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Mature tree transplanting: Science supports best management practice

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Replicated research on transplanting mature trees (trunk diameter > 750 mm) is not practical. Instead, we must apply the knowledge we have gained from studying smaller trees to maximise success at this larger scale. This article summarises our understanding of tree biology and horticulture contributing to the successful transplanting of trees, e.g. root loss and regrowth, water stress, carbohydrate status, root ball size, preparatory root and canopy pruning, timing of operations. The specific detail of the transplanting operations undertaken on four mature trees in Hong Kong in the last 15 years is then evaluated to examine the extent to which the arboricultural factors may have contributed to the outcome of each operation.

Keywords: establishment; survival; upright; water stress

Introduction

Transplanting mature trees in an upright position, where the entire canopy may be kept intact without pruning or bending branches, is becoming increasingly common in upscale development projects when there is sufficient commercial or green heritage value. Success rates are high. Efforts to maximise the amount of root system retained in the root ball, to reduce post-transplanting stress induced by sudden water imbalance, have led practitioners to form very large root balls. Trees with weights up to 450 tonnes have been moved. The mechanics of lifting such specimens are complex, and they are typically moved only short distances.

Replicated research is not practical on mature transplanted trees, but applying the knowledge developed from research on transplanting nursery grown trees, while accounting for known differences between mature trees and nursery transplants, can provide insight into the likely responses of mature trees to transplanting. Applying this research-based information to experiences of transplanting mature trees can help to generate an understanding of the arboricultural practices that influence the success of such operations.

How transplanting affects trees

Transplanting is the term used to describe the digging and replanting of field-grown trees. The portion of the root system lost when the tree is dug must be replaced for the tree to become established in its new location.

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Transplant stress

Water stress induced by root loss during transplanting can contribute to an extended period of transplant stress. Transplant stress is a consequence of the sudden imbalance between the root system and the crown resulting from a reduction in the capacity of the root system to absorb and transport moisture without commensurate reduction in water loss from the crown through transpiration. The root : shoot ratio is an expression of the physical and physiological balance between the root system and the canopy. Trees with lower root : shoot ratios generally have a reduced chance of surviving transplanting compared with those with greater root: shoot ratios (Hermann, 1964; Lopushinsky & Beebe, 1976; South & Mitchell, 1999).

Root loss during transplanting of field-grown nursery trees can be extensive, particularly for fine roots, which are imperative for water uptake. Only 5–18% of the fine, water-absorbing roots (<2.0 mm diameter) are retained in the root ball (Gilman, 1988; Gilman & Beeson, 1996b; Gilman, & Black, 1992; Watson & Sydnor, 1987). This loss of fine roots has the potential to create high levels of water stress. Successful transplanting depends, in part, on how soon new root growth can be initiated and developed in the soil outside the root ball to restore water balance (Watson, 1992). Additional factors affecting the degree of water stress experienced by a tree during transplanting include the extent of root pruning prior to transplanting, the moisture-holding capacity of the root ball soil, the cohesion and integrity of the root ball during handling affecting the root–soil contact in the rhizosphere (Sands, 1984) and possible differential characteristics with the surrounding soil of the receptor site.

The physiological symptoms of transplant stress can include a lack of stomatal control, tissue inelasticity and desiccation, low shoot water potential and reduced photosynthesis (Blake, 1983; Folk, Grossnickle, & Russell, 1995; Grossnickle, 1988; Kaushal & Aussenac, 1989; Nambiar, 1984; Stoneham & Thoday, 1985; Unterscheutz, Ruetz, Geppert, & Ferrell, 1974). Morphological responses include shorter twig elongation and crown dieback (Haase & Rose, 1993). Water stress, in combination with mechanical shock (Koeser & Stewart, 2009; McKay, Gardiner, Mason, Nelson, & Hollingsworth, 1993) and environmental extremes (McKay, 1996), may predispose a transplanted tree
AQ2 to attack by insects and pathogens.

Overcoming transplanting stress is broadly a reflection of tolerance to root loss and ability to regenerate roots to support the aboveground portion of the tree. Transplanting success for a tree can be seen as a process of overcoming the stress and regaining its previous shoot growth rate. Stresses act on both root and shoot development (Waring & Schlesinger, 1985), and in responding to change the tree must actively alter its growth patterns to re-establish internal balance. The capacity of a tree to do this is a product of its species, vigour and the available resources within the tree (robustness). Trees with low vigour have less internal resources to cope with the demands of transplanting and are likely to transplant less successfully. It is likely that faster growing species, with a greater ability to regenerate roots and respond to changes in the environment, are likely to be most successful in recovering from transplanting stress.

Carbohydrate availability after transplanting

Reference to synthesis and storage of carbohydrates limiting growth of recently transplanted trees is common, but there is little research support this contention. Non-structural carbohydrates for root growth are obtained from storage during shoot growth and from new photosynthates after shoot growth ceases (Dickson, Tomlinson, & Isebrands, 2000a, 2000b; van den Driessche, 1987; Sloan & Jacobs, 2008). Both sources can be adequate to support root growth when needed.

The loss of roots during transplanting is often assumed to result in a critical shortage of stored carbohydrates on the basis that much of the storage capacity (woody root tissue) is removed. This is not consistent with the literature. The percentage of total root biomass captured in the root ball, including large (carbohydrate storing) roots, can be 53–100% for trees up to 60 mm trunk diameter (Gerhold & Johnson, 2003; Gilman & Beeson, 1996b) and 29–83% for trees 60–200 mm trunk diameter (Gerhold & Johnson, 2003).

The concentration of carbohydrates is usually higher in the roots than in the shoots, but as the root : shoot ratio naturally decreases with age (larger trunk and branches), the proportion of carbohydrates stored in the trunk and branches increases relative to the roots. In adult trees, the stem, branches and leaves may store more carbohydrates than the root system (Kozlowski & Pallardy, 1997). Roots of mature almond trees represented 13 per cent of total tree biomass and only 36% of non-structural carbohydrates (Esparza, Dejong, & Weinbaum, 2001).

Moisture in the limited amount of soil in the root ball can be depleted very quickly (Watson et al., 1992). AQ3 Though water stress can reduce photosynthesis (Geisler & Feree, 1984; Kozlowski & Keller, 1966), when water is in short supply, assimilate is directed more towards the roots (Chung & Trlica, 1980; Finn & Brun, 1980; Waring & Schlesinger, 1985). Because allocation for shoot growth is reduced, water stress that does not completely halt photosynthesis may actually increase carbohydrates to the root system (Bradford & Hsiao, 1982; Galvez, Landhausser, & Tyree, 2011; Wagner, 1987).

While root loss can create stress and reduce photosynthetic leaf area (Kjelgren, Cleveland, & Foutch, 1994; Struve & Joly, 1992; Watson, 2004), the reduced photosynthate production (Geisler & Feree, 1984) may not limit root growth or storage. Levels of stored carbohydrates (amount of carbohydrate per gram tissue) in roots can be higher in transplanted trees one year after planting than in trees that are not moved (Watson & Himelick, 1982).

