growing). Four may be required in controlled (greenhouse) growing conditions.

This year it has been difficult to obtain Alar 85, and Bonzi, has been used as an alternative. At this stage it is unknown if this alternative is as effective and if the application rate has been correct (10 to 15 ml litre^{-1}).

Selection of *Lophostemon confertus* Provenances for Use in Urban Landscapes

Geoffrey S. Williams
Burnley College, Faculty of Agriculture, Forestry and Horticulture, University of Melbourne, Burnley Gardens, Swan Street, Richmond, VIC 3121

INTRODUCTION

Among the many factors that limit urban tree establishment and growth, drought, compaction, and low soil oxygen levels are perhaps the most critical (Handreck and Black, 1994; Hitchmough, 1994; Kozlowski, 1985; Patterson, 1976). The potential for a given plant to succeed via its genetic make-up rather than the availability of resource inputs must be maximised. One genetic improvement strategy that has proved highly successful and is standard practice in forestry is provenance selection which is the process of tapping into naturally occurring within-species variation (Turnbull and Griffin, 1986). Trials have shown that provenances in many species differ in an enormous range of characteristics, including the factors of interest to landscape professionals such as drought tolerance (Pallardy, 1981) and temperature tolerance (Widrlechner, 1994). *Lophostemon confertus* is a widely used tree in urban south-eastern Australia. It is distributed naturally in habitats associated with rainforest along Australia's east coast. This species has many desirable urban tree characteristics such as an attractive, luxuriant canopy, long life span, and low incidence of limb sheer. While generally reliable under a range of conditions, it is suspect on sites where drought, flooding, or compaction are of above average severity. It is likely that in many cases the current horticultural stocks are derived from the warmer, higher rainfall regions such as coastal northern NSW, simply because these areas are more conveniently located for seed collectors than drier sites further inland or colder sites at higher altitudes. Similarly, where natural variation in flooding tolerance occurs, there is no guarantee that cultivated forms are derived from the most flood-prone populations, which usually means those growing in riparian or other habitats that experience seasonal or prolonged periods of waterlogging (Gill, 1970). The fact that waterlogging tolerance is correlated with compaction tolerance in urban trees makes the identification of such populations even more imperative (Hitchmough, 1994).

MATERIALS AND METHODS

Species Selection and Seed Collection. Seed collection was undertaken in Autumn-Winter 1992 and 1993. Twelve forms of *L. confertus* were collected across its range from coastal north-central NSW to Cairns and from a cultivated form growing in a street in the suburb of South Melbourne.

Habitat Analysis. The aims of the habitat analysis were to:

- Assess the degree to which sites varied in specific characteristics and therefore indicate the potential for divergence among various populations within species in various genetic characteristics.
- Assess the climatic extremes under which a given species exists and compare these to the same factors that exist in various urban sites, and identify provenances which may "match" specific urban situations and regions.
- Allow any genetic differences that were identified to be correlated with habitat factors.

Soil moisture stress was measured as the mean ratio between evaporation and rainfall of the four driest months (Gentilli, 1971), and seasonal warmth was measured on a heat summation or degree-day basis, using 15C as the baseline temperature (Yim and Kira, 1975). In both cases, data used as the basis of calculations was obtained from the Bureau of Meteorology National Climate Centre. Drainage was evaluated simply by assessing the evidence for flooding or high water table at each site at the time of seed collection.

Morphology. Leaf area and root system morphology of the *Lophostemon* provenances were examined. Six-month-old seedlings grown in 75-mm tubes were used in each case. Root morphology was considered in terms of the ratio of fine roots (<1 mm dm) to woody roots (>1 mm dm). Roots were separated from the growing media using a sieve, and dry weight of roots in both size classes obtained.

Growth Rate. Seedlings of each *Lophostemon* provenance were established in 25-cm diameter "spring-ring" containers and placed in an irrigated, outdoor nursery growing area in a completely randomised layout. Height of each replicate was measured after 1 year.

