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Genetic conservation of a threatened Neotropical palm through community-management of fruits in agroforests and second-growth forests

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ABSTRACT

The commercial exploitation of non-timber forest products (NTFPs) has been widely promoted to achieve both conservation and economic outcomes in the management of tropical forests by local communities, but monitoring the impacts of NTFPs harvesting is still challenging. Monitoring genetic diversity is a promising approach to assess harvesting impacts and guide best practices. Here, we evaluated the value of community-managed agroforests and secondary forests for conserving genetic structure and diversity of *Euterpe edulis*, an endemic palm explored for fruit and palm heart production. We used SSR markers to compare genetic diversity in populations growing in protected areas, in agroforests and in second-growth forests managed for fruit production in the coastal Atlantic Forest of Brazil. In addition, we investigated the genetic diversity of seeds extracted during pulp removal, which have been used in *E. edulis* reintroduction programs. Overall, high levels of genetic diversity were observed for all populations (mean allelic richness = 7.06; mean expected heterozygosity = 0.787), with no significant differences in genetic diversity among agroforests, second-growth forests and protected areas. Managed forests and protected areas had low to intermediate levels of genetic differentiation (global Fixation Index = 0.085), indicating the existence of gene flow among them. Seeds extracted during fruit pulp removal had as high genetic variability as populations growing in protected areas, thus evidencing the potential of using these seeds to recover overexploited populations. Thus, community-management of NTFPs in agroforests and second-growth forests may support genetic conservation of this threatened species, complementing the conservation role of protected areas.

1. Introduction

Deforestation and overexploitation of forest resources are major threats to global biodiversity (Henle et al., 2004; Kim et al., 2015). Protected areas have been established to safeguard the irreplaceable value of old-growth forest ecosystems (Barlow et al., 2007; Gibson et al., 2011), but it is now clear that conservation interventions should go beyond the establishment of protected areas (Chazdon et al., 2009), and also promoting land uses that safeguard biodiversity persistence (Melo et al., 2013). Sustainable management of existing remnants and reforestation of degraded lands have thus become increasingly important to complement the strict protection of forest ecosystem to conserve tropical biodiversity, especially in poor developing regions.

Conservation and forestry organizations have promoted the commercial exploitation of non-timber forest products (NTFPs) as an alternative or complementation to timber management when the objective is to achieve both conservation and production outcomes (Arnold and Pérez, 2001; Ticktin, 2004). The overarching assumption is that NTFP harvesting has a reduced impact on forest structure and biodiversity compared to timber harvesting, but still provides a continuous cash flow to local populations and indigenous communities. However, market-driven increases in the rate

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of extraction of NTFPs may led to overexploitation of commercially valued species (Kusters et al., 2006; Peres, 2010; Muler et al., 2014). Ecological impacts of NTFP exploitation may take longer to be perceived and require alternative approaches to be measured. In this context, monitoring genetic diversity can be an effective way to assess the underlying impacts of NTFP management on exploited species (Dawson et al., 2014).

Forestry practices that maintain genetic diversity in the long term are needed as an integral component of sustainable forest management (FAO, 2016). Monitoring genetic diversity is relevant for guiding best practices on forest management, helping to maintain genetically viable populations of exploited species and other native species living in forest remnants or being impacted by management interventions. However, the impacts of forest management on genetic diversity have been assessed essentially in timber exploitation (Degen et al., 2006; Schaberg et al., 2008; Ratnam et al., 2014; Soliani et al., 2016), while it has been neglected for NTFPs (but see Gaoue et al., 2014). Genetic impacts of NTPFs exploitation are expected to be mediated by different factors like the part of plant being exploited, the intensity of exploitation, the biological characteristics of species (mating system, pollen and seed dispersal mechanisms), and spatial distribution of individuals (Ticktin, 2004; Ratnam et al., 2014). When NTFPs are exploited in reforested areas, is also relevant to assess the conservation value of different types of reforestation, a relevant issue for validating the promise of the emerging global forest and landscape restoration initiatives for conserving tropical biodiversity (Thomas et al., 2014).

Here, we evaluated the value of community-managed agroforests (tree plantations mixed with crops) and secondary forests (naturally regenerated forests, without human assistance) for conserving genetic structure and diversity of *Euterpe edulis* Mart., an endemic palm explored for fruit and palm heart production in the Brazilian Atlantic Forest. This species is threatened due to overexploitation of its palm heart (MMA, 2008). As an alternative to palm heart production, fruit management of *E. edulis* to produce pulp-based products has been promoted in the Atlantic Forest region by policies, forestry organizations and environmental NGOs to reconcile income generation in local communities with the conservation of this species and the associated fauna (Ball and Brancalion, 2016). We used SSRs markers to compare genetic structure and diversity of populations growing in protected areas and in agroforests and secondary forests managed by local communities at the buffer zones of protected areas. In addition, we investigated the genetic diversity of seeds extracted during pulp removal of fruits harvested in managed agroforests and second-growth forests, which have been used in *E. edulis* reintroduction programs within protected areas.

