THE POTENTIAL OF NATIVE WOODY PLANTS FOR ENCHANCING THE URBAN WATERWAYS AND WATER BODIES ENVIRONMENT IN SINGAPORE

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Raffles Museum of Biodiversity Research and
Singapore-Delft Water Alliance
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Hugh T. W. Tan[1] and C. K. Yeo[2]

[1]Department of Biological Sciences, Faculty of Science, National University of Singapore
14 Science Drive 4, Singapore 117546, Republic of Singapore
[2]Singapore-Delft Water Alliance, Faculty of Engineering, National University of Singapore,
Blk E1, #08-25, 1 Engineering Drive 2, Singapore 117576, Republic of Singapore
Email: dbsttw@nus.edu.sg (HTTW); cveyck@nus.edu.sg (CKY)

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Email: ask.rmbr@gmail.com

Singapore-Delft Water Alliance
Faculty of Engineering
National University of Singapore
Blk E1, #08-25, 1 Engineering Drive 2
Singapore 117576
Republic of Singapore
Website: http://www.sdwa.nus.edu.sg/
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Cover photograph by Hugh T. W. Tan. The pilot project of the ABC Waters Programme of the Public Utilities Board at Kolam Ayer along the Kallang River, Singapore. Woody and non-woody plants have been used effectively to create a beautiful landscape along the banks of the waterway. It is a good start that at least a few native species were used for this design.

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CONTENTS

ABSTRACT

Vascular plants used horticulturally include herbaceous (non-woody) and woody plants such as climbers, shrubs, treelets and trees.

Native woody plant species are those which naturally occur in Singapore and their use for planting along Singapore's waterways and water bodies can provide environmental and ecological services which include glare reduction, reduction in heat absorption, reflectance and radiation, reduction in soil erosion and improving water quality, reflectance and absorption of sound so reducing sound pollution, provision of shade, increasing relative humidity through transpiration, dust trapping, providing shelter or habitats for native animals, plants, lichens and algae, food for animals, phytoremediation (phytoextraction, rhizofiltration, phytostabilisation, phytodegradation, phytovolitalisation, hydraulic control, phytorestoration), shading and green coverage of concrete embankments or other structures, flow modification, vertical greening, and green roofing.

Woody native plants are also important for aesthetics, being the most major component of landscape designs, have historical and cultural value because of their longevity, are a potential source of useful economic products and genes for useful biomedical and industrial products, as well as enhance education and recreation.

However, like all plants, native or exotic, herbaceous or not, woody plants also have their drawbacks. Fortunately, with proper maintenance and regular inspections as a matter of routine, problems arising could be minimized.

INTRODUCTION

Plants in landscape designs are usually thought of mainly for aesthetics, but plants provide environmental and ecological services, both for the benefit of humans and other organisms. Plants also can help in phytoremediation, but most research on this very interesting and important topic have centred on herbaceous (non-woody) plants. Here, we will make the case for woody plants being more advantageous for phytoremediation and other environmental and ecological services for enhancing the urban waterways and water bodies environment in Singapore.

DEFINITIONS

Plants are usually photosynthetic (because some are saprophytic or holoparasitic), chlorophylls a- and b-containing organisms with cellulose cell walls, and that store their photosynthates such as starch inside the double-membrane-bounded chloroplasts where it is produced, and include the green algae, and the land plants—bryophytes (liverworts, hornworts, mosses), club and spike mosses, horsetails, ferns, gymnosperms (cycads, ginkgo, conifers, gnetophytes) and angiosperms (basal angiosperms, eudicots and monocots) (Judd et al., 2007).

Vascular plants are those plants containing vascular tissues for conducting food (phloem) or water (xylem) (Judd et al., 2007). They include the club and spike mosses, horsetails, ferns, gymnosperms and angiosperms, are the most visible component in Singapore landscaped parks, gardens and streetscapes. In Singapore, there are no native horsetails, and ginkgo of the gymnosperms does not naturally grow here.

Woody plants are those with woody tissues such as secondary xylem tissue in the case of the gymnosperms (Fig. 1) and eudicots (Fig. 2) (Evert, 2006), or sclerenchyma tissue ("woody" as defined by us, in a broad sense) in the case of monocots like bamboos (Fig. 3), dracaenas (Fig. 4) or palms (Fig. 5). Most of the larger plants in Singapore—the trees, shrubs and climbers—are woody.

Fig. 1. Caribbean pine (*Pinus caribaea*), an exotic gymnosperm often cultivated in Singapore. Note the woody trunk which is the source of commercial pine timber sold the world over. (Photograph by: Hugh T. W. Tan).

Fig. 2. The nationally critically endangered crabapple mangrove or berembang (*Sonneratia caseolaris*) is a eudicot tree of the mangrove forest and that can tolerate growing in freshwater. Note the vertically growing breathing roots at its base, typical of many mangrove plants. This plant is in HortPark of the National Parks Board. It is commercially available, but can be grown by seed from native stock. (Photograph by: Ang Wee Foong).

Fig. 3. Buloh lemang (*Schizostachyum brachycladum*) is a typical bamboo. Bamboos are actually large grasses, whose stems (culms) are woody and can grow very tall. (Photograph by: Hugh T. W. Tan).

Fig. 4. The cornstalk plant (*Dracaena fragrans*) is a monocot with woody stems. (Photograph by: Hugh T. W. Tan).

Enhancement pertains to improving in quality, or ameliorating. The enhancements owed to plants are listed in detail in the section on "Uses of Plants (Particularly Woody Species)".

