

Variations in Carbon Dioxide Efflux by Stem Height in Six Arborescent Palm Species

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Abstract. Background: Stem respiration is influenced by elevation, but this phenomenon has not been adequately studied for palms. Therefore, the influence of stem height on carbon dioxide efflux (E_s) was determined for 6 palm species. Methods: Gas exchange protocols were employed to determine E_s . The lowest height was 35 cm above the root collar, and the greatest height was 20 cm below the oldest living leaf in the crown. Results: A consistent baseline flux was observed for the midlength of the stems, a moderate increase in E_s occurred at the lowest elevation, and a substantial increase in E_s occurred at the highest elevation. The midheight flux ranged from $0.9 \mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$ for *Corypha utan* to $2.3 \mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$ for *Carpentaria acuminata*. The basal increase in E_s averaged 63% and was greatest for *C. utan* and least for *Phoenix sylvestris*. The apical increase in E_s averaged 157% and was greatest for *Wodyetia bifurcata* and least for *C. acuminata*. A quadratic model described the influence of stem height on stem E_s . Conclusion: The moderate increase of E_s at the lowest stem height was consistent with the influence of root-respired carbon dioxide entering the stem in xylem mass flow then conducting radially to the stem surface. The substantial increase in E_s at the highest stem height was consistent with proximity to the growth respiration of the large primary thickening meristem of the pachycaulous palm stem. These findings confirm that the elevation of the stem influences palm E_s , and the elevation pattern is consistent among every species.

Keywords. Carbon Flux; *Cocos*; *Roystonea*; Stem Respiration; Strata; Stratification; Stratum.

BACKGROUND

Regional and global carbon cycles are directly influenced by carbon dioxide (CO_2) emissions from tree stem surfaces (Yang et al. 2016; Vargas and Barba 2019). A greater understanding of stem respiration and the fate of stem CO_2 flux is of global importance. The influence of stem elevation on CO_2 efflux based on surface area (E_s) has received considerable attention, with the lowest stem heights often exhibiting an increase in E_s when compared with elevated stem heights (Bloemen et al. 2013; Kunert 2018; Tarvainen et al. 2018). Most of this research effort has focused on lignophyte tree species that increase in stem diameter by bifacial secondary vascular cambium and construct canopies with multibranch architecture. In these tree species, stem diameter decreases with increased canopy height, and this canopy trait may determine how elevation influences E_s . Stem diameter and geometry may exert a direct influence on E_s , and small diameter stems exhibit less radial resistance

to CO_2 conductance (Sprugel 1990; Cavaleri et al. 2006; Ryan et al. 2009; Bréchet et al. 2025). Therefore, the influences of stem height on E_s of these lignophyte species may be mediated through the canopy architecture and stem geometry rather than height per se.

Many arborescent spermatophyte species produce pachycaulous stems. The simplicity of this stem design removes some of the complications in interpreting the influence of stem height on E_s . One study of how stem height influenced E_s of pachycaulous stems focused on stems of cycads (Marler and Krishnapillai 2020b). Although an increase of E_s was reported at the lowest stem height, an even greater increase occurred at the highest elevation and was attributed to respiration within the large primary thickening meristem (PTM). Palms comprise an interesting group of monocot plants with unique stem construction traits (Tomlinson 1990, 2006; Tomlinson and Hugggett 2012; Balslev et al. 2016). Like cycads, the stem is a thick pachycaulous structure with radial growth

primarily occurring within the PTM near the apex. To my knowledge, only one paper covering stem elevation over the entire stem height and E_s of palm trees has been reported (Cavaleri et al. 2006). This study used CO₂ efflux of leaf petioles rather than E_s for the highest stem height, so interpretations of the direct influence of stem height on E_s were equivocal.

The objectives herein were to determine the influence of stem height on E_s for 6 representative arborescent palm species. Species that are commonly used in the urban forests throughout Asia were selected. I predicted the influence of stem height on palm E_s would be similar to that of arborescent cycad species, as both plant groups construct pachycaulous stems that rely on a large PTM for the bulk of radial growth.

