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Soil-mediated effects on potential *Euterpe edulis* (Arecaceae) fruit and palm heart sustainable management in the Brazilian Atlantic Forest

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ABSTRACT

Euterpe edulis is an endangered species due to palm heart overharvesting, the most important non-timber forest product of the Brazilian Atlantic Forest, and fruit exploitation has been introduced as a low impacting alternative. However, *E. edulis* is a keystone species for frugivores birds, and even the impact of fruit exploitation needs to be better investigated. Since this species occurs over contrasting habitats, the establishment of site-specific standards and limits for exploitation may also be essential to achieve truly sustainable management. In this context, we sought to investigate how soil chemical composition would potentially affect *E. edulis* (Arecaceae) palm heart and fruit exploitation considering current standards of management. We studied natural populations found in Restinga Forest and Atlantic Rainforest remnants established within Natural Reserves of São Paulo State, SE Brazil, where 10.24 ha permanent plots, composed of a grid of 256 subplots (20 m $\times$ 20 m), were located. In each of these subplots, we evaluated soil chemical composition and diameter at breast height of *E. edulis* individuals. Additionally, we evaluated fruit yield in 2008 and 2009 in 20 individuals per year. The Atlantic Rainforest population had a much higher proportion of larger diameter individuals than the population from the Restinga Forest, as a result of habitat-mediated effects, especially those related to soil. Sodium and potassium concentration in Restinga Forest soils, which have strong negative and positive effect on palm growth, respectively, played a key role in determining those differences. Overall, the number of fruits that could be exploited in the Atlantic Rainforest was four times higher than in Restinga Forest. If current rules for palm heart and fruit harvesting were followed without any restriction to different habitats, Restinga Forest populations are under severe threat, as this study shows that they are not suitable for sustainable management of both fruits and palm heart. Hence, a habitat-specific approach of sustainable management is needed for this species in order to respect the demographic and ecological dynamics of each population to be managed. These findings suggest that any effort to create general management standards of low impacting harvesting may be unsuccessful if the species of interest occur over a wide range of ecosystems.

1. Introduction

Soil is a major determinant of the composition and functioning of terrestrial ecosystems (Lambers et al., 2008). Variations in the precipitation regime, relief position, and parent material may result in a highly heterogeneous mosaic of soil types in the landscape (Brady and Weil, 1996). In particular, tropical forests are recognized for their habitat heterogeneity, including small-scale variation in soil attributes, resulting in soil-related habitat specialization in plant species (Fine et al., 2004; Palmiotto et al., 2004; Baltzer et al., 2005; John et al., 2007). As a result, if a given commercial tropical forest species occur over contrasting soil types, some of its important life-history traits can be affected. Consequently, site-specific standards and limits for exploitation may be essential to achieve truly sustainable management. Indeed, the proposal of any strategy of sustainable management of forest products has to be supported by empirical and/or scientific data on the ecology and demography of the population to be managed within a given geographical distribution (Ticktin and Shackleton, 2011). As highlighted by Ticktin (2004), "environmental variation presents a challenge to our current understanding of ecological impacts of non-timber forest products extraction". However, this question has not been broadly investigated to date (Ticktin, 2004).

The exploitation of the neotropical palm *Euterpe edulis* – locally know as "palmiteiro" – provides a valuable template for studying the possible need for site-specific standards of management as a

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result of soil-mediated effects on plant growth and reproduction. This understory palm (5–20 m tall) endemic to the Atlantic Forest biome occurs in different forest types from 30°S to 15°S (Henderson et al., 1997; Silva Matos et al., 1999). Palmiteiro provides the edible palm heart, the apical meristem and developing undifferentiated leaves of palms' stem, which is the most important non-timber forest product exploited from the Brazilian Atlantic Forest. Additionally, palmiteiro fruit pulp has also been introduced as a southeastern equivalent of the Amazonian "açaí" (*Euterpe oleraceae*) – a concentrated lipid- and sugar-rich pulp of palm fruits used for several edible purposes (Fagnani, 2007) – and now standards for sustainable fruit exploitation are needed to supply this new production chain.

However, historical overharvesting for palm heart production has drastically reduced its population to the level of risk of extinction (Dransfield et al., 1988), and several local extinctions have been observed (Galetti and Fernandez, 1998). As differentiated from *E. oleraceae*, an indigenous palm of Amazonian basin which is also used for fruit and palm heart exploitation (Muñiz-Miret et al., 1996; Pollak et al., 1995), palmiteiro is a single-stemmed palm and does not re-sprout after harvesting, which leads to the death of the palm after the stem is cut for palm heart extraction (Reis et al., 2000). In order to compensate for the collapse of palm heart supply in privately owned forest fragments, illegal extraction has reached alarming levels inside protected areas and has ultimately endangered the last pristine and old-growth remnants (Galetti and Chivers, 1995; Orlande et al., 1996; Galetti and Fernandez, 1998; Reis et al., 2000). To aggravate the problems derived from overharvesting, palmiteiro is consumed in periods of food scarcity by at least 30 bird and 13 mammal species, some of which are endangered (Galetti and Fernandez, 1998; Fadini et al., 2009). As in other cases of overharvesting, several ecological, economic, and social problems have been observed as a result of uncontrolled exploitation of this species (Peres, 2010).