The waterways environment in Singapore is defined as all the areas in and immediately adjacent to drains, canals, streams and rivers in Singapore that carry water continuously or may be dry until rain, e.g., Bukit Timah Canal, Kallang River, Lanchar Canal, Singapore River, Sungei Asam, Sungei Batu Kretek, Sungei Besar, Sungei Buloh Besar, Sungei Changi, Sungei Choa Chu Kang, Sungei Jurong, Sungei Kadut Canal, Sungei Kangkar, Sungei Ketapang, Sungei Khatib Bongsu, Sungei Lanchar, Sungei Mamam, Sungei Pandan, Sungei Peng Siang, Sungei Pinang, Sungei Poyan, Sungei Punggol, Sungei Selarang, Sungei Seletar, Sungei Seletar Simpang Kiri, Sungei Sembawang, Sungei Serangoon, Sungei Simpang, Sungei Simpang Kiri, Sungei Simpang Mak Wai, Sungei Tampines, Sungei Tengeh, Sungei Tho Pek Kong, Sungei Ulu Pandan (Fig. 6), as well as numerous unnamed canals.

The environment of the water bodies include the areas in and adjacent to the 17 reservoirs (Jurong Lake, and Bedok, Kranji, MacRitchie, Murai, Pandan, Upper Peirce, Lower Peirce, Poyan, Pulau Tekong, Sarimbun, Upper Seletar (Fig. 7), Lower Seletar and Tengeh Reservoirs, as well as the new reservoirs: Marina, Punggol and Serangoon Reservoirs) and the ponds in the various nature reserves, public parks (Fig. 8), golf courses, or private gardens.

Fig. 5. The nibung palm (*Oncosperma tigillarium*), a native coastal species, growing from an island in Swan Lake, Singapore Botanic Gardens, one of the water bodies in Singapore. Nibung is another monocot with a woody trunk. The wood is so strong and durable that it even surpasses those of most eudicots, and only it can be used for the piles in kelongs (giant fish traps in the sea). It can grow in wet ground of freshwater, as seen here, or brackish water, its natural habitat. (Photograph by: Hugh T. W. Tan).

Fig. 6. Sungei Ulu Pandan ("Pandan Canal") is typical of the canals in Singapore with a low-flow channel in the centre, widening significantly above for high volume and flow rates during downpours. The canals are designed to move water out to the sea quickly, to prevent flooding. However, this makes it difficult to plant anything along the banks, because the fast flows will tear the plants out. (Photograph by: Hugh T. W. Tan).

Fig. 7. Upper Seletar Reservoir. (Photograph by: Hugh T. W. Tan).

Fig. 8. Pond in Bishan Park 1. (Photograph by: Hugh T. W. Tan).

PLANT TYPES BASED ON THEIR HABIT (GENERAL FORM)

Plants are divided into various types based on the general form they take. Specifically, they can be divided as follows:

1. Woody (possessing wood in their stems and roots)
    a. Tree: Large, woody plant with a single trunk, e.g., African mahogany, flame-of-the-forest, rain tree, tembusu (Fig. 9).
    b. Treelet: Small, tree, e.g., coffee, papaya (Fig. 10), sugar apple.
    c. Shrub: Usually short, woody plant with two or more trunks, e.g., the hibiscuses, ixoras (Fig. 11), lantana.
    d. Scandent plant: Half climbers, but a rather rare kind of habit, e.g., bougainvillea (Fig. 12), jasmine.
    e. Climber or trailer: Plant with a weak stem and climbs on other plants or structures by twining, clasping roots or tendrils, or grow flat on the ground, e.g., *Bauhinia kockiana*, congea, garlic vine, maiden's jealousy (Fig. 13), *Uvaria grandiflora*.

2. Non-woody (herbaceous; without woody tissues, with softer, more flexible tissues)
    a. Herb: Usually small, non-woody plant, e.g., balsam, most leafy green vegetables, gingers, bananas.
    b. Climber or trailer (creeper): As in the woody climber above, except that the plant does not become woody, e.g., carpet grass (trailer; Fig. 14), cucumber (climber), kang kong (trailer), money plant (climber).

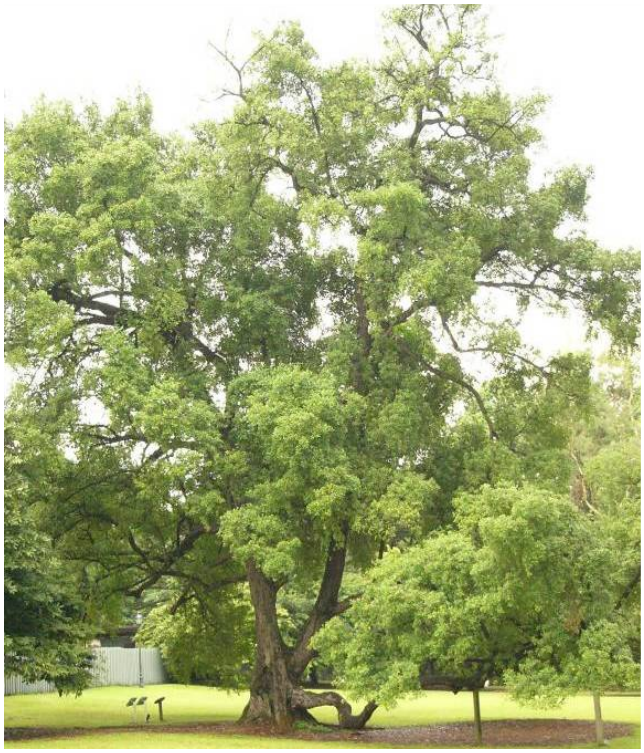

Fig. 9. Tembusu (*Fagraea fragrans*) is a tree. This specimen is the individual featured on the S$5 bill, and a favourite of visitors to the Singapore Botanic Gardens. This tree is also a Heritage Tree. (Photograph by: Hugh T. W. Tan).