MATERIALS AND METHODS

Street trees in Angeles City, Philippines, were employed for this study from December 2023 until October 2024. Six palm species were selected for inclusion: *Carpentaria acuminata* (H. Wendl. & Drude) Becc.; *Cocos nucifera* L.; *Corypha utan* Lam.; *Phoenix sylvestris* (L.) Roxb.; *Roystonea regia* (Kunth) O.F. Cook; and *Wodyetia bifurcata* A.K. Irvine. The *C. utan* and *R. regia* trees were devoid of flowers or fruits, but there were flowers and developing fruits on the other 4 species. The 6 trees received weed control and periodic removal of senesced leaves and reproductive structures but no other horticultural care. The trees were selected due to close proximity, such that every tree could be rapidly accessed for each data collection date. Moreover, they were growing in open beds with mulch or managed grass covering the soil (fine loamy, smectitic, isohyperthermic, Vertic Equiaquent) and were not in close proximity to any hardscapes. The trees were thriving and healthy in appearance.

Stem height categories for E_s measurements were fixed at 35 cm to characterize the lowest stem height near the root collar and 20 cm below the oldest retained leaf petiole to characterize the maximum stem elevation. The heights of the intermediate elevations were determined by the overall tree height of each individual and were usually in increments of 100 cm. A telescopic ladder was employed to reach the elevations above 2 m.

A CIRAS EGM-4 analyzer fitted with a SRC-1 closed system chamber (PP Systems, Amesbury, MA, USA) was used to quantify the E_s at each predefined stem height category. The use of a horizontally oriented

soil chamber has been previously reported for tree E_s measurements (Xu et al. 2000; Zhao et al. 2017). A ring of modelling clay approximately 10 cm in diameter was placed on the stem surface to form a malleable seal, then the SRC-1 chamber was inserted into the modelling clay to provide a closed chamber of 1.171-L volume. The use of modelling clay to form sealed gas exchange chambers has been previously reported (Marler and Krishnapillai 2020b; Marler and Lindström 2020). The EGM-4 recorded air temperature and the increase in CO₂ above ambient for a 2-min period. The change in CO₂ was used to calculate E_s . Three periods of efflux were conducted at equidistant radial positions for each stem height, and the mean E_s was used as the value for each height category for each replication.

The stem surface temperature was measured with an infrared thermometer (Milwaukee Model 2267-20; Milwaukee Tool, Brookfield, WI, USA). Relative humidity was determined with a sling psychrometer. Stem diameter at the height of each flux measurement and total stem height were recorded. Although the time of day has been shown to exert no influence on palm stem E_s (Marler and Lindström 2020), the time of day was limited to 09:00 hr to 15:00 hr to restrict the measurements to the middle of the photoperiod. The 6 trees were in close proximity, and each tree required about 1 h to complete on each measurement date. All 6 trees were measured on each of the 6 experimental dates of 21 December 2023, 15 February 2024, 27 April 2024, 26 June 2024, 31 August 2024, and 18 October 2024. The dates were treated as replications ($n = 6$). The low temperature for the antecedent night and high temperature for the day of measurement were recorded. The total rainfall for the antecedent week was recorded for each measurement date.

The basal E_s , the apical E_s , and the mean E_s of all intermediate stem heights for each replication were subjected to one-way ANOVA to evaluate differences among the species. Parametric prerequisites were confirmed with Shapiro-Wilk Test for normality and Bartlett's Test to confirm equal variances. Means separation was by Tukey's HSD for response variables that were significant. The E_s data for each replication were displayed in scatter plots to reveal the influence of stem height on E_s . These plots revealed the approximate fit of a quadratic relationship, so regression analysis was used to fit quadratic models for combined data for each species. In order to look at the influence

of temperature and precipitation on palm E_s , a Pearson's correlation analysis was conducted with mean stem E_s , low temperature, high temperature, and rainfall as the variables for each species separately. Statistical procedures were conducted with R version WebR 0.5.0 (R Foundation, Vienna, Austria).

RESULTS

Air temperature ranged from 26 °C to 32 °C, and stem surface temperature ranged from 25 °C to 32 °C. Stem temperature was typically 1 °C less than air temperature during most measurement periods. The relative humidity ranged from 58% to 68%. The tree height was variable, causing the apical stem height to range from 5.8 m for *W. bifurcata* to 9.8 m for *R. regia* (Figure 1). Stem dimensions varied greatly among the species. Stem circumferences were least for *C. acuminata* and greatest for *C. utan* (Figure 1).

