OnLine Journal of Biological Sciences

Original Research Paper

Evaluating Plant Species Suitability for a Substrate-Free Tropical Green Roof

[1]Bruno R. Silva, [2]André Mantovani, [3]Dulce G. Mantuano, [4]Sylvia Meimaridou Rola and [5]Maria C. Barbosa

[1]*Curatorship of Living Collections, Research Institute of Rio de Janeiro Botanical Garden, Rua Pacheco Leão, 915, Bromeliário, Horto, Rio de Janeiro, RJ, Brasil, CEP 22460-030*
[2]*Structural Botany Laboratory, Research Institute of Rio de Janeiro Botanical Garden, Brazil*
[3]*Plant Ecophysiology Laboratory, Biology Institute, Botany Department, Federal University of Rio de Janeiro, Cidade Universitária, Rio de Janeiro, RJ, Brasil, CEP 21941-901*
[4]*Postgraduation Program of Architecture (PROARQ) – Department of Construction Technology, Faculty of Architecture, Federal University of Rio de Janeiro, Cidade Universitária, Rio de Janeiro, RJ, Brazil, CEP 21941-901*
[5]*Geotechnical Laboratory Prof. Jacques Medina - LABGEO, Coppe, Federal University of Rio de Janeiro, Cidade Universitária, Rio de Janeiro, RJ, Brazil, CEP 21941-901*

Article history
Received: 09-03-2018
Revised: 18-07-2018
Accepted: 08-10-2018

Corresponding Author:
Andre Mantovani
Structural Botany Laboratory, Research Institute of Rio de Janeiro Botanical Garden, Brazil
Email: andre@jbrj.gov.br

Abstract: Greenroofs reduce building exterior-interior thermal flux and mitigate high internal air temperatures, especially in tropical climates. Tropical greenroofs are given little attention and their use remains restricted to a very low percentage of roofs due to high costs compared to traditional roofs, weight overload (mainly due to the chosen substrate) and potential waterproofing problems. We here present an alternative greenroof technique based on a reduction of the current Modern Extensive Greenroof (MEG) technique to half of its original layers. The feasibility of superficially rooting plant species from extreme habitats was tested in full scale on a single family house over three consecutive years. The innovative horticultural system is based on a substrate-free method, which has several advantages over traditional systems, including easier maintenance and minimal total weight. The reduced layout also lowers material and labor costs, facilitating widespread retrofitting of installations, mainly on low income houses in urban areas of developing countries. From a sparse initial planting, total coverage was attained in two years and 218 taxa, belonging to 20 families and various growth types, were successfully grown on the new greenroof system. Species were able to survive and grow even though signs of dynamic photoinhibition were detected. The viability of the plant assemblage together with the ability to store water due to a high degree of succulence among species indicates a broad potential for research into the use of cultivated epiphytic, lithophytic and psammophilous flora for the installation of tropical greenroofs.

Keywords: Greenroof, Substrate-Free, Tropical, Epithyte, Lithophyte

Introduction

Urban green areas and local temperature reductions are intimately related (Susca *et al*., 2011). Poor vegetation coverage is common in densely urbanized areas, which have very few residual spaces on the ground level that can be greened (Madre *et al*., 2014). Thus, attention was increasingly turned towards the greening of roofs, which constitutes from 20-25% (Akbari *et al*., 2003) to over 30% (Frazer, 2005) of the urban surface.

Greenroofs are artificial environments separated from the earth by a building or another structure where plants are cultivated on a special medium (Osmundson, 1999). Among many other advantages over conventional roofs, such technique greatly reduces the effects of heating (Vecchia, 2005). After over 30 years of testing and improvements, the Modern Extensive Greenroof (MEG) system has become the most internationally used technique to construct greenroofs in temperate regions (Köhler and Poll, 2010). Although problems with this

Science Publications

technique are likely uncommon, they are usually difficult to solve due to the complex six-layered structure of MEG roofs (Thuring and Dunnett, 2014): Waterproofing membrane, root barrier, drainage, filter, water storage and growing medium (soil or substrate). The system therefore has a high installation and maintenance cost (Wong *et al.*, 2003) which may prevent its widespread application, especially in developing countries.

Another limiting factor for tropical greenroof implementation is plant survival. Plant selection and testing for greenroof applications have taken place mainly in temperate climate (Dunnett and Nolan, 2004; Durhman *et al.*, 2006; Dunnett *et al.*, 2008; Getter and Rowe, 2008; 2009; Getter *et al.*, 2009; Lundholm *et al.*, 2010), with a set of conditions that are radically different from those of the hot-humid tropics (Tan and Sia, 2009). A more encompassing literature (Silva, 2016) provides more information on greenroof advantages and comparisons between tropical and temperate greenroofs. The general lack of scientific knowledge about the flora capable of surviving in stressful conditions (e.g., high solar irradiance, drought, heat) prevailing on greenroofs installed in tropical climate (Laar and Grimme, 2006; Parizotto and Lamberts, 2011) turns the biological component, especially the choice of plant species, the main aspect for the success in these regions.

The Earth´s 35 recognized "biodiversity hotspots" host 77% of the world´s endemic flora (Mittermeier *et al.*, 2011). Considering that several of these hotspots are located in the tropics, making such "biological capital" into a protagonist in an extremely rich source of plant material that can be tested for greenroof implementation under tropical conditions. Thus, epiphytes from tree canopies (Benzing, 1990), lithophytic species from inselbergs (Porembski and Barthlott, 2000) and psammophilous species from sand coastal dunes (Mantovani and Iglesias, 2005; 2010) can be valuable due to their adaptations to harsh tropical abiotic conditions.

Innovative approaches are required to further the adoption of greenroof installations in tropical climates, which includes minimizing the complexity and cost of this technique. The reduction in complexity should be followed by a careful selection of cultivated plants suited to grow under the stressful conditions prevailing on tropical rooftops. In the present study, our objective is to describe in detail a new greenroof technique and its implementation, to compare its initial financial costs with the leading MEG technique and to evaluate its influence on physiological plant performance of this extreme-adapted flora. The proposed new technique suits extensive and semi-intensive (Magill *et al.*, 2011) greenroofs under tropical conditions, enabling lower-cost and accessible (Dunnett *et al.*, 2008) installations that, as such, is applicable on low income houses in urban areas of the developing world.

Materials and Methods

Experimental Tropical Greenroof

Experiments were performed on a an actual occupied house rather than on a dimensionally reduced rooftop or greenhouse grown module which are typically used in studies of this subject (Oberndorfer *et al.*, 2007; Laar *et al.*, 2001; Simmons *et al.*, 2008; Farrell *et al.*, 2012; 2013).

The proposed new method is based upon simplifications of available technologies, using the MEG technique as a starting point (Thuring and Dunnett, 2014). The system consists of a new substrate-free greenroof technique comprising only three layers from the structural roof top: Thin geotextile, waterproofing membrane and thick geotextile, which are half of the MEG number. The drainage, root barrier and substrate layers that are used in MEG were removed.

The experimental tropical greenroof was installed in December 2012, on a single family house at Niterói, Rio de Janeiro State, Brazil (lat. 22°55'S, long. 42°58'W, alt. 150 m). The 250 m^2 rooftop was completely covered with the three layers and included an overhead irrigation system (Fig. 1) and pathways.

The structural roof is distributed in two 10% inclined planes with north and south water flow directions and consists of pre-molded steel reinforced concrete pieces intercalated with ceramic bricks covered by steel reinforced concrete. Viapol® brand additive was added to the top concrete layer for waterproofing, followed by Sikatop 108® brand of superficial sealer for additional waterproofing. The first layer applied was a RT 10 (10 KN rip tension) geotextile (Bidin® brand) directly over the smoothed concrete mortar and along the water flow directions. This caused a soft base to be formed for the installation of the waterproofing membrane, avoiding any sharp tips that could damage it. Joining of linear parts was done by using a hot air thermo-welding machine. The second layer was a 0.8mm thick waterproofing PVC membrane (Vinilona®, Sansuy® company) associated with geotextile (top side) that was installed with pieces perpendicular to the water flow directions. Joining of linear parts was done by thermo-welding with the addition of PVC glue. Over that, the third and final layer was a RT 16 (16 KN rip tension) geotextile (Bidin®) that was laid along the water flow directions (perpendicular to the waterproofing membrane orientation) acting as the rooting media. Sections were glued together with a polyurethane construction adhesive, since thermal welding could damage the waterproofing membrane below (Fig. 2). This layer functions as a rooting medium, enabling water to flow by capillarity between its polyester fibers, thus characterizing a soilless horticultural system that functions in a similar way to an ebb and flood hydroponic system with rooting on synthetic fibrous materials (Logendra and Janes, 1997).

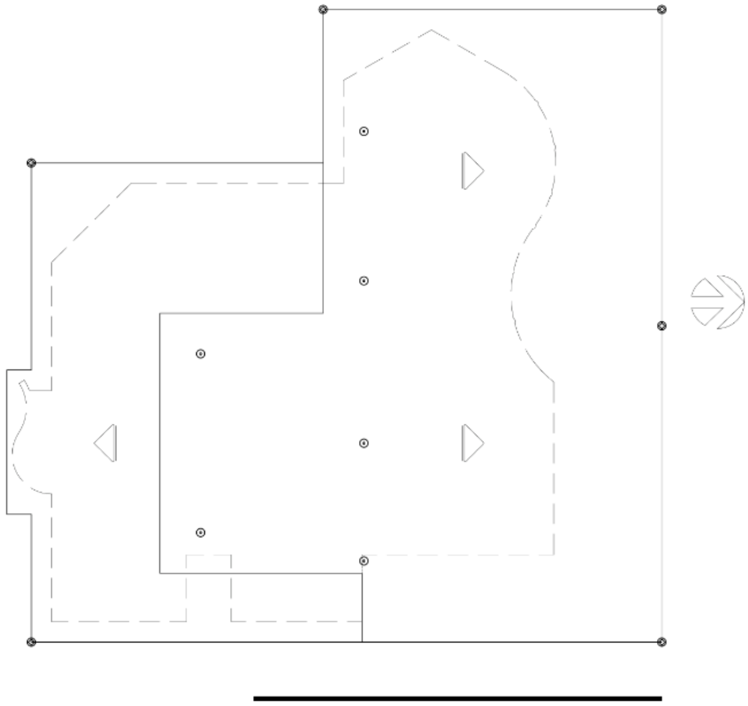

Fig. 1: Roof plan (solid line) of a single-family house designed for the installation of an experimental tropical greenroof technique, which consists of three layers: Thin geotextile, waterproofing membrane and thick geotextile. Arrows indicate directions of water flow and dashed lines indicate external walls. Roof total area is 250 m^2. Irrigation sprinkler positions are indicated by and . Project was installed at Niterói municipality, Rio de Janeiro State, Brazil in December 2012

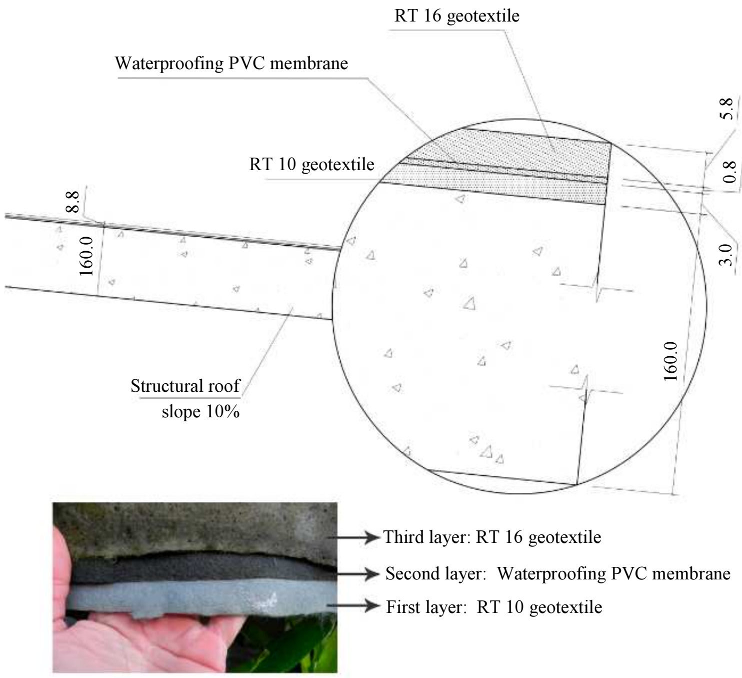

Fig. 2: Detailed roof cross section of a three layered tropical greenroof technique. Cross section of roof covered by the three layers that are responsible for waterproofing and rooting media (all dimensions in mm) and picture of the three layers

A 10 cm edge of the three layers covered the roof perimeter and was left beyond the thickness of the concrete slab in order to any excess water drips into the water collecting gutter for reuse (Fig. 3), plus avoiding any backwash. The pathways were installed by fixing 130 granite stone slabs (aprox. 40×40 cm) using sand and Portland cement mortar. Stones were installed leveled and diagonally oriented along the water flow directions, in order to avoid interrupting the water flow and creating undesirable water retention upstream and dry bands downstream. A very small amount (ca. 20 Kg; 0.08 kg/m^2) of natural soil from the nearby forest was crushed and evenly spread over the entire geotextile surface to maximize fungi and bacterial biodiversity (Brenneisen, 2006; McGuire *et al*., 2013).