The root system of an established tree requires 10–15 times more carbohydrates for fine root turnover than for growth of woody roots (Janssens, Sampson, Curiel-Yuste, Carrara, & Ceulemans, 2002). Carbohydrates required to support root turnover in a transplanted tree that has lost the majority of its fine roots will be substantially reduced. Even very vigorous regenerated root growth from the smaller root system probably requires less energy than normal turnover and expansion of an intact root system. The amount of carbohydrates produced by the crown and stored in the transplanted tree is probably adequate to support the reduced level of overall root growth in the period immediately following transplanting.

Root pruning

Root pruning in advance of transplanting can increase the amount of fine roots in the root ball (Watson & Sydnor, 1987), increase the proportion of small roots (<3.0 mm) over large roots at the edge of the root ball (Gilman & Anderson, 2006; Gilman, Stodola, & Marshall, 2002) and promote root regeneration after planting (Gilman, 2001). These fine water-absorbing roots can help to reduce post-transplanting water stress. The longer the time between root pruning and transplanting, the more chance for fine roots to develop and grow.

Root pruning during active shoot growth can reduce root regeneration, presumably because of competition for carbohydrates when reserves are at the annual minimum

(Watson & Himelick, 1982) and should be avoided. Root loss from root pruning during active shoot growth can suppress crown development (Geisler & Feree, 1984; Koeser & Stewart, 2009). This can discourage root pruning in the nursery if it decreases growth during production, but could be an advantage for transplanted mature trees if it acclimates them to transplanting stress (Gilman, 1994).

Compensatory crown pruning

Research has shown that pruning to reduce or thin the crown at planting is of little benefit. Pruning to reduce transpiration enough to balance the large loss of fine absorbing roots is not practical. A tree can lose as much as 90% of its water-absorbing root system during transplanting and a similar reduction in transpiration through crown pruning would ruin the natural shape of the tree. Altering root: shoot ratios by removing leaf surface may also inhibit growth through reduction of photosynthetic surface (Kozlowski & Davies, 1975)

Most studies indicate that moderate crown pruning at planting has little or no effect on the future growth of roots or shoots on small trees (Evans & Klett, 1984; Hummel & Johnson, 1986; Schnelle & Klett, 1992; Shoup, Reavis, & Whitcomb, 1981). One study on larger (290 mm trunk diameter) trees with substantial root loss did show that dieback was reduced when 30% of the leaf area was pruned out after the loss of an estimated 75% of the root system from trenching on three sides (Watson, 1998).

When a tree is planted during the dormant season, leaf expansion will be reduced the next season to at least partially balance with the reduced water supply from the roots (Kjelgren et al., 1994; Struve & Joly, 1992; Watson, 2004). This natural reduction in leaf surface area will reduce the need for pruning.

Transplanting injury

With any root or canopy pruning operation, the size of pruning cut affects the time and resources required for the tree to close the wound. It is reasonable to expect that wounds may be larger on mature transplanted trees. Large cuts which take a longer to close may present greater opportunity for decay to develop. Some (Balder, Dujesiefken, Kowol, & Schmitz-Felten, 1995; Santamour, 1985; Whitney, 1961), but not all (Watson, 2008), studies report that root decay increases as pruned root size increases. Pruning cuts or physical impact injury requires wound responses which impose energy demands on the tree and alter the structure–function relationship within the stem (Schoeneweiss, 1981).

Vibration during lifting and transportation may disturb the root–soil contact within the root ball (Sands, 1984), and percussive impacts may result in accidental impact wounding of surface roots, stems and branches. These can exacerbate transplanting stress and reduce root growth potential and survival (Koeser & Stewart, 2009; McKay, 1996; McKay et al., 1993; Tabbush, 1986).

Establishment after transplanting and the influence of season

Establishment after transplanting is influenced by the following: morphological characteristics of the tree (Harris & Gilman, 1991); environmental conditions (e.g. the soil); the physiological state of the tree (e.g. proportion of root and canopy retained) (Struve, Burchfield, & Maupin, 2000); transplanting time of year; and cultural practices following transplanting (Gilman, 1990).

Root growth rate is highly affected by soil temperature. In the north temperate climate of the upper Midwestern United States (USDA zone 5), the post-transplanting establishment period is approximately 12 months per 25 mm trunk diameter, i.e. 4 years for a 100 mm trunk diameter tree (Struve et al., 2000; Watson, Himelick, & Smiley, 1986). In climates where the soils are warm all year round, roots grow more rapidly, and trees establish sooner. In the subtropical climate of northern Florida (USDA zone 10), trees established at approximately one year for a 100 mm trunk diameter tree after transplanting (Beeson & Gilman, 1992b; Gilman & Beeson, 1996a).

The length of time that a tree requires to regenerate its root system into an adequate soil volume varies by the extent of root spread before transplanting. It has been estimated that it will take a 100 mm trunk diameter field-grown nursery tree (USDA zone 5) approximately five years to fully establish and a 250 mm trunk diameter tree approximately 13 years (Watson, 1985).

Warm, moist soils and moderate air temperatures (low transpiration) are optimum for rapid root growth, minimised stress and successful transplanting (Harris, Bassuk, Zobel, & Whitlow, 1995; Harris & Fanelli, 1999; Richardson-Calfee & Harris, 2005). In tropical and subtropical ecosystems, seasonality in root growth is primarily associated with plant water status (Thongo M'bou et al., 2008), which reflects available soil water in the rhizosphere (Halter, Sands, Nambiar, & Ashton, 1996). Rates of root elongation are higher in rainy seasons than during dry seasons (Green, Dawson, Proctor, Duff, & Elston, 2005).

Size-related changes in tree growth and resource allocation

Because of changes in resource allocation, the capacity of a tree to respond to change generally declines with age. Mature trees may have less shoot elongation, lower photosynthetic rates, lower stomatal conductance as well as lower transpiration rates (less potential for water and nutrient uptake) than younger specimens (Lauderdale, Gilliam, Eakes, Keever, & Chappelka, 1995).

Coley, Bryant, and Chapin (1985) noted that resource availability is a capacitor on the long-term success of trees. Clark and Matheny (1991) developed this point, arguing that resource costs to mature trees involved in maintaining their larger size and coping with an increasing accumulation of wound response compartments, progressively lowering the amount of carbohydrate available for growth. They further suggested that rates of recovery from wounds should be slower for mature trees.

Switzer, Nelson, and Smith (1968) provided an interesting analysis of stem volume changes in trees with increasing size. Over time, the ratio of photosynthetic (leaves) to non-photosynthetic (branches) tissues decreases on a dry weight basis from 1:1 to 1:12 in birch and to 1:8 in pine. Ovington (1957) analysed the dry matter distribution in Pinus sylvestris trees of varying ages. When trees were eight years old, approximately 65% of the total plant dry matter was found in needles and fine roots. By 55 years, approximately 60% of the total plant dry matter was located in the main stem. Needles and fine roots held a minor proportion of the total dry matter.