The mid-elevations of the stems exhibited relatively homogeneous E_s for all 6 arborescent palm species in this study (Figure 1). In contrast, the apical and basal elevations exhibited increased E_s when compared with the mid-elevation E_s . The increase in E_s at the apical stem elevation was greater than the increase at the basal stem height. This vertical pattern enabled a significant quadratic model to describe the influence of stem height on E_s for all 6 species (Figure 1).

The mid-elevation E_s exhibited 2.4-fold difference among the species and separated into 4 groups (Table 1). The apical E_s exhibited a 2.3-fold difference among the species and also separated into 4 groups. The basal E_s was more variable overall with a 2.7-fold difference among the species, and the means separated into 5 groups. The ranking among the species was not consistent for the 3 stem height categories. Mid-elevation E_s was greatest for *C. acuminata*, but this species did not exhibit the greatest apical or basal E_s . The ranking for apical E_s was *R. regia* = *P. sylvestris* > *W. bifurcata* > *C. acuminata* > *C. nucifera* = *C. utan*. The ranking for basal E_s was *R. regia* > *C. acuminata* > *P. sylvestris* > *W. bifurcata* = *C. utan* > *C. nucifera*. These dissimilarities of how the species ranked for each stem elevation category caused the relative increase in E_s at the apical and basal heights to differ among the species. For example, *P. sylvestris* exhibited an increase in basal E_s above that of the mid-elevation E_s that was only 23%, but *C. utan* exhibited a 113% increase in this trait. Similarly, *C. acuminata* exhibited an increase in the apical E_s above that of the

mid-elevation E_s that was only 63%, but *W. bifurcata* exhibited a 290% increase in this trait. The quadratic parameter for the *W. bifurcata* regression model was more than twice that of any other species (Figure 1), confirming the substantial nonlinear increase in E_s near the apex.

The Pearson's correlation analyses did not reveal a consistent influence among the palm species for the relationship between high temperature, low temperature, or antecedent rainfall and palm stem E_s (Table 2). High temperature ranged from 30 °C to 36 °C and was moderately correlated with *C. nucifera* but not the other species. Low temperature ranged from 23 °C to 28 °C and was moderately correlated with *C. acuminata* and *P. sylvestris* but not the other species. Antecedent rainfall amount ranged from 10 mm to 81 mm and was moderately correlated with *R. regia* but not the other species. Under the conditions of this study, these climate variables were not effectual predictors for palm E_s .

DISCUSSION

The urban ecosystem is a complex system in which trophic interactions and species assemblies are shaped by anthropogenic filters interacting with the local background biodiversity (Egerer and Buchholz 2021). The tree community is a crucial component of that urban system, as trees exert a profound influence on ecosystem services (Locosselli and Buckeridge 2023). The direct study of urban ecology in these biomes, often referred to as anthromes, has become an integral part of urban studies (Kueffer 2020; Pickett et al. 2024). Managing and understanding the globe's urban tree population requires more research to enable human well-being in the urban environment (Locosselli and Buckeridge 2023). This study has addressed these universal issues by adding to our understanding of how stems of urban palm trees contribute to the CO₂ cycle.

The similar diameter throughout the height span of a palm stem, the lack of stem branching, and the radial symmetry of the crown of compound leaves combine to generate the well-known gestalt appearance of palm trees (Tomlinson 1990). These same traits describe most arborescent cycad trees (Norstog and Nicholls 1997). Unlike lignophyte tree species with radial stem construction occurring within bifacial secondary vascular cambium throughout every stem height category, radial enlargement activity of

