure 3 A multi-node cutting of *Alloxylon flammeum*, now rooted, showing the reduced leaf area of the original cutting, and an extensive root system developed by 16 weeks after setting and placement under a misting system.

Detailed results of all these studies are yet to be published. However the following provides an overview of: rootability (number of the cuttings with roots as a proportion of the number of cuttings set expressed as a percentage), the average number of roots per rooted cutting, and the effects of some cuttings treatments applied to three of the species.

For the comparison of species for rootability and roots formed per rooted cutting, shoots from 11 species (Table 2) were cut into 5 and 10 cm sections (these are referred to subsequently as cuttings). The base of each cutting was then dipped in a commercial rooting hormone containing 0.8% I.B.A prior to setting in 100 cm^3 tubes (Vic forestry tubes) containing, as rooting medium, a 3:2 mixture of vermiculite and sterile peat or perlite. The numbers of cuttings set per species varied greatly (35 to 386), reflecting the relative prolificacy of shoot production following topping of hedge plants.

The cuttings were placed in a shadehouse (60% shade) with frequent mist irrigation supplied via foggers (controlled by a balance arm and mercury switch misting unit). This maintained a thin film of water on the leaves at all times, reduced temperatures and minimised water loss from the cuttings.

Further experimental settings of cuttings were carried out in October and December 1994. Additional species tested in these settings included the five species named above that were established in hedge rows in March 1994. These settings included 315 cuttings of *A. cunninghamii* with varying numbers of cuttings of apical (132) and progressively more basal segments (Walker *et al.* 1996b). In all cases, rootability and roots per cutting with roots were assessed by counts made 16 weeks after setting.

For *C. odorata, G. fasciculiflora* and *E. grandis*, studies were also made of the effects of shoot length, segment order, cutting length and diameter and clone identity on rootability and number of roots per rooted cutting. Data were analysed as a 3 x 5 factorial for each trait.

Field trials of seedlings and rooted cuttings

The rooted cuttings produced by the five hardwood species that gave rootabilities greater than 50% (Table 2) were planted as identified clones into two field trials to compare their growth and tree quality with that of seedlings. Two trials, one on the north Queensland coastal lowlands ("Coast trial") and the other on the Atherton Tableland ("Tableland trial"), were established early in 1995. A third trial using coniferous species was established on the Atherton Tableland in 1996 to observe the performance of rooted cuttings clones of *A. robusta* (kauri pine) and *A. cunninghamii* (hoop pine). In view of the preliminary nature of all the field trials, and resources available, the data obtained were not analysed statistically.

Plantings of hardwoods (1995)

Coast trial

This trial was planted in March 1995 at Utchee Creek near Innisfail on land owned by a participant in the CRRP. The site was almost flat at approximately 50 m above sea level (asl) with mean annual rainfall (MAR) of approximately 3000 mm. The soil was a red earth derived from metamorphosed parent material. The site had been used previously for sugar cane cropping. Site preparation included ripping of planting lines to 30 cm depth at 5 m intervals. Prior to planting, the lines were treated with knockdown and pre-emergent herbicides to kill grasses and other weeds. Planting was at 3 m spacings along the ripped lines.

The experimental design was randomised complete block (RCB) with three replications of the nine treatments (seedlings and rooted cuttings of four species, and rooted cuttings only of the fifth species, *Alloxylon flammeum*) (Table 3). Plots, each of a single species as either rooted cuttings or seedlings, comprised five rows of four trees.

During the first four years, weed control with herbicidal sprays was applied as required to ensure weed competition, especially from grasses, was minimised. After 1999 the maintenance of the trial was left in the hands of the landowner. The growth rate and health of the trees deteriorated after the fourth year due to highly competitive tropical grasses invading the trial.

The diameter at breast height over bark (DBHOB) and tree height were measured (where possible) in May 1998 when the trials were 3.5 years old. Notes were made in June 2003 on the relative performances of the species.

Table 3 Summary of 3.5 year survival and height, and of later observations on seedlings and clones of five hardwood species established in Coast and Tableland (T'land) field trials in 1995.

Species, type of planting stock and (no.) of rooted cuttings in Coast & T'land trials	Survival (%) [1]		Height (m)		8-yr DBHOB (cm)		Observations made in June, 2003
	Coast	T'land	Coast	T'land	Coast	T'land	
Acacia aulacocarpa							Growth good on both sites; but form very poor
Seedlings	100	43	5.66	6.05			
Clones	97	22	4.78	3.83			
Alloxylon flammeum							Growth poor on both sites
Seedlings			No seedlings				
Clones	74	13	2.83	1.88			
Cedrela odorata							Growth much better on T'land site – cf *Gmelina*
Seedlings	93	100	3.65	6.89			
Clones	89	100	2.96	7.93			
Elaeocarpus grandis							Best-/equal-best-growth species on both sites
Seedlings	100	85	5.87	5.61	7.48	9.61	
Clones	95	86	6.42	7.89	7.58	9.87	
Gmelina fasciculiflora							Growth very poor on T'land site – cf *Cedrela*
Seedlings	100	80	3.83	0.91			
Clones	97	51	3.12	1.15			

[1] *Survival calculated on basis of number of plants planted per plant type per species, ie. 60 and 40 in Coast and T'land trials respectively.*

Tableland trial

This was planted in 1995 at Yungaburra, on the land of a participant in the CRRP. The site had a slight slope to the south east at approximately 800 m a.s.l with MAR of approximately 1200 mm. The soil was a red kraznozem derived from basalt. The site had been fallow for several years and occasionally carried some grazing cattle. Site preparation involved forming rows of small mounds at 5 m intervals with a double pass plough. Prior to planting, the lines were treated with knockdown and pre-emergent herbicides to kill grasses and weeds. Planting was at 3 m spacings along the lines.