Trees apportion resources between growth and defence. Over time, resources are shifted to protective measures such as thick bark and defensive chemicals. Longevity of angiosperms is correlated with increased investment in defences (Loehle, 1988), which must slow down the growth rate. Carbon allocation to storage and reproductive functions increased with age to the detriment of carbon allocation to growth (Genet, Bréda, & Dufrêne, 2009). At maturity, a tree exhibits decreased shoot growth (Borchert, 1975).

The capacity for rapid root growth after transplanting may also be reduced in mature trees for similar reasons, but has not been studied.

Relationship between root ball dimensions and transplant size

Root ball volume and shape determine both the extent of original root system retained and the quantity of original soil resources to support growth immediately after transplanting. Standards for field-grown nursery transplants in the United States (Anon., 2014), Europe (Anon., 2010) and Hong Kong (Architectural Services Department (ArchSD), 2012) define root ball diameter as a ratio with trunk diameter (root ball ratio). The largest trunk diameter size tree covered in each is 200, 190 and 150 mm, respectively. The standards are based on practical experience and have been used successfully for years. In all of them, root ball ratio decreases as trunk diameter increases. *American National Standards for Tree Care Operations* (Anon., 2012) provide standards for transplanting more mature specimens in the United States. The root ball ratio continues to decline up to 450 mm trunk diameter as well.

While root ball size appears to decrease relative to trunk size based on root ball diameter, the volume of the root ball, and presumably the amount of roots contained within it, is increasing relative to trunk diameter. When comparing 50 mm and 450 mm trunk diameter trees included within the range of the nursery and arboriculture standards, the root ball diameter : trunk diameter ratio decreases from 12:1 to 9:1, respectively. However, the root ball volume : trunk diameter ratio increases from 20:1 to 343:1.

The arboriculture transplanting standard (Anon., 2012) specifies a root ball ratio of 8:1 for trees larger than 450 mm trunk diameter. Figure 1 shows the relationship between root ball diameter and volume for trees up to 1500 mm diameter based on this consistent ratio. Volume continues to increase faster than diameter and is well-matched with an estimate of leaf area (Nowak, 1996) (Figure 1). Water absorption by the root system and loss through transpiration are presumably well-matched.

If instead of a constant root ball ratio for trees larger than 450 mm, the ratio continued to be reduced at the same rate as for trees 200 to 450 mm, the ratio would reach AQ4 4.5:1 for 1500 mm trunk diameter trees. While the diameter increase would be slowed only modestly, the increase in root ball volume would be reduced much more severely (Figure 1) and be out of synch with leaf area. This imbalance could increase post-transplanting stress.

It may also be noted that many mature trees that are transplanted are growing in urban settings, where the low availability of soil moisture, low permeability, poor aeration and high concentrations of soluble salts in the soil add to the risk of post-transplanting stress (Kozlowski, 1987). Tree root distribution is limited by many physical constraints (Gerhold & Johnson, 2003) and tends to be more variable than for nursery trees grown in prepared ground. Urban trees tend to be more shallow-rooted (Day, Wiseman, Dickinson, & Harris, 2010), with a high proportion of root biomass likely to occur in the upper layers of the soil (Henwood, 1973), the benefit of root capture through increasing root ball depth would decline as the corresponding disadvantage of increased lifting weight rose. This is reflected in the recently issued Hong Kong tree transplanting guidelines (Greening, Landscape & Tree Management Section (GLTMS), 2014) which suggest that root ball depth could be limited to 1000 mm.

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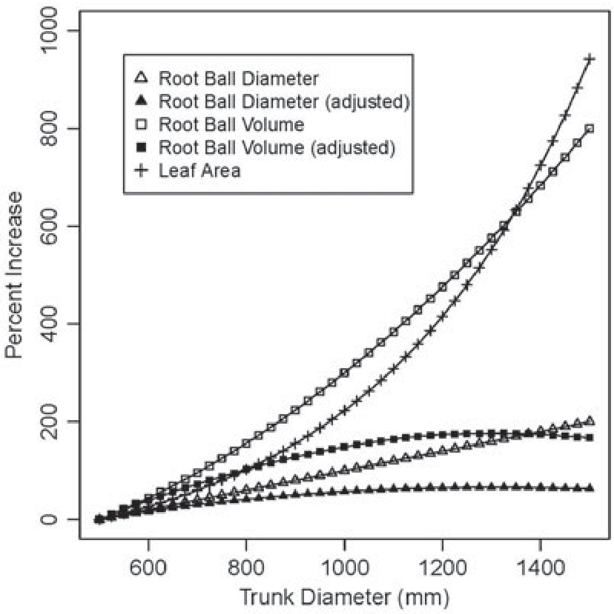

Figure 1. Relationship between trunk diameter and root ball root ball dimensions for trees larger than 450 mm trunk diameter.
Notes: Dimensions are calculated based on a constant ratio as described in the Arboriculture AQ9 Standard (Anon., 2012a) and also at an adjusted ratio as described for smaller trees in the standard. The curves have been smoothed for clarity.

Hong Kong case studies

More than 30 mature trees have been transplanted in Hong Kong over the last 15 years, the majority of these have been strangler. (epiphytes, *Urostigma* subgenus *of Ficus*). Four recent case studies, compiled from site observations and interviews with practition- AQ10 ers involved, illustrate some of the common arboricultural issues. Table 1 summaries key data recorded for each operation. Hong Kong's warm temperate/subtropical climate (USDA zone, 10a) has similar patterns of temperature, humidity and evaporation to areas of southern Florida and southern Louisiana in the United States, Southern Portugal, Kolkata, India, and Queensland, Australia.

In the absence of any local technical guidelines for mature tree transplanting (at the time), a customised transplanting methodology was developed by each project team of arborists and engineers based on the following: international guidelines, anecdotal reports of previous local transplanting projects, and detailed assessment of the tree condition and project constraints.

Penny's Bay, Lantau: Mock Peepul Tree, **Ficus rumphii**

The tree had been growing within a former shipyard area, with a derelict single story dormitory block along one side, under the canopy, approximately 50 m from the trunk.

Minor canopy pruning undertaken in December 2002 (13 months before relocation) to remove small diameter (<100 mm) internal crossing branches and one large (250 mm) broken branch reduced the canopy by approx. 15% (estimated from photographs), without reducing overall height or spread.

The tree had surface roots extending up to 3.0 m from the trunk on all sides. Parallel exploratory trenches were dug (December 2002), perpendicular to the building, each

Table 1. Mature tree transplanting case studies: key data.