Flooding Tolerance. Seedlings of five *Lophostemon* provenances were established in a pinebark-based, soilless potting media in 8-cm-diameter Root Maker pots. There were two treatments; flooding and control, and seven replicates per provenance per treatment. Flooded plants were inserted into a 150-mm bed of sand/loam mix inside a shallow (200 mm), wide, waterproof tank, at spacings of approximately 200 mm. The tank was then filled with water to a depth of 40 mm above the rim of the pot, and this water level maintained throughout the 12-week duration of the flooding period. The control treatment was a replicate of the flooded treatment, except that the tank was not filled with water following insertion of the containers into the sand/loam medium. At the end of the 12-week period, all plants were removed from the tanks, and, still inside the Root Maker pots, potted into standard 14-cm pots containing coarse unsieved river sand. These pots were then placed inside a glasshouse for a recovery period of 4 weeks during which time a weekly application of liquid fertiliser was provided. At the end of this period, the Root Maker pots were gently removed from the surrounding standard pot, and any roots protruding through the holes in the walls of the pots were washed from the sand. Dry weight of all roots outside the Root Maker pots was obtained for each replicate as a measure of postflooding recovery capacity. Provided a species can survive a period of flooding, its capacity to recover rapidly and exploit improving conditions is likely to be more important than its capacity to actually grow during the waterlogged period.

Table 1. Comparison of environmental characteristics of 12 *Lophostemon confertus* habitats and two urban centres.

Site	Altitude (M)	Habitat	Soil moisture stress indicator[1]	Heat[2] Summation (C)
Melbourne			1.62	554
Sydney			2.96	1125
Seal Rocks (nth-cntl NSW, NE of Newcastle)	30	littoral rainforest	4.76	1157
Carrai State Forest (nth-cntl NSW, W of Kempsey)	570	wsf	2.78	653
Dorrigo (northern NSW)	320	srf	4	1107
Bellinger River Estuary (nthn NSW, S of Coffs Harbour)	1	mixed riparian forest adjacent to mangroves, alluvium	3.15	1389
Brunswick Heads (northern NSW)	5	wsf/srf ecotone	3.42	1779
Lamington National Park (sthn QLD, SW of Brisbane)	700	wsf/srf ecotone	4.54	829
Toowoomba (southern QLD)	650	margins of dry rainforest	2.04	1079
Mudlow Gap (sthn QLD, W of Gympie)	300	open, grassy eucalypt woodland,basalt	1.74	1374
Rockhampton (central QLD)	240	dry rainforest on scree	1.19	2136
Eungella National Park (nthn QLD, W of Mackay)	720	mixed riparian forest, alluvial sand, periodic flooding	2.35	1319
Lake Tinaroo (far nth QLD, W of Cairns)	700	open eucalypt woodland	0.87	2019
Crater Lake National Park (far nth QLD, W of Cairns)	1000	tropical forest/wsf ecotone	1.4	1782

[1] Mean ratio rainfall : evaporation for the 4 driest months. Increased soil moisture stress is indicated by lower values.

[2] Degree days above 15C. Cooler climates are indicated by lower values.

Abbreviations: nth=north, nthn=northern, sthn=southern, wsf=wet sclerophyll forest, srf= subtropical rainforest, w=west.

RESULTS AND DISCUSSION

Habitat Analysis. Soil moisture stress, waterlogging, and thermal regime varied significantly from site to site. Table 1 is a summary analysis of the habitats of a selection of the *Lophostemon confertus* provenances. The visual characteristics of the provenances in situ varied dramatically, ranging from very tall, straight forest trees with large leaves in wet, high altitude sites to dwarf, crooked, multistemmed trees with small leaves in dry habitats. The results of the morphology trials indicate that at least some of this variation had a genetic basis.

Morphology. Mean leaf area of *Lophostemon* provenances inhabiting the driest sites was about half that of mesic provenances (Table 1). Variation in leaf area among provenances of several species has been recorded, and is attributed to adaptation in response to soil moisture deficits (Pallardy, 1981), although variation in nutrient availability is also a strong selectional influence on leaf size (Pate and McComb, 1981). Small leaves are more effective heat exchangers, so plants with small leaves are better able to avoid injuriously high temperatures following stomatal closure. More importantly, under xeric conditions, leaf transpiration rate decreases significantly with decreasing leaf area (Pallardy, 1981). There were also significant differences in root morphology among provenances (see below under "Waterlogging Tolerance".

Growth Rate. There were significant differences in growth rate among *Lophostemon* provenances but these did not correlate with growing season temperature; the slowest growing provenances were those from dry or coastal habitats (Table 1). Variation in growth rate among provenances has been attributed to an adaptational response to soil moisture deficit (Pallardy, 1981). Grime (1979) argues that slow growth rate is a common evolutionary response of plants to stressful habitats.