Financial Analysis

Material and installation costs to the proposed technique for tropical greenroofs were estimated in order to be compared with MEG widespread technique. A MEG related technique was budgeted for a tropical scenario, contemporarily, by Rosseti *et al.* (2013). To maintain the reference for the estimated values, costs were presented in American dollars. The rate of R$ 2.10/1 US$ for December 2012, was used to convert costs (Source: Banco Central do Brasil).

Biodiversity at the Experimental Greenroof

A sparse initial planting started on January 2nd and finished on March 31st of 2013. It consisted of 230 species belonging to 20 plant families comprising native and exotic taxa. Species habit was classified following IUCN red list (2017). The high taxonomic diversity tested aimed to establish a broad list of greenroof candidate species for the tropics (Tan and Sia, 2009) under the new proposed technique. Species were selected according to similarity of the roof abiotic conditions as well as native environmental parameters and availability of saplings. Smaller plants were simply laid directly on the superficial geotextile layer (Fig. 4) and larger ones were fastened in place with ceramic bricks until rooting took place. Species with pendant growth were introduced along the roof edges by attaching them to the irrigation pipes.

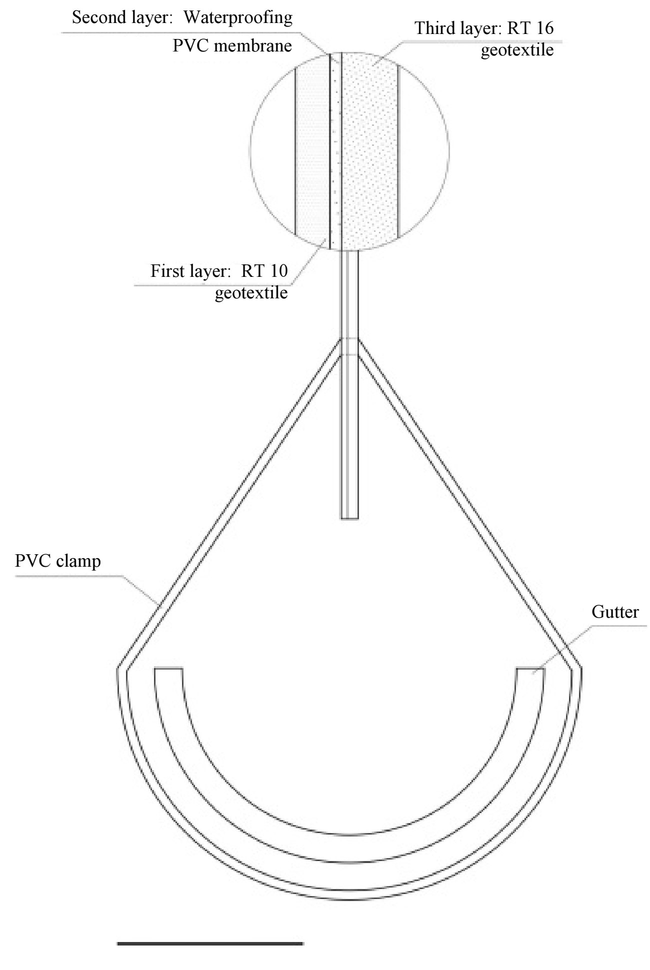

Fig. 3: Specially developed gutter attached to hanging edge of the three layers

Fig. 4: Tropical greenroof showing Brazilian native bromeliad *Neoregelia compacta* (arrow) planted directly on the 3rd layer (*) superficial (RT 16 geotextile). Greenroof was installed as an experimental low cost and simplified three-layer technique, note stone paths (**)

The majority of introduced plant families is succulent and has CAM photosynthetic metabolism, as both parameters offer resistance to high temperatures and to periodical drought (Lüttge, 2004). However, C3 plant species were also used. This diversified initial planting followed literature recommendation (Köhler, 2006) in order to improve plant survival (Nagase and Dunnett, 2010; Wolf and Lundholm, 2008) and greenroof services, such as runoff and temperature reductions (Lundholm *et al.*, 2010).

Conservation of endangered species is a positive consequence of greenroof (Köhler, 2006). Whenever available, these species were also introduced following IUCN red list (2017), Martinelli and Moraes (2013), Tropicos database (2016), CNC Flora (2015) or CITES (2016).

Maintenance of the Experimental Tropical Greenroof

Maintenance of the proposed greenroof involved irrigation and plant invasion control. Vegetation maintenance was done by controlling introduced plant growth to avoid overgrowing among individuals and manually removing invasive colonizing species (e.g., *Cyperus rotundus*). Occasional plant material substitution was needed during the initial phase of installation until plant acclimation was achieved.

Overhead irrigation was chosen because of its greater efficiency for greenroofs (Rowe *et al.*, 2014) and was applied shortly after sunset on days without precipitation. Irrigation was done via six internal Rainbird® 360° spray heads and six external Rainbird® 2045-PJ-08 impact sprinklers located on the corners (Fig. 5). The average volume input was 20 L/min and the irrigation remained on for about 15 minutes on average. Thus, about 300 L of water was consumed in every irrigation event. The irrigation system had to be kept unclogged and to deliver even amounts of water. This irrigation schedule keeps the rooting media periodically humid and bromeliad tanks partly filled, since these take a few days without precipitation to become completely empty (Zotz and Thomas, 1999).

Even without specific root barrier the growth of superficially rooting species presented no root penetration into the structural roof or any detectable puncture over the three year period on the Sansuy® Vinimanta waterproofing membrane that had a five year warranty against leaks. The weeding frequency was about once every three months, took about three man-hours to be completed and was compatible with the maintenance required for roofs on the same region commonly covered by ceramic tiles.

Plant growth and Morphophysiology

A method based upon DIA (digital image analysis) (Sendo *et al.*, 2010; Barker and Lubell, 2012) was used in order to evaluate plant horizontal coverage for nine selected species. A digital Nikon Coolpix P100 camera set to 10 Mpixels resolution was connected to a tripod facing directly downwards. Photographs of fixed positions were repeated weekly during the establishment period from March 31st to April 6th, 2013. Images were analyzed using ImageJ program, following Sendo *et al.* (2010), in order to calculate coverage area, data being log transformed prior to graphing (Niklas, 1994).

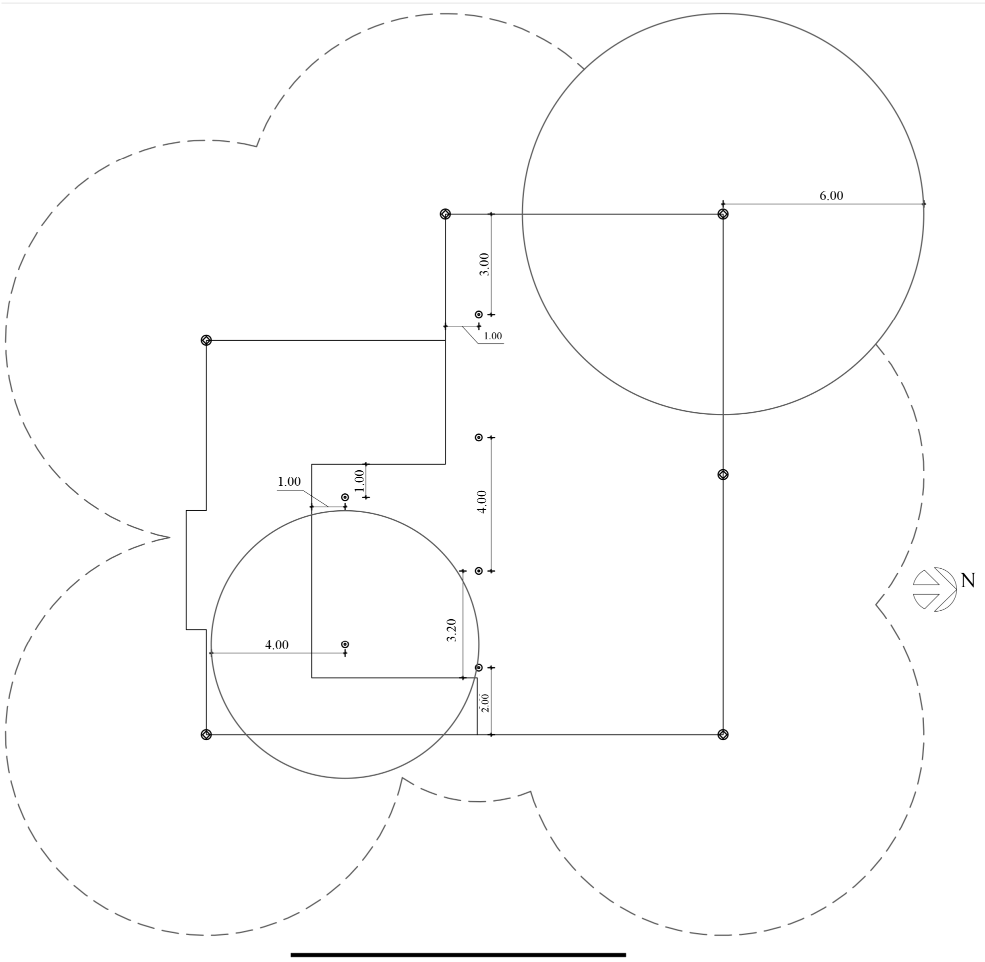

Fig. 5: Irrigation sprinkler positions indicated by ⊚ and ⊚ and action radius covering entire roof indicated by circles. For clarity, dashed lines represent external perimeter of watering

Plant morphophysiological parameters were used to characterize the flora after three years of cultivation under the newly proposed greenroof technique. Leaf succulence improves water storage and thermal stability and was evaluated following Mantovani (1999). Circular leaf sections, which were obtained with cork borers, were kept moistened with humidified filter paper under dark conditions and under 7°C for 24 h in order to maximize fresh weight. Posteriorly, leaf specimens were dried until constant weight under 60°C. Fresh and dry weights were determined on a 0.001 g Ohaus precision balance. Succulence was quantified by the ratio (maximum fresh weight-dry weight)/leaf area.

Leaf physiological status of greenroof plants was also evaluated by its efficient photosynthetic quantum yield capacity obtained via a chlorophyll fluorescence analysis under light adapted conditions (Genty *et al.*, 1989). Fluorescence is adequate to provide insights into the ability of plants to tolerate environmental stresses and into the extent to which those stresses have damaged the photosynthetic apparatus (Maxwell and Johnson, 2000). Genty´s yield parameters were determined through a modulated Pulse Amplitude fluorometer (MINI-PAM, H. Walz, Effeltrich, Germany) during dawn (6:00 to 7:00), before the incidence of direct sunlight and also during the afternoon (13:30 to 14:30) when plants were subjected to high Photosynthetic Photon Flux Density (PPFD) conditions surpassing 1,800 μmoles m^{-2} s^{-1}. We stated that overall conditions under the new greenroof technique were sufficient for plant survival under non photoinhibitory conditions. Therefore, yield parameters collected at dawn should be higher than 0.7 (Genty *et al.*, 1989).

Statistical Analyses

Normal distribution of data was evaluated by the Kolmogorov-Smirnov (K-S) test and homogeneity of variances was evaluated by the Levene test. Succulence comparisons among families were performed using

One-way ANOVA. Genty´s Yield comparisons among families and day time were performed using respectively One-way ANOVA and Paired t-test (p<0.05; Zar, 1996). Multi pairwise comparisons were performed using Tukey test.