The experimental design was as the same as that of the Coast trial, ie. a RCB, but with two replications. There were rooted cuttings of each of five species and seedlings of all species except *Alloxylon flammeum* (Table 4). Plots contained four rows of five trees.

During the first four years, weed control was carried out by the application of herbicidal sprays to ensure weed competition was minimised. After 1999 the maintenance of the trial was left in the hands of the landowner. The Tableland site was grazed (cattle) from 1999. Less competition from grasses than in the coastal site led to better continued growth and survival.

Diameter breast high over bark (DBHOB) and tree height were measured (where possible) in May 1998 when the trial was 3.5 years old. Subsequently, the trial was observed at various times including in June 2003 when notes were made on the appearance of each species.

Planting of conifers (1996)

This trial was planted in Compartment 202 Dreghorn, State Forest 310, Gadgarra on the Atherton Tableland in January 1996. The site is located on a 10-15% slope at 650 m a.s.l. with a MAR of approximately 2000 mm. The soil was a red krasnozem derived from basalt. Originally, the site carried upland rainforest that was cleared in June 1939 and planted with hoop pine in December 1939. This crop was harvested between 1992 and 1995. Site preparation for the 1996 trial comprised contour strip ploughing at 5 m row spacing (two passes with plough). A second rotation *A. cunninghamii* plantation was established in February 1995 on the area, except for a section that was left vacant for the clonal trial.

The planting stock for the trial was rooted cuttings of clones of *A. robusta* (six clones) and *A. cunninghamii* (Papua New Guinea provenance, ten clones). No seedling controls were available for planting. The different age, provenance and management of the adjacent *A. cunninghamii* plantation precluded its use for the establishment of sample plots with which to compare the clones.

The planting comprised species-separate, unreplicated plots of six rows by 18 trees (108 plants) of each species at 5m x 2.5m spacing. On average, there were 18 and 10 rooted cuttings per clone for the *A. robusta* and *A. cunninghamii* respectively, but numbers per individual clone varied considerably. Weed control was the same as that applied in the adjacent commercial plantation, i.e. occasional herbicide sprays.

DBHOB was measured in May 2003 when each tree was also scored (1 to 4 scale) for stem breakage point (% of total height), lean (degrees of displacement from vertical), axis persistence (proportion of total height from ground to first fork) and stem straightness (combination of the number and severity of bends). For ‘breakage’ and ‘lean’, high scores indicated good trees; the reverse was the case for ‘axis persistence’ and ‘straightness’.

Results

Hedge development and rootability of cuttings

The data collected on shoot production in this part of the work are reported (for the hedges planted in 1993) as species’ means in Table 2.

In the hedges, it was observed that some species grew very slowly, and some did not respond to hedging with prolific shoot production. For example, *C. sublimis* and *M. heterophylla* plants grew very slowly and neither species produced sufficient quantities of shoots, cuttings nor rooted cuttings for adequate field testing.

The latter comment applied to several other species, most notably the *Flindersia* species, *B. involucrigera* and *C. australe*. In contrast, *E. grandis* and *G. fasciculiflora* responded to hedging with prolific shoot production such that averages of 17.1 and 13.7 shoots per hedge were produced in a three month period respectively (Table 2).

The rootability (percentage), mean number of roots per cutting and the average number of shoots collected per hedge plant over a three month period from April through to July of 1994 for the 11 hardwood species are presented in Table 2. The average of all species for the three propagation parameters were 36.6%, 5.7 roots and 6.2 shoots, but the ranges among species varied greatly – from 0.6 to 86.7%, 1.0 to 17.2 roots and 2.0 to 17.1 shoots (Table 2).

The greatest overall success was with *E. grandis* which exhibited high rootability (73%), above average number of roots per cutting (8.7) and the highest shoot production in a three month period (17.1 shoots per hedge). No other species ranked as well for all three propagation parameters, though

Cedrela odorata came close, being first for rootability (86.7%) and roots per cutting (17.2), but equal 5th for mean number of shoots per hedge (4.6).

Other species with prospects for amenability to VP, based here on arbitrary criteria of rootabilities greater than 50% and a ranking of fifth or better among the 11 species for at least one of the other two propagation traits, were *Alloxylon flammeum, A. aulacocarpa* and *Gmelina fasciculiflora.*

Unfortunately, *B. involucrigera* and all four of the *Flindersia* species had relatively very low rootabilities (0.6% and 3.0% - 14.3% respectively) and below average numbers of roots per cutting; and the *Flindersia* species had low shoot production (all less than 3.3 shoots per hedge in a three month period). However, *B. involucrigera* was relatively prolific in shoot production (average of 7.3), ranking third. Although *C. australe* averaged 26.8% rootability (rank 6), the number of roots per cutting and number of shoots per hedge plant were low (2.0 and 4.6 respectively).

Rootability of the conifer *A. cunninghamii* was high at 89.4% for apical cuttings (Table 4) and is reported more fully below. With this species (and the other conifer, *A. robusta*), the shoot multiplication rate from each hedge was low due to the strong dominance of the tallest orthotrophic shoot in each hedged plant, a characteristic of *A. cunninghamii* described elsewhere (Nikles *et al.*, 2004 a).

Table 4 Means for rootability of *Araucaria cunninghamii* cuttings taken as apical and progressively more basal segments of shoots from seedling hedges (from Walker *et al.* 1996b).

