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The Potential of Non-Vascular Epiphytes in Water Storage in the Montane Atlantic Forest †

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Abstract: Non-vascular epiphytes play diverse roles in ecosystems and are known as biological indicators due to their sensitivity to environmental conditions. The objective of this study was to evaluate the water storage potential provided by this group in Tropical Forests. The study was carried out in the Montane Atlantic Forest which is located at the Serra do Mar State Park, Brazil in five permanent plots (three old growth forests, one that was subjected to selective logging, and one late succession forest). The non-vascular epiphyte biomass was estimated using an allometric model and the amount of water stored in the wet biomass was calculated from the estimated dry biomass. The amount of water stored in the non-vascular epiphytes that were installed in old growth areas was higher than it was in the other ones, and the amount of water was higher in the understory.

Keywords: water storage; non-vascular epiphytes; Montane Atlantic Forest

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1. Introduction

The Brazilian territory hosts two of the world's main tropical forests, and the Atlantic Forest is one of them. Considered to be one of the 25 biodiversity hotspots [1] and one of the most vulnerable hotspots in climate change scenarios [2], among its diverse physiognomies, the Montane Atlantic Forest exhibits exuberant vegetation that contains a large community of non-vascular epiphytes (mostly bryophytes). This group plays important roles for the functioning of ecosystems, which include providing habitat for organisms and participating in nutrient cycling. They also contribute to local diversity [3] and are good indicators of forest integrity [4], and they are known as biological indicators due to their sensitivity to the environmental conditions and their poikilohydric nature [5]. The biomass of non-vascular epiphytes (carbon stock) indirectly informs us about the water storage capacity of these Montane Forest areas [6] since they have in their structure different arrangements for the interception of atmospheric water [7] and thus, contribute significantly to the hydrological cycles in these ecosystems [8]. The objective of this work was to evaluate the potential of non-vascular epiphytes to store water in Tropical Forests.

2. Materials and Methods

2.1. Study Area

The study was carried out in Serra do Mar State Park (Núcleo Santa Virgínia), São Paulo, Brazil. The park shelters part of the longest Atlantic Forest remnant which covers a steep coastal mountain range, with there being frequent mists on the top [9]. The vegetation is structurally diverse, and it is classified as montane moist dense forest [10]. The average annual temperature is 17 °C, the annual precipitation reaches values of 2.300 mm, and the average monthly rainfall is never lower than 60 mm even in the dry season between July and August [11,12]. For this study, we selected five permanent plots of 1 ha each which were established under the BIOTA/FAPESP Functional Gradient Project: 3 ha of old growth forest (plots K, L, M in [12]/NSV-01, NSV-02, NSV-03 in [13]), 1 ha which was subjected to selective logging (plot N in [12]/NSV-04 in [13]), and 1 ha of late succession forest (plot T in [14]/NSV-05 in [13]). In the plots where there was a human disturbance, it took place approximately 40 years ago. All of the plot data can be accessed on the ForestPlots.net digital platform (www.forestplots.net) [13].

2.2. Sampling and Analysis

In each of the five plots, all of the live stems with DBH $\geq$ 0.8 cm were included in the inventory, and they had their DBH measured, their height estimated, and they were classified according to ICE-av (0 to 3). ICE-av is an index that is adapted from [15], and it was implemented to classify stems according to the trunk and branch coverage by the non-vascular epiphytes: ICE-av 0 = absence of non-vascular epiphytes; ICE-av 1 = up to 25% of the trunk and branches covered by non-vascular epiphytes; ICE-av 2 = 25% to 75% of the trunk and branches covered by non-vascular epiphytes; and ICE-av 3 = more than 75% of the trunk and branches covered by non-vascular epiphytes (Figure 1) [16].