Plant growth per species was compared through linear ordinary regressions fitted for log transformed data (log of area value + 1). Differences in growth rates were detected by comparing the angular coefficients (i.e., scaling exponent, α) (Niklas, 1994), using Standardized Major Axis Tests and Routines (SMATR) (Warton *et al.*, 2006).

Both succulence and chlorophyll fluorescence parameters were measured respectively for 114 and 156 species belonging to 14 botanical families. The objective was to compare and detect potential plant families whose species could be better suited to be grown under the new greenroof technique proposed. Regarding succulence, the measurement of three individuals was used to represent each species. Subsequently, at least three species were used to obtain the mean value for family category, except for Araceae, Clusiaceae, Euphorbiaceae and Pandanaceae which were represented by only two species, while just one species was evaluated for Asteraceae. As for the quantum yield parameter, the same procedure was done to obtain mean value for each family category. Other than for Araceae, Clusiaceae, Melastomataceae and Pandanaceae, all other families were represented by at least three different species. Moreover, quantum yield was measured twice a day, at 06:00 and 14:00, to obtain mean values for the daytime category. Yield variation along the day was used to evaluate photoinhibition recover.

Statistical procedures were performed using *Statistica* software. Significance was assumed at p<0.05 (Zar, 1996).

Results

Financial Analysis

The installation of the newly proposed greenroof system in three layers cost US$ 31.84/m^2. Of these, the largest investment (52%) was related to the waterproofing membrane, followed by the acquisition and planting of vegetation (22%). The remainder of the cost involved manpower and geotextile purchase (4.5 and 6.5% each item, respectively) (Table 1).

In order to compare the proposed technique with costs of available greenroof installations, data from a contemporary study was analyzed (Rosseti *et al.*, 2013), which dealt specifically with the Brazilian economic scenario. Disregarding the structural roof, the final cost for the greenroof installations found by these authors was US$ 71.20/m^2. Costs for the experimental greenroof, when keeping the same values for the vegetation found by these authors, are presented in Table 1. The proposed technique is 56% lower in total cost when compared to Rosseti *et al.* (2013).

Biodiversity at the Experimental Greenroof

The growth of vegetation at the newly proposed technique was followed for three consecutive years. An artificial plant community (Fig. 6) with high diversity established itself on the roof, taking two years to achieve full coverage (Fig. 7a-7e).

Of the approximately 230 species and cultivars (hybrids and horticultural varieties) initially introduced, a total of 218 species belonging to 20 botanical families not only survived, but grew and flowered on the experimental green roof (Appendix 1). The distribution of families displays a strong predominance of Bromeliaceae and Cactaceae with 38 and 21% of the total diversity, respectively. Followed by Orchidaceae (6%), Apocynaceae (4%), Euphorbiaceae (2%), Araceae (2%), Melastomataceae (1%), Clusiaceae (1%) and Amaryllidaceae (1%). In the selected families 64% are monocots and 35% are dicots and only 1% ferns. The exotic families are mentioned separately: Asparagaceae (9%), Crassulaceae (3%) and Xanthorhoeaceae (3%).

Concerning growth forms, the diversity is distributed as: Herbs with 49%; succulents (34%); large shrubs (5%); small trees (4%); succulent shrubs (3%); vines (3%); succulent trees (1%); small shrubs (0.5%) and hydrophytes (aquatics) in bromeliad tanks (0.5%). As for the habit, we found a strong predominance (63%) of epiphytes (29%), lithophytes (23%) or both (11%). Besides these, other species adapted to multiple substrates add up a significant 30%, such as lithophyte or terrestrial (26%) and epiphyte or terrestrial (3%) and lithophyte, epiphyte or terrestrial (1%). Finally, 5% are terrestrial and 2% psammophilous.

Fig. 6: Established plant community, May 2015

Fig. 7: Cronosequence of a tropical greenroof installation in Southeastern Brazil. **A**. Greenroof with three layers (thin geotextile, waterproofing membrane and thick geotextile) recently installed without vegetation-December 2012. **B**. Early planting of tropical species-March 2013. **C**. Steady clonal growth-October 2013. **D**. Established artificial community fully covering the roof area-May 2015. **E**. Artificial tropical greenroof community that has become stable on the long term-March 2016

Table 1: Financial costs for installation of a tropical greenroof in three layers estimated for a 250 m^2 roof area. Note that the cost of the waterproofing membrane includes its installation

Item	Quantity	Total price	Cost per m^2
RT 10 geotextile	253 m^2	US$ 410.82	US$ 1.62
RT 16 geotextile	253 m^2	US$ 545.76	US$ 2.16
0.8 mm thick water Proofing PVC membrane	283.14 m^2	US$ 4,991.76 (installed)	US$ 17.63
Vegetation	Aprox. 5 seedlings/m^2	US$ 1,678.57	US$ 7.14
Labor for installing RT 16 geotextile and planting	80 hours-man at R$ 8.75/h	US$ 333.33	US$ 1.42
Total Cost (US dollars)			US$ 7,960.25
(Cost /m^2)			US$ 31.84/m^2

Regarding the origin of the diversity present, most species (51%) are native from Brazil, of which 40% are endemic and only 11% also occur in other countries. On the other hand, exotics are also expressively represented, with 42% of the total, mostly from Mexico, South Africa and Madagascar. Only 7% are not natural species, or were developed artificially in the form of hybrids (2%) or cultivars (5%). It is important to stress that a significant contribution to diversity comes from the cultivation of pendulous growing species in the eaves, especially the north and south ones. These individuals are exposed to higher substrate moisture due to the roof slope, representing 28% of total diversity, compared to 66% for species restricted to the roof itself and only 6% in both situations. In terms of conservation of rare or endangered species, 3% are evaluated as critically endangered, 8% are endangered and 4% vulnerable. A table listing the diversity grown on the experimental greenroof and supplementary information is presented in Appendix 1.

Plant Growth and Morphophysiology

All plant species analyzed were able to increase the initial surface area covered along 10 weeks ($R^2 = 0.82$ to 0.96; $p<0.001$). The only exceptions were *Agave gypsophylla* and *Neoregelia concentrica*, with surface area increasing just during the last two weeks of monitoring. The species studied differed in relative growth along the experiment which lasted over two months, as indicated by multiple comparison of slopes (P = 0.023 to 0.0001). The highest coverage rate was presented by *Callisia repens*, which more than tripled the coverage compared to the starting area (Fig. 8a-8c), with an average rate growth of about 500 cm^2/week.

The closely related *Callisia fragrans* and *Callisia warszewicziana* showed lower growth rates, from about 5 to 20 cm^2/week. *Tradescantia pallida* and *Tradescantia zebrina* were also steady and relatively fast growers, the first at about 40 cm^2/week and the second showing occasional dormant periods followed by prompt recoveries varying from 10 to 40 cm^2/week. *Kalanchoe fedtschenkoi*, on the other hand, raised its covered area by 1.5 times over the same period, showing growth rates around 7 cm^2/week. The species of bromeliad *Neoregelia concentrica* hardly increased coverage: Only 0.04 times. *Echeveria gibbiflora* showed variable growth around 10 cm^2/week (Fig. 9).

Succulence and quantum yield values obtained by chlorophyll fluorescence are shown by botanical family (Fig. 10). The largest succulence value was found for the stem of *Opuntia ficus-indica* (Cactaceae), over 19,000 g/m^2. Most of the species studied, however, were evaluated for leaf succulence, which ranged from 203.24 g/m^2 (*Philodendron warszewiczii*, Araceae) to 15,296.49 g/m^2 (*Senecio crassissimus*, Asteraceae). In terms of family averages, the smallest and highest values of leaf succulence were 217.10 g/m^2 and 6,876.72 g/m^2 respectively for Araceae and Xanthorrhoeaceae. The Bromeliaceae and Orchidaceae families had average succulences of 989.75 g/m^2 and 1,394.91 g/m^2, respectively. Regarding percentages, 20% of the taxa had succulence values below 500 g/m^2, 53% from 500 to 2,000, 18% from 2,000 to 5,000 and only 9% above 5,000 g/m^2.

The photochemical quantum yield was measured over two periods of the day, morning and afternoon, when the intensity of light levels with photosynthetic capacity exceeded 1,800 $\mu mol\ m^{-2}s^{-1}$. Dawn and dusk values were significantly different (Paired t-test $p<0.05$) for the families shown on Fig. 11. The vast majority of quantum yield values (expressed by Genty`s parameter) were above 0.7 during the morning (Fig. 11), except for some species, for example: *Alocasia* 'Amazonica' (Araceae); *Chamaedorea seifrizii* (Arecaceae); *Sansevieria* 'Alva', *Sansevieria ehrenbergii* (Asparagaceae); *Aechmea amicorum, Aechmea cefaloides* and *Aechmea pectinata* (Bromeliaceae) with values from 0.55 to 0.68. However during the afternoon all species had a strong and significative ($p<0.05$) reduction in yield, with values even lower than 0.4, except for Clusiaceae with yield values at dusk around 0.66. Extreme cases have been shown by species *Pitcairnia* sp. 1 (Bromeliaceae) and *Heterocentron elegans* (Melastomataceae) with values reduced to 0.21 and 0.18.

Fig. 8: Growth of *Callisia repens* on top of a tropical greenroof installed in southeastern Brazil. Photographs were taken at the same position and were used to estimate growth rate through covered area. **A**. One week of growth. **B**. Five weeks of growth. **C**. Ten weeks of growth. Scale bar equals 20 cm

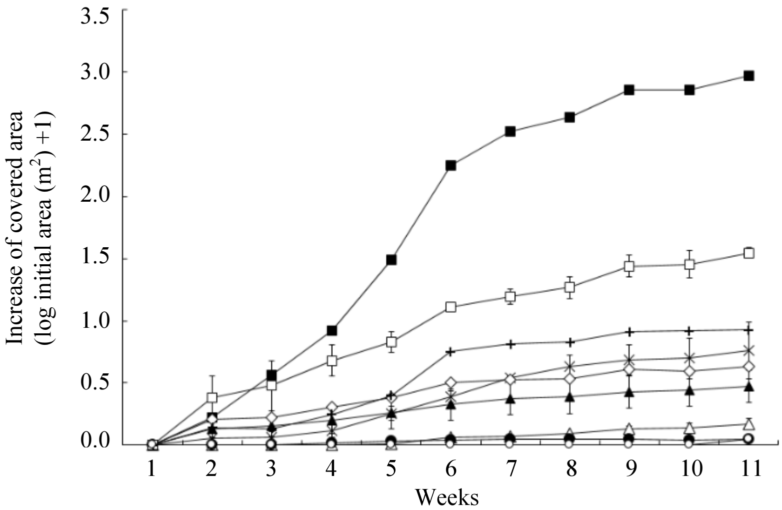

Fig. 9: Surface coverage exhibited by eight different plant species over 10 weeks. Data are related to the initial area covered on the first day of the experiment. Bars indicate standard deviation. Symbols: (■) *Callisia repens*; (□) *Kalanchoe fedtschenkoi*; (+) *Callisia warszewicziana;* (×) *Callisia fragrans*; (◊) *Tradescantia pallida*; (▲) *Echeveria gibbiflora*; (Δ) *Tradescantia zebrina*; (○) *Agave gypsophylla*; (●) *Neoregelia concentrica;* (n=1 to 3 patches)

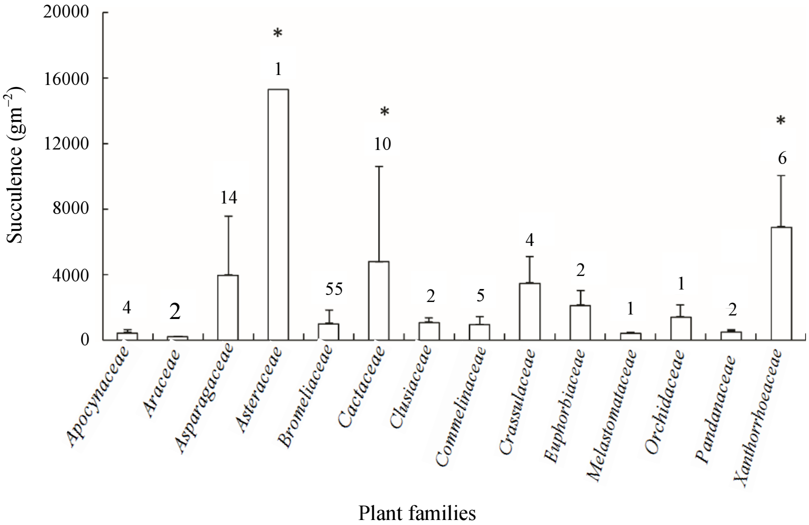

Fig. 10: Succulence for 114 species of vascular plants belonging to 14 different plant families growing after three years on the proposed Tropical Greenroof. Succulence is presented by bars for average of each botanical family and dashed line for standard deviation. Number of species per family is indicated above respective bar. Asterisk indicate significant difference (p<0.05) (n = 3 for each plant species)

