USING e-ANNOTATION TOOLS FOR ELECTRONIC PROOF CORRECTION

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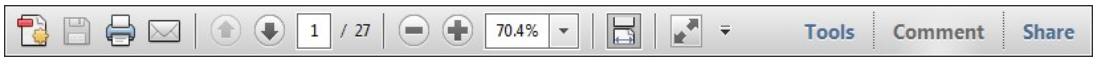
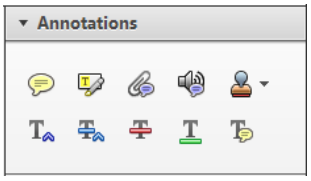


This will open up a panel down the right side of the document. The majority of tools you will use for annotating your proof will be in the Annotations section, pictured opposite. We've picked out some of these tools below:



1. Replace (Ins) Tool – for replacing text.

Strikes a line through text and opens up a text box where replacement text can be entered.

How to use it

- Highlight a word or sentence.
- Click on the Replace (Ins) icon in the Annotations section.
- Type the replacement text into the blue box that appears.

2. Strikethrough (Del) Tool – for deleting text.

Strikes a red line through text that is to be deleted.

How to use it

- Highlight a word or sentence.
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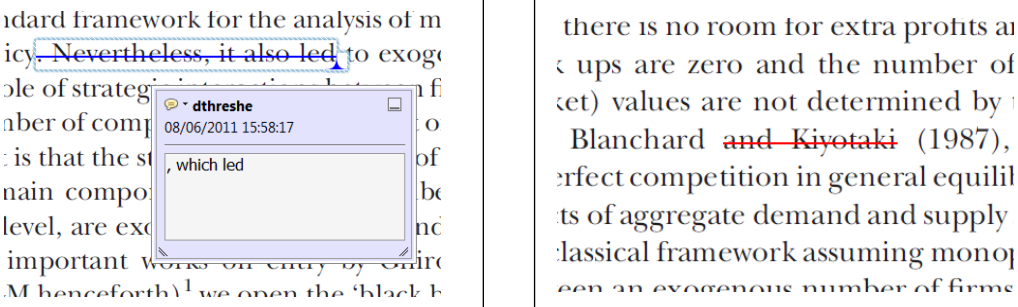

3. Add note to text Tool – for highlighting a section to be changed to bold or italic.

Highlights text in yellow and opens up a text box where comments can be entered.

How to use it

- Highlight the relevant section of text.
- Click on the Add note to text icon in the Annotations section.
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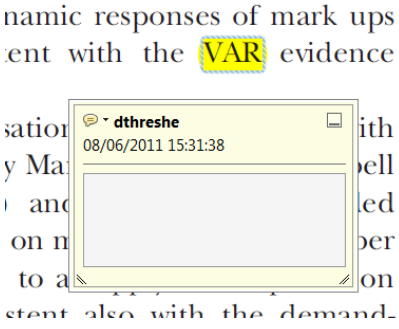

4. Add sticky note Tool – for making notes at specific points in the text.

Marks a point in the proof where a comment needs to be highlighted.

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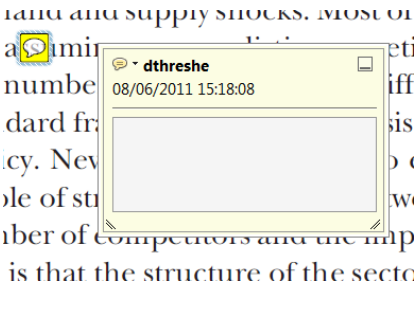
- Click at the point in the proof where the comment should be inserted.
- Type the comment into the yellow box that appears.



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Inserts an icon linking to the attached file in the appropriate place in the text.

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- Click on the Attach File icon in the Annotations section.
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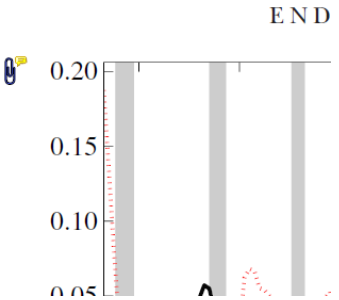

6. Drawing Markups Tools – for drawing shapes, lines and freeform annotations on proofs and commenting on these marks.

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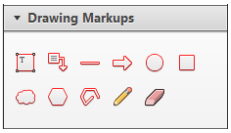

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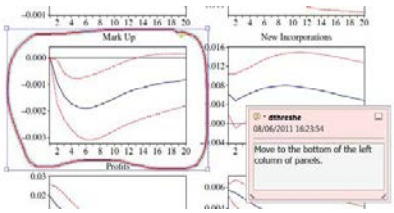
- Click on one of the shapes in the Drawing Markups section.
- Click on the proof at the relevant point and draw the selected shape with the cursor.
- To add a comment to the drawn shape, move the cursor over the shape until an arrowhead appears.
- Double click on the shape and type any text in the red box that appears.



Ecological outcomes and livelihood benefits of community-managed agroforests and second growth forests in Southeast Brazil

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ABSTRACT

The Forest and Landscape Restoration movement has emerged as an approach to reconcile biodiversity conservation, ecosystem services provisioning and human well-being in degraded landscapes, but little is known so far about the potential of different reforestation methods to achieve these objectives. Based on this gap, we assessed the ecological outcomes and local livelihood benefits of community-managed agroforests and second growth forests to assist natural regeneration in the coastal Atlantic Forest of Brazil. We investigated and compared agroforests and secondary forests according to their structure and floristic composition in 51 circular plots of 314 m², their role in supporting local livelihoods (45 semi-structured interviews) and the use and cultural importance of plant species (61 interviews). Agroforests and, more remarkably, managed secondary forests (1) re-established a well-developed forest structure, with a higher density of tree-sized individuals and similar basal area compared to nearby old growth forests; (2) were composed by a rich array of native species, including five threatened species, but had lower species richness than old growth remnants; and (3) improved local livelihoods by supplying market valuable and culturally important plants, including 231 native ethnospecies. Overall, local production systems showed remarkable potential to engage smallholders of developing tropical countries in Forest and Landscape Restoration and contribute to achieve its overall goals. We advocate the promotion of these systems as effective Forest and Landscape Restoration approaches in multi-scale programs and policies.