Waterlogging Tolerance. There was significant variation in response to flooding among the five *Lophostemon* provenances tested (Table 1). It was expected that if variation existed, the Eungella and Bellinger River provenances would be the most tolerant since these were both riparian. In fact the Eungella provenance proved to be the second least tolerant, while the Bellinger River provenance was less tolerant than the nonriparian Mudlow Gap form. The Eungella and Bellinger River forms must experience at least occasional flooding, since flood debris was located above the soil level of these plants. Presumably, however, the duration and/or frequency of these floods have not been severe enough to exert sufficient selection pressure on these populations to bring about specialised adaptations to flooding (Gill, 1970). Provenances with finer, less woody root systems showed the greatest tolerance of flooding (Table 1). The Rockhampton and Eungella provenances were the least tolerant and had the lowest ratio of fine to woody roots. These inhabited a rock scree slope and granitic sand habitat, respectively, while the remaining forms originated from sites with finer soil textures. Variation in root system morphology has been correlated with capacity to regenerate new roots following transplanting and root pruning (Gillman, 1990; Struve and Moser, 1984). Capacity to regenerate more roots may explain the better recovery of the fine-rooted provenances.

CONCLUSION

The present study shows that differences among *L. confertus* provenances may potentially be used to directly improve the performance of the species in urban south-eastern Australia. The Mudlow Gap provenance grows in a relatively dry habitat, recovered from flooding more successfully than the other provenances tested (including a cultivated form), and had smaller leaves than any other provenance—a trait that in this species tends to produce a more attractive canopy. The Toowoomba provenance experiences a relatively severe period of soil moisture deficit, and despite its location in south-eastern Queensland experiences a relatively cool temperature regime owing to high elevation. The Lake Tinaroo provenance, originating from a dry, relatively warm habitat with deep sandy soils, may be well suited as an urban tree in the hot climate and dry sands of Perth. In the long term plant breeding could be used to develop forms with the maximum number of desirable characteristics.

Acknowledgments. The study is being undertaken as part of a Master of Applied Science Degree at VCAH Burnley. The author would like to thank the College, Ronneby Trees, Australian Geographic Magazine, the Queen Elizabeth Trust and the Horticultural Research and Development Corporation for financial assistance, as well as Dr. Greg Moore for his supervision and helpful comments on the text and Dr. James Hitchmough for his help in establishing the project.

LITERATURE CITED

Gentilli, J. 1971. The main climatological elements. In: J. Gentilli (ed.). Climates of Australia and New Zealand. Elsevier, Amsterdam.

Gill, C.J. 1970. Flooding tolerance of woody species—A review. Forestry Abstr. 3:671678.

Gillman, E.F. 1990. Tree root growth and development. II. Response to culture, management, and planting. J. Envir. Hort. 8 (4):220-227.

Grime, J.P. 1979. Plant strategies and vegetation processes. Wiley, New York.

Handreck, K. and **N. Black.** 1994. Growing media for ornamental plants and turf. Rev. Ed. University of New South Wales Press, Kensington, NSW.

Hitchmough, J.D. 1994. Urban landscape management. Inkata Press, Sydney.

Kozlowski, T.T. 1985. Soil aeration, flooding, and tree growth. J. Arbor. 11(3):85-96.

Pallardy, S.G. 1981. Closely related woody plants. In: T.T. Kozlowski (ed.). Water deficits and plant growth Volume VI. Academic Press, New York.

Pate, J.S. and **A.S. McComb.** 1981. The biology of Australian plants. University of Western Australia Press, Nedlands, WA.

Patterson, J.C. 1975. Soil compaction and its effects upon urban vegetation. In: S. Santamour, H.D. Gerhold, and S. Little (eds.). *Better trees for metropolitan* landscapes. National Arboretum, Washington D.C.

Struve, D.C. and **B.C. Moser.** 1984. Root system and root regeneration characteristics of pin and scarlet oak. HortScience, 19(1):123-125.

Turnbull, J.W. and **A.R. Griffin.** 1986. The concept of provenance and its relationship to infraspecific classification in forest trees. In: B.T. Styles (ed.). Intraspecific classification of wild and cultivated plants. Clarendon Press, Oxford.

Widrlechner, M.P. 1994. Environmental analogs in the search for stress-tolerant landscape plants. J. Arbor. 20(2):114119.

Yim, Y. and **T. Kira.** 1975. Distribution of forest vegetation and climate in the Korean Peninsula. I. Distribution of some indices of thermal climate. Japn. J. Ecol. 25(2):77-88.