Fig. 10. The papaya (*Carica papaya*) may be considered a treelet, as it usually grows short. Pedants may quibble that its trunk is only half-woody, and thus, not considered a true treelet. (Photograph by: Hugh T. W. Tan).

Fig. 11. Ixora (*Ixora coccinea*) is a good example of a shrub. Note the multiple woody stems arising from this plant at the right edge of a hedge consisting of a series of shrubs. (Photograph by: Hugh T. W. Tan).

Fig. 12. Bougainvillea (*Bougainvillea* 'Elizabeth Angus') is a scandent plant. If short enough, it can support itself, but when the branches and stem grow longer, they hang down, and will overflow flower beds as seen here. (Photograph by: Hugh T. W. Tan).

Fig. 13. Maiden's jealousy (*Tristellateia australasiae*) is a climber: (a) Young plants climbing a trellis; (b) Established plants in a park in Singapore, showing their yellow flowers. (Photographs by: Hugh T. W. Tan).

Fig. 14. Carpet grass (*Axonopus compressus*), a native of the Southern USA, Central and South America, is the most common grass species grown in Singapore, and likely the most common plant species in Singapore! Most lawns consist of this species. Note the trailing stems covering the banks of this drain. Locally, it is referred to incorrectly as "cow grass" which refers to *Paspalum conjugatum* (more correctly called "buffalo grass"), a Tropical American grass which superficially resembles carpet grass. (Photograph by: Hugh T.W. Tan).

PLANT TYPES BASED ON THEIR ORIGIN (NATURAL DISTRIBUTION)

Plants may be divided as follows:

1. Wild species (species not deliberately planted by humans)
    a. Native (indigenous)—Plants that occur in the country where they evolved over thousands or millions of years and not introduced there by humans.
        i. Extinct species—Species previously recorded to occur in the country, but now no longer growing there. Based on an arbitrary rule of thumb, species not sighted or collected in the last thirty years.
            1) Nationally extinct—Species only extinct in Singapore, but found elsewhere globally. About 31% of the Singapore vascular plant flora is in this state (Tan, 2008).
            2) Globally extinct—Species that were endemic (only occurring) to Singapore, and now thought to be extinct. There are three globally extinct species in the Singapore vascular plant flora (Tan, 2008).
        ii. Threatened species—Rarer species which are under some degree of threat of extinction.
        iii. Common species—Species frequently encountered in many areas.
    b. Non-native (exotic) plants—Species deliberately or accidentally introduced by humans into the country.
        i. Alien species (naturalised species)—Exotic species which have adapted so well to the country that they are reproducing regularly for generations, and spreading to many areas on their own.
        ii. Escapes from cultivation (casuals)—Exotic species which have not adapted well to the country that they are restricted to the sites they were introduced by accident.

2. Cultivated species—Species deliberately planted by humans in managed habitats.
    a. Native (indigenous)— Plants that occur in the country where they evolved over thousands or millions of years and not introduced there by humans.
    b. Non-native (exotic) plants— Species deliberately introduced by humans into the country.

There is a clear world-wide trend to use native species for planting in home gardens and other managed areas to eliminate the possibility of invasive exotic species outcompeting native species in their countries of introduction. Invasive exotic species are the second largest cause of native species extinctions after habitat destruction (Wilson, 1999) and create serious economic and ecological problems for many countries. Also, each country ought to be responsible for maintaining its own genetic resources, and as such, the whole world benefits in the long run because genetic resources translates into genes that may code for useful plant products such as pharmaceuticals to help mankind combat diseases or other ailments.

ADVANTAGES OF NATIVE VERSUS EXOTIC PLANT SPECIES

Native species have these advantages over non-natives (Tan & Morgany, 2001):

1. Native plants are generally best adapted to the local climate and soils where they naturally grow.

2. Native plants provide food (nectar, pollen, seeds, leaves, etc.) and shelter to native animals, since they evolved together.

3. Native plants are less likely to spread into areas of human development, unlike some exotic species which become invasive weeds because the country of introduction lacks the pathogens or herbivores which would normally keep them in check, e.g., water hyacinth (*Eichhornia crassipes*; Figs. 15, 17), water spangle (*Salvinia molesta*; Fig. 15, 16).

4. Native plants are interesting because of the interactions with native fauna such as animal pollinators or dispersers.

5. Native plants are as aesthetically pleasing as exotic ornamentals and will provide a more unique look since plants tend to be geographically specific (Tan & Chua, 2003). Native plants used to landscape Singapore will provide a different look compared to that composed of plants from South America, commonly used for tropical cities the world over, e.g., flame-of-the-forest (*Delonix regia*), rain tree (*Albizia saman*, formerly *Samanea saman*) (Fig. 18).

Fig. 15. Water hyacinth (*Eichhornia crassipes*; centre) and water spangle (*Salvinia molesta*; surrounding) are two invasive, aquatic weeds that annually cost the Singapore government a great deal for their removal from affected reservoirs. Both were introduced deliberate: water hyacinth, as an ornamental, and water spangle, for education. The water hyacinth plants in Singapore do no produce seed, and only propagate vegetatively, or else the problem will even be worse! (Photograph by: Hugh T.W. Tan).

Fig. 16. Water spangle (*Salvinia molesta*) covered a large part of Upper Peirce Reservoir (then called Peirce Reservoir) in 1978. (Photograph by: Wee Yeow Chin).

Fig. 17. Dredging in the Kranji Reservoir, to remove the non-native, aquatic weeds such as lotus (*Nelumbo nucifera*) and water hyacinth. In the background is the city of Johor Bahru, Peninsular Malaysia. (Photograph by: Hugh T. W. Tan).