Location in Hong Kong	Penny's Bay, Lantau (Figure 3)	Yuet Wah Street, Kwun Tong (Figure 4)	University of Hong Kong, West Gate (Figure 5)	Cheung Chun San Tsuen, Kam Tin (Figure 6)
Species	*Ficus rumphii*	*Ficus microcarpa*	*Ficus microcarpa*	*Ficus microcarpa*
Date transplanted	January 2004	April 2011	June 2010	January 2013
Estimated age	65 years	70 years	35 years	60 years
Canopy (ave. spread/area)	21.0 m/415 m^2	21.0 m	9.5 m/71.0 m^2	23.0 m/415 m^2
Height	12.5 m	14.0 m	11.0 m	17.5 m
Trunk form/diameter	Single stem trunk, prominent surface roots. dbh 1.1 m	Multiple trunks, overall spread 2.5 × 2.5 m. Many lignified aerial roots. dbh 1.3 m	Multiple trunks overall spread 1.2 × 1.8 m. Many lignified aerial roots. dbh 1.0 m	Multiple trunks overall spread 6.0 × 3.5 m. Some lignified aerial roots. dbh 1.5 m
Canopy reduction	Approx. 15%. 12 months in advance	Approx. 20%. 10 months in advance	Approx. 20%. Three months in advance. 10% during move	Approx. 10%. 12 months in advance
Known site restrictions on rooting pattern	Originally growing on a beach. Low building 5 m on one side, road on the other	Tree growing on top of a steep slope. Roadway on opposite side	Tree growing in a planter, with structures and road to sides, and concrete slab below	Growing beside a pond. Area partly overfilled with building debris
Root ball size/area/depth	7.5 × 7.5 m (square)/56.0 m^2/2.0 m	6.0 × 6.0 m (octagonal)/31.5 m^2/1.9 m	5.0 × 3.0 m (irregular)/15.0 m^2/0.5 m	5.5 × 8.0 m (irregular)/44.0 m^2/1.4 m ave
Root ball ratio/volume	6.8:1/112 m^3	4.6:1/60 m^3	4.25:1/7.5 m^3	4.5:1/61. 6 m^3
Soil condition	400 mm topsoil over coarse sand (former beach)	300 mm topsoil over decomposed granite, underlain with rock	Sandy, silty loam	Silty clay (pond bund material, possibly hydric)
Mapping the position of major roots	Exploratory trenches hand dug around the tree	Exploratory trenches were hand dug around the tree	Exploratory trenches along edge of planter	Exploratory trenches were hand dug around the perimeter of the root ball
Root observations	Many surface roots up to 3.0 m from the trunk. Few roots within the root trenches none deeper than 400 mm. Few roots under the base plate	Many surface roots up to 2.5 m from the trunk. Few roots within the root trenches, none deeper than 700 mm. Few roots under the base plate	Dense mass of roots close to the trunk, no roots observed deeper than 700 mm	Many surface within the area of the trunk mass. Few roots within the root trenches, none deeper than 600 mm

Root pruning (two stage pruning)	Trenching to form the sides of the root ball. Stages six months apart. Dec 2002, Jun 2003	Trenching to form the sides of the root ball, in stages, June 2010 and November 2010	Trenching to form the sides of the root ball, 3 months prior to lifting. Mar 2010	Trenching to form the sides of the root ball. Stages six months apart. Jan 2012, Jul 2012
Max. roots severed	75 mm diameter	200 mm diameter	100 mm diameter	200 mm diameter
Root biomass retained	85% (estimate)	90% (estimate)	80% (estimate)	50% (estimate)
Constructed planting space	Low mound within the landscape some 25 m wide × 2.0 m deep	Planting pit, approx. 9.0 × 7.0 m × 2.0 m deep	Planting pit, approx. 6.0 × 4.0 m × 1.5 m deep	Low mound within the landscape some 15-20 m wide × 1.5 m high
Canopy dieback	Approx. 10%	Approx. 5%	Approx. 15%	Approx. 35%
Period of transplant aftercare	28 months	30 months	24 months	24 months ongoing
Watering	Daily watering (field capacity) for 18 months to soil surface and at depth, wetting of trunk	Daily watering of soil surface (to field capacity) for 12 months, and occasional wetting of trunk	Daily watering (field capacity) for six months to soil surface, wetting of trunk	Daily watering (field capacity) to soil surface and at depth, wetting of trunk, canopy mist system
Observed physiological responses	Transplanted in its deciduous period. Return to full growth within a few months	Complete defoliation and instant refoliation within a couple of weeks. No apparent transplant shock	Transplant shock. Little growth in first 18 months, gradual improvement in shoot elongation since, but still less than normal	Transplant shock, dieback. Little new foliage growth since move

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4.0 m from the centre of the tree (some 6.0–7.0 m within the drip line). Very few roots were uncovered, typically these were less than 20 mm diameter and the largest was only 50 mm dia. Exposed roots were cut cleanly and the trenches backfilled with a fertile, free-draining sandy loam topsoil. The root trenches were watered thoroughly every day to field capacity.

The existing soil profile was 400 mm of dark loamy topsoil overlying marine sand. The lack of roots in the excavated trenches suggested that there might be a concentration of roots immediately under the tree trunk, so the root ball area was set as 7.5 × 7.5 m. A root ball depth of 2.0 m was calculated by the maximum lifting weight (250 tonnes) in that location. With a trunk diameter of 1.1 m, the root ball ratio was 6.8:1.

Trenches were dug on the other two sides six months later (June 2003) to form the root ball. Again no sizeable roots were discovered. In December 2003, the trenches were re-excavated to allow the root ball box to be formed. A dense mass of fine roots (<2.0 mm dia × 0–60 mm long) was observed around each of the cut root ends. These were more pronounced for the roots on the first two sides of excavation which had 6 months longer to regenerate. These were wrapped and preserved within the boxed root ball. Small areas of canopy dieback (<10% of the total canopy volume) were observed after the second root pruning.

Profile sheet steel piles were driven horizontally under the tree to form the base plate. Further sheet piles were used to fabricate the sides of the box. The base plate and tree were lifted on hydraulic jacks, and the sand directly under the tree was excavated to allow a haul road to be formed. No roots > 25 mm diameter were encountered under the tree (Figure 2).

In January 2003, the tree was lowered onto a high capacity low loading truck and hauled 1200 m to a temporary holding location. The tree was maintained within its box and after seven months was relocated to its final location. Upon arrival to its final location, the tree was set on flat ground and the sides of the box were removed. A new landscape was constructed with imported sandy loam topsoil placed around the root ball to create a low mound some 25 m wide. The base plate was not removed due to concerns about the potential settlement. The porosity of the base plate, elevated position and sandy root ball soil were considered sufficient to ensure adequate drainage.

Figure 2. Penny's Bay Tree.

Figure 3. Yuet Wah Street Tree.

Figure 4. HKU Tree.