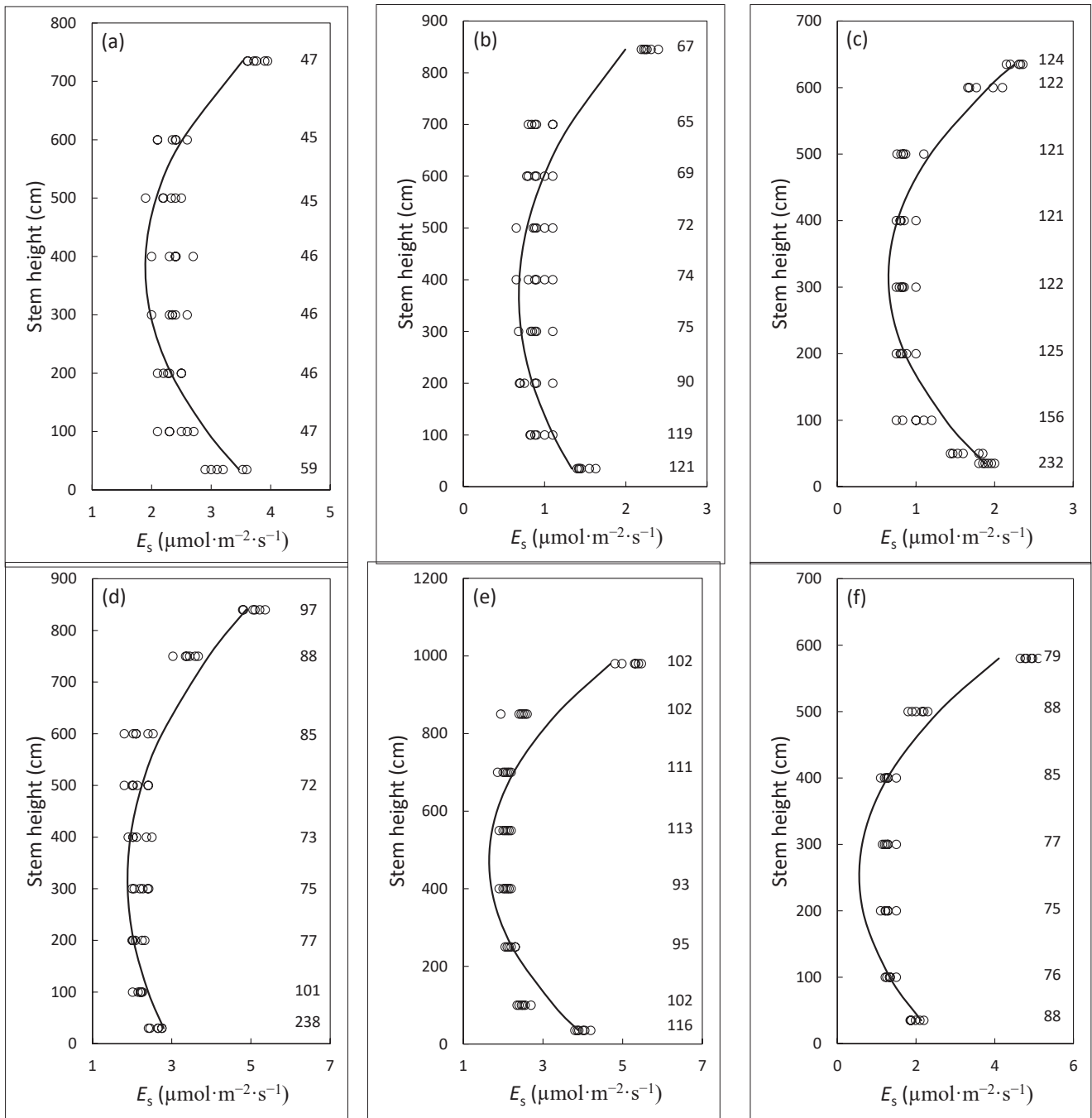


Figure 1. The relationship between stem strata and stem carbon dioxide efflux (E_s) for 6 arborescent palm species. (a) *Carpentaria acuminata*; (b) *Cocos nucifera*; (c) *Corypha utan*; (d) *Phoenix sylvestris*; (e) *Roystonea regia*; and (f) *Wodyetia bifurcata*. Solid lines represent the quadratic model calculated from regressing E_s onto elevation, with axes transposed. Numbers on the right vertical axis represent stem circumference (cm) at each stem elevation. Models for each species were:

(a) $E_s = 3.80 - 0.010 \times \text{height} + 0.000013 \times \text{height}^2$; $r^2 = 0.93$

(b) $E_s = 1.48 - 0.004 \times \text{height} + 0.000006 \times \text{height}^2$; $r^2 = 0.86$

(c) $E_s = 2.21 - 0.010 \times \text{height} + 0.000016 \times \text{height}^2$; $r^2 = 0.96$

(d) $E_s = 2.99 - 0.007 \times \text{height} + 0.000011 \times \text{height}^2$; $r^2 = 0.95$

(e) $E_s = 4.27 - 0.011 \times \text{height} + 0.000012 \times \text{height}^2$; $r^2 = 0.88$

(f) $E_s = 2.68 - 0.017 \times \text{height} + 0.000033 \times \text{height}^2$; $r^2 = 0.84$

Table 1. Characteristics of stem carbon dioxide efflux of 6 palm species on 6 dates from December 2023 until October 2024 in Angeles City, Philippines. The species within each column with the same letter are not different according to Tukey's HSD (honest significant difference) test. E_s (stem carbon dioxide efflux).