Segment	No. cuttings set	Rootability (%)
1 (apical)	132	89.4
2	91	67.0
3	61	55.7
4	26	30.8
5 (basal)	5	20.0

It was observed that, of the propagation media and rooting chemicals tested, the best appeared to be a mixture 3:2 of sterile peat and perlite, with 0.8% IBA; and most species produced roots from both single and multi-nodal cuttings.

Effect of propagation treatment

Results of analyses of the effects of five cuttings treatments on the VP traits rootability and total numbers of roots per rooted cutting of *C. odorata, E. grandis* and *G. fasciculiflora* are given in Table 5. There was a very strong statistical significance of differences for clonal identity (ie. between clone means) for all three species for both traits. The other, four treatments had variable and generally inconsistent effects with respect to propagation traits and species. For example, these four treatments had significant effects on roots per cutting of one species (*C. odorata*), but only cutting length affected rootability in this species. In contrast, only one treatment (shoot length) significantly affected roots per cutting of *G. fasciculiflora,* while only one treatment (cutting diameter) did not significantly affect its rootability. Cutting diameter was not significant for rootability of any of the three species nor, for *G. fasciculiflora,* with respect to number of roots; however, it played a relatively minor role in affecting numbers of roots in the other two species (Table 5). Perhaps these barely discernible patterns are to be expected in the case of species from three very different taxonomic families.

Table 5 Results of an analysis of variance (showing F values) of the effects on rooting parameters of four cutting treatments assessed on three species - *Cedrela odorata, Elaeocarpus grandis* and *Gmelina fasciculiflora.*

Parameter	Rootability			Number of roots per rooted cutting		
Treatment	*C. odorata*	*E. grandis*	*G. fasciculiflora*	*C. odorata*	*E grandis*	*G. fasciculiflora*
Shoot length	ns	ns	2.3***	2.1*	ns	5.3***
Segment order	ns	1.1*	1.5**	1.8*	ns	ns
Cutting length	3.6**	ns	1.5**	2.3***	ns	ns
Cutting diameter	ns	ns	ns	3.7**	2.6*	ns
Clonal identity	37.1***	21.9***	34.0***	32.8***	34.2***	64.6***

*Asterisks indicate levels of statistical significance: * (0.05), ** (0.01) *** (0.001).*

The data for each of the same three hardwood species were tested for differences in rootability dependent on which segment a cutting represented along a coppice shoot (from apically to basally). Results suggested *G. fasciculiflora* was the only species in which there was a clear trend of increasing rootability and of numbers of roots produced per rooted cutting as cuttings were taken more basally, ie. fourth-segment cuttings rooted better (69.7%) than apical cuttings (43.3%), and had more roots (averages of 4.8 and 3.1 respectively).

The overall rootability of the 315 *A. cunninghamii* (conifer) cuttings set from five different segments representing apical and progressively more basal portions of shoots was 70.5%. Numbers of cuttings per segment and corresponding rootability means are given in Table 4. Although not analysed statistically, the results suggested a trend of decreasing rootability as cuttings were sourced from segment progressively more distant from the apex, a trend opposite to that of the hardwood *G. fasciculiflora*, as mentioned above.

Field trials of seedlings verses rooted cuttings

Planting of hardwoods (1995)

The results of this analysis is presented in Table 3, should be interpreted cautiously because rooted cuttings of only five hardwood species (one without accompanying seedling controls) could be planted, in one year only (1995), and the maintenance these trials was sub-optimal after 1999.

Coast trial

Survival 3.5 years after planting was high to very high (more than 89%) for both seedlings and rooted cuttings of all species except *A. flammeum* (the rooted cuttings-only sample for this species showed 74% survival). It is evident from the means given in Table 3 that there were no large differences in survival of seedlings versus rooted cuttings for any of the four species that could be compared.

The best species - plant type combination for height at 3.5 years was the *E. grandis* rooted cuttings (6.42 m); least tall were the *A. flammeum* clones (2.83 m). The *E. grandis* rooted cuttings were more than half a meter taller, on average, than seedlings of that species (5.87 m) giving nearly a 10% superiority. Results were opposite for the other three species in which rooted cuttings were only from 84% to 81% of the height of seedlings. The *A. aulacocarpa* rooted cuttings at 4.78 m were the next tallest after *E. grandis*, but it was observed that their form was very poor since all trees were multi-stemmed. *C. odorata* and *G. fasciculiflora* trees grew at similar rates (averages close to 3 m), with seedlings performing moderately better that the rooted cuttings for both species.

Tableland trial

Survival rates were high for rooted cuttings and seedlings of *C. odorata* (both 100%) and *E. grandis* (86%, 85%). However, for the other two species where the plant types could be compared (*A. aulacocarpa* and *G. fasciculiflora*), survival of rooted cuttings (at 22% and 51% respectively) was only 51% and 64% of the survival rates of seedlings. *A. flammeum* rooted cuttings showed extremely low survival (13%).

The best species - plant type combination for height on this site were the *C. odorata* and *E. grandis* rooted cuttings (7.93 m and 7.89 m respectively). The rooted cuttings of *C. odorata* averaged one meter taller than the seedlings (6.89 m), while the *E. grandis* rooted cuttings averaged more than two meters taller than the seedlings (5.61 m). The *G. fasciculiflora* seedlings and rooted cuttings and *A. flammeum* clones grew poorly averaging 0.91 m, 1.15 m and 1.88 m respectively. The rooted cuttings of *A. aulacocarpa* (averaging 3.83 m) grew much more poorly than seedlings (6.05 m).