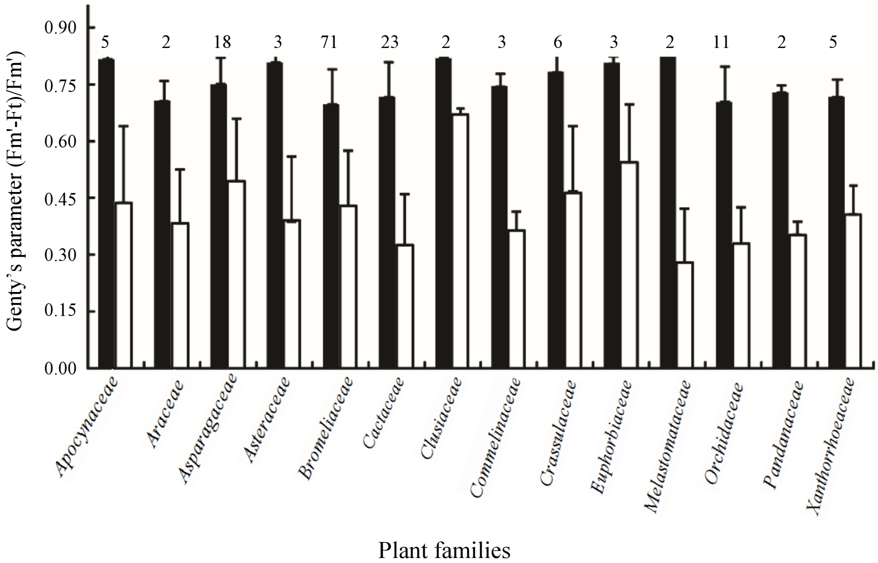

Fig. 11: Photochemical properties for 156 species of vascular plants belonging to 14 plant families growing after three years on the proposed tropical greenroof. Photochemical yield (Yield ((Fm'-Ft)/Fm') measured in the morning (black bars) and afternoon (white bars). Data are presented by bars for average of each botanical family and dashed line for standard deviation. Number of species per family is indicated above respective bar. (n = 3 for each plant species)

Discussion

Previously, greenroofs were built for leisure and aesthetics. Yet, currently, a much more practical approach has prevailed (Henry and Frascaria-Lacoste, 2012), focusing mainly on rainfall management and reduction of energy (Fioretti *et al.*, 2010). The new greenroof technique presented here is comparatively less complex and costly than MEG, besides sustaining growth of native and exotic plants under tropical conditions. Comparing with MEG, the absence of the drainage layer was counterbalanced by an inclined structural roof. In spite of not having a specific root barrier, there was no root penetration into the structural roof and no detectable puncture on the waterproofing membrane. This may have been avoided by the adequate plant choice of superficially rooting species. Additionally, the substrate layer was replaced by an ebb and flood system with rooting on the superficial geotextile.

Results of species growth and the sustained diversity demonstrate the potential for substrate-free systems to be used as a major greenroof technique under tropical climates as long as an adequate array of species is selected (Tan and Sia, 2009). The semi-intensive nature of the experimental greenroof facilitated maintenance, as well as the simplicity of extensive systems to the accessibility and the most prominent vegetation of intensive ones (Magill *et al.*, 2011).

Financial Analysis

Establishing widespread greenroof infrastructure is essential for the manifestation of its benefits on an urban ecosystem level (Getter and Rowe, 2006; Carter and Fowler, 2008). The life cycle analysis performed by Wong *et al.*, (2003) showed that, after 10 years, a conventional flat roof will accumulate a greater cash input than an extensive greenroof and after 40 years it will cost down to 25% less than for the conventional roof (Clark *et al.*, 2008). Since the initial investment is still 10 to 14% higher in a greenroof than in its conventional counterpart, a reduction of only 20% maintenance cost would demonstrate its advantages (Carter and Keeler, 2008). The new technique proposed is less than half (44.7%) of MEG conventional greenroof technique. The lower cost has the potential to ease the implementation of widespread greenroof infrastructure, which can greatly benefit from environmental policy instruments (Carter and Fowler, 2008). These financial results, added to the potential weight reduction, reinforce the applicability for this new technique to be used as a retrofit over various kinds of pre-existing roof surfaces (Castleton *et al.*, 2010).

Biodiversity at the Experimental Greenroof

Köhler (2006) using MEG under a temperate climate found a maximum of 64 species on a 200 m^2 greenroof. Two hundred and eighteen taxa were successfully cultivated on the tropical experimental greenroof, which is a higher number even considering the reduction in complexity of the proposed technique. This indicates that a high diversity is possible, which may have been sustained by mechanisms of facilitation driven by plant-plant interactions (Cook-Patton and Bauerle, 2012).

Another aspect of the high diversity introduced in the presented greenroof technique is the great variation of growth forms and plant sizes, amplifying niches on greenroofs (Cook-Patton and Bauerle, 2012). The fact that various growth forms (herbs, succulents, large shrubs, small trees, succulent shrubs, vines, succulent trees and small shrubs) were evenly distributed in our studied greenroof, favored plant-plant positive interactions. For example, taller specimens offer valuable shade and wind protection for smaller ones. These facilitation mechanisms are well known from extreme ecosystems such as deserts (Franco and Nobel, 1989), canopies (Nieder *et al.*, 2001) and sand dunes (Mantovani and Iglesias, 2001).

It faces the fact that the concept of a greenroof, although artificial, is a dynamic ecosystem. Thus, it can account for the stronger performance of certain mixtures of life-forms, such as "tall forbs, grasses and succulents" found by Lundholm *et al.* (2010), when compared to life forms individually planted on the same greenroof system. These authors suggest that niche complementarity or facilitation mechanisms may have a strong influence on greenroof biodiversity, involving not only plants but also fauna (Brenneisen, 2006; Beatrice and Vecchia, 2011).

Similar proportions of native and exotic taxa survived the three years experiment. The survival rate is related to the fact that native species are not always the best to adapt or to be used on greenroofs and that nativeness does not, in itself, confer better ecological properties to any given greenroof (Dunnett, 2006).

Plant Growth and Morphophysiology

Success of the proposed technique was based upon plant choice from extreme lithophytic (Porembski and Barthlott, 2000), psamophyllous (Mantuano *et al.*, 2006) and epiphytic (Benzing, 1990) habitat. Plants grown on the tropical experimental greenroof share a resistance to solar irradiance surpassing 1,800 μmoles m^{-2} s^{-1}, periodical drying of the rooting media, air temperatures higher than 40°C, rooting media over 60°C and strong winds. This may be accounted for by the high frequency of CAM photosynthetic metabolism among the studied species (Kluge and Ting, 1978) which, along with elevated succulence, improves water use efficiency (Lüttge, 2004). Succulence can also generate thermal buffering capacity (Ball *et al.*, 1988) enhancing survival under high air and leaf temperatures (Leigh *et al.*, 2012). Other reasons are the efficient alternative mechanisms of water and nutrients absorption such as foliar trichomes and root velamen of Bromeliaceae and Orchidaceae (Benzing, 1990), respectively, accounting for 42% of the diversity. These factors contribute to the complete greenroof coverage in approximately two years, even though initial plant introductions was purposely sparse and no chemical or organic fertilizers were applied.

Coverage rates varied from seven to 40 cm^2/week (except for *Callisia repens* with 500) and our best performing species were *Kalanchoe fedtschenkoi*, *Callisia warszewicziana, Callisia fragrans* and *Tradescantia pallida* in decreasing order. Growth rates varying from 5 to 20 cm^2/week were found with 7.5 and 10cm substrate thickness using MEG cultivation (Durhman *et al.*, 2007; Bousselot *et al.*, 2010). Adequate plant choice is capable of overcoming the barrier of substrate absence as shown by similar growth rates in relation to MEG.

Plant survival on the greenroof was not dependent upon succulence, which varied from 20% of the taxa bellow 500 g/m^2 to 9% above 5,000 g/m^2. Similar findings under a hot Australian climate (Farrell *et al.*, 2012) reinforce this idea: *Sedum spurium* had the lowest succulence (500 g/m^2) and, despite that, survived longer droughts than native psammophilous species, such as *Disphyma crassifolium* (Aizoaceae) with 3,100 g/m^2. This median range correlates to about 40% of the taxa in the present study and it is specifically similar to our results for native lithophytes such as *Dyckia brevifolia* (Bromeliaceae) with 3,495 g/m^2. Subsequently, Farrell *et al.* (2013) demonstrated that native lithophytes with much lower succulence than *Sedum* species, commonly used on greenroofs, can also be drought tolerant and thus good candidates for greenroof use.

Survival and growth on the experimental tropical greenroof has occurred despite diurnal photoinhibition. The majority of quantum yield values were lower than 0.5 when measured during the early afternoon, but were followed by nightly recovery to values above 0.7 during the morning. Such a photochemical recovery was expected, again based upon the choice of plants adapted to extreme tropical solar irradiance on exposed rock outcrops and tree branches (Mattos *et al.*, 1997).

Chlorophyll fluorescence on greenroofs has also been evaluated by numerous authors (Durhman *et al.*, 2006; Getter *et al.*, 2009; Getter and Rowe, 2009; Nektarios *et al.*, 2011; Rowe *et al.*, 2014; Provenzano *et al.*, 2010) because of its potential to reveal and quantify plant stress on such extreme environments. Yield values tipically decreased for plants exposed to more severe drought stress such as those grown under a lower frequency of watering (Durhman *et al.*, 2006) and have also shown a considerable degree of independence from substrate thickness (Getter and Rowe, 2009) but were higher for plants cultivated under overhead irrigation (Rowe *et al.*, 2014) such as the kind employed in our experimental greenroof.

A complex interaction of abiotic factors influences plant survival and growth under the extreme conditions prevailing on tropical greenroofs. To interpret isolated traits such as succulence could provide misleading conclusions. Rather, a set of characters acting together are able to grant resistance to drought, thermal regulation and photochemical inhibition recovery. Proper choice of plants is a key element for the functionality of the new technique. However, it is useless if deprived of a regular water supply in the form of irrigation. Thus, the rich tropical extreme-adapted biodiversity is an important ally in order to spread the newly proposed method, being able to furnish an immense array of varied plant material to be tested and adapted to these new artificial ecosystems.

Conclusion

Substrate free greenroofs are viable under the extreme conditions of tropical humid climates as long as plant choice is based upon shallow rooting epiphytic, lithophytic and psamophyllous species and occasional overhead irrigation is applied. This new system comes from an extreme reduction of the MEG and the consequent minimization of cost for materials and laborand offers many advantages over traditional methodologies, including reduced total weight, easy maintenance and widespread retrofitting possibilities. Future research should focus on lowering of irrigation water used and alternative systems such as dripping as well as fertilizer applications to improve plant growth and survival. Ecological interactions capable of maximizing long-term plant survival as well as associated fauna are also relevant topics to be investigated. Finally, this new technique provides us with the possibility of using tropical epiphytic, lithophytic and psamophyllous species from previously established cultivations, avoiding removal and damage in their natural habitat.

Acknowledgment

We thank Carolina Reis, Ligia Bicalho, Lawrence Rocha and Juliana Silva for the support during sample collection for succulence and the subsequent lab work, Ligia Bicalho for calculating coverage areas and Carolina Corrêa Abramovicz for improvements to the English version of this manuscript.

Funding

This study was partially supported by funding from the Coordination for the Improvement of Higher Education Personnel (CAPES) (www.capes.gov.br), Brazil.

Author's Contributions

Bruno R. Silva: Designed and implemented the new technique purposed, contribute writing the manuscript.

André Mantovani: Collected and analyzed the morpho-physiological data, contribute writing the manuscript and its revision.

Dulce Mantuano: Analyzed the study findings, contribute writing the manuscript and its revision.

Sylvia M. Rolla and Maria C. Barbosa: Contribute writing the manuscript.

Ethics

This article is original and contains unpublished material. The corresponding author confirms that all of the other authors have read and approved the manuscript and there are no ethical issues involved.