Fig. 18. The rain tree (*Albizia saman*, formerly *Samanea saman*). This species ranges naturally from Mexico to Peru and Brazil, but has been introduced to the tropics the world over. It is the most commonly cultivated tree (native or exotic), in Singapore! (Photograph by: Hugh T. W. Tan).

ADVANTAGES OF WOODY VERSUS HERBACEOUS PLANT SPECIES

Native woody plant species have these advantages over herbaceous (non-woody) species:

1. Low maintenance costs of simple tree and turf landscape designs. More complex designs involving herbaceous, annual plants, will require replacement at the end of the growing season, and hence more maintenance. Herbaceous plants also tend to grow quicker, meaning more pruning and removal of horticultural waste. The National Parks Board has also recently introduced high species diversity, massed planting designs which mimic the tropical rain forest, but alas, utilizes many non-native species (Fig. 19).

2. Larger plants define the landscape, and larger plants are woody. Larger plants also mean fewer plants are needed to landscape an area.

3. Larger plants form the framework of the habitat for wild areas such as forests, so have an important role to play in the ecosystem and can significantly modify the habitat through the shade, wind sheltering, temperature reduction, increasing humidity, provision of nutrients through leaching, leaf litter, food for animals, etc.

4. All plants provide amelioration of the environment but the larger size and deeper roots of woody plants means potentially a greater volume of substrates ameliorated relative to herbaceous plants.

Fig. 19. High species diversity, multiple-layered, mass planting landscape design of the National Parks Board at the Cluny Road-Napier Road junction. This simulates the natural forest type of Singapore—the tropical rain forest—but unfortunately, also includes some exotic species. (Photograph by: Hugh T. W. Tan).

5. Larger biomass production of woody plants relative to herbaceous plants may make up for them not even being hyperaccumulators since a lower uptake rate but accumulated in a much larger biomass can significantly increase the absolute amount of the removed pollutant (Pulford & Watson, 2003). Repeated harvesting could also be performed thus making more extensive use of plants for phytoextraction. This has been termed the short rotation coppice by Dutton & Humpherys (2005). Some woody species such as the native sendudok (*Melastoma malabathricum*) accumulates aluminium (Fig. 20) (Watanabe et al., 2005)

6. Plants remove carbon dioxide (CO_2) from the air when they manufacture starch from carbon dioxide, water, and sunlight. Woody plants have a larger, much longer-lasting biomass for sequestration of carbon, so will be useful to help Singapore achieve a more carbon-neutral economy. The harvesting of fast-growing, temperate, woody crops such as eucalypts (*Eucalyptus* species), poplars (*Populus* species) and willows (*Salix* species), has been suggested by Rockwood et al. (2004) as a solution to groundwater contamination with the bonus of satisfying the worldwide demand for firewood which may be used for power generation. Fast-growing, coppicing, native species such as the Malayan banyan (*Ficus microcarpa*; Fig. 21) or the Benjamin fig (*Ficus benjamina*) could be tropical substitutes for the temperate species mentioned by Rockwood et al. (2004).

Fig. 20. The sendudok (*Melastoma malabathricum*), is a species known to hyperaccumulate aluminium. It is a native species found in secondary forest and forest fringes. Its seeds are used in the famous "poh chai" pills to treat diarrhoea in traditional Chinese medicine. (Photograph by: Hugh T. W. Tan).

Fig. 21. The Malayan banyan (*Ficus microcarpa*), a fast-growing native fig, is a species of wide ecological amplitude, meaning that it can grow in many habitats, from coastal to inland, wet to dry soil, in the ground and on rocks and trees. (Photograph by: Hugh T. W. Tan).

7. Woody plants generally have a longer lifespan so require less maintenance in that they do not require frequent replacement. The sequestration of carbon is also for a longer period, with most of the carbon locked up in the trunk wood. Tropical rain forest trees have lifespan ranges estimated from growth rates to be 35 to 2,000 years (Condit et al., 1993), or from ^{14}C-dating to be 200 to 1400 years (Chambers et al., 1998).

8. Woody plants are habitats for many more organisms, e.g., algae, lichens, other plants that grow on them (epiphytes, hemi-parasites, climbers; Fig. 22), as well as animals (perching, nesting, roosting).

9. Woody plants are a larger food source for more desirable animals (e.g., beautiful fruit-eating birds, fruit bats, butterflies, moths, squirrels, tree shrews, civets), and one large tree may develop much material which can feed many native animal species.

DRAWBACKS OF NATIVE AND EXOTIC WOODY SPECIES

Woody species, whether native or exotic will have their drawbacks (see Sreetheran, 2009 for more information). These include:

1. Because of their large size, when woody trees fall because of death, disease, strong winds and/or rain, they may damage property or cause death or injury. Some tree species are more prone to falling and causing damage such as the non-native, invasive tree species, albizia (*Falcataria moluccana*, formerly *Paraserianthes falcataria*, or *Albizia falcataria*; Fig. 23) which is blacklisted by the National Parks Board (NParks). A falling albizia tree on 15 May 2007 killed a woman in Bukit Batok Nature Park, the first recorded fatality in the records of