Sites combined

Survival

In the 1995 trials, survival on the Coast site was high for all species and for both seedlings and rooted cuttings. However, on the Tableland site, both plant types of *A. aulacocarpa* and the rooted cuttings of *A. flammeum* survived very poorly (Table 3). Since *A. aulacocarpa* cuttings especially had a large average number of roots (Table 2), this result is surprising. It may have been due to unrepresentative damage by cattle and/or weeds.

Growth performance of rooted cuttings vs seedling

Comparisons were possible for four species and for height only. In general, the height differences were neither large nor consistent – except that the *E. grandis* rooted cuttings were taller than seedlings of this species at both sites. At the Coast, the rooted cuttings of *E. grandis* only were taller (6.42 m) than seedlings (5.87 m). On the Tableland, the rooted cuttings of *E. grandis* and *C. odorata* (equally tall on average – 7.9 m) were clearly superior to seedlings, while the reverse was the case for *A. aulacocarpa.*

Whereas the rooted cuttings of *E. grandis* surpassed the seedlings in height at age 3.5 years at the Coast and Tableland sites by 9.4% and 41% respectively, the respective differences in DBHOB at eight years of age were only 1.3% and 2.7%.

Clone effect

For all species, it was observed that individual clones of rooted cuttings substantially out-grew the seedlings, and there were large differences between clones within species. For example, the mean height of the *G. fasciculiflora* seedlings at the Coast site (3.8m) was higher than that of the rooted cuttings (3.1 m); however, the mean height of individual clones ranged from 1.3 m for clone 19 to 4.45 m for clone 9. Clonal variation of lower magnitude was also observed in *C. odorata* and *E. grandis*. This opens up possibilities, if confirmed, for rapid improvement of growth through testing and selecting clones in some species.

Species-by-site

With one exception, all species in the 1995 plantings had good early survival on both sites, the poor result shown for *A. aulacocarpa* on the Tableland site (Table 3) being due, most likely, to cattle damage. The *C. odorata* seedlings grew twice as well on the Tableland site, with the clones almost three times taller. On the other hand the *G. fasciculiflora* grew better on the Coast site. The *A. aulacocarpa* grew well on both sites; however, stem form was poor (on both sites) with each tree multi-stemmed. The *A. flammeum* performed better on the coastal site, where it was more than one meter taller than the Tableland cohorts. *E. grandis* out-grew all other species on both sites. These inconsistencies suggest taxa by site interaction could be strong for species, such as *C. odorata*, perhaps need careful matching with location. Alternatively, *E. grandis* gave indications of broad adaptability.

Observations made in both plantings in June 2003

A visual assessment of both 1995 sites in June 2003 indicated that inadequate management of weeds in the Coast trial, and of grazing in the Tableland trial, had compromised these trials. Both seedlings and clones of *E. grandis* on both sites and of *C. odorata* on the Tableland site, still showed promise under the conditions that prevailed.

Planting of conifers (1996)

The results at seven years of age, presented in Table 6, need to be interpreted cautiously, because the planting did not include seedlings, was unreplicated and was established at a single site.

Table 6 Performance at seven years of age of clones from rooted cuttings of *A. cunninghamii* and *A. robusta* planted in the Gadgarra State Forest, Atherton Tableland.

Species	No. of clones	No. of trees	Survival (%)	DBHOB (cm) Spp mean (=*a*)	Best clone (=*b*)	Percent increase (*b*-*a*)
A. cunninghamii	10	87	80.6	15.35	16.78	9
A. robusta	6	88	82.4	9.26	11.09	20

Note: DBHOB – diameter breast high over bark.

Both species gave high average field survival (80.6% and 82.4% respectively). The numbers of trees surviving per clone (not shown) ranged from 7 to 13 for *A. cunninghamii* (an average of 10 had been planted per clone), except for one clone of which only three were planted; and 11 to 15 for *A. robusta* (an average of 10 had been planted per clone), except for one clone which had 22 surviving from 26 planted. There were considerable differences in clone means for DBHOB as indicated by the means of best clones versus species means expressed as a percentage (9% and 20% for *A. cunninghamii* and *A. robusta* respectively). However, since the planting was unreplicated, these observations must be interpreted cautiously.

The trees had been scored in May 2003 for straightness, stem breakage, lean and axis persistence. However, the results (not tabulated) showed only very small differences between species and between clones within species. In general, the *A. cunninghamii* clones were impressive in growth and straightness; the latter observation was not expected on the basis of past experience with some unimproved Papua New Guinea hoop pine seedling stock (Nikles and Robson 2004).

Discussion

There appear to be large differences among the 11 hardwood species in terms of their responses to the various treatments. However, only one species 'stood out' as highly satisfactory on all evaluation criteria and that was *E. grandis*.

The finding of high VP potential for *E. grandis*, a native rainforest species with seed very slow to germinate (Nikles *et al.* 1994) suggest rooted cuttings could substitute for seedlings in many future plantings of this species. Moreover, *E. grandis* showed highly significant variation of rootability and roots per cutting between clones, and clonal differences in survival and growth were also observed in the field trials. These preliminary findings indicate it could be a good candidate for family and clonal forestry, if commercial planting were contemplated in suitable areas. Furthermore, its superior performance in other, widespread CRRP plantings (of seedlings) across a range of soils and rainfalls as well (Bristow *et al.* Chapter 6) indicates it is a species that could be planted with considerable confidence where a rainforest species with high survival, rapid growth and the particular wood properties of *E. grandis* (Bootle 1995) are prime requirements.

The responses and prospects of the other species are now discussed, first the hardwoods and then the conifers. In both cases this discussion is in the approximate order of their apparent amenability to VP.