References

Akbari, H., L.S. Rose and H. Taha, 2003. Analyzing the land cover of an urban environment using high-resolution orthophotos. Landscape Urban Plan., 63: 1-14. DOI: 10.1016/S0169-2046(02)00165-2

Ball, M.C., I.R.B. Cowan and D.F. Graham, 1988. Maintenance of leaf temperature and the optimisation of carbon gain in relation to water loss in a tropical mangrove forest. Aust. J. Plant Physiol., 15: 263-276. DOI: 10.1071/PP9880263

Banco Central do Brasil. BCB, Brasilia. http://www.bcb.gov.br

Barker, K.J. and J.D. Lubell, 2012. Effects of species proportions and fertility on *Sedum* green roof modules. HortTechnology, 22: 196-200. horttech.ashspublications.org/content/22/2/196.full

Beatrice, C.C. and F. Vecchia, 2011. Avaliação do potencial de uso de três espécies vegetais como cobertura leve de telhados em edificações. R C A. Unilasalle, 5: 1-5. DOI: 10.18316/134

Benzing, D.H., 1990. Vascular Epiphytes: General Biology and Related Biota. 1st Edn., Cambridge University Press, UK, ISBN-10: 0521266300, pp: 354

Bousselot, J.M., J.E. Klett and R.D. Koski, 2010. Extensive green roof species evaluations using digital image analysis. HortScience, 45: 1288-1292.

Brenneisen, S., 2006. Space for urban wildlife: Designing green roofs as habitats in Switzerland. Urban Habitats, 4: 27-36.

Carter, T. and L. Fowler, 2008. Establishing greenroof infrastructure through environmental policy instruments. Environ. Manage., 42: 151-164. DOI: 10.1007/s00267-008-9095-5

Carter, T. and A. Keeler, 2008. Life-cycle cost–benefit analysis of extensive vegetated roof systems. J. Environ. Manage., 87: 350-363. DOI: 10.1016/j.jenvman.2007.01.024

Castleton, H.F., V. Stovin, S.B.M. Beck and J.B. Davison, 2010. Green roofs; building energy savings and the potential for retrofit. Energy Build., 42: 1582-1591. DOI: 10.1016/j.enbuild.2010.05.004

CITES, 2016. CITES Appendix II. https://cites.org/eng/app/index.php

Clark, C., P. Adriaens and F.B. Talbot, 2008. Greenroof valuation: A probabilistic economic analysis of environmental benefits. Environ. Sci. Technol., 42: 2155-2161. DOI: 10.1021/es0706652

CNC Flora, 2015. http://cncflora.jbrj.gov.br/portal/

Cook-Patton, S.C. and T.L. Bauerle, 2012. Potential benefits of plant diversity on vegetated roofs: A literature review. J. Environ. Manage., 106: 85-92. DOI: 10.1016/j.jenvman.2012.04.003

Dunnett, N.P., 2006. Green roofs for biodiversity: Reconciling aesthetics with ecology. Proceedings of 4th North Fourth Annual International Green Roof Conference: Greening Rooftops for Sustainable Communities, May 11-12, The Cardinal Group, Boston, MA. Toronto, pp: 221-236.

Dunnett, N.P. and A. Nolan, 2004. The effect of substrate depth and supplementary watering on the growth of nine herbaceous perennials in a semi-extensive green roof. ActaHort, 643: 305-309. DOI: 10.17660/ActaHortic.2004.643.40

Dunnett, N., A. Nagase, R. Booth and P. Grime, 2008. Influence of vegetation composition on runoff in two simulated green roof experiments. Urban Ecosyst., 11: 385-398. DOI: 10.1007/s11252-008-0064-9

Durhman, A.K., D.B. Rowe and C.L. Rugh, 2006. Effect of watering regimen on chlorophyll fluorescence and growth of selected green roof plant taxa. HortScience, 41: 1623-1628.

Durhman, A.K., D.B. Rowe and C.L. Rugh, 2007. Effect of substrate depth on initial growth, coverage and survival of 25 succulent green roof plant taxa. HortScience, 42: 588-595.

Farrell, C., R.E. Mitchell, C. Szota, J.P. Rayner and N.S.G. Williams, 2012. Green roofs for hot and dry climates: Interacting effects of plant water use, succulence and substrate. Ecol. Eng., 49: 270-276. DOI: 10.1016/j.ecoleng.2012.08.036

Farrell, C., C. Szota, N.S.G. Williams and S.K. Arndt, 2013. High water users can be drought tolerant: Using physiological traits for greenroof plant selection. Plant Soil, 372: 177-193. DOI: 10.1007/s11104-013-1725-x

Fioretti, R., A. Palla, L.G. Lanza and P. Principi, 2010. Green roof energy and water related performance in the Mediterranean climate. Build Environ., 45: 1890-1904. DOI: 10.1016/j.buildenv.2010.03.001

Franco, A.C. and P.S. Nobel, 1989. Effect of nurse plants on the microhabitat and growth of cacti. J. Ecol., 77: 870-886. DOI: 10.2307/2260991

Frazer, L., 2005. Paving Paradise: The peril of impervious surfaces. Environ. Health Perspect., 113: A456-A462. DOI: 10.1289/ehp.113-a456

Genty, B., J.M. Briantai and N.R. Baker, 1989. The relationship between quantum yield of photosynthetic electron transport and quenching of chlorophyll fluorescence. Biochim. Biophys. Acta, 990: 87-92. DOI: 10.1016/S0304-4165(89)80016-9

Getter, K.L. and D.B. Rowe, 2006. The role of extensive green roofs in sustainable development. HortScience, 41: 1276-1285.

Getter, K.L. and D.B. Rowe, 2008. Media depth influences *Sedum* green roof establishment. Urban Ecosyst., 11: 361-372. DOI: 10.1007/s11252-008-0052-0

Getter, K.L. and D.B. Rowe, 2009. Substrate depth influences sedum plant community on a green roof. HortScience, 44: 401-407.

Getter, K.L., D.B. Rowe and M.C. Bert, 2009. Solar radiation intensity influences extensive greenroof plant communities. Urban Urban Gree., 8: 269-281. DOI: 10.1016/j.ufug.2009.06.005

Henry, A. and N. Frascaria-Lacoste, 2012. The greenroof dilemma: Discussion of Francis and Lorimer (2011). J. Environ. Manage., 104: 91-92. DOI: 10.1016/j.jenvman.2012.03.040

IUCN Red List, 2017. The international union for conservation of nature. IUCN Global Species Programme Red List Unit, Cambridge. http://www.iucnredlist.org/

Kluge, M. and I.P. Ting, 1978. Crassulacean Acid Metabolism. 1st Edn., Springer-Verlag, New York, ISBN-10: 0387089799, pp: 209.

Köhler, M., 2006. Long-term vegetation research on two extensive green roofs in Berlin. Urban Habitats, 4: 3-26.

Köhler, M. and P.H. Poll, 2010. Long-term performance of selected old Berlin greenroofs in comparison to younger extensive greenroofs in Berlin. Ecol. Eng., 36: 722-729. DOI: 10.1016/j.ecoleng.2009.12.019

Laar, M. and F.W. Grimme, 2006. Thermal comfort and reduced flood risk through green roofs in the tropics. Proceedings of the 23rd Conference on Passive and Low Energy Architecture, Sept. 6-8, Geneva, Switzerland.

Laar, M., C.G. Souza, V.L.A. Paiva, N.A. Amigo and S. Tavares *et al*. 2001. Estudo de aplicação de plantas em telhados vivos extensivos em cidades de clima tropical. Anais do VI Encontro Nacional e III Encontro Latino-Americano de Conforto no Ambiente Construído, Nov. 11-14, CD-ROM, São Pedro, São Paulo.

Leigh, A., S. Sevanto, M.C. Ball, J.D. Close and D.S. Ellsworth, 2012. Do thick leaves avoid thermal damage in critically low wind speeds? New Phytol., 194: 477-487. DOI: 10.1111/j.1469-8137.2012.04058.x

Logendra, L.S. and H.W. Janes, 1997. Hydroponics tomato production: Growing media requirements. Acta Hort., 481: 483-486. DOI: 10.17660/ActaHortic.1999.481.56

Lundholm, J., J.S. MacIvor, Z. MacDougall and M. Ranalli, 2010. Plant species and functional group combinations affect greenroof ecosystem functions. Plos One, 5: e9677-e9677. DOI: 10.1371/journal.pone

Lüttge, U., 2004. Ecophysiology of Crassulacean Acid Metabolism (CAM). Ann Bot., 93: 629-652. DOI: 10.1093/aob/mch087

Madre, F., A. Vergnes, N. Machon and P. Clergeau, 2014. Green roofs as habitats for wild plant species in urban landscapes: first insights from a large-scale sampling. Landscape Urban Plan., 122: 100-107. DOI: 10.1016/j.landurbplan.2013.11.012

Magill, J.D., K. Midden, J. Groninger and M. Therrell, 2011. A history and definition of green roof technology with recommendations for future research. Research Papers. http://opensiuc.lib.siu.edu/gs_rp/91

Mantovani, A. and R.R. Iglesias, 2001. Bromélias terrestres na restinga de Barra de Maricá, Rio de Janeiro: Influência sobre o microclima, o solo e a estocagem de nutrientes em ambientes de borda de moitas. Leandra, 16: 17-37.

Mantovani, A. and R.R. Iglesias, 2005. Quando aparece a primeira escama? Estudo comparativo sobre o surgimento de escamas de absorção em três espécies de bromélias terrestres de restinga. Rodriguésia, 56: 73-84. DOI: 10.1590/2175-78602005568705

Mantovani, A. and R.R. Iglesias, 2010. The effect of water stress on seed germination of three terrestrial bromeliads from restinga. Braz. J. Bot., 33: 201-205. DOI: 10.1590/S0100-84042010000100017

Mantovani, A., 1999. Leaf morpho-physiology and distribution of epiphytic aroids along a vertical gradient in a Brazilian rain forest. Selbyana, 20: 241-249.

Mantuano, D.G., C.F. Barros and F.R. Scarano, 2006. Leaf anatomy variation within and between three "resting" populations of *Erythroxylum ovalifolium* Peyr. (Erythroxylaceae) in Southeast Brazil. Rev. Bras. Bot., 29: 209-215. DOI: 10.1590/S0100-84042006000200002

Martinelli, G. and M.A. Moraes, 2013. Livro vermelho da flora do Brasil., Centro Nacional de Conservação da Flora, Rio de Janeiro Andrea Jakobsson.

Mattos, E.A., T.E. Grams, E. Ball, A.C. Franco and A. Haagkerwer *et al*., 1997. Diurnal patterns of chlorophyll a fluorescence and stomatal conductance in several species of coastal vegetation in southeastern Brazil. Trees, 11: 363-369. DOI: 10.1007/PL00009680

Maxwell, K. and G.N. Johnson, 2000. Chlorophyll fluorescence - a practical guide. J. Exp. Bot., 51: 659-668. DOI: 10.1093/jexbot/51.345.659

McGuire, K.L., S.G. Payne, M.I. Palmer, C.M. Gillikin and D. Keefe *et al*., 2013. Digging the New York City Skyline: Soil fungal communities in Green Roofs and City Parks. PloS One, 8: e58020-e58020. DOI: 10.1371/journal.pone.0058020

Mittermeier, R.A., W.R. Turner, F.W. Larsen, T.M. Brooks and C. Gascon, 2011. Global Biodiversity Conservation: The Critical Role of Hotspots. In: Biodiversity Hotspots, Zachos, F.E. and J.C. Habel (Eds.), Springer Publishers, London, pp: 3-22.

Nagase, A. and N. Dunnett, 2010. Drought tolerance in different vegetation types for extensive green roofs: Effects of watering and diversity. Landscape Urban Plan., 97: 318-327.

Nektarios, P.A., I. Amountzias, I. Kokkinou and N. Ntoulas, 2011. Greenroof substrate type and depth affect the growth of the native species *Dianthus fruticosus* under reduced irrigation regimens. Hort. Sci., 46: 1208-1216.

Nieder, J., J. Prosperí and G. Michaloud, 2001. Epiphytes and their contribution to canopy diversity. Plant Ecol., 153: 51-63. DOI: 10.1023/A:1017517119305

Niklas, K.J., 1994. Plant Allometry: The Scaling of form and Process. University of Chicago Press, Cambridge, ISBN-10: 226-58081-4.