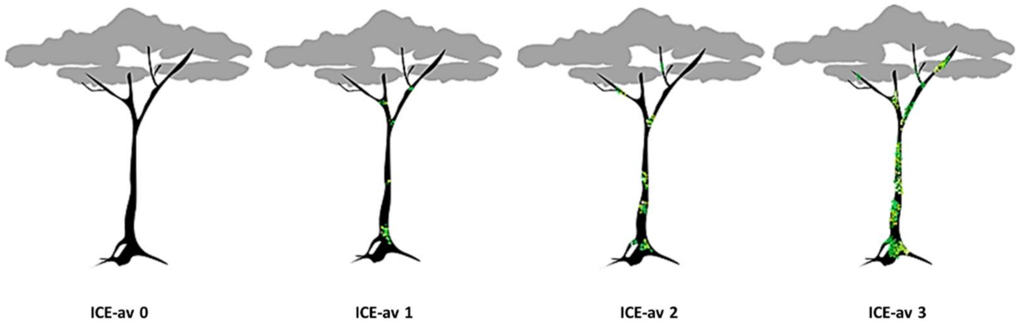

Figure 1. Schematic representation of the four classes of the Non-vascular Epiphyte Coverage Index (ICE-av).

We used data from the forest inventory to select trees to estimate the non-vascular biomass, their water content and how the water which was stored by non-vascular epiphytes varied along tree trunks. We randomly select 30 trees, 10 of which belonged to ICEav 1, 2 and 3, and we sampled the non-vascular epiphytes of different heights and in cardinal orientations. We adapted the method in [17] which considers four vertical zones: zone 1 (from 0 to 1.30 m from the base); zone 2 (intermediate region of the trunk); zone 3 (up to 1.30 m below the branching); zone 4 (the branches). Furthermore, the four cardinal directions (N, S, W, and E) were determined for each tree using a compass. In each of the four faces within each zone, an area was delimited for the sampling [18], with a fixed height of 20 cm and a variable width ($\frac{1}{4}$ of the perimeter) summing up 480 sampling units. The samples were weighed for their fresh weight and then, oven-dried to obtain the dry weight. The water content was estimated by the difference between the dry weight and the fresh weight, reaching values of, on average, 80% of the estimated biomass. The sampling was carried out between June and November 2018.

We used the height and ICE-av values which were applied to an allometric equation [16] to estimate the non-vascular epiphyte biomass per single trunk and then, we summed them up to estimate the non-vascular epiphyte biomass per plot. Finally, the water contents were weighted by the sampling unit area. The water content of the non-vascular epiphytes in the trees of different diameter classes (from 4.8 to 10 cm, from 10 to 30 cm, from 30 to 50 cm, and above 50 cm) was also investigated. This division was adopted to make it possible to compare the results with other studies of forest structure in the Neotropical region [19]. Trees that were up to 30 cm DBH occupy the understory of forests, and those with a diameter greater than that are considered to be canopy and emergent trees.

We performed a Linear Mixed Model which was fitted by Restricted Maximum Likelihood (REML) where water (g.cm^{-2}) was considered to be a response variable, while the

DBH (cm), zone, face, ICE-av, and disturbance were considered to be explanatory variables. The tree trunk and plot were added to the model as random effects. Water was the cubic root which was transformed to achieve normality, and the p values were calculated using Satterthwaite degrees of freedom. The residuals were visually inspected to detect the departure of the premises. The analyses were carried out using the package *lme4* which was implemented in R.

3. Results

Among all of the phorophytes that we visited in the plots, almost 93% of them had non-vascular epiphytes. These epiphytes stored between 913.4 L and 1330.7 L water per hectare in the old growth forests, 530.9 L/ha in the selectively logged area, and 703.8 L/ha in the late successional forest (Table 1). The non-vascular epiphytes that grew in the understory trees (4.8 to 30 cm of DBH) stored approximately 50% of the total water that was stocked (Table 2).

Table 1. Values of dry biomass of non-vascular epiphytes (kg/ha) and of water stored in these epiphytes (L/ha), in each of the permanent plots studied.

Plot	Dry Biomass of Non-Vascular Epiphytes (kg/ha)	Water Stored in Non-Vascular Epiphytes (L/ha)
Old growth 1	203.24	913.46
Old growth 2	200.63	1154.98
Old growth 3	220.24	1330.75
Selective logging	179.83	530.96
Late sucession	185.97	703.84

Table 2. Water stored in non-vascular epiphytes (L) for each diameter class (cm).

Class of Diameter (cm)	Water Stored in Non-Vascular Epiphytes (L)
4.8 to 10	372.73
10 to 30	2191.16
30 to 50	1372.44
More than 50	696.15

According to the model only the zone and ICE-av significantly affected the water storage ($p < 0.5$) (Table 3). The water storage decreased in the higher zones and increased with the higher ICE-av values (Figure 2). The remaining variables showed no statistically significant effect.