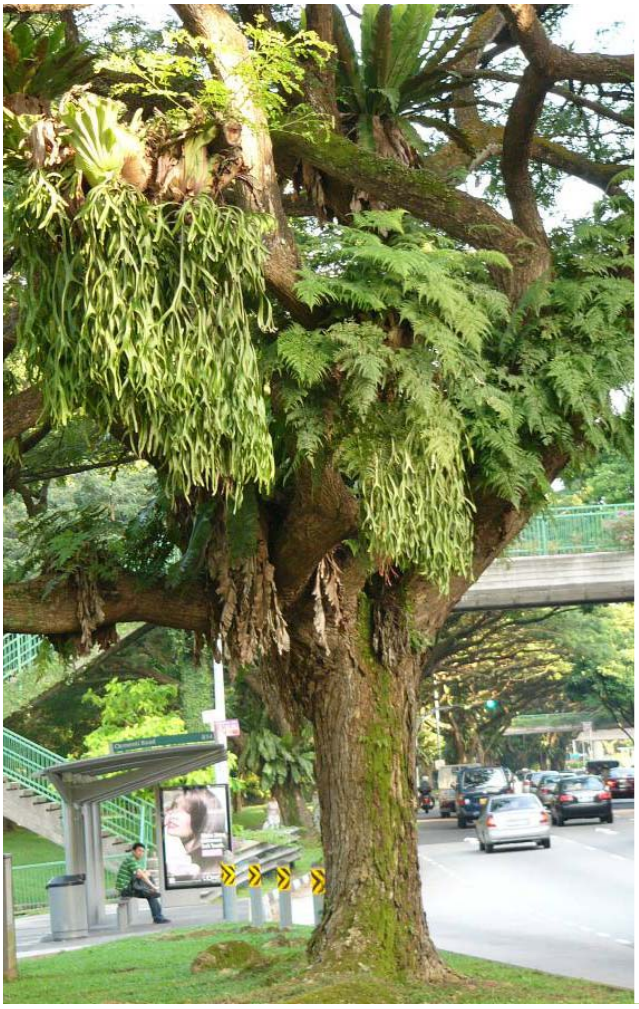

Fig. 22. The rain tree, although exotic, has the saving grace of being the host tree for several native epiphytes (plants that grow on other plants), such as the bird's nest fern, rabbit's foot fern, and stag's horn fern seen on this specimen. (Photograph by: Hugh T. W. Tan).

Fig. 23. Albizia (*Falcataria moluccana*, formerly *Paraserianthes falcataria* or *Albizia falcataria*), is a fast-growing tree from the Moluccas. Unfortunately, it is short-lived and has weak wood and roots, so falls down often, to damage human property and life. (Photograph by: Hugh T. W. Tan).

the NParks (Teh & Quek, 2007). During the Southwest Monsoon period in Singapore from Apr. to Oct. when strong winds called the Sumatras blow, many trees of all species fall, causing great inconvenience and danger especially if they fall on roads.

2. Trees, like all plants, shed their leaves. Some species will shed their leaves seasonally, whereas others do so continually—the more common condition. The native sea almond or ketapang (*Terminalia catappa*) sheds its leaves usually twice per year (Jan. or Feb. and Jul. or Aug.; Corner, 1988), so requiring extra effort by the road sweepers for a few weeks per year. The upside of seasonal shedding is that leaf fall is less during the other periods. Also, aesthetically, the change in leaf colours, give the impression of seasonal change that is absent in otherwise boring, aseasonal Singapore.

3. Trees may flower profusely, and produce much pollen which may be allergenic. Male trees of the native casuarina or ru (*Casuarina equisetifolia*) produce a lot of wind-dispersed pollen which may cause allergies in people. A solution to this is to plant female trees which do not produce pollen. Although plants are not sex-distinguishable before flowering, known female trees may have stem cuttings made from its branches and the rooted cuttings planted out.

Excess flowers and fruits can produce a mess beneath the tree. Certain tree species may attract bees when in flower, and this may pose a danger to the public. Of course, one easy solution is not to plant any one species en masse, so the amount of flowers is never very high. High diversity planting also ensures that disease epidemics or pest outbreaks do not occur.

4. The spreading roots of trees may damage driveways, roads, banks of canals, and other built structures. The spreading roots of the exotic rain tree can damage car parks. The solution is to utilize species with less damaging roots when cultivation is near sensitive built structures.

5. Tall trees may be struck by lightning and the probability of this occurring is higher in Singapore, which has one of the highest rates of lightning activity in the world (National Environment Agency, 2002)! However, lightning arrestors may be installed on selected tall trees to protect the trees and their surroundings. The NParks installs lightning arrestors on trees in parks and even the nature reserves, both for the protection of trees and members of the public (Fig. 24).