Oberndorfer, E., J. Lundholm, B. Brass, R. Coffmann and H. Doshi *et al*., 2007. Green roofs as urban ecosystems: Ecological structures, functions and services. Bioscience, 57: 823-833. DOI: 10.1641/B571005

Osmundson, T., 1999. Roof Gardens: History, Design and Construction. WW Norton and Company, New York.

Parizotto, S. and R. Lamberts, 2011. Investigation of greenroof thermal performance in temperate climate: A case study of an experimental building in Florianópolis city, Southern Brazil. Energ. Build., 43: 1712-1722. DOI: 10.1016/j.enbuild.2011.03.014

Porembski, S. and W. Barthlott, 2000. Granitic and gneissic outcrops (inselbergs) as centers of diversity for desiccation-tolerant vascular plants. Plant Ecol., 151: 19-28. DOI: 10.1023/A:1026565817218

Provenzano, M.E., M. Cardarelli, F. Saccardo, G. Colla and A. Battistelli *et al*., 2010. Evaluation of perennial herbaceous species for their potential use in a green roof under mediterranean climate conditions. Acta Hortic., 881: 661-667. DOI: 10.17660/ActaHortic.2010.881.109

Rosseti, K., L. Durante, I. Callejas, M. Nogueira and J. Nogueira, 2013. Abordagem sobre as barreiras e benefícios da utilização do sistema de telhado verde em áreas urbanas de regiões tropicais. Brazil. Geograph. J.: Geosci. Humanities Res. Medium, 4: 55-77.

Rowe, D.B., M.R. Kolp, S.E. Greer and K.L. Getter, 2014. Comparison of irrigation efficiency and plant health of overhead, drip and sub-irrigation for extensive green roofs. Ecol. Eng., 64: 306-313. DOI: 10.1016/j.ecoleng.2013.12.052

Tropicos database, 2016. http://tropicos.org/

Sendo, T., M. Kanechi, Y. Uno and N. Inagaki, 2010. Evaluation of growth and green coverage of ten ornamental species for planting as urban rooftop greening. J. Jpn. Soc. Hortic. Sci., 79: 69-76. DOI: 10.2503/jjshs1.79.69

Silva, B.R., 2016. Telhados verdes em clima tropical: Uma nova técnica e seu potencial de atenuação térmica. PhD Thesis, Coppe – Instituto Alberto Luiz Coimbra de Pós-Graduação e Pesquisa de Engenharia, Universidade Federal do Rio de Janeiro, Brazil.

Simmons, M.T., B. Gardiner, S. Windhager and J. Tinsley, 2008. Green roofs are not created equal: the hydrologic and thermal performance of six different extensive green roofs and reflective and non-reflective roofs in a sub-tropical climate. Urban Ecosyst., 11: 339-348. DOI: 10.1007/s11252-008-0069-4

Susca, T., S.R. Gaffin, G.R. Dell'osso, 2011. Positive effects of vegetation: Urban heat island and green roofs. Environ. Pollut., 159: 2119-2126. DOI: 10.1016/j.envpol.2011.03.007

Tan, P.Y. and A. Sia, 2009. Understanding the performance of plants on non-irrigated green roofs in Singapore using a biomass yield approach. Nat. Singapore, 2: 149-153.

Thuring, C.E. and N. Dunnett, 2014. Vegetation composition of old extensive green roofs (from 1980s Germany). Ecol. Process, 3: 1-11. DOI: 10.1186/2192-1709-3-4

Vecchia, F., 2005. Cobertura Verde Leve (CVL): Ensaio experimental. In: Anais do VIII Encontro Nacional de Conforto no Ambiente Construído (ENCAC) e IV Encontro Latino-Americano de Conforto no Ambiente Construído, Oct. 5-7, Maceió.Alagoas.

Warton, D.I., I.J. Wright, D.S. Falster and M. Westoby, 2006. Bivariate line-fitting methods for allometry. Biol. Rev., 81: 259-291. DOI: 10.1017/S1464793106007007

Wolf, D. and J.T. Lundholm, 2008. Water uptake in green roof microcosms: effects of plant species and water availability. Ecol. Eng., 33: 179-186. DOI: 10.1016/j.ecoleng.2008.02.008

Wong, N.H., S.F. Tay, R. Wong, C.L. Ong and A. Sia, 2003. Life cycle cost analysis of rooftop gardens in Singapore. Build. Environ., 38: 499-509. DOI: 10.1016/S0360-1323(02)00131-2

Zar, J.H., 1996. Biostatistical Analysis. Prentice Hall, New Jersey, ISBN-10: 0130845426.

Zotz, G. and V. Thomas, 1999. How much water is in the tank? Model calculations for two epiphytic bromeliads. Ann. Bot., 83: 183-192. DOI: 10.1006/anbo.1998.0809

Appendix 1

List of species grown under the three-layer technique proposed for a tropical greenroof. Scientific names updated according to the online taxonomic database Tropicos (2016) (http://tropicos.org/). Conservation status obtained from IUCN Red List (2017) (http://www.iucnredlist.org/); Martinelli and Moraes (2013); CNCFlora (2015) (http://cncflora.jbrj.gov.br/portal/) or CITES CITES (2016) Appendix II

Family	Species	Origin	Growth form	Habit	Conservation
Acanthaceae	*Ruellia simplex* Wright endemic	Native not Herb	Terrestrial	Not listed	
Amaryllidaceae	*Allium fistulosum* L.	Exotic	Herb	Terrestrial	Not listed
Amaryllidaceae	*Allium tuberosum* Rottler ex Spreng.	Exotic	Herb	Terrestrial	Not listed
Apocynaceae	*Adenium obesum* (Forssk.) Roem. and Schult.	Exotic	Arbusto suculento	Lithophyte	Not listed
Apocynaceae	*Huernia macrocarpa* Schweinfurth ex K. Schum.	Exotic	Succulent	Lithophyte	Not listed
Apocynaceae	*Orbea caudata* subsp. *Rhodesiaca* (L.C. Leach) Bruyns	Exotic	Succulent	Lithophyte	Not listed
Apocynaceae	*Pachypodium geayi* Costantin and Bois	Exotic	Árvore succulent	Lithophyte	CITES Appendix II
Apocynaceae	*Pachypodium lamerei* Drake	Exotic	Árvore succulent	Lithophyte	CITES Appendix II
Apocynaceae	*Pachypodium saundersii* N.E. Br.	Exotic	Arbusto suculento	Lithophyte	Not listed
Apocynaceae	*Plumeria rubra* L.	Exotic	Tree - small	Terrestrial	Not listed
Apocynaceae	*Stapelia hirsuta* L.	Exotic	Succulent	Lithophyte	Not listed
Araceae	*Alocasia* 'Amazonica'(Alocasia sanderiana x Alocasia lowii)	Híbrido artificial	Herb	Terrestrial	Not applicable
Araceae	*Colocasia esculenta* var. *aquatilis* Hassk.	Exotic	Aquática	Aquatic	Least Concern (IUCN)
Araceae	*Philodendron crassinervium* Lindl.	Native endemic	Liana	Epithyte/ Lithophyte/ HemiEpithyte	Not listed
Araceae	*Philodendron warszewiczii* K. Koch and C.D. Bouché	Exotic	Liana	Epithyte/ Lithophyte	Not listed
Arecaceae	*Bismarckia nobilis* Hildebrandt and H. Wendl.	Exotic	Tree - small	Terrestrial	Least Concern (IUCN)
Arecaceae	*Chamaedorea seifrizii* Burret	Exotic	Shrub - large	Terrestrial	Not listed
Asparagaceae	*Agave americana* var.*marginata*	Exotic	Shrub - large	Lithophyte/	Not listed

	Trel.				Terrestrial
Asparagaceae	*Agave attenuata* Salm-Dyck	Exotic	Shrub - large	Lithophyte/ Terrestrial	Not listed
Asparagaceae	*Agave franzosinii* P.Sewell	Exotic	Shrub - large	Lithophyte/ Terrestrial	Not listed
Asparagaceae	*Agave gypsophila* Gentry	Exotic	Shrub - small	Lithophyte	Not listed
Asparagaceae	*Agave vilmoriniana* (leaves erect) A. Berger	Exotic	Shrub - large	Lithophyte	Not listed
Asparagaceae	*Agave vilmoriniana* (spiraled leaves)A. Berger	Exotic	Shrub - large	Lithophyte	Not listed
Asparagaceae	*Agave weberi* F. Cels ex J. Poiss.	Exotic	Shrub - large	Lithophyte/ Terrestrial	Not listed
Asparagaceae	*Beaucarnea recurvata* Lem.	Exotic	Shrub - large	Lithophyte/ Terrestrial	Not listed
Asparagaceae	*Dracaena draco* (L.) L.	Exotic	Tree - small	Lithophyte/ Terrestrial	Vulnerable (IUCN)
Asparagaceae	*Dracaena reflexa* var. *angustifólia* Baker	Exotic	Tree - small	Lithophyte/ Terrestrial	Not listed
Asparagaceae	*Sansevieria* 'Alva'	Híbrido artificial	Succulent	Lithophyte/ Terrestrial	Not applicable
Asparagaceae	*Sansevieria ehrenbergii* Schweinf. ex Baker	Exotic	Succulent	Lithophyte/ Terrestrial	Not listed
Asparagaceae	*Sansevieria* 'Fernwood'	Artificial cultivar	Succulent	Lithophyte/ Terrestrial	Not applicable
Asparagaceae	*Sansevieria masoniana* Chahinian	Exotic	Succulent	Lithophyte/ Terrestrial	Not listed
Asparagaceae	*Sansevieria parva* N.E. Br.	Exotic	Succulent	Lithophyte/ Terrestrial	Not listed
Asparagaceae	*Sansevieria trifasciata* 'Bantel´s Sensation'	Artificial cultivar	Succulent	Lithophyte/ Terrestrial	Not applicable
Asparagaceae	*Sansevieria trifasciata* 'Black Coral'	Artificial cultivar	Succulent	Lithophyte/ Terrestrial	Not applicable
Asparagaceae	*Sansevieria trifasciata* 'Moonshine'	Artificial cultivar	Succulent	Lithophyte/ Terrestrial	Not applicable
Asparagaceae	*Sansevieria trifasciata* var *laurentii* (De Wild.) N.E. Br.	Exotic	Succulent	Lithophyte/ Terrestrial	Not listed
Asteraceae	*Senecio crassissimus* Humbert	Exotic	Succulent	Lithophyte/ Terrestrial	Not listed
Asteraceae	*Senecio serpens* G.D. Rowley	Exotic	Succulent	Lithophyte/ Terrestrial	Not listed
Asteraceae	*Senecio* sp.				
Bromeliaceae	*Acanthostachys strobilacea* (Schult. and Schult.f.) Klotzsch	Native not endemic	Succulent	Epithyte	Not listed
Bromeliaceae	*Aechmea amicorum* B. R. Silva and H. Luther	Native endemic	Herb	Psammophilous	Endangered (Martinelli and Moraes, 2013)
Bromeliaceae	*Aechmea bambusoides* L.B. Sm. and Reitz	Native endemic	Herb	Epithyte	Vulnerable (Martinelli and Moraes, 2013)
Bromeliaceae	*Aechmea blanchetiana* (Baker) L.B. Sm.	Native endemic	Herb	Psammophilous	Not listed
Bromeliaceae	*Aechmea cephaloides* J.A.Siqueira and Leme	Native endemic	Herb	Epithyte/ Terrestrial	Not listed
Bromeliaceae	*Aechmea chantinii* (Carrière) Baker	Native not endemic	Herb	Epithyte	Not listed
Bromeliaceae	*Aechmea comata* (Gaudich.) Baker	Native endemic	Herb	Epithyte/ Lithophyte	Not listed
Bromeliaceae	*Aechmea correia-araujoi* E. Pereira and Moutinho	Native endemic	Herb	Epithyte	Not listed
Bromeliaceae	*Aechmea depressa* L.B. Sm.	Native endemic	Herb	Epithyte/ Terrestrial	Endangered (Martinelli and Moraes, 2013)
Bromeliaceae	*Aechmea distichantha* Lem.	Native endemic	Herb	Lithophyte/ Epithyte/ Terrestrial	Not listed