Figure 5. Cheung Chun San Tsuen Tree.

The tree was watered to field capacity daily, via holes drilled into the soil. As shoot growth was seen to be at normal levels during the spring season following final relocation, targeted irrigation was stopped except on dry days when the irrigation system of the surrounding ornamental landscape (approx. 5.0 L/m^2/day) was used.

The tree did not exhibit any long-term signs of transplant stress. There was no crown dieback or decline in subsequent shoot growth, and it came into full foliage in the spring after final relocation. The tree's positive growth response was attributed by the project team to the high proportion of root that had been captured in the root ball, and the intensive watering throughout.

Yuet Wah Street, Kowloon: Banyan, **Ficus microcarpa**

The tree was prominently located within a high-rise urban district, at the crest of a slope, with a road above and amenity planting areas to either side. Transplanting to an adjacent park was proposed as part of an urban redevelopment project.

Canopy pruning was undertaken (June 2010) 10 months prior to transplanting, to reduce its width by 20% to fit the space available at the receptor site, and to remove dead wood and small (<100 mm) crossing branches. There was no reduction in height.

The tree had a composite trunk, approximately 1.3 m in diameter, comprising main stems surrounded by multiple (25–250 mm dia.) lignified aerial roots, with many new aerial roots (<2 mm) hanging immediately around the trunk. These had been pruned occasionally in the past to prevent them from reaching the ground and developing into more stems.

A number of large surface roots extended up to 2.5 m from the trunk. The subsurface root system had been constrained by both the slope and road. Parallel exploratory trenches were dug by hand (June 2010), within the silty clay soils of the planting areas, approximately 3.0 m from the centre of the tree. Few roots were encountered in the trenches: all were < 50 mm and appeared to be in good condition. The deepest of these was recorded at 700 mm. The roots were cut cleanly and the trenches were backfilled with fertile, free-draining sandy loam topsoil and watered daily.

Trenches were dug on the remaining sides in November 2010 to form a 6.0 × 6.0 m root ball, with a root ball ratio of (4.6:1). The root ball was mitred at the corners to reduce its volume. The soil depth was variable due to the slope. Taking account of the small number of roots found in the trenches, the root ball was formed at the maximum practical depth of 1.9 m.

Small areas of dieback (<5% of the total canopy) appeared after the second root pruning. The cut lignified aerial roots rapidly regenerated new soft aerial roots around the cut ends and were able to re-establish after transplanting.

Eight weeks before transplanting (February 2011), the trenches were re-excavated to form the root ball box. Cut ends of roots had generated numerous fine roots (<2 mm × 0–30 mm long), mostly within the first pair of trenches. These were preserved and packed with soil, as the root ball box was constructed around them. Few roots (all < 10 mm dia.) were observed in the soil under the tree when lifted, indicating that a large proportion of the root system had been captured in the root ball.

Steel tubes were hydraulically inserted horizontally under the tree to form the base plate, and welded to steel lifting beams underneath. Profile sheet steel piles and steel beams were used to fabricate the root box sides. A separate steel gantry was constructed around the root ball box to hoist the tree up on hydraulic jacks, so the area under the tree could be consolidated and a rail system constructed underneath. The tree was lowered onto bogeys on the rails and winched slowly across the road to the receptor site.

The tree was reset into a planting pit approximately 12.0 × 12.0 m, and backfilled with a fertile, free-draining sandy loam topsoil. Subsoil drainage pipes were laid around the base of the pit, and up the sides of the root ball to ensure soil drainage.

Banyan is evergreen in Hong Kong although it replaces most of its old leaves as new ones are produced in the spring (February to May). Immediately after transplanting in April 2011, the tree shed all its leaves (old and new), but within two weeks had produced completely new foliage. Incidents of sudden defoliation and immediate re-foliation have been reported for Banyan trees on other construction sites in the Territory, in response to very sudden ground movement (settlement) or change in groundwater level. Such disturbances may interrupt water uptake causing the tree to rapidly defoliate as a means of minimising water loss. If the disturbance is short-lived, and fine roots are not damaged, then the tree immediately can rapidly re-foliate.

After this event, the tree exhibited no substantial signs of transplant stress, and shoot growth was comparable to what it had been before the move. Rapid thickening of surface roots observed since relocation suggests vigorous root growth into the surrounding soil.

University of Hong Kong, Pokfulam: Banyan, **Ficus microcarpa**

The tree was located in a small planter bed at the entrance to the Hong Kong University main campus. The planter was defined by a concrete staircase on one side and road curbs to the others. The tree needed to be moved to make space for infrastructure works. Transplanting was agreed as a greening measure late in the construction process; only three months were available for preparation.

No preparatory canopy pruning was undertaken, except for the removal of one long side branch, in March 2010, to enable the tree to pass along the available movement corridor to the receptor site. The overall reduction in canopy volume was approx. 20%. There was no reduction in height.

The tree had a composite trunk diameter approx. 1.0 m comprising several main stems surrounded by multiple small (25–150 mm) lignified aerial roots, with some soft aerial roots (<2 mm) hanging immediately around the trunk. The tree had surface roots, but these did not extend to the edges of the planter.

Exploratory trenches, 300 mm wide, were dug by hand along each side of the planter, (March 2010). A concrete slab was discovered 700–800 mm below the surface forming a partial base to the planter. The soil had a loose sandy, stony structure with little organic content. Roots were encountered at all depths of the trench excavations, (typically < 30 mm dia.). No roots > 100 mm had to be cut. The trenches were backfilled with fertile, free-draining sandy loam topsoil and watered daily to keep the soil at field capacity. Immediately prior to the move in June 2010, the trenches were re-excavated to form the root ball. Some fine roots (<1.0 mm) had just started to regenerate around the cut ends of roots.

The planter and trenching limited the size of the root ball to some 5.0 × 3.5 × 0.7 m, giving a root ball ratio of (4.25:1).

Due to a lack of work space alongside, it was not possible to insert a solid base plate, so the root ball was wrapped with hessian and wire, and rigged for lifting with heavy straps. In tilting the tree to allow the hessian and straps to be inserted underneath, the upper layer of soil (approx. 400 mm depth) separated from the remaining soil below, exposing a dense but very shallow root system. Despite the root ball being wrapped in hessian, the sandy soil continued to fall away from the roots during transportation, and ultimately, the tree was planted in a mostly bare-rooted condition. The roots were wetted during the move and did not desiccate noticeably.

Without the weight of the soil, it was decided that the tree could be lifted by crane using padded straps wrapped around the lower trunk. This resulted in substantial tearing of the soft bark on three of the stems. The total weight of the tree and root ball was estimated to be < 15.0 tonnes. It was transported 70 m on a flatbed truck while being held with a hydraulic lifting arm. Three sizeable branches (50–150 mm dia.) were broken during transit, and these had to be pruned away. The total reduction in canopy volume was approx. 30%.