Species	Mid-elevation E_s ($\mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$)	Apical E_s ($\mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$)	Basal E_s ($\mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$)
<i>Carpentaria acuminata</i>	2.30 ± 0.09a	3.76 ± 0.08c	3.22 ± 0.10b
<i>Cocos nucifera</i>	0.95 ± 0.06d	2.24 ± 0.05d	1.48 ± 0.04e
<i>Corypha utan</i>	0.89 ± 0.06d	2.31 ± 0.06d	1.90 ± 0.05d
<i>Phoenix sylvestris</i>	2.13 ± 0.09ab	5.06 ± 0.15ab	2.61 ± 0.06c
<i>Roystonea regia</i>	2.04 ± 0.08b	5.22 ± 0.16a	3.98 ± 0.11a
<i>Wodyetia bifurcata</i>	1.25 ± 0.07c	4.87 ± 0.11b	1.91 ± 0.05d
$F_{5,30}$	75.22	399.74	224.69
P	< 0.001	< 0.001	< 0.001

Table 2. The correlation of stem carbon dioxide efflux (E_s) of 6 palm species with measurement day high temperature, measurement day low temperature, and cumulative rainfall during antecedent 7 days in Angeles City, Philippines. All correlations were non-significant except *R. regia* and *W. bifurcata* E_s and high temperature.

Species	High temperature	Low temperature	Rainfall
<i>Carpentaria acuminata</i>	0.31	0.63	0.40
<i>Cocos nucifera</i>	0.68	0.51	-0.27
<i>Corypha utan</i>	-0.17	-0.11	0.33
<i>Phoenix sylvestris</i>	0.30	0.66	-0.08
<i>Roystonea regia</i>	-0.03	0.41	0.61
<i>Wodyetia bifurcata</i>	0.01	-0.48	-0.48

the palm and cycad stem occurs primarily in the PTM near the apex (Stevenson 1980; Tomlinson 1990, 2006; Tomlinson and Huggett 2012). As predicted, the influence of stem height on palm E_s in this study was remarkably similar to how elevation influenced cycad E_s (Marler and Krishnapillai 2020b). With the exception of the highest and lowest elevations, the remainder of the stem heights exhibited homogeneous E_s regardless of overall tree height. This homogeneous trait of palm mid-elevation E_s was reported elsewhere (Cavaleri et al. 2006). The similarities of palm and cycad E_s indicate that the influence of stem height on E_s may be similar among all plant groups that produce pachycaulous stems.

The increased basal E_s of these palm stems was consistent with the contributions of respired CO_2

from root tissues that enter root xylem then move to stem tissues in xylem mass flow. This root-derived CO_2 responds to the radial conductance gradient toward the stem surface as soon as it passes through the root collar and enters the basal stem tissues. Some estimates indicate that half of the root-respired CO_2 may enter the atmosphere by way of E_s (Bloemen et al. 2013). This increase in basal stem E_s due to root-derived CO_2 was substantial at 35-cm stem height but was not observable at the 100-cm stem height in this palm study or in cycad stems (Marler and Krishnapillai 2020b). Many studies of E_s utilize diameter at breast height (DBH)(usually 1.3 m) as the lowest stem elevation, illuminating the use of methods that fail to include a stem elevation close enough to the root system to capture the increased E_s derived

from root respiration. The influence of soil surface characteristics on soil efflux may also alter basal E_s of lignophytes by influencing the movement of CO_2 from roots to stems (Marler 2023). The influence of soil surface gas exchange characteristics on basal E_s of palms, cycads, and other pachycaulous trees has not been determined.