The introduced species, *C. odorata,* also showed high amenability to VP (especially if shoot production in hedges could be enhanced) and, potentially, to clonal selection. However, with this species it appears very desirable to allocate it to locations and/or sites rather carefully since its growth in the field was very much better at the Tableland than the Coast site in the present study (the latter site had edaphic constraints). The species registered 'moderate' growth rates in each of the three soil type-rainfall regimes in which it was tested under the CRRP, but numbers of trees measured per site were small (Bristow *et al.* Chapter 6).

Keenan *et al.* (1998) reported 9.5 year performance of several *C. odorata* provenances grown as seedlings as part of a species trial on a Coast site near Innisfail, north Queensland on a much better soil ('red, weakly laterised kraznozem derived from basalt') than that of the Coast site. Survival at this site was high. The mean height of the best two, well-replicated, *C.odorata* provenances (17.1 m) was similar to that of the better teak (*Tectona grandis*) (16.9 m), but the basal area per ha of the former was 40% higher. All *C. odorata* provenances (except one from Colombia, which also had the best height growth, bole length and form) were attacked by the shoot borer *Hypsipyla robusta*; however, resistance to and recovery from attack appeared to vary among provenances and was greater than that of *Toona ciliata* (in a separate, mixed planting with *C. odorata*) and *Swietenia macrophylla*, the latter species (though surviving well) still exhibiting almost 100% multi-stemmed trees in 2004 as a result of early attack (Nikles pers. obs.). At 17.5 years of age, the *C. odorata* in this species trial still exhibited good growth and survival, though apparently less than that of *Pinus caribaea* var. *hondurensis* Barr. and Golf and *A. robusta*, and much poorer stem form than these two species. Thus *C. odorata* appears to have potential for commercial planting in north Queensland, but work on wood quality evaluation, assembly of germplasm (especially from the promising Colombian provenance), breeding, clone testing and site matching would be required before *C. odorata* cuttings could be recommended confidently for establishment in commercial plantings in the region.

In studies near Sydney of *A. flammeum* reported by Donovan *et al.* (1999), semi-hardwood cuttings from four year old, potted seedlings subjected to two humidity regimes and two bottom heat treatments, the best result (presented as 'mean root class' based on scores from 1 to 6), was a mean root class of 3.42. (We presume this was equivalent to approximately 57% rootability). *A. flammeum* was more amenable to VP in the present study (71.8% rootability). However, survival of its rooted cuttings at the Coast site was rather lower (at 74%) than commonly desired, and extremely poor at the Tableland site (13%). Its growth was among the poorest of the five species at both sites. Although this species is widely propagated vegetatively and planted as an ornamental, its in-stand growth rate was not evaluated in CRRP plantings reviewed by Bristow *et al.* Chapter 6), and no other information is available. More work on growth and adaptability in mixed or pure-stand deployment would be required with this species to determine its utility for plantings other than ornamental.

Two other hardwood species (*A. aulacocarpa* and *G. fasciculiflora*) could be considered potentially amenable to VP if a customisation technique resulted in sufficient improvement in one or two of the propagation traits (rootability, roots per plant and shoots per hedge per time). *A. aulacocarpa* appeared somewhat deficient in shoot production, but the latter might be enhanced by improved hedging technique. Growth of *A. aulacocarpa* rooted cuttings was moderate on both field sites; however, survival and stem form were very poor on the Tableland site, possibly due to cattle damage.

Nikles *et al.* (1998) reported on a collaborative genetic improvement and conservation program of the then QFRI and the Commonwealth Scientific and Industrial Research Organisation (CSIRO) that involved, among other things, clone tests of *A. aulacocarpa* established in north Queensland using rooted cuttings from hedges developed from cuttings taken from shoots produced on 80, three year old trees selected for superior growth and straightness in a large base population of seedling seed orchards (SSOs) that were pollarded at about 1 m above ground. In all, the SSOs comprised 304 open-pollinated families of several Papua New Guinea provenances. All selections gave some rooted cuttings, but only about one half of the clones had a rootability in excess of 50%. Three clone tests of varying numbers of clones plus comparable seedlings, and a clonal seed orchard (CSO) of 63 clones, but no seedling controls, were established with rooted cuttings in the field. Analyses of the results of measures of height, diameter and stem straightness score undertaken at 22 or 26 months at two sites showed: a) slight superiority of clones to seedlings for height, but the reverse for diameter; b) significant superiority of clones over seedlings for stem straightness; c) significant differences between clones for all three traits at both sites; and d) significant, positive genetic correlations of clone means between sites.

These results for height growth of seedlings versus rooted cuttings at one site (coastal) did not conform to the indications from the trials reported in Table 3 (seedlings taller than rooted cuttings at both Coast and Tableland sites, both plant populations derived from unimproved source material). However, this would be expected because of the intense, phenotypic selection applied in the choice of trees included in the clone tests reported in Nikles *et al.* (1998). The strong differences between clones in growth and stem form support results with many other species (Sedgley and Griffin, 1989). The stability of clone performance across divergent sites found by Nikles *et al.* (1998), if confirmed, would augur well for simplified breeding of *A. aulacocarpa* (without regionalisation). The collaborative program progressed to the planting of a small, second-stage base population in 1997. Unfortunately, however, this resource was lost a few years later; and it proved impractical to maintain the 63-clone CSO. (Thirty clones remain at the coastal-site test which could function as a CSO if managed adequately). Thus, prospects for utilising this species, known to be slower growing than three other tropical acacias and the *A. mangium* x *A. auriculiformis* hybrid (Kha 2001), in north Queensland seem limited.