The move took less than 60 min, and the tree was replanted directly into an at-grade planter, 1.5 m deep and approximately twice the volume of the original planter. This was backfilled with a fine sandy loam topsoil which was compacted and watered in around the roots. The underlying subsoil was free-draining, so additional subsoil drainage was considered unnecessary. A custom made steel box frame, set at the base of the pit and extending 1.5 m above ground, was constructed as an anchor structure for cable wires used to secure the tree in location. Additional cables were anchored to adjacent pavements.

The tree was watered daily after transplanting to maintain field capacity, until the start of the wet season in spring 2011. Some areas of dieback developed within the canopy during the root pruning and transplanting operations (approx. 15% of the remaining canopy). Very little shoot elongation was observed in the canopy in the rest of 2010 and in 2011, but the tree has shown steady signs of recovery since spring 2012. Growth (by end of 2014) was still slower than that on surrounding trees of the same species (shorter twig elongation), and although the canopy has recovered full foliage, it remains comparatively thin. This suggests a long-term recovery from transplant stress.

The relative success of the operation, despite the operational difficulties, was attributed by the project team to the retention of a high proportion of the tree's root system due to the highly condensed original growing environment, the short period of time that the tree was out of the ground and the intense watering after re-planting.

Cheung Chun San Tsuen, new territories: Banyan, **Ficus microcarpa**

The tree was located on the bank of a former village fishpond. Transplanting was proposed by the owner as part of a redevelopment of the site as a means of preserving some of its green heritage.

The tree had a composite trunk mass comprising multiple stems and lignified aerial roots, with an aggregate diameter of approx. 1.5 m, spread over an area of 6.0 × 3.5 m. There was extensive decay within the older central stems, but the newer stems on the outer edges were healthy.

A limited amount of canopy pruning was undertaken in December 2011, which reduced the volume by approx. 10%, but did not reduce overall height. Ten large lignified aerial roots (100–250 mm) arising from the canopy (approx. 5–6 m from the centre of the trunk mass) had to be cut at soil level to keep the root ball to a manageable size. The portions of these aerial roots in the soil were essentially “satellite” root systems that had increased the total root mass, but these were not moved with the tree.

At the same time, parallel exploratory trenches were dug approx. 2.0 m from the outer limit of the trunk mass to determine the extent of the roots. Soil was progressively removed from the inner face of the trench until roots > 25 mm were encountered. The soil was a poorly drained (possibly hydric) silty clay. No roots were found deeper than 600 mm. The condition of the roots was variable due to the poor soil environment. Exposed roots were cut cleanly and trenches were backfilled with fertile, free-draining sandy loam topsoil and watered daily to field capacity.

Trenches were excavated on the other two sides in June 2012, to form an asymmetrically shaped root ball some 8.0 × 5.5 m, which reflected the limit of observed roots. The final root ball ratio was estimated at (4.5/1). Due to the slope and the need to form a horizontal base plate (to facilitate the chosen moving technique), the depth of the root ball varied from 0.6 to 2.0 m over the longer axis.

Substantial areas of dieback in the previously healthy outer canopy (>15%) developed after the first root pruning. This increased after the second root pruning.

Trenches were re-excavated in December 2012, and the root ball box formed using sheet steel and welded steel ring beams. Some short fine roots (<2 mm × 0–10 mm long) had developed at the ends of the cut roots but only in the first two trenches dug. Short (<100 mm long) new soft aerial roots grew from the cut ends of each of the lignified aerial roots, but had yet to reach the ground. Other case study trees had greater root growth over the same time periods.

The base plate was formed by the hydraulic insertion of 2.0 × 4.0 m × 20 mm flat metal sheets horizontally under the tree. These were progressively welded together. There was some subduction of the soil at the edge of the root ball during their insertion. A second set of steel plates was then inserted under the base plate to form a continuous sheet steel ground surface over which the tree would move. Numerous loose circular-section steel rods were then inserted between the two sets of plates to allow the root ball base plate to slide freely over the steel ground surface below.

In January 2013, the tree was winched 150 m to its new location. The sliding technique allowed the tree to be freely rotated or directed as it moved. The tree was set on level ground, and the sides of the box and base plates were removed. Fertile, free-draining sandy loam topsoil was placed around the root ball to create a low mound within the landscape some 15–20 m wide. Although the underlying silty clay soil was not free draining, the raised level of the tree ensured that the root ball drained adequately.

The tree was watered daily after transplanting via holes drilled into the root ball (approx. 700 mm deep × 50 mm dia.) to keep the soil at field capacity. Dieback in the crown continued to increase to approx. 35% of total canopy volume. A misting system was installed at the top of the trunk to increase the humidity level within the canopy with the hope that it would minimise stomatal water loss. This was run for several hours a day, but was ineffectual in preventing dieback. Such irrigation systems may only be effective for a short period immediately after transplanting (Bates & Niemera, 1994; Beeson & Gilman, 1992a). There has been very little new twig and leaf growth in the 24 months since it was moved.

Factors contributing to success

Transplanting large, mature trees successfully may seem improbable, but these examples and others (Webb, 1995) show that success rates can be high, and it is being done more frequently. Growth of the Penny's Bay and Yuet Wah Street trees returned to normal within 24 months, based on a visual assessment of the foliage, twig elongation, surface root condition and aerial root elongation. This is a much shorter period of time relative to tree size than has been reported for field-grown nursery trees, even in a similar climate (Beeson & Gilman, 1992b; Gilman & Beeson, 1996a). The HKU tree was recovering slowly after 54 months and the Cheung Chun San Tsuen tree was still in decline after 24 months. The relative success of transplanting and speed of recovery is likely to be influenced by a number of factors, individually or in combination.

Nature of Ficus *root systems*

Transplanting in an upright position allows a large proportion of the mature tree canopy to be retained intact. Minimising transplant stress in such trees requires that as much root system (absorptive capacity) as possible be retained during the transplanting process, yet the overall volume of the root ball is constrained by the capacity to lift and move the great weight safely. The case studies suggest that shaping the root ball in relation to the pattern of roots observed on the ground surface and within the exploratory trenches is likely to retain a higher proportion of the root system in relation to weight, than adopting standardised geometric root ball shapes.

Contrary to expectations (based on what is generally accepted about the spreading nature of root systems of most tree species), the minimal evidence of cut roots in the exploratory trench and root ball excavations, and under the root ball when lifted during transplanting, indicated that all four *Ficus* trees had shallow, narrowly constrained root systems, with root biomass concentrated in the upper (700 mm) soil layer and close to the trunk. This was corroborated by the HKU tree when the whole root system was exposed during lifting. This can be an advantage when transplanting trees as mature specimens. There are no published reports of the natural root distribution of *Ficus* species in natural soils for comparison, but the poor quality urban soils, as well as possible physical constraints typical of urban settings (Day et al., 2010; Gerhold & Johnson, 2003), likely contributed to the limited spread and depth of the root systems of these trees.