DOI: 10.3844/ojbsci.2018.401.423

Bromeliaceae	*Aechmea floribunda* Mart. ex Schult. and Schult. f.	Native endemic	Herb	Epithyte/ Terrestrial/ Psammophilous	Not listed
Bromeliaceae	*Aechmea leptantha* (Harms) Leme and J.A. Siqueira	Native endemic	Herb	Epithyte/ Lithophyte/ Terrestrial	Not listed
Bromeliaceae	*Aechmea nudicaulis* (cv. 1)(L.) Griseb.	Native not endemic	Herb	Epithyte/ Lithophyte	Not listed
Bromeliaceae	*Aechmea nudicaulis* (cv. 2)(L.) Griseb.	Native not endemic	Herb	Epithyte/ Lithophyte	Not listed
Bromeliaceae	*Aechmea orlandiana* L.B. Sm.	Native endemic	Herb	Epithyte	Critically endangered (Martinelli and Moraes, 2013)
Bromeliaceae	*Aechmea pectinata* Baker	Native endemic	Herb	Epithyte/ Terrestrial	Not listed
Bromeliaceae	*Aechmea pineliana* (Brongn. ex Planch.) Baker	Native endemic	Herb	Epithyte/ Lithophyte/ Psammophilous	Not listed
Bromeliaceae	*Aechmea* 'Purple Gem'	Híbrido artificial	Herb	Epithyte	Not applicable
Bromeliaceae	*Aechmea tocantina* Baker	Native not endemic	Herb	Epithyte/ Lithophyte	Not listed
Bromeliaceae	*Alcantarea glaziouana* (Leme) J.R.Grant	Native endemic	Herb	Lithophyte	Endangered (Martinelli and Moraes, 2013)
Bromeliaceae	*Alcantarea nahoumii* (Leme) J.R.Grant	Native endemic	Herb	Lithophyte	Vulnerable (Martinelli and Moraes, 2013)
Bromeliaceae	*Alcantarea odorata* (Leme) J.R.Grant	Native endemic	Herb	Lithophyte	Not listed
Bromeliaceae	*Alcantarea vinicolor* (E.Pereira and Reitz) J.R.Grant	Native endemic	Herb	Lithophyte	Endangered (Martinelli and Moraes, 2013)
Bromeliaceae	*Ananas* (Nahoum)	Artificial cultivar	Herb	Lithophyte/ Terrestrial	Not applicable
Bromeliaceae	*Ananas comosus* (L.) Merr.	Artificial cultivar	Herb	Lithophyte/ Terrestrial	Not applicable
Bromeliaceae	*Billbergia amoena* var. *rubra* M.B. Foster	Native endemic	Herb	Epithyte	Not listed
Bromeliaceae	*Billbergia* 'Hallelujah'	Artificial cultivar	Herb	Epithyte	Not applicable
Bromeliaceae	*Billbergia* sp. 1		Herb	Epithyte	
Bromeliaceae	*Brocchinia micrantha* (Baker) Mez	Exotic	Herb	Lithophyte/ Terrestrial	Not listed
Bromeliaceae	*Canistrum alagoanum* Leme and J.A.Siqueira	Native endemic	Herb	Epithyte/ Lithophyte	Endangered (Martinelli and Moraes, 2013)
Bromeliaceae	*Canistrum aurantiacum* E. Morren	Native endemic	Herb	Epithyte/ Terrestrial	Endangered (Martinelli and Moraes, 2013)
Bromeliaceae	*Cryptanthus schwackeanus* Mez	Native endemic	Herb	Lithophyte	Not listed
Bromeliaceae	*Deuterocohnia meziana* Kuntze ex Mez	Native not endemic	Herb	Lithophyte	Vulnerable (Martinelli and Moraes, 2013)
Bromeliaceae	*Dyckia brevifolia* Baker	Native endemic	Succulent	Lithophyte	Not listed
Bromeliaceae	*Dyckia choristaminea* Mez	Native endemic	Succulent	Lithophyte	Not listed
Bromeliaceae	*Encholirium horridum* L.B. Sm.	Native endemic	Succulent	Lithophyte	Endangered: EN B2ab(iii) (Martinelli and Moraes, 2013)
Bromeliaceae	*Fosterella sp.*		Herb	Lithophyte	
Bromeliaceae	*Hechtia rosea* E. Morren ex Baker	Exotic	Succulent	Lithophyte	Not listed
Bromeliaceae	*Hohenbergia castellanosii* L.B. Sm. and Read	Native endemic	Herb	Psammophilous	Endangered (Martinelli and Moraes, 2013)
Bromeliaceae	*Hohenbergia correia-araujoi* E.	Native endemic	Herb	Epithyte	Critically endangered

	Pereira and Moutinho				(Martinelli and Moraes, 2013)
Bromeliaceae	*Hohenbergia pennae* E. Pereira	Native endemic	Herb	Lithophyte	Not listed
Bromeliaceae	*Hohenbergia sp. 1*	Native endemic	Herb	Lithophyte	
Bromeliaceae	*Hohenbergia sp. 2*	Native endemic	Herb	Lithophyte	
Bromeliaceae	*Hohenbergia sp. 3*	Native endemic	Herb	Lithophyte	
Bromeliaceae	*Hohenbergia sp. 4*	Native endemic	Herb	Lithophyte	
Bromeliaceae	*Neoregelia camorimiana* E. Pereira and I.A. Penna	Native endemic	Herb	Epithyte	Not listed
Bromeliaceae	*Neoregelia carcharodon* (Baker) L.B. Sm.	Native endemic	Herb	Epithyte/ Terrestrial	Not listed
Bromeliaceae	*Neoregelia compacta* (Mez) L.B. Sm.	Native endemic	Herb	Epithyte/ Lithophyte	Not listed
Bromeliaceae	*Neoregelia concentrica* (Vell.) L.B. Sm.	Native endemic	Herb	Epithyte/ Terrestrial	Not listed
Bromeliaceae	*Neoregelia cruenta* (R.Graham) L.B.Sm.	Native endemic	Herb	Psammophilous/ Lithophyte	Not listed
Bromeliaceae	*Neoregelia* cv. 1	Artificial cultivar	Herb	Epithyte/ Lithophyte	Not applicable
Bromeliaceae	*Neoregelia* 'Fireball'	Artificial cultivar	Herb	Epithyte/ Lithophyte	Not applicable
Bromeliaceae	*Neoregelia leviana* L.B. Sm.	Native not endemic	Herb	Epithyte	Not listed
Bromeliaceae	*Neoregelia pendula* L.B. Sm.	Exotic	Herb	Epithyte	Not listed
Bromeliaceae	*Neoregelia* 'Sarada'	Artificial cultivar	Herb	Epithyte/ Lithophyte	Not applicable
Bromeliaceae	*Orthophytum* sp. 1		Herb	Lithophyte	
Bromeliaceae	*Orthophytum vagans* M.B. Foster	Native endemic	Herb	Lithophyte	Not listed
Bromeliaceae	*Pitcairnia encholirioides* L.B. Sm.	Native endemic	Herb	Lithophyte	Endangered (Martinelli and Moraes, 2013)
Bromeliaceae	*Pitcairnia* 'Rhubarb'	Artificial cultivar	Herb	Lithophyte	Not applicable
Bromeliaceae	*Pitcairnia* sp. 1		Herb	Lithophyte	
Bromeliaceae	*Pitcairnia staminea* Lodd.	Native endemic	Herb	Lithophyte	Not listed
Bromeliaceae	*Portea alatisepala* Philcox	Native endemic	Herb	Epithyte/ Terrestrial	Vulnerable (Martinelli and Moraes, 2013)
Bromeliaceae	*Quesnelia edmundoi var. intermedia* E. Pereira and Leme	Native endemic	Herb	Epithyte	Not listed
Bromeliaceae	*Quesnelia marmorata* (Lem.) R.W.Read	Native endemic	Herb	Epithyte	Not listed
Bromeliaceae	*Tillandsia andreana* E. Morren ex André	Exotic	Herb	Epithyte	Not listed
Bromeliaceae	*Tillandsia araujei* Mez	Native endemic	Herb	Lithophyte	Endangered (Martinelli and Moraes, 2013)
Bromeliaceae	*Tillandsia bulbosa* Hook.	Native not endemic	Herb	Epithyte	Not listed
Bromeliaceae	*Tillandsia ehlersiana* Rauh	Exotic	Herb	Epithyte	Not listed
Bromeliaceae	*Tillandsia filifolia* Schltdl. and Cham	Exotic	Herb	Epithyte	Not listed
Bromeliaceae	*Tillandsia funckiana* Baker	Exotic	Herb	Epithyte	Not listed
Bromeliaceae	*Tillandsia ionantha* Planch.	Native not endemic	Herb	Epithyte	Least Concern (IUCN)
Bromeliaceae	*Tillandsia jonesii* T. Strehl	Native endemic	Herb	Lithophyte	Critically endangered (Martinelli and Moraes, 2013)
Bromeliaceae	*Tillandsia juncea* (Ruiz and Pav.) Poir.	Exotic	Herb	Epithyte	Not listed
Bromeliaceae	*Tillandsia nidus* Rauh and Lehmann	Exotic	Herb	Epithyte	Not listed
Bromeliaceae	*Tillandsia schiedeana* Steud.	Exotic	Herb	Epithyte	Not listed
Bromeliaceae	*Tillandsia seleriana* Mez	Exotic	Herb	Epithyte	Not listed
Bromeliaceae	*Tillandsia streptophylla* Scheidw. ex C. Morren	Exotic	Herb	Epithyte	Not listed

DOI: 10.3844/ojbsci.2018.401.423

Bromeliaceae	*Tillandsia tricholepis* Baker	Native not endemic	Herb	Epithyte	Not listed
Bromeliaceae	*Tillandsia xerographica* Rohweder	Exotic	Herb	Epithyte	Not listed
Bromeliaceae	*Vriesea costae* B. R. Silva and Leme	Native endemic	Herb	Lithophyte	Critically endangered (Martinelli and Moraes, 2013)
Bromeliaceae	*Vriesea saundersii* (Carrière) E. Morren ex Mez	Native endemic	Herb	Lithophyte	Not listed
Bromeliaceae	*Vriesea sp.* 1	Native endemic	Herb	Lithophyte	
Bromeliaceae	*Wittrockia superba* Lindm.	Native endemic	Herb	Epithyte/ Lithophyte	Endangered (Martinelli and Moraes, 2013) CITES Appendix II
Cactaceae	*Cactacea sp.* 1				
Cactaceae	*Cactacea sp.* 2				CITES Appendix II
Cactaceae	*Cactacea sp.* 3				CITES Appendix II
Cactaceae	*Cactacea sp.* 4				CITES Appendix II
Cactaceae	*Coleocephalocereus fluminensis* (Miq.) Backeb.	Native endemic	Succulent	Lithophyte	Endangered (Martinelli and Moraes, 2013); CITES Appendix II
Cactaceae	*Consolea macracantha* A. Berger	Exotic	Succulent	Lithophyte/ Terrestrial	Least Concern (IUCN); CITES Appendix II
Cactaceae	*Echinopsis pachanoi* (Britton and Rose) Friedrich and G.D. Rowley	Exotic	Succulent	Lithophyte/ Terrestrial	Least Concern (IUCN); CITES Appendix II
Cactaceae	*Hatiora sp.* 1		Succulent	Epithyte	CITES Appendix II
Cactaceae	*Hylocereus polyrhizus* (F.A.C. Weber) Britton and Rose	Exotic	Succulent	Epithyte/ Lithophyte	CITES Appendix II
Cactaceae	*Hylocereus undatus* (Haw.) Britton and Rose	Native not endemic	Succulent	Epithyte/ Lithophyte	CITES Appendix II
Cactaceae	*Lepismium cruciform* (Vell.) Miq.	Native not endemic	Succulent	Epithyte	Least Concern (IUCN); CITES Appendix II
Cactaceae	*Mammillaria elongata* DC.	Exotic	Succulent	Lithophyte	Least Concern (IUCN); CITES Appendix II
Cactaceae	*Opuntia ficus-indica* (L.) Mill.	Native not endemic	Succulent	Lithophyte/ Terrestrial	Data Deficient (IUCN); CITES Appendix II
Cactaceae	*Pereskia aculeata* Mill.	Native not endemic	Succulent	Lithophyte/ Terrestrial	Least Concern(IUCN); CITES Appendix II
Cactaceae	*Pereskia grandifolia* Haw.	Native endemic	Succulent	Lithophyte/ Terrestrial	Least Concern(IUCN); CITES Appendix II
Cactaceae	*Pilosocereus pachycladus* F. Ritter	Native endemic	Succulent	Lithophyte/ Terrestrial	Least Concern(IUCN); CITES Appendix II
Cactaceae	*Pilosocereus ulei* (K. Schum.) Byles and G.D. Rowley	Native endemic	Succulent	Lithophyte	Endangered B1ab(iii) (IUCN); CITES Appendix II
Cactaceae	*Rhipsalis baccifera* (Sol.) Stearn	Native not endemic	Succulent	Epithyte	Least Concern(IUCN); CITES Appendix II
Cactaceae	*Rhipsalis cereoides* (Backeb. and Voll) Backeb.	Native endemic	Succulent	Lithophyte	Near Threatened (IUCN); Critically endangered (Martinelli and Moraes, 2013); CITES Appendix II
Cactaceae	*Rhipsalis clavata* F.A.C.Weber	Native endemic	Succulent	Epithyte	Near threatened (IUCN); CITES Appendix II
Cactaceae	*Rhipsalis elliptica* G. Lindb. Ex K. Schum.	Native endemic	Succulent	Epithyte	Least Concern (IUCN); CITES Appendix II
Cactaceae	*Rhipsalis ewaldiana* Barthlott and N.P.Taylor	Native endemic	Succulent	Epithyte	Data Deficient (IUCN); CITES Appendix II
Cactaceae	*Rhipsalis flagelliformis* N.P. Taylor and Zappi	Native endemic	Succulent	Epithyte	CITES Appendix II
Cactaceae	*Rhipsalis grandiflora* Haw.	Native endemic	Succulent	Epithyte	Least Concern (IUCN); CITES Appendix II