Table 3. Parameters tested in the Linear Mixed Model and its signaificance values.

Parameter	Estimate	*p*-Value
DBH	0.00	0.78
Zone 2	−0.03	0.01
Zone 3	−0.05	0.00
Zone 4	−0.08	0.00
Face N	0.01	0.48
Face W	0.00	0.67

Table 3. *Cont.*

Parameter	Estimate	p-Value
Face S	−0.00	0.81
ICE-av 2	0.04	0.14
ICE-av 3	0.11	0.00
Selective logging	−0.00	0.91
Mature forest	0.00	0.88

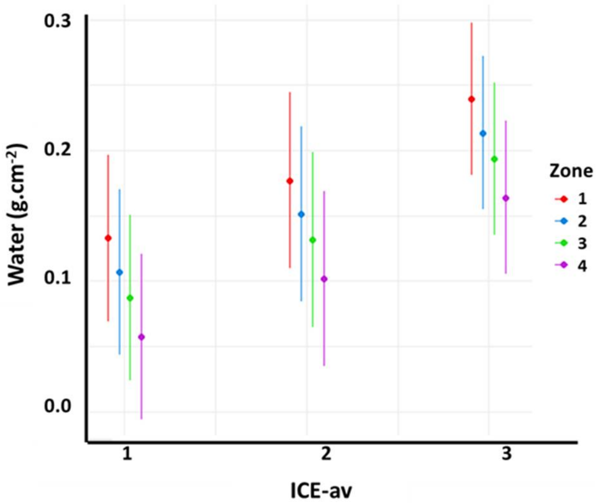

Figure 2. Amount of water in non-vascular epiphytes in each ICE-av CLASS (0 to 3) and in each ecological zone of the phorophyte (1, 2, 3 and 4). Bars indicate 95% confidence interval.

4. Discussion

Our results show that the non-vascular epiphytes store large amounts of water, creating wet microhabitats along the tree trunks and contributing to the system's water flows. This is the first time, that we know of, that this quantification has taken place for the Montane Atlantic Forest in Brazil, and we are aware that the potential storage may be even greater since the sampling occurred outside of the rainy season. The highest amount of water that was stored in the non-vascular epiphytes was found in the old growth forests (between 913.4 L and 1330.7 L of water per hectare), while the lowest amounts were identified in the selective logging plot (530.9 L/ha). This pattern indicates the effects of disturbance on the forest structure on the epiphytic community integrity and thus, on the water storage capacity.

In a similar study [20], in a gradient from the lowland to the Montane Forests in southern Thailand, it was found that the water storage by the epiphytic bryophytes ranged from 1.2 to 2.4 times their dry weight, reaching 1500 L per hectare in the higher altitudes. The authors of [21] also identified that epiphytes intercepted 724 mm of water over a year in a cloud forest in Tanzania, a value that represents 18% of the total annual rainfall at the site. Although studies such as this are still scarce, they are essential for understanding the maintenance of high humidity in the forest canopy and understory [22]. We observed no significant effect of the faces on water storage. This pattern might be due to the presence of clouds and mists throughout the year, which are associated with low solar irradiance and high humidity below the canopy [9–23]. Steep slopes and microtopography also reinforce these characteristics. It is worth mentioning that the epiphytes located in the lower ecological zones are subject to higher humidity and lower desiccation conditions due to the occurrence of low solar incidence, which may explain the greater water retention since these are microclimatic conditions that contribute to the survival of non-vascular epiphytes [24]. Tree stems of up to 30 cm of DBH also occupy this lower position in the forest stratum, and they are also subjected to these conditions, which explains the greater amount of water that is stored in the epiphytes of these phorophytes.

5. Conclusions

The capacity of non-vascular epiphytes to intercept and store water is a feature that makes them essential components for the ecosystem's functioning. In a scenario of land use and climate changes, they may be the first ones to be impacted by shifts in the forest structure, the increase in temperature, and the variation in the rainfall seasonality. Those factors impact not only the non-vascular epiphytes but also the entire community where they belong.

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