Soft and woody aerial roots are thought to be able to absorb water osmotically in high humidity conditions (Liu, Fu, Luo, & Guo, 2011). Although this is not a primary mode of water uptake, it may help the tree overcome periods of water stress. The exploratory trench excavation of the Cheung Chun San Tsuen tree revealed that lignified aerial roots arising from the edge of the canopy can give the tree the ability to extend their root systems into soil well beyond the main concentration of roots extending from the trunk. Since these roots were beyond the perimeter of the root ball, and the below-ground root system arising from them could have constituted a substantial proportion of the tree's total root system, their loss is likely to have increased water stress and may have been a key factor in the decline of the Cheung Chun San Tsuen tree.

Formation of new stems from aerial roots in mature *Ficus spp.* allows new pathways between the root system and the canopy, without going through the trunk. The addition of new stems in this way may also create a unique ageing pattern which could lessen problems of resource allocation between growth and defence encountered in older tree species, which is likely to give them an advantage in recovering from transplanting.

Advance root pruning

The ability to re-establish root function rapidly in order to regain water balance is a product both of the portion of the root system retained intact within the transplanted root ball, and the speed and extent to which the tree can initiate and elongate new roots. Root pruning before transplanting trees can promote new root growth before and immediately following transplanting (Gilman, 2001) that can help the tree regain water balance more quickly.

Roots of the Penny's Bay and Yuet Wah Street trees were pruned in two stages, over 12 and 10 months, respectively. Both trees showed minimal stress and recovered quickly. The HKU tree, which had only three months between root pruning and moving, had less regenerated roots from the cut ends when moved. While potentially a contributing factor, the tree's slower recovery is probably due more to the disruption of the root ball.

Root pruning interval appeared to have limited influence on transplanting outcome for these mature trees. The volume of new root growth produced from the cut ends was observed to increase with longer time periods between pruning and transplanting. The proportion of new root growth in relation to the volume of original root system moved in the root ball of these mature trees, however, may have been minimal, especially when compared to much smaller trees in the published study (Gilman, 2001). Advance root pruning, usually in stages, may trigger a physiological adaptation to the resulting water stress prior to moving the tree that increases success.

Root ball size

In addition to the physiological differences between young trees and mature trees, the mechanics of lifting and moving have an increasing influence on transplanting operations as tree size increases. Methods of transplanting very large trees have progressed over time (Figure 6). Trees are typically lifted in an upright position by crane or hydraulic jacks via a lifting beam immediately below a structural base plate comprising a row of sheet or tubular steel piles inserted horizontally under the tree. The sides of the root ball are enclosed in steel sheet or wrapped in hessian, laced and wired. Trees are then moved on flat-bed trailers, multi-wheeled crawler transporters or specially constructed railways.

Ambitions to maximise the amount of root system retained in the root ball to reduce post-transplanting stress induced by sudden water imbalance have to be balanced with the capacity of the equipment used to lift and move the tree. Trees moved this way

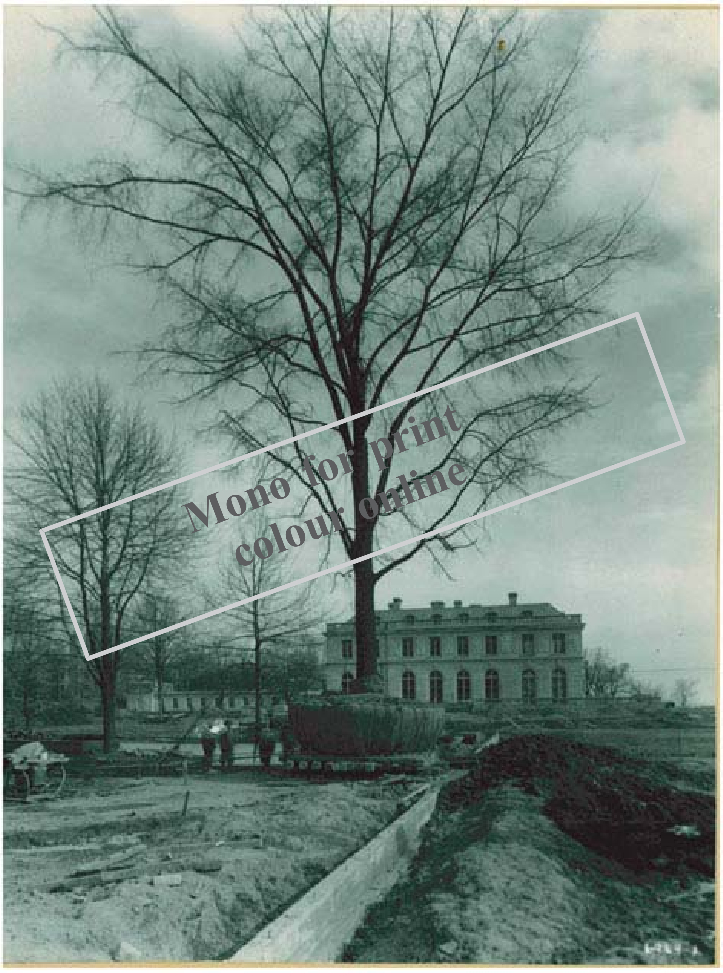

Figure 6. Early image of a mature tree (approx. 22.5 m high, 675 mm trunk diameter) being moved in an upright position.
Source: Photograph by Charles Irish from the International Society of Arboriculture archives.

typically weigh between 50 and 250 tonnes, although trees up to up to 450 tonnes have been moved (Watson & Himelick, 2013). By comparison, the largest hydraulic tree spade (Environmental Designs Inc., 2013) forms a root ball weighing approximately 45 tonnes.

Standards for field-grown nursery trees (Anon., 2010, 2014) specify a diminishing ratio of root ball to trunk diameters, though this may not necessarily equate to a reduced proportion of root system being moved (Gerhold & Johnson, 2003), as the volume of the root ball continues to increase. For more mature trees, the standard root ball ratio, based on diameters, remains constant above 450 mm trunk diameter (Anon., 2012). At this consistent diameter ratio and no increase in depth, the root ball volume continues to increase at a greater rate relative to the trunk diameter (Figure 1), effectively increasing the relative root ball size for larger trees.

The root ball ratios of the four trees were substantially lower than these standards. The root ball ratio for Yuet Wah Street tree was the largest (6.8:1) and the volume approximately equal to the standard root ball volume even when adjusted to 1.0 m depth suggested by the new transplanting guidelines (Greening, Landscape & Tree Management Section (GLTMS), 2014). The tree is recovering well.

The Penny's Bay tree was moved with a much smaller root ball ratio (4.6:1) and volume that was only approximately 40% of a standard root ball ratio, but near the adjusted ratio described above. The tree is also recovering rapidly after transplanting, suggesting that continued reduction in the root ball ratio based on diameter may not jeopardise transplanting success.