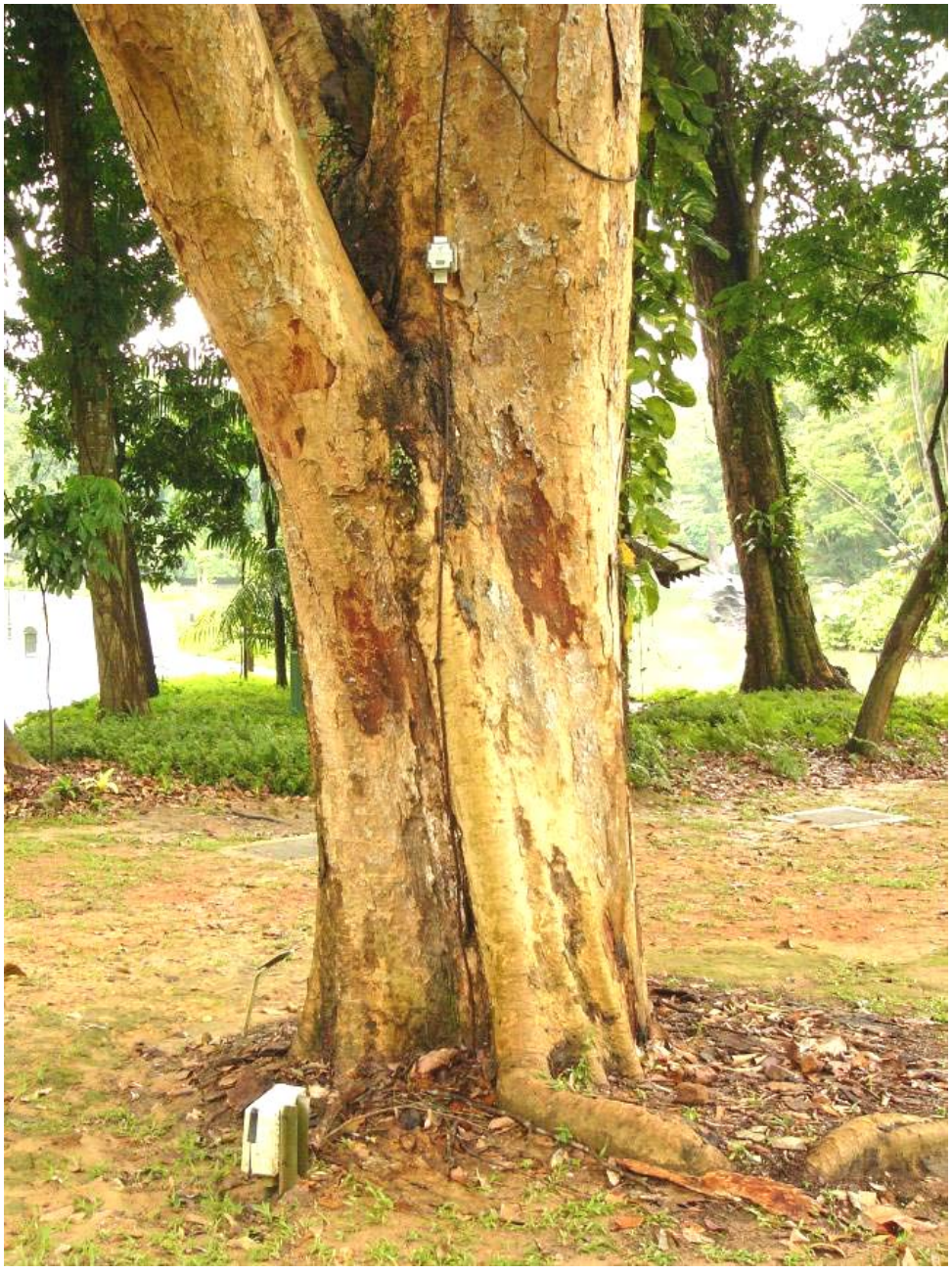

Fig. 24. Lightning arrestor system on a tree in the Singapore Botanic Gardens. Note the cable going vertically up the trunk and the white junction boxes. However, trees in more isolated areas may have their cabling stolen by metal thieves, as has happened in the last few years in Singapore. (Photograph by: Hugh T. W. Tan).

6. When motor vehicles collide with trees, drivers and passengers are likely to be severely injured, because the tree's large mass causes rapid deceleration of the car. In the Garden City of Singapore, trees are grown close to the road, so this problem is not easily solved, short of planting trees further away from the road edge. Of course, drivers may drive within speed limits to reduce their chance of injuries.

7. Trees and dense shrubs may house bees' or hornets' nests, since greenery is their natural site for nest-building. However, these dangerous insects also build their nests anywhere convenient, such as buildings, fences, lamp posts, etc. (Chan, 1972). Rubber (exotic species), rambutan (native), mango (exotic) and coconut (native) trees appear to be preferred by hornets for nesting (Chan, 1972).

8. Branches of trees may snap off in wind or heavy rain when extra strain is placed on it. Branches angled more acute than about 30° to the vertical should be pruned off to ensure less probability of breakage, especially for trees along roadsides. Dead, damaged or diseased branches should also be removed, because they will ultimately break off and fall down. Strongly leaning trees should also be felled. Multiple trunks arising from a single rootstock as a result of coppicing are also prone to fall. A regular inspection of trees has to be implemented as the NParks does for the trees under its charge.

9. Cavities in trees from rotting wood or from branches previously cut, can be breeding holes for mosquito larvae. These need to be filled up with a suitable medium.

For large woody plants to give their best, they need to be maintained and regularly inspected by a trained arborist, to ensure minimal problems.

USES OF PLANTS (PARTICULARLY WOODY SPECIES)

Plants have many useful functions for humans. These include:

1. Aesthetics (beautification)
   a. Woody plants are used in landscape design or as 'green wallpaper' in the built-up environment (Fig. 25).
   b. Historical and cultural value because of their longevity [e.g., Heritage Trees Scheme of the National Parks Board, which highlights trees that serve as important green landmarks of Singapore (National Parks Board, 2008), Fig. 9].

2. Conservation
   a. Useful economic products were extracted from Singapore's plants in the past, such as timber, fruits, tannins, gums, medicines, etc.
   b. Plants may be a store of genetic resources for potential biomedical and industrial uses await discovery, so plants should not be allowed to go extinct (Fig. 26 of *Catharanthus roseus*, from Madagascar, the source of the alkaloids, vinblastine and vincristine, used for treatment of childhood leukemia).

3. Recreation
   a. Hikes through forested areas are for exercise and for adventure.
   b. Nature lovers can practice photography of birds and flowers or other natural wildlife in areas landscaped predominantly by woody plants.

Fig. 25. The ABC Waters Programme pilot project at Kolam Ayer along the Kallang River presents a much more aesthetically pleasing canal with its sides planted up.

Fig. 26. The periwinkle (*Catharanthus roseus*) from Madagascar is the source of useful alkaloids in the treatment of childhood leukemia. (Photograph by: Hugh T. W. Tan).

Fig. 27. Surface roots of Malayan banyan (*Ficus microcarpa*) reducing soil erostion and holding back the soil of an earth bank at Astrid Hill, Singapore, preventing landslip. (Photograph by: Hugh T. W. Tan).

