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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 sensibility 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 located at the Serra do Mar State Park, Brazil in 5 permanent plots (3 old growth forests, 1 subjected to selective logging, 1 of late succession forest). Non-vascular epiphyte biomass was estimated using an allometric model and the amount of water stored in wet biomass was calculated from the estimated dry biomass. The amount of water stored in non-vascular epiphytes installed in old growth areas was higher than 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

Brazilian territory hosts two of the world's main tropical forests, and the Atlantic Forest is one of them. Considered one of the 25 biodiversity hotspots [1] and one of the most vulnerable hostspots 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], known as biological indicators due to their sensibility to 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 frequent mists on the top [9]. Vegetation is structurally diverse and classified as montane moist dense forest [10]. The average annual temperature is 17°C, the annual precipitation reaches values of 2.300mm 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 5 permanent plots of 1 ha each 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 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 plot data can be accessed on the ForestPlots.net digital platform (www.forestplots.net) [13].

2.2 Sampling and Analysis

In each of the 5 plots all live stems with DBH ≥ 4,8cm were included in the inventory, had their DBH measured, their height estimated and were classified according to ICE-av (0 to 3). ICE-av is an index adapted from [15] and implemented to classify stems according to trunk and branch coverage by non-vascular epiphytes (Figure 1) [16].

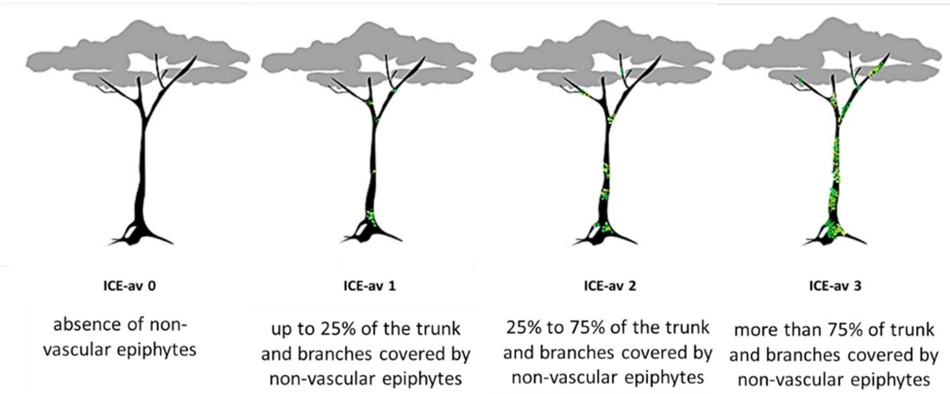

Figure 1. Schematic representation of the four classes of the Non-vascular Epiphyte Coverage Index (ICE-av).

We used data from the forest inventory to select trees to estimate the non-vascular biomass, their water content and how the water stored by non-vascular epiphytes varied along tree trunks. We randomly select 30 trees, 10 of which belonging to ICEav 1, 2 and 3, and sampled non-vascular epiphytes in different heights and cardinal orientations. We adapted the method by [17] which considers four vertical zones: zone 1 (0 to 1.30m from the base); zone 2 (intermediate region of the trunk), zone 3 (up to 1.30m below the branching) and zone 4 (branches). Furthermore, the four cardinal directions (N,S,W,E) were determined for each tree using a compass. In each of the 4 faces within each zone, an area was delimited for sampling [18], with a fixed height of 20 cm and variable width (¼ of the perimeter) summing up 480 sampling units. Samples were weighed for fresh weight and then oven-dried to get 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. Sampling was carried out in June and November 2018.

We used height and ICE-av applied to an allometric equation [16] to estimate non-vascular epiphyte biomass per single trunk and then summed up to estimate non-vascular epiphyte biomass per plot. Finally, water contents were weighted by sampling unit area. The water content of non-vascular epiphytes in trees of different diameter classes (4.8 to 10 cm, 10 to 30 cm, 30 to 50 cm, 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 up to 30cm DBH occupy the understory of forests, and those with a diameter greater than that are considered canopy and emergent trees.

We performed a Linear Mixed Model fited by Restricted Maximum Likelihood (REML) where Water ($g.cm^{-2}$) was considered a response variable, while DBH (cm), Zone, Face, ICE-av and Disturbance were considered explanatory variables. Tree Trunk and Plot were added to the model as random effects. Water was cubic root transformed to achieve normality and p values were calculated using Satterthwaite degrees of freedom. Residuals were visually inspected to detect the departure of premises. Analyses were carried out in package *lme4* implemented in R.

3. Results

Among all the phorophytes visited in the plots, almost 93% had non-vascular epiphytes. These epiphytes stored between 913.4l and 1330.7l of water per hectare in 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 occur in understory trees (4.8 to 30 cm of DBH) store approximately 50% of the total water 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 Zone and ICE-av significantly affected water storage ($p<0.5$)(Table 3). Water storage decreased in higher zones and increased with higher ICE-av's (Figure 2). The remaining variables showed no statistically significant effect.

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

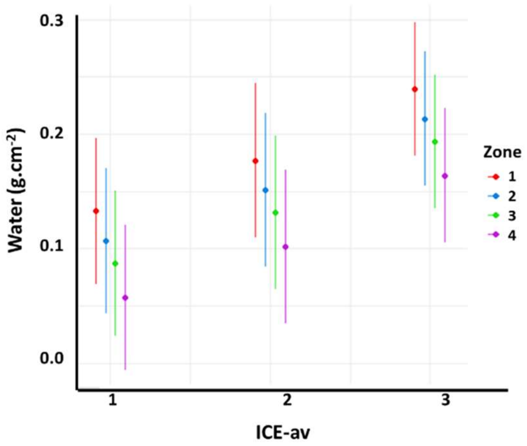

Figure 2. Amount of water in non-vascular epiphytes in each ICE-av class (0 to 3) and in each ecological zone of the phorophyte (1, 2, 3 and 4). Bars indicate 95% confidence interval.

4. Discussion

Our results show that non-vascular epiphytes store large amounts of water, creating wet microhabitats along tree trunks and contributing to the system's water flows. This is the first time, from what we know, 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 sampling occurred out of the rainy season. The highest amount of water stored in non-vascular epiphytes was found in old-growth forests (between 913.4l and 1330.7l of water per hectare) while the lowest amounts were identified in the selective logging plot (530.9 l/ha). This pattern indicates effects of disturbance on forest structure, on epiphytic community integrity and thus, on water storage capacity.

In a similar study, [20] in a gradient from lowland to Montane Forests in southern Thailand it was found that water storage by epiphytic bryophytes ranged from 1.2 to 2.4 times their dry weight, reaching 1,500 liters per hectare in higher altitudes. [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 like this are still scarce, they are essential for understanding the maintenance of high humidity in forest canopy and understory [22]. We observed no significant effect of faces on water storage. This pattern might be due to the presence of clouds and mists all over the year, which are associated with low solar irradiance and high humidity below canopy [9-23]. Steep slopes and microtopography also reinforce these characteristics. It is worth mentioning that epiphytes located in the lower ecological zones are subject to higher humidity and lower desiccation due to the occurrence of low solar incidence, which may explain the greater water retention since these are microclimatic conditions that contribute to survival of non-vascular epiphytes [24]. Tree stems with up to 30 cm of DBH also occupy this lower position in the forest stratum and are also subjected to these conditions, which explains the greater amount of water stored in the epiphytes of these phorophytes.

5. Conclusion

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 forest structure, the increase in temperature and variation in rainfall seasonality. Those factors impact not only non-vascular epiphytes but also the entire community where they belong.

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