The Cheung Chun San Tsuen tree was moved with a similar root ball ratio (4.5:1), but lost numerous lignified aerial roots growing from the outer canopy, suggesting a higher proportion of the active root system may have been lost and the calculated root ball ratio may understate the amount of root loss. It was still in decline two years after transplanting. Its weak vigour prior to transplanting may be contributing to the poor performance as well (see below).

Recovery of the HKU tree has been somewhat slow, but probably more related to the loss of integrity of the root ball rather than the lower root ball ratio (4.25:1). The small canopy of the HKU tree relative to trunk diameter (canopy: trunk ratio was approx. half of what would be common for mature *Ficus microcarpa* in Hong Kong) (author's unpublished records) compared to the other trees may have mitigated the loss of the root balls soil.

Standards are generally considered as guidelines with flexibility to make adjustments based on specific conditions. Experience of these case studies and other mature tree transplants supports a smaller root ball ratio (based on diameters) for mature trees in good health, potentially reduced even further after root exploration.

Tree condition

Though not unique to mature trees, condition prior to transplanting is an important consideration. This is demonstrated by the Cheung Chun San Tsuen tree which had internal decay and the condition of the roots was variable due to the poor soil environment prior to transplanting. Limited new root growth observed in the exploratory trenches at the time of transplanting suggests this tree had reduced root growth potential (Deans, Lundberg, Cannell, Murray, & Sheppard, 1990) and reflects the reduced vigour. The method used to insert the base plates under this tree may have disturbed the soil: root interface more than the other trees and heightened the water imbalance contributing to the canopy dieback. The tree began to die back after the initial root pruning 12 months before transplanting and has continued to decline in the 24 months after transplanting. Retention of some of the in-ground roots on the lignified aerial roots may have reduced the decline of this tree. The other three trees were all in good condition prior to transplanting and are all recovering well.

Root ball integrity

If stress caused by transporting the tree from site to site is to be minimal, preserving the integrity of the root ball is essential. Boxing the sides of the root ball in each case reflected concerns about the root ball collapsing, as with Penny's Bay tree where the root ball was largely sand. Anecdotal evidence (pers. comm. with Transplant Industries Inc. Australia) suggests that if the soil is cohesive, then the sides may not need rigid containment. Wrapping the sides of the root ball with hessian and wire with a rigid structure under the root ball is common in other locations. This would substantially reduce the weight of the structure, which may make lifting easier, or allow larger diameter root balls to be moved.

Despite the almost complete loss of soil from the root ball of the HKU tree, it appears to be recovering gradually. This suggests that root–soil contact may not be the most influential factor in determining transplanting success in these mature *Ficus* spp. If the roots are kept moist throughout, the tree is replanted quickly and in good quality soil, and temporary structural support can be provided, then bare root transplanting for mature trees might be possible. It would have substantial operational advantages with the much lighter weight being much easier to move and replant. Bare root transplanting of larger nursery stock trees was common 100 years ago and appears to be regaining popularity.

Replanting and aftercare

With such a large investment in moving mature trees to protect, creating optimum conditions for re-establishment is essential. The quality of the growing environment after transplanting was substantially better than the existing condition for all four trees. The soil used in both the root trenches and the re-planting works was a good quality, free-draining sandy loam with a high nutrient content. The volume of soil in the re-planting location was also greater than the original, either much larger planting pits or purpose made landscapes constructed around them, and was free draining. This would have facilitated rapid root re-growth.

Each tree was maintained by the project team for 24–36 months after transplanting. This included regular arboricultural assessment to inform horticultural maintenance operations. Regular irrigation can improve survival after planting (Shober et al., 2009; Wiese et al., 2009). Generous irrigation was provided after transplanting in all four case studies. The reported ambition of each project team was to water as much as possible to be sure to avoid desiccation. Although overwatering was a distinct possibility, especially where the root ball soil was not free draining, e.g. the Cheung Chun San Tsuen tree, no problems were reported. It was clear, however, that the canopy misting system for that tree was not effective.

Local climate

Water stress is often the primary cause of stress after transplanting. The partial root system moved with the tree must supply water lost through the leaves in transpiration. Even in established trees, if the amount of evapotranspiration exceeds the ability of the root system to absorb moisture from the soil, water stress will result even if the soil is kept moist. This situation is encountered more frequently in transplanted trees with their reduced root systems.

Hong Kong summers are very warm, but also very humid. Temperature and evaporation rate are similar to Baton Rouge, Louisiana in the United States (Farnsworth, Thompson, & Peck, 1982; Hong Kong Observatory, 2012). Temperatures are high from April to November (mean daily maximum > 25 °C) and both rainfall (>300 mm/month) and relative humidity (>80%) are high from March to September. Growth can be extended by artificial watering until December when temperatures decline.

Spring and summer are customarily the preferred time for transplanting trees in Hong Kong because soil and atmospheric moisture are high, and will remain so during the early months of the recovery period. *Ficus microcarpa* produces most of its crown growth in the spring, but root and shoot growth appears to continue throughout the summer and autumn. The lengthy period that is favourable for root growth creates greater flexibility in the timing of preparation and transplanting operations. This may account for the limited influence that timing of root pruning and moving had on transplanting outcome for these four mature trees.

Summary

Examining these case studies in the context of the scientific literature on tree transplanting suggests that if the mature tree root system is healthy, kept largely intact, and is replanted in good quality soil conditions, chances of survival and establishment can be excellent. This is even with a relatively short preparation period and at most times of the year. The findings of the case studies are summarised below.

- These two species of *Ficus* are capable of rapid, adaptive growth,
- Aerial roots may have allowed more rapid root re-growth to help overcome water balance,
- When the original condition of roots was good, the trees coped well with stress and established well,
- Root pruning in advance may have been beneficial, so long as it was not undertaken within periods of active shoot growth,
- The trees all had relatively shallow rooting profiles (as a result of poor soil conditions), so a high percentage could be captured within a (manageable) root ball. Root balls of maximum 1.2 m depth may have been adequate,
- Root ball ratios were considerably smaller than standards for smaller trees (as low as 4.25:1); however, the root ball volumes were larger in relation to trunk diameter than called for by transplanting standards for smaller trees,
- Percentage root capture in relation to lifting weight was maximised by shaping the root ball to the actual root pattern. Percentage of root biomass lost in transplanting was roughly estimated to be small,
- Lifting via a structural base plate avoided disturbance of the soil root interface,
- Subtropical climate in Hong Kong results in high soil temperatures and atmospheric humidity that are conducive to low stress,
- Trees moved in an upright position allowed the canopy to be retained largely intact which can facilitate production of energy for root growth,
- Roots allowed to grow back into better soils (after root pruning and after relocation), and much larger volume of soil to root into after relocation,
- Thorough monitoring and maintenance, especially watering, after root pruning and after relocation.

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