DOI: 10.3844/ojbsci.2018.401.423

Cactaceae	*Rhipsalis oblonga* Loefgr.	Native endemic	Succulent	Epithyte	Vulnerable B2ab (ii, iii, iv, v) (IUCN); CITES Appendix II
Cactaceae	*Rhipsalis paradoxa* (Salm-Dyck ex Pfeiff.) Salm-Dyck	Native endemic	Succulent	Epithyte/ Lithophyte	Endangered (Martinelli and Moraes, 2013); Least Concern (IUCN); CITES Appendix II
Cactaceae	*Rhipsalis pentaptera* A.Dietr.	Native endemic	Succulent	Epithyte	Critically Endangered (IUCN); CITES Appendix II
Cactaceae	*Rhipsalis* sp. 1	Native endemic	Succulent	Epithyte	CITES Appendix II
Cactaceae	*Rhipsalis* sp. 2	Native endemic	Succulent	Epithyte	CITES Appendix II
Cactaceae	*Rhipsalis* sp. 3	Native endemic	Succulent	Epithyte	CITES Appendix II
Cactaceae	*Rhipsalis* sp.4	Native endemic	Succulent	Epithyte	CITES Appendix II
Cactaceae	*Rhipsalis* sp.5	Native endemic	Succulent	Epithyte	CITES Appendix II
Cactaceae	*Rhipsalis* sp.6	Native endemic	Succulent	Epithyte	CITES Appendix II
Cactaceae	*Rhipsalis sulcata* F.A.C.Weber	Native endemic	Succulent	Epithyte	Data Deficient (IUCN); CITES Appendix II
Cactaceae	*Rhipsalis teres* (Vell.) Steud.	Native endemic	Succulent	Epithyte	Least Concern(IUCN); CITES Appendix II
Cactaceae	*Rhipsalis triangularis* Werderm.	Native endemic	Succulent	Lithophyte	Critically Endangered (IUCN); CITES Appendix II
Cactaceae	*Schlumbergera truncata* (Haw.) Moran	Native endemic	Succulent	Epithyte/ Lithophyte	Vulnerable (IUCN); CITES Appendix II
Cactaceae	*Selenicereus anthonyanus* (Alexander) D.R. Hunt	Exotic	Succulent	Epithyte	Least concern (IUCN); CITES Appendix II
Cactaceae	*Selenicereus grandiflorus* (L.) Britton and Rose	Exotic	Succulent	Epithyte/ Lithophyte	Least concern (IUCN); CITES Appendix II
Cactaceae	*Selenicereus megalanthus* (K. Schum. ex Vaupel) Moran	Exotic	Succulent	Epithyte/ Lithophyte	CITES Appendix II
Cactaceae	*Selenicereus* sp. 1		Succulent	Epithyte	CITES Appendix II
Cactaceae	*Weberocereus bradei* (Britton and Rose) G.D. Rowley	Exotic	Succulent	Epithyte	Vulnerable (IUCN); CITES Appendix II
Cactaceae	*Winterocereus aureispinus* (F. Ritter) Backeb.	Exotic	Succulent	Lithophyte	Endangered (IUCN); CITES Appendix II
Cactaceae	*Winterocereus colademononis* (Diers and Krahn) Metzing and R. Kiesling	Exotic	Succulent	Epithyte/ Lithophyte	CITES Appendix II
Cactaceae	*Winterocereus* sp.		Succulent	Epithyte/ Lithophyte	CITES Appendix II
Clusiaceae	*Clusia fluminensis* (landscape clone)	Native endemic	Tree - small		Not listed
Clusiaceae	*Clusia fluminensis* Planch. and Triana	Native endemic	Tree - small	Lithophyte	Not listed
Commelinaceae	*Callisia fragrans* (Lindl.) Woodson	Exotic	Succulent	Lithophyte/ Terrestrial	Not listed
Commelinaceae	*Callisia repens* (Jacq.) L.	Exotic	Herb	Lithophyte/ Terrestrial	Not listed
Commelinaceae	*Callisia warszewicziana* (Kunth and Bouché) D. R. Hunt	Exotic	Herb	Lithophyte/ Terrestrial	Not listed
Commelinaceae	*Tradescantia pallida* var. *purpurea* Rose) D.R. Hunt	Exotic	Herb	Lithophyte/ Terrestrial	Not listed
Commelinaceae	*Tradescantia zebrina* Heynh.	Exotic	Herb	Lithophyte/ Terrestrial	Not listed
Convolvulaceae	*Ipomoea pes-caprae* (L.) R. Br.	Native not endemic	Liana	Psammophilous	Not listed
Crassulaceae	*Bryophyllum beauverdii* (Raym. -Hamet) A. Berger	Exotic	Liana	Epithyte/ Lithophyte	Not listed
Crassulaceae	*Bryophyllum daigremontianum*(Raym. -Hamet and H. Perrier) A. Berger	Exotic	Succulent	Lithophyte/ Terrestrial	Not listed
Crassulaceae	*Crassula obliqua* Aiton	Exotic	Arbusto suculento	Lithophyte/ Terrestrial	Not listed
Crassulaceae	*Graptopetalum paraguayense* (N.E. Br.) E. Walther	Exotic	Succulent	Lithophyte/ Terrestrial	Not listed
Crassulaceae	*Kalanchoe fedtschenkoi* Hamet and H. Perrier	Exotic	Succulent	Lithophyte/ Terrestrial	Not listed

Crassulaceae	*kalanchoe orgyalis* Baker	Exotic	Succulent	Lithophyte/ Terrestrial	Not listed
Crassulaceae	*Kalanchoe tubiflora* Raym.-Hamet	Exotic	Succulent	Lithophyte/ Terrestrial	Not listed
Didiereaceae	*Alluaudia procera* (Drake) Drake	Exotic	Árvore succulent	Lithophyte/ Terrestrial	Lower Risk/near threatened (IUCN); CITES Appendix II
Doryanthaceae	*Doryanthes palmeri* W. Hill ex Benth.	Exotic	Succulent	Lithophyte/ Terrestrial	Vulnerable under the New South Wales Threatened Species Act (1995)
Euphorbiaceae	*Euphorbia enterophora* Drake	Exotic	Arbusto suculento	Lithophyte/ Terrestrial	Least concern (IUCN); CITES Appendix II
Euphorbiaceae	*Euphorbia* sp.2		Arbusto suculento	Lithophyte/ Terrestrial	CITES Appendix II
Euphorbiaceae	*Euphorbia* sp.3		Arbusto suculento	Lithophyte/ Terrestrial	CITES Appendix II
Euphorbiaceae	*Ricinus communis* L.	Exotic	Tree - small	Terrestrial	Not listed
Iridaceae	*Neomarica caerulea* (Ker Gawl.) Sprague	Native endemic	Herb	Lithophyte/ Terrestrial	Not listed
Lamiaceae	*Rosmarinus officinalis* L.	Exotic	Shrub - large	Lithophyte/ Terrestrial	Not listed
Melastomataceae	*Heterocentron elegans* (Schltdl.) Kuntze	Exotic	Liana	Lithophyte/ Terrestrial	Not listed
Melastomataceae	*Tibouchina heteromalla* (D.Don) Cogn.	Native endemic	Shrub - large	Lithophyte/ Terrestrial	Not listed
Orchidaceae	*Aganisia cyanea* (Schltr.) Rchb.f.	Native not endemic	Herb	Epithyte	CITES Appendix II
Orchidaceae	*Arundina bambusifolia* Lindl.	Exotic	Herb	Terrestrial	CITES Appendix II
Orchidaceae	*Brassavola tuberculata* Hook.	Native endemic	Herb	Epithyte/ Lithophyte	CITES Appendix II
Orchidaceae	*Cattleya intermedia* Grah.	Native endemic	Herb	Epithyte/ Lithophyte	Vulnerable (Martinelli and Moraes, 2013); CITES Appendix II
Orchidaceae	*Cattleya schilleriana* Rchb. f.	Native endemic	Herb	Epithyte	Endangered (Martinelli and Moraes, 2013); CITES Appendix II
Orchidaceae	*Coilostylis parkinsoniana* (Hook.) Withner and P.A.Harding	Exotic	Herb	Epithyte	CITES Appendix II
Orchidaceae	*Cyrtopodium glutiniferum* Raddi	Native endemic	Herb	Lithophyte	CITES Appendix II
Orchidaceae	*Dendrobium anceps* Sw.	Exotic	Herb	Epithyte	CITES Appendix II
Orchidaceae	*Epidendrum ibaguense* Kunth	Native not endemic	Herb	Lithophyte/ Terrestrial	CITES Appendix II
Orchidaceae	*Epidendrum secundum* Jacq.	Native not endemic	Herb	Epithyte	Least concern: Red list CNCFLORA; CITES Appendix II
Orchidaceae	*Epidendrum* sp.1	Native endemic	Herb	Lithophyte	CITES Appendix II
Orchidaceae	*Epidendrum vesicatum* Lindl.	Native endemic	Herb	Epithyte	Least concern: Red list CNCFLORA; CITES Appendix II
Orchidaceae	*Myrmecophila tibicinis* (Bateman) Rolfe	Exotic	Herb	Epithyte	CITES Appendix II
Orchidaceae	*Vanilla chamissonis* Klotzsch	Native not endemic	Liana	Epithyte/ Lithophyte	CITES Appendix II
Pandanaceae	*Pandanus baptistii* Misonne	Exotic	Herb	Lithophyte/ Terrestrial	Not listed
Pandanaceae	*Pandanus utilis* Bory	Exotic	Tree - small	Terrestrial	Not listed
Piperaceae	*Peperomia serpens* (Sw.) Loudon	Native not	Liana	Epithyte endemic	Least concern: Red list CNCFLORA
Polypodiaceae	*Phlebodium decumanum* (Willd.) J. Sm.	Native not endemic	Herb	Epithyte	Not listed
Polypodiaceae	*Platycerium bifurcatum* (Cav.) C. Chr.	Exotic	Herb	Epithyte	Not listed
Xanthorrhoeaceae	*Aloe* sp.	Exotic			
Xanthorrhoeaceae	*Aloe aculeata* Pole-Evans	Exotic	Succulent	Lithophyte	CITES Appendix II

DOI: 10.3844/ojbsci.2018.401.423

Xanthorrhoeaceae	*Aloe arborescens* Mill.	Exotic	Succulent	Lithophyte/ Terrestrial	CITES Appendix II
Xanthorrhoeaceae	*Aloe aristata* Haw.	Exotic	Succulent	Lithophyte/ Terrestrial	CITES Appendix II
Xanthorrhoeaceae	*Aloe dawei* A. Berger	Exotic	Succulent	Lithophyte/ Terrestrial	CITES Appendix II
Xanthorrhoeaceae	*Aloe petrophila* Pillans	Exotic	Succulent	Lithophyte/ Terrestrial	CITES Appendix II
Xanthorrhoeaceae	*Aloe vera* (L.) Burm. f.	Exotic	Succulent Terrestrial	Lithophyte/	Not listed