An increase in E_s at higher elevations in trees is not exclusive to palms. Indeed, greater E_s in the highest elevations has been reported in other tree growth forms (Cavaleri et al. 2006; Katayama et al. 2014; Tarvainen et al. 2014; Araki et al. 2015; Marler and Krishnapillai 2020b). One of the factors that influences CO_2 efflux from a stem surface is the diffusion and conductance resistance imposed by tissues that are peripheral to the internal sources of free CO_2 (Bowman et al. 2005; Steppe et al. 2007; Ryan et al. 2009; Wang et al. 2019; Stutz and Anderson 2021). A reduction in this radial resistance in the smaller diameter stems in the upper canopy may be one of the reasons that higher elevations in lignophyte tree species exhibit increased E_s . But when compared to lignophyte trees, the diameter of palm stems is similar for the entire vertical span of the tree (Tomlinson 1990). The substantial increase in E_s at the apical stem elevation of palm trees is therefore not likely a reduction in resistance to radial CO_2 movement but rather the close proximity to the metabolically active PTM as a concentrated source of respired CO_2 . This explanation has been discussed for cycad pachycaulous stems (Marler and Krishnapillai 2020b). Interestingly, excised sections of heart of palm from *Bactris gasipaes* Kunth also exhibited an increase in respiration for the apical sections compared to the lower stem height sections (Fonseca et al. 2019), indicating greater metabolic activity of these internal tissues closer to the stem apex.

Palms and Cycads

Although there were similarities in how stem height influenced E_s for palms (reported herein) and cycads (Marler and Krishnapillai 2020b), a more detailed discussion about E_s of these two plant groups is warranted. First, the differences in E_s among these palm species was greatest in the basal stem elevation. These results were not consistent with cycad E_s , where the mid-elevation E_s was more variable among 6 species than basal E_s (Marler and Krishnapillai 2020b). These observations deserve further study

and may indicate that the peripheral ground tissues separating xylem tissues from the basal stem surface may offer more variable resistance to CO_2 conductance among palm species than among cycad species.

Second, the differences in E_s among the 6 palm species averaged 2.5-fold for the 3 stem height categories, but the differences in E_s among 6 cycad species was only 1.8-fold (Marler and Krishnapillai 2020b). Although both groups construct pachycaulous stems, the internal construction approaches are dissimilar. The distinct cylinders of cycad vascular tissue (Norstog and Nicholls 1997) may lead to less variations in E_s among species than the diffuse and scattered vascular bundles of palm stems (Tomlinson 1990, 2006). An extensive survey in a common garden setting revealed the absolute range in basal E_s among numerous cycad species was $5.5 \mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$, and this range was $6.8 \mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$ among palm species (Marler 2022). Elucidating the influential stem traits that differentially control E_s in palms versus cycads remains to be studied. One avenue to pursue may be the taxonomic differences of cortex diameter (e.g., Marler et al. 2010), as a wider cortex would offer greater resistance to xylem-derived CO_2 conductance toward the stem surface.

Third, lignophyte tree E_s was influenced by time of day, but palms and cycads exhibited homogeneous E_s throughout a diel cycle (Marler and Lindström 2020). The substantial peripheral ground tissue that separates vascular tissue from stem surfaces in the pachycaulous stems of palms and cycads may account for the homogeneous E_s throughout the diel cycle. This stem trait may also be the reason that lignophyte tree species with minimal tissues peripheral to the active vascular tissues exhibited greater mean E_s than palm or cycad species (Marler 2022).

Fourth, biotic and abiotic stressors that decrease stem nonstructural carbohydrates may generate a decline in E_s of cycads (Marler 2020). This phenomenon should be studied for palm species to more fully understand how natural and anthropogenic disturbances modulate palm E_s .

Geography

The literature on palm E_s is limited, but the number of species that have been reported is considerable. The Philippine E_s reported herein was greater than palm E_s reported from Costa Rica (Cavaleri et al. 2006) and Peru (Robertson et al. 2010) but similar to