Three important lessons have emerged from this critical situation: (1) simple top-down prohibition of palmiteiro extraction is not effective (Orlande et al., 1996); (2) non-controlled, business-as-usual extraction of this keystone species results in overharvesting, (3) sustainable management of palm heart, and especially fruits, may be the solution for reconciling palmiteiro exploitation with its long-term conservation in managed forests. Fortunately, methods of palm heart sustainable management have been investigated in the last years (Reis et al., 2000; Freckleton et al., 2003). However, none of these studies considered variations of potential palm heart exploitation in the different habitats occupied by the species. Consequently, the application of current management standards in populations growing in sites with different soil characteristics and population dynamics may produce different results, including overharvesting. Fruit exploitation has not being explored so far by research. Hence, there is growing demand for implementing and improving palmiteiro exploitation in natural populations, and habitat heterogeneity is one of the key factors to be incorporated into future programs of sustainable management. As with palmiteiro, other commercial tropical species exploited for non-timber forest products grow under different, and sometimes contrasting, habitat conditions (Ticktin and Shackleton, 2011), therefore this case study may provide relevant insights into the need for site-specific standards of low-impact forest management.

We sought to investigate in this work how habitat-mediated effects, and specifically soil chemical composition, would potentially affect palmiteiro palm heart and fruit exploitation, considering current standards of management, in different forest types of the Brazilian Ombrophilous Dense Atlantic Forest. Additionally, we discussed the need for site-specific standards for improving current proposals of low-impact harvest regimes for this species.

2. Materials and methods

2.1. Study sites

We studied palmiteiro populations of Restinga Forest and Atlantic Rainforest within Natural Reserves of São Paulo State, SE Brazil, where 10.24 ha (320 × 320 m) permanent plots were located (Fig. 1). The study areas of Restinga Forest and Atlantic Rainforest in which these plots are located are 22,500 ha and 37,793 ha in size, respectively. Palmiteiro is the most abundant species in the areas of Restinga Forest and Atlantic Rainforest included in this study, corresponding respectively to 19.8% (300 individuals/ha) and 21.5% (240 individuals/ha) of the trees with diameter at breast height (DBH) > 4.8 cm (Projeto Parcelas Permanentes, 2006). Restinga Forest and Atlantic Rainforest are vegetation types included in the Ombrophilous Dense Atlantic Forest, which is part of the Atlantic Forest domain. Thereby, they are contiguous vegetation types included in the same ecosystem. We chose to study soil-mediated effects on potential palmiteiro exploitation in Restinga and Atlantic Rainforest because palm heart has been harvested predominantly in these forest types and the emerging exploitation of fruits can follow the same trend. The Atlantic Rainforest occurs throughout the Atlantic mountain range, predominantly in steeper slopes from 50 to over 1500 m above sea level, as well as in lowlands from 0 to 50 m, while Restinga forests occur over geologically young sandy and nutrient-poor lowlands created and destroyed by cyclical changes in the sea level (Gomes et al., 2007) (Fig. 1). The mosaic of vegetation types of Restinga constitutes marginal habitats predominantly formed by the colonization of other flora present in neighboring areas at the Atlantic mountain range (Scarano, 2002). Despite the high floristic richness of the permanent plots of Atlantic Rainforest (205 species with DBH > 4.8 cm) and Restinga Forest (114 species with DBH > 4.8 cm), these study areas had less than 14% species similarity (Projeto Parcelas Permanentes, 2006), which reflects their different habitat conditions. Since Restinga Forest and Atlantic Rainforest share large areas of contact (no dispersal limitation) and are submitted to the same Equatorial Climate (Af according to Köepen classification), divergences in vegetation composition are probably driven by their remarkable soil differences (Table 1).

2.2. Palm size and soil chemical content

Each permanent plot was composed by a grid of 256 subplots (20 m × 20 m), which were individually used for evaluating DBH of palmiteiro individuals and soil chemical content. Only individuals with DBH > 4.8 cm were considered. Soil samples obtained at 5–25 cm depth were used in the analysis. We chose to evaluate the effect of soil chemical content in palm size by using only 5–25 cm depth samples because most nutrient-absorbing palm roots are included in this soil layer. In addition, we were more interested in evaluating the direct effects of soil, so that we preferred to not evaluate the samples obtained at 0–5 cm depth, which are basically constituted by litterfall; deeper soil samples (80–100 cm) were not used because they poorly contribute to nutrient supply as a result of the low concentration of fine roots in this soil layer and reduced cation content. Soil pH was determined by potentiometry in $CaCl_2$ solution, Al was extracted in KCl and determined by acid–base titulation, and H + Al was extracted in SMP buffer and determined by potentiometry (van Raij et al., 2001). P, K, Ca, Na, and Mg were extracted in ion exchange resin (EMBRAPA, 1997). Soil cations were determined by spectrophotometry and P by colorimetry (van Raij et al., 2001). The dataset of the Permanent Plots Project-BIOTA/FAPESP were used to access these data.