It is important to consider that the Atlantic Forest was historically exploited for palm heart production, and it is was difficult to find protected areas that had not suffered any type of interference. For this study, we choose the protected areas which had the least intervention and with longer natural regeneration time to be used as reference. Even considering that protected areas may not represent well-conserved populations, we hypothesized that community-managed populations and the seeds they produce will have lower genetic diversity than populations found in protected areas for two main reasons. First, the establishment of *E. edulis* populations in managed systems would potentially be accompanied by strong founder effects, as already observed for an Amazonian palm in regenerating forests (Sezen et al., 2005), which would increase the detrimental effects of genetic drift. Local communities have also increased the abundance of *E. edulis* in agroforests through direct seeding and enrichment plantings with nursery-grown seedlings, without any information on their genetic diversity. Consequently, the selection of few seed-trees may occur in Atlantic Forest restoration (Brancalion et al., 2012a) and result in founding populations with low genetic diversity. Secondly, intensive harvesting of seeds or fruits could drive next generation to founder effects, bottleneck and dysgenic selection (Lowe et al., 2005; Dawson et al., 2014). Moreover, the reduction of fruits due to intensive harvesting may compromise the activity of animal dispersers (Moegenburg and Levey, 2002) and reduce gene flow through seeds, thus favoring inbreeding depression.

2. Materials and methods

2.1. Study species

We selected the palm *Euterpe edulis* Mart. for this study, a keystone palm species widely distributed in the Brazilian Atlantic Forest (Genine et al., 2009; Leitman et al., 2015). This species once supplied large quantities of palm heart to national and international markets, which constituted the most economically important NTFP of the Atlantic Forest (Reis et al., 2000a; Andrade et al., 2012). However, *E. edulis* is a single stemmed palm that do not resprout after palm heart extraction, so exploitation of this NTFP cause the death of palms and result in markedly declines in abundance (Muler et al., 2014). The intensive extraction of palm heart from the 1960s forward led to the decline of natural populations in both protected areas and private lands, and this species is now threatened of extinction (MMA, 2008; Silva-Matos et al., 1999). In the last ten years, fruit pulp production has been promoted as a sustainable alternative to commercial exploitation of palm heart (Souza et al., 2016). *E. edulis* berries are used for producing a frozen pulp very similar to that of the Amazonian *açaí* (*Euterpe oleracea* Mart.), a much appreciated delicatessen in local and international food markets (Favreto, 2010; Brancalion et al., 2012a,b).

The establishment of extensive protected areas in the southern portion of the Atlantic Forest to conserve the largest continuous forest remnants of the biome (Ribeiro et al., 2009), associated to land use restrictions in their buffer zones, have compromised the livelihoods of local communities living in the region that traditionally relied on slash and burn agriculture. Different reforestation approaches, mostly based on natural regeneration and agroforestry practices, have been promoted in the buffer zones of protected areas to support local livelihoods and to reduce the pressure on the protected populations of *E. edulis* (Ball et al., 2014). Agroforestry practices rely on the integration of trees in agricultural production to create sustainable land use systems and reconcile current livelihoods demands with traditional practices employed by local communities. *E. edulis* berries are the major NTFP exploited from many of these reforested vegetation, and some local communities also sell *E. edulis* seeds extracted at large amounts during fruit depulping, and nursery-grown seedlings produced with these seeds (Souza et al., 2016).

2.2. Study area

The study was carried in the Atlantic rainforest, inside the *Serra do Mar* State Park and its buffer zones, in São Paulo state, Southeastern Brazil (Fig. 1). This state park covers 332,000 hectares and is the largest protected area within the entire Atlantic Forest (Ribeiro et al., 2009). We sampled *E. edulis* in areas of natural regeneration distributed along two altitudinal gradients of the *Serra do Mar* state park: *Picinguaba* (PIC) station, located at the municipality of Ubatuba (lowland and submontane rainforests) and *Santa Virgínia* (SV) station, located at the municipality of São Luis do Paraitinga (montane rainforest). We assessed genetic diversity in three forest types: (1) protected areas (PA): old-growth forests without *E. edulis* fruit harvesting, but with historical illegal