G. fasciculiflora had a moderate rootability of 52.3%, ranked second among 11 hardwood species for rate of shoot production, but gave below average roots per cutting. Improvement of rootability and roots per cutting would be desirable. This might be achieved technologically and certainly via clone selection, since strong clonal differences in these propagation parameters were demonstrated (Table 3). However, the growth of rooted cuttings was disappointing, especially at the Tableland site where prospects for utilising this species seem limited. It is worth noting that the hedges of this species retained at the Walkamin nursery provided the only source material for supplying the small demand for planting stock for a period due to the unavailability of seedling stock. Seed production and seed viability is often low while storage is problematic and germination is very protracted (Nikles *et al.* 1994).

All four of the *Flindersia* species and some other species of reforestation interest, including *B. involucrigera* and *C. australe,* are not likely to be suitable candidates for VP because of their low to very low rootability and very low rankings for one or both of the other propagation traits. In CRRP plantings, *C. australe* grew moderately well on soils from basalt (highly fertile), but slowly elsewhere (Bristow *et al.* Chapter 6). Though both these species would seem, therefore, to have limited prospects for industrial plantings in north Queensland, *C. australe* has potential for rehabilitation and mixed-species plantings as constraints on availability of regular supplies of nursery stock from seed (storage life approximately three months –D. Goschnick pers. comm.) or rooted cuttings might be alleviated by the collection and use of small, wildling plants that are often abundant in natural forest.

The non-amenability of the *Flindersia* species to VP is particularly unfortunate in the case of *F. brayleyana*. It is an acclaimed cabinet wood species that has been planted in small amounts over many years (Anon. 1983; Keenan, 1998), and grew moderately well to fast over a wide range of conditions in CRRP plantings (Bristow *et al.* Chapter 6). However, Anon. 1983 found that both enrichment planting (or underplantings in natural forest) and open planting of *F. brayleyana* were unsatisfactory in trials in north Queensland. In contrast, plantings of the species in south Queensland in mixture with *A. cunninghamii* in the Mary Valley, and as underplants in young *Pinus* plantations in the Beerburrum area, have given impressive results; in the latter case *F. brayleyana* was the most productive of six rainforest species tested all of which had high survival and small, merchantable logs at 38 years of age (JA Simpson pers. comm.). Moreover, there was some evidence that the total production of the pine – maple mixture was greater than that of pure pine. Thus there could be an ongoing call for limited amounts of planting stock of *F. brayleyana*. Satisfaction of the demand would appear to be feasible only via seed collections from the wild, or via seed orchards although none have been established yet.

However, seed production is sporadic (extremely little seed has been produced in a clone bank of grafts planted in the Kuranda State Forest in the 1950s – authors' observations), and pod collections from spaced, in-forest trees [as opposed to isolated, more accessible ('paddock') or forest-edge trees which may sustain considerable inbreeding] are now expensive (S. Kitchener pers. comm.). It is encouraging to note that heavy crops of seeds occur in forest and remnant paddock trees in some years (A. Irvine and R. Lott pers. comm.) and that widely-spaced seedlings of some of the *Flindersia* species reported on here are capable of fruiting by 10 years of age (E. Wiles pers. comm.).

With regard to the two conifers, *Araucaria cuninghamii* is a species regularly planted commercially on the Atherton Tableland in north Queensland (Anon. 2002) using seed from clonal orchards of the breeding program in south Queensland (Nikles *et al.* 2004 b). A CSO of principally Papua New Guinea provenances established near Atherton in 1995 is producing significant crops of seed cones which, however, are expected to contain mostly infertile seeds due to the limited production of pollen to date (Nikles pers. obs 2004). Prospects for deploying south Queensland and Papua New Guinea *A. cunninghamii* hybrids in the future seem promising in view of their superiority at four years of age (Dieters *et al.* 2000), their excellence at almost nine years of age (G. Nikles pers. obs. 2004) and the high rootability of the species as reported in the present paper. The latter feature is conducive to propagation of superior hybrid families or clones.

Bristow *et al.* (Chapter 6) reporting around eight-year growth of CRRP plantings of this species in five soil type – rainfall regimes, found it produced 'moderate' growth across this wide range of conditions thus showing its versatility as a species for plantings. The high rootability of apical cuttings from seedlings in this study (89.4%) supported the good results reported for south Queensland provenance seedlings - averages of 82.3% and 75.3% across 15 and 12 families respectively (Walker *et al.* 1996b). Good, seven year survival and growth of the clones reported on here (Papua New Guinea provenance), and similar survival and growth of rooted cuttings and seedlings of south Queensland provenances in south Queensland trials planted in the early 1990s (M.J. Johnson pers. comm.), would encourage consideration of VP to maximise the use of scarce seed of outstanding families from the breeding program, especially if the low multiplication rate from hedges could be overcome (Nikles *et al.* 2004 a,b).