4. Military uses
   a. Forests are areas dominated by trees. Training areas employed by the Singapore Armed Forces include the Central Catchment and Bukit Timah Nature Reserves and the forested areas surrounding the reservoirs in the Western Catchment Area, as well as Pulau Tekong.

5. General environmental and ecological services provided by woody plants
   a. There is glare reduction by the plants surrounding human habitation, since plants usually absorb all other wavelengths except for green.
   b. Plants reduce heat absorption, reflectance and radiation by plants surrounding buildings. Plants have a shading effect, and also transpire, so the latent heat of evaporation of water cools down the plant significantly, and hence, the surroundings. Plants do not reflect significant amounts of infra-red radiation, responsible for heating.
   c. Reduction in soil erosion through the growth of extensive root systems on slopes and level ground, since the roots hold the soil together (Fig. 27). Bare ground areas in contrast will lose much of its soil during a heavy downpour.
   d. Sound reflectance and absorption by the foliage of trees and shrubs.
   e. Shade cast by trees along roads, footpaths and car parks.
   f. Increasing relative humidity in the air through transpiration by the foliage of plants.
   g. Improving water quality through ultrafiltration (rhizofiltration) by the roots of the trees surrounding reservoirs.

h. Trapping dust in the foliage of plants (Chakre, 2006), so removing it from the air. This will be more useful for people living near roads where dust is spread by vehicles.
i. Animal (shelter), plant (hemi-parasites, epiphylls, epiphytes and climbers), lichen and algal habitats may be found in shrubs and trees (Fig. 22).
j. Animal food (for native insects, birds, bats, small mammals, etc.) as provided by the flowers, fruits, seeds, seedlings, and leaves of the plants.
k. Wood-air bathing (shinrin-yoku)—The Japanese believe that health benefits may be derived from walking through forested areas, and hold symposia on this topic which is as yet unrecognized in most of the rest of the world (Maloof, 2004). It is believed that trees release volatile compounds, the most abundant of which are monoterpenes. Dietary monoterpenes are known to prevent and cure cancers and many chemotherapy drugs consist of monoterpenes. So, feeling better after a walk through a forest may be more than just obtaining fresh air, exercise and sunshine and involve "getting a high" from the trees!

6. Specific environmental and ecological services that may or are provided by woody plants for the canal environment
   a. Phytoremediation, the use of plant to decontaminate the environment (soil, water) (reviewed by Barceló & Poschenrieder, 2003)
      i. Phytoextraction—Reduction of soil metal concentrations can be done by growing plants with a high capacity for metal accumulation in shoots. Ideally they should show high metal accumulation in shoots and high biomass production. However, hyperaccumulator species usually do not produce big biomass. Sendudok (*Melastoma malabathricum*; Fig. 20), for example, is a woody hyperaccumulator of aluminium (up to 1 % w/w) (Watanabe et al. 1998). Therefore, species that accumulate lower metal concentrations with high biomass production can be sought. On harvesting, high-price metals can be recovered from plant material, or else, it can be incinerated. Willows (*Salix* species; Fig. 28) and poplars (*Populus* species) are temperate woody plants thought to have phytoextraction potential in a list consisting of otherwise herbaceous plants.

Fig. 28. The Beijing willow (*Salix babylonica*), a native of China, is one of the few willows that can grow in Singapore. (Photograph by: Hugh T. W. Tan).

ii. Rhizofiltration—Metals in contaminated surface waters or wastewaters may be absorbed or precipitated on roots or other submerged organs of aquatic plants. Thus, the plants must be metal-resistant, have a high surface area for absorption and tolerate hypoxia. Willows and poplars (*Salix* and *Populus* species, respectively) are temperate woody plants thought to have rhizofilitration potential in a list consisting of otherwise herbaceous plants.

iii. Phytostabilization—Metals in soils or sediments are immobilized by adsorption onto roots or precipitation in the rhizosphere. By decreasing mobility, they prevent leaching and groundwater pollution, and reduce the metals' bioavailability. It is supposed here that plants needed for phytostabilization are necessarily woody and deep rooting and that do not translocate in order to perform this function.

iv. Phytodegradation—Organic pollutants are decomposed through plant enzymes or products. Yu et al. (2005) reported willow (*Salix* species) able to degrade cyanide.

v. Rhizodegradation—Organic pollutants are decomposed by rhizosphere microorganisms. The Portia tree (*Thespesia populnea*; Fig. 29), sea trumpet (*Cordia subcordata*; Fig. 30) and *Myoporum sandwicense* have been reported by Tang et al. (2004) to degrade petroleum hydrocarbon in soil. The first two species are natives of Singapore.

Fig. 29. The Portia tree (*Thespesia populnea*): (a) Flowers on a leafy branch; (b) Unripe fruits on a leafy branch. (Photographs by: Wang Luan Keng).