that reported from Thailand (Marler and Lindström 2020; Marler 2022). A direct comparison of E_s for 5 of the Philippine species herein with E_s for the same species in Thailand is possible. Although variation occurred among the 5 species, on average the Thailand E_s was 46% greater than the Philippines E_s (Marler 2022), indicating geographical differences may substantially influence palm E_s . A study of the influence of stem height on E_s of *Mauritia flexuosa* L.f. stems reported less E_s at the stem base than at higher strata (Soosaar et al. 2022), which contrasted with the results reported herein. This Peruvian study occurred in peatlands, and the anaerobic soil conditions may have increased basal stem adventitious root formation. Indeed, soil water content may directly influence E_s (Bréchet et al. 2025). Copious basal adventitious roots in palm stems may separate the peripheral tissues known as pseudobark (Broschat 2013) from cortex tissues (Tomlinson 1990), and this physical separation may hinder radial conductance of CO_2 at this stem elevation. The soils from the current study and other palm studies (Marler and Lindström 2020; Marler 2022) were well-drained, and basal adventitious roots may have been more limited than in the peatland study in Peru. These findings reveal the need to study E_s of singular palm species under various soil conditions to tease apart the modulating influences of root zone conditions on stem E_s . Other candidates for this research agenda may be the coastal palm species such as *Nypa fruticans* Wurmb that often grows among inundated brackish or saline soils. The influences of weather and season on palm E_s may also influence global carbon cycles. For example, Manning et al. (2019) reported substantial seasonal differences in E_s of the oil palm *Elaeis guineensis* Jacq. The seasonal differences in temperature and rainfall did not substantially influence E_s in the current study.

Future Research

One of the goals of single-tree quantification of E_s is to scale up the estimation of carbon fluxes to habitat, regional, and global scales. Accurate modelling of carbon fluxes in the global carbon cycle (Yang et al. 2016; Salomón et al. 2022; Mills et al. 2025) will require more refined estimates of the factors that influence E_s at the single-tree level. Surprisingly little is known about palm tree E_s , and the contrasting results that have been reported among studies has raised more questions than answers. As research

continues, calculating whole tree E_s based on a single height of palm stems cannot be justified. For example, the commonly used DBH for quantifying E_s of trees would severely underestimate the total CO_2 emissions from palm tree stems, because the substantial increase in CO_2 efflux at the apical and basal elevations would be excluded from the data. Reporting E_s data without a detailed description of experimental soil conditions may add ambiguity to the research agenda because water status and soil surface characteristics may substantially modulate E_s at the local level (Soosaar et al. 2022; Marler 2023). Using single-season data may over- or under-estimate annual E_s (Manning et al. 2019). Habitat-level estimates of CO_2 exchange cannot be based on data sets that are restricted to lignophyte trees if a study habitat contains pachycaulous trees such as cycads and palms. These trees can represent dominant components of some forests, with more than 6,400 palm plants per ha (Vormisto et al. 2004) and more than 10,000 cycad plants per ha (Marler and Krishnapillai 2020a) reported in some locations. Using data sets that are restricted to lignophyte E_s to extrapolate to community-level carbon flux estimates in these forests would clearly generate inaccurate estimates.

The relationship of CO_2 efflux and O_2 influx at a single stem height is useful for determining the proportion of efflux attributed to elevation-specific stem respiration and the proportion attributed to CO_2 imported from lower tissues within xylem mass flow (Salomón et al. 2024; Jardine et al. 2025). These measurements could be used to confirm if the increase in basal E_s is xylem-derived and the increase in apical E_s is derived from PTM respiration.

This study was restricted to the urban forest. No direct comparisons of the E_s of urban trees have been made with the E_s of undisturbed natural forest trees, but the contrasting environmental conditions may influence E_s . For example, the light pollution from street lights, the changes in soil hydraulics due to hardscapes, the elevated temperatures due to the heat island effect, and the particulate air pollution in the urban environment may directly influence palm tree physiology. Further studies are needed to more fully understand the differences and similarities of palm tree E_s as influenced by environmental conditions.

CONCLUSIONS

The E_s of 6 arborescent palm species as influenced by stem elevation revealed a homogeneous pattern among

the species, with the stem's midsection exhibiting similar E_s at every height category, the stem's basal elevation exhibiting a moderate increase in E_s as compared to the midsection, and the stem's apical elevation exhibiting a substantial increase in E_s as compared to the midsection. Root-derived CO_2 entering the stem through mass flow likely accounted for the basal increases in E_s . Construction respiration of the large PTM likely accounted for the apical increases in E_s . The substantial influence of palm stem elevation on E_s indicated that upscaling measurements of E_s to the stand level requires the measurement of carbon dioxide efflux for the full range in stem height. The quantity of carbon dioxide that is emitted by palm trees will need to be factored into future estimations of the role of the tropical urban forest as a carbon sink.

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Conflicts of Interest:

The author reported no conflicts of interest.