No record is now available of the rootability of the other conifer in the study, *A. robusta*. It is thought to have been similar to that of *A. cunnninghamii* since similar numbers of cuttings were likely to have been set, and the same number of rooted cuttings was available for field planting of each species (108 plants). Although the seven year diameter of the *A. robusta* was only 60% of that of the *A. cunninghamii* in the unreplicated planting of this study, growth of the former species in the CRRP plantings reviewed by Bristow *et al.* (Chapter 6) was rated in the same diameter-growth-rate class (moderate) as *A. cunninghamii* in the three, soil type – rainfall regimes where they could be compared. However, in longer-term comparisons in south Queensland, *A. robusta* is outgrown by *A. cunninghamii* (Nikles 2004). *Agathis robusta* has an unusual capacity to be propagated vegetatively via root shoots and rooted shoots are known to develop into impressive stands to at least 16 years of age in south Queensland (Nikles 2004). Following a series of early studies on the induction and management of root shoots from *A. robusta* seedlings in south Queensland, it was concluded that, by this means, "a planting program could be supported once plants (seedlings) are established in the nursery" (Haley 1957). In the species trial reported by Keenan *et al.* (1998), *A. robusta* now (at 17.5 years of age) appears second only to *P. caribaea* in survival and growth (Nikles pers. obs.). The excellent wood quality and exceptional natural pruning capacity of *A. robusta* (Nikles 2004) also are attractive features of this species that should be taken into account when considering species for planting in north Queensland. [The wisdom of planting *A. robusta* extensively in some areas in south Queensland is questionable due to the heavy losses of near-mature plantations in the Mary Valley in the 1960s caused, primarily, by attacks of the kauri coccid, though better site and provenance selection might make plantation establishment more successful in the future (Nikles 2004)].

The very strong effect of clone differences on both rootability and total number of roots per rooted cutting in the three hardwood species assessed directly (Table 5), and the observed effect on propagation and field performance on additional species included in this preliminary study, is in keeping with results from many other tree species (Sedgley and Griffin 1989).

There were no obvious differences in growth between cuttings and seedlings of most species. However, for each species there were individual clones that substantially out-grew the seedlings and their clonal cohorts. The ability of *C. odorata* and *E. grandis* to root well, develop many roots and produce shoots prolifically, survive and grow well opens up possibilities for rapid improvement of growth via clone testing, selection and deployment of superior clones.

Consideration of the history of the work overviewed here reveals a number of problems associated with research that is essentially long-term: adequacy and continuity of funding, staff continuity, changes in priorities of funding bodies and research providers, how to ensure security and good management of field trials that are often distant from the bases of research workers, and others.

In hindsight, it is evident that the research overviewed here, although revealing *E. grandis* as a species with much promise for VP and deployment as rooted cuttings clones, was inadequately funded in terms of amount and continuity. As a result, it was not possible to adequately study hedge management, to test customisation of propagation protocol, to establish and properly maintain good field tests with sufficient species for a long enough period to obtain clear leads, nor to follow-up on preliminary leads. This experience provides a clear lesson with regard to future work of this kind – it would need to be funded adequately for some 15 years, and have clear protocols for managing changes of staff and of research priorities, and field trials.

Conclusions

A small number of the species tested were amenable to vegetative propagation and deployment as rooted cuttings, so problems associated with the regular production of seedlings in sufficient numbers to meet demands need not be a constraint on their deployment to plantings. Where *Elaeocarpus* *grandis* planting stock is required in quantity on a regular basis, the use of rooted cuttings and, in the case of commercial deployment, clonal testing and deployment of superior clones, backed by conservation of diversity, should be considered – this is an approach demonstrated successfully elsewhere with a variety of species.

Further studies aimed at determining the specific requirements for improving amenability to propagation vegetatively should be considered for the following species: *Acacia aulacocarpa, Agathis robusta* and, especially, *Araucaria cunninghamii ,* as well as other very desirable rainforest tree species of unknown amenability to vegetative propagation not included in the work described here.

For some other species among those tested, consideration of their particular constraints would be required if domestication and deployment by VP were contemplated. These include *Cedrela odorata* (assembly of appropriate germplasm, breeding, improvement of shoot production in hedges and careful site matching); *A. flammeum* (potential for and utility in plantings other than ornamental); and *Gmelina fasciculiflora* (potential for improvement of rootability and roots per cutting, and for considerably improved growth rate in plantings).

Future nursery and field trials of the kind described here should be integrated and only considered for implementation in cases where adequacy and continuity of funding support, including adequate arrangements for security and management of field trials, are likely to be assured for an appropriate period of the order of 15 years.

Acknowledgements

Dr Russell Haines (then at QFRI) conceived the project, negotiated its acceptance by the CRRP Committee and maintained interest in it, thus encouraging the participants. Project planning was undertaken by Steven Walker who also directed implementation. Nick Kelly and Grant White are thanked for dedicated technical assistance in this project. Internal reviewers Drs Susan House and Mark Hunt are thanked for useful editorial suggestions.

References

Anon. 1983. Rainforest research in north Queensland. Queensland Department of Forestry, Position paper, Brisbane.

Anon. 2002. DPI Forestry Yearbook 2001-2002. A record of achievement. Queensland Government, Department of Primary Industries, Brisbane.

Arnold, R.J., Gonzales, A. and Abarquez, A. 1998. Domestication of exotic Acacia species in Bukidnon Province, Philippines. In (Eds) Turnbull, J.W., Crompton, H.R. and Pinyopusarerk, K. *Recent developments in acacia planting*. Canbera, pp. 136-142. ACIAR Proc. No. 82.

Bootle, K.R. 1983. Wood in Australia: Types, Properties and Uses. McGraw-Hill, Sydney.

Collins, S. and Walker, S. 1998. Propagation of red cedar by cuttings. In *Managing and Growing Trees Training Conference*. Kooralbyn Hotel Resort, Kooralbyn, Queensland, 19-21 October 1998. Farm Forestry and Vegetation Management, pp 347-353.

Dieters, M.J., Johnson, M.J. and Nikles, D.G. 2000. Inter-provenance hybrids of hoop pine *(Araucaria cunninghamii)*. In Dungey, H.S., Dieters M.J. and Nikles, D.G. (Compilers)..*Hybrid Breeding and Genetics of Forest Trees*. Proceedings of QFRI/CRC-SPF Symposium. Noosa, Queensland, Australia, 9-14 April 2000. pp. 413-418. Queensland Department of Primary Industries, Brisbane.