Fig. 30. Sea trumpet (*Cordia subcordata*): (a) Flowers on a leafy branch; (b) Unripe fruits on a leafy branch. Each fruit consists of the calyx (the sepals; in white) surrounding a nut. (Photographs by: Wang Luan Keng).

vi. Phytovolatilization—Pollutants are taken up by plants and released into the air by transpiration, in the original form or after metabolic modification. Several crop species, such as *Brassica*, beetroot (*Beta vulgaris*) and rice (*Oryza sativa*) have been reported to be able to volatilize selenium (Zayed et al., 1998), but this may have narrow relevance to metals with volatile chemical forms like selenium and mercury. In the case of mercury, plants genetically engineered with a bacterial mercury reductase gene have been suggested (Heaton et al., 2000).

vii. Hydraulic control—Plants that absorb large amounts of water are used to prevent the spread of contaminated water. Phreatophytes can be used for cleaning saturated soils and contaminated aquifers. Gum trees (*Eucalyptus* species) and pines (*Pinus* species; Fig. 1) have been used to lower salinity and level of the ground of land affected by agricultural salinization (Bari et al., 1992).

viii. Phytorestauration (phytorestoration)—Revegetation of barren areas to provide cover for soil, to prevent movement of contaminated soil particles. However, prior conditioning may be needed to enable plants to colonize the polluted substrate.

b. Tolerance of flash flooding conditions by rheophytes that are plants "which in nature confined to the beds of swift-running streams and rivers and grow there up to flood-level, but not beyond the reach of regularly occurring flash floods" (van Steenis, 1981). There are about 271 species of woody plants identified as rheophytes out of a total of 396 (van Steenis, 1981). Singapore canals have maximum flow rates of about 2–3 m s^{-1} (7.2–10.8 km h^{-1}) (Public Utilities Board, Singapore, personal communication) during periods after heavy downpours, where water levels are also very high, so the canals behave like natural spate streams or rivers, which are those characterised by spates—"large discharges of water caused by heavy rains in the catchment area" (van Steenis, 1981). There are no Singapore native plant species of rheophytes, but exotic species such as the Beijing willow (*Salix babylonica*; native of China; Fig. 28), false heather (*Cuphea hyssopifolia*; Mexico, Honduras and Guatemala; Fig. 31), green and yellow aralia (*Osmoxylon lineare* typical and yellow-leafed forms; the Philippines), myrtle-leafed leaf-flower (*Phyllanthus myrtifolius*; Sri Lanka; Fig. 32), oleander (*Nerium oleander*; South Europe and South Asia), Indian oleander (*Nerium indicum*; South Asia) and trumpet flower (*Thevetia peruviana*; Central and South America) are cultivated here and commercially available. However, species such as the Benjamin fig (*Ficus benjamina*) or the Malayan banyan (*Ficus microcarpa*; Figs. 21, 27) are plants that can grow on rocks, so should be able to tolerate flash floods because of the strong root systems. The Malayan banyan, further, grows naturally along river banks, so is tolerant of wet conditions.

c. Cover of concrete embankments or structures (bridges). Climbers (trailers) are very suitable for this purpose. The seashore morning glory (*Ipomoea pes-caprae*; Fig. 33) is a commonly used species for growing over granite block revetments abutting the seafront or banks of reservoirs in Singapore. However, it has its disadvantages in that it is a semi-annual, and tends to peter out once it has fruited. It needs to be replanted again to revitalize it. A more woody, perennial climber, such as the three-leafed vine (*Cayratia trifolia*), that can tolerate hot, dry conditions, such as canal or reservoir banks, or seawalls, is better (Fig. 34).

d. Flow modification. Rheophytes (see above S/No. 6. b. above) may be grown along the banks in the zone which is flooded during heavy downpours to reduce flow rates. They have strongly anchored roots and the springy stems and low-resistance leaves enable them to withstand the fast flows without being pulled out by the water.

e. Use for vertical and roof greening. Woody climbers are lightweight, low maintenance and more environmentally friendly to irrigate and maintain because they can be rooted in the ground at the foot of the building and can grow upwards and over the roof by climbing on synthetic, UV-resistant, thin filaments or netting. Irrigation can be mostly

Fig. 31. False heather (*Cuphea hyssopifolia*) is commonly used as a border in landscape designs in Singapore. (Photograph by: Hugh T. W. Tan).

Fig. 32. The myrtle-leafed leaf flower (*Phyllanthus mryrtifolius*) is used as a border or in flower beds as here. (Photograph by: Hugh T. W. Tan).

Fig. 33. Seashore morning glory (*Ipomoea pes-caprae*), a native sandy beach species is a perennial favourite for greening seawalls or banks of reservoirs or canals: (a) A flower, leaves and part of the trailing stem; (b) Reservoir banks covered with cultivated seashore morning glory, growing in a habitat which it does not naturally occur. (Photograph by: Hugh T. W. Tan).

Fig. 35. Three-leafed vine (*Cayratia trifolia*), a native seaside climber that can be used to cover seawalls and banks of canals: (a) A retaining wall covered with *Ficus pumila* and the vine; (b) The vine can grow very vigorously as on the trellis in the NUS Native Plant Demonstration Garden. (Photographs by: C. K.Yeo).

by rainwater collected at the ground and supplemented by an automatic drip irrigation system with rain sensors, so saving the cost of pumping water upwards to the roof because climbers have relatively large vessels in their stems that allow easy transport of the water through their narrow but elongated stems. Climbers which are rooted in the ground also do not need soil at the rooftops, many of which were not originally designed and built for heavy loads.

CONCLUSIONS

It is advantageous to use native woody shrubs, treelets, trees or climbers (trailers) propagated from local provenance for cultivation along Singapore waterways for their numerous environmental and ecological services which include glare reduction, reduction in heat absorption, reflectance and radiation, reduction in soil erosion and improving water quality, reflectance and absorption of sound so reducing sound pollution, provision of shade, increasing humidity through transpiration, trapping dust, providing shelter or habitats for native animals, plants, lichens and algae, food for animals, phytoremediation (phytoextraction, rhizofiltration, phytostabilisation, phytodegradation, phytovolitalisation, hydraulic control, phytorestoration), coverage of concrete embankments or other structures, flow modification, vertical and roof greening.

Woody plants are also for aesthetics, being the most major component of landscape designs, have historical and cultural value because of their great longevity, are a potential source of useful economic products and genes for useful biomedical and industrial products, as well as enhancing education and recreation.

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INDEX

Page numbers of illustrations are in **bold**.