Donovan, N.J., Offord, C.A. and Tyler, J.L. 1999. Vegetative cutting and *in vitro* propagation of the tree waratah, *Alloxylon flammeum* P. Weston and Crisp (family Proteaceae). *Australian Journal of Experimental Agriculture* 39: 225-229.

Evans, J and Turnbull, J. 2004. Plantation forestry in the tropics. 3rd edition. Oxford University Press, Oxford.

Haley, C. 1957. The present status of tree breeding work in Queensland. Paper for 7th British Commonwealth Forestry Conference, 1957. Queensland Forestry Department, Brisbane.

Keenan, R.J. 1998. Farm forestry in the tropics: potential and pitfalls. In *Plantations and Regrowth Forestry: A Diversity of Opportunity: Proceedings Australian Forest Growers Biennial Conference*. Lismore, 1998. Pp 217-227.

Keenan, R.J., Annandale, M. and Bragg, A. 1998.Ten-year growth performance of exotic and native species in the coastal lowlands of north Queensland (Experiment 708 Ath.). Queensland Department of Primary Industries, Forestry Research Institute, Brisbane, Queensland. Internal report.

Kha, L.D. 2001. Studies on the use of natural hybrids between *Acacia mangium* and *A. auriculiformis* in Vietnam. Agricultural Publishing House, Hanoi.

Longman, K.A. and Wilson, R.H.F. 1993. Tropical trees: Propagation and planting manuals. Vol. 1 – Rooting cuttings of tropical trees. Commonwealth Science Council, Commonwealth Secretariat Publications, London.

Nikles, D.G. 2004. Aspects of the biology and plantation development of kauri pine (*Agathis robusta* C.Moore ex F.Muell.) in Queensland. In (Eds) Bieleski, R.L. and Wilcox, M.D. *The Araucariaceae. Proceedings of International Araucaria Symposium*. Auckland, New Zealand, 14–17 March 2002. pp 396-407. The International Dendrological Society.

Nikles, D.G. and Robson, K.J. 2004**.** A review of some pilot plantings of klinki pine (*Araucaria hunsteinii* K. Schum.) compared to hoop pine (*A. cunninghamii* Ait. ex D. Don) in north Queensland, Australia. In (Eds) Bieleski, R.L. and Wilcox, M.D. *The Araucariaceae. Proceedings of International Araucaria Symposium*. Auckland, New Zealand, 14–17 March 2002. pp 321-327. The International Dendrological Society.

Nikles, D.G., Haines, R.J. and House, S.M. 1994. Tree improvement strategies to support farm forestry in Queensland, with specific recommendations for the Community Rainforest Reforestation Program. Queensland Forestry Research Institute, Brisbane.

Nikles, D.G., Harwood, C.E., Robson, K.J., Pomroy, P.C. and Keenan, R.J. 1998. Management and use of ex situ genetic resources of some tropical *Acacia* species in Queensland. In (Eds) Turnbull, J. W., Crompton, H.R. and Pinyopus arerk, K. *Recent developments in acacia planting*. ACIAR Proc. No. 82. Canberra. pp 184-196.

Nikles, D.G., Dieters, M.J., Johnson, M.J., Setiawati, Y.G.B. and Doley, D.D. 2004(a). The reproductive biology of hoop pine (*Araucaria cunninghamii* Ait. ex D. Don) and its significance in a genetic improvement programme. In (Eds) Bieleski, R.L. and Wilcox, M.D. *The Araucariaceae. Proceedings of International Araucaria Symposium*. Auckland, New Zealand, 14–17 March, 2002. pp 200-211. The International Dendrological Society.

Nikles, D.G., Dieters, M.J. and Johnson, M.J. 2004(b). Genetic improvement and conservation of hoop pine (*Araucaria cunninghamii*) in Queensland. In (Eds) Bieleski, R.L. and Wilcox, M.D. *The*

Araucariaceae. Proceedings of International Araucaria Symposium. Auckland, New Zealand, 14–17 March, 2002. pp 377-391. The International Dendrological Society.

Sedgley, M. and Griffin, A.R. 1989. Sexual reproduction of tree crops. Academic Press.

Walker, S.M., Haines, R.J., and Dieters, M.J. 1996(a). Beyond 2000: clonal forestry in Queensland. In (Eds) Dieters, M.J. Matheson, A.C. Nikles, D.G. Harwood, C.E. and Walker S.M. *Tree Improvement for Sustainable Tropical Forestry*. Proc. QFRI-IUFRO Conf., Caloundra, Queensland, Australia. 27 October-1 November 1996. Queensland Forestry Research Institute, Gympie. pp. 351-354.

Walker, S.M., White, G.M., Radddatz, C.J. and Johnson, M.J. 1996(b). Update of hoop pine cuttings research. Proc. Seed production strategy group meeting, Queensland Department of Primary Industry-Forestry, Gympie, Queensland.

Appendix 1

Seedlot number and provenance (where known) for species used in the study.

Species	Seedlot no.	Seed provenance
Acacia aulacocarpa	3330, 17873	Wimpim-Oriomo, W Province, PNG
Agathis robusta	3562	Wongabel State Forest, plantation
Araucaria cunninghamii (PNG)	0006	Danbulla State Forest, plantation
Alloxylon wickamii	X = not known	X = not known
Flindersia pimentaliana	4260	X
Musgravea heterophylla	X	Kuranda State Forest, natural stand