Abstract in Portuguese is available with online material.

Key words: Atlantic Forest; community engagement; *Euterpe edulis*; juçara; local ecological knowledge; local livelihoods; restoration monitoring; tropical reforestation.

Tropical forests have been cleared at unprecedented rates in the last decades in developing countries (Sloan & Sayer 2015), with far reaching negative consequences for biodiversity, climate and human well-being at multiple scales (Bullock *et al.* 2011). In order to mitigate this process and safeguard conserved ecosystems from human-mediated disturbances, a historical movement to establish protected areas across the tropics has been led by governments and conservation NGOs (Soares-Filho *et al.* 2010, Juffe-Bignoli *et al.* 2014). This strategy has generally involved some type of exclusion or marginalization of human activity from natural areas, following the premise that human intervention in these areas leads to their degradation.

Although such land-sparing approaches can be successful when dealing with strict conservation of biodiversity (Timm *et al.* 2009), it can further exacerbate land degradation and associated 'wicked problems' when socioeconomic, cultural, and environmental aspects are neglected (Wilshusen *et al.* 2002, Shahabuddin & Rao 2010). The response to contemporary environmental problems must include the needs and livelihoods of local communities living in natural and semi-natural tropical areas, in addition to strictly protecting areas of high conservation priority (Wunder *et al.* 2014). Traditional production systems also have to be considered when addressing food security, complementing the role of agricultural commodities' production in very intense production systems (Pretty *et al.* 2003, Tscharntke *et al.* 2012).

The Forest and Landscape Restoration movement (hereafter FLR) has emerged as an approach to reconcile biodiversity conservation, ecosystem services provisioning, food, fuel, and fiber production in degraded landscapes, contributing to species extinctions prevention, climate change mitigation, and poverty alleviation (Mansourian & Vallauri 2014, Laestadius *et al.* 2015, Suding *et al.* 2015, Chazdon & Uriarte 2016). The success of FLR initiatives will rely heavily on the strong involvement and participation of local communities and key stakeholders (Sayer *et al.* 2013, Lamb 2014, Chazdon *et al.* 2016). Indeed, when restoration initiatives originate outside of local communities, community engagement is low and may lead to restoration failures (Ball *et al.* 2014, Bennett *et al.* 2014). To ensure the success of restoration outcomes, local stakeholders have to be involved in the planning, implementation, and management steps of FLR programs to guarantee that their needs are met and that they are acknowledged as active players in the process (Celentano *et al.* 2014, IUCN & WRI 2014).

Stronger involvement of local communities may ultimately enhance FLR environmental outcomes, instead of being a threat to ecosystem protection (Guariguata & Brancalion 2014). For instance, community managed forests have shown to be effective

Received 10 December 2015; revision accepted 28 July 2016.

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in maintaining forest cover in different tropical regions (Nepstad *et al.* 2006, Bray *et al.* 2008, Porter-Bolland *et al.* 2012), as opposed to the general perspective that human use of natural ecosystems leads to a permanent conversion of natural forests to other land uses. For many millennia, traditional shifting cultivators have developed adaptive management strategies that maintain the forest regeneration cycle, as well as support livelihoods and sustain high levels of forest cover (Berkes *et al.* 2000, Miller & Nair 2006, Chazdon 2014). Indeed, good forest management practices are directly associated with long-inhabited communities who utilize and are reliant upon forest systems for their own well-being (Chhatre & Agrawal 2009).

Agroforestry systems- agroforests are broadly defined as the intentional integration of shade trees with agricultural crops or livestock (Bhagwat *et al.* 2008), while managed secondary forests are usually fallows from shifting cultivation with varying degrees of human intervention. These agroecosystems have been important transitional land uses between pastures/crop fields and well-developed, old growth tropical forests (Wiersum 2004, Ranganathan *et al.* 2008, Chazdon 2014). Their open canopy permits growth of locally demanded agricultural crops intercropped with either spontaneously regenerating or planted native and exotic woody species of importance for livelihoods and trading (Vieira *et al.* 2009). While succession advances in agroforests and managed secondary forests, stand structure and composition becomes more similar to neighboring natural forests (Piotto *et al.* 2009), providing habitat to native species and re-establishing ecosystem functions relevant for human well-being (Wiersum 2004, McNeely & Schroth 2006).

Brazil offers enormous potential to implement assisted forest regeneration through agroforestry and managed secondary forest systems within the context of FLR. Local production systems have been used for centuries in different regions of the country, based on the exploitation of non-timber forest products (NTFPs) from native species (Anderson *et al.* 1995, Montagnini *et al.* 2011, Schroth *et al.* 2011). In spite of their importance for local communities, such traditional systems have been neglected in policy formulation that still assumes a simplistic duality between conservation (*i.e.*, creating new protected areas) vs. production (*i.e.*, subsidies for expanding deforestation frontiers and land use intensification for producing agricultural commodities). In the face of the ambitious challenge established by the new Brazilian Forest Code to restore 21 million hectares of native ecosystems in private lands in the next 20 yr (Soares-Filho *et al.* 2014), the involvement of smallholders in the process will be crucial (Vieira *et al.* 2009). Despite this need, some policy makers and enforcement agencies are still unsure about the potential of traditional production systems to recover tropical forests' composition and structure in degraded agricultural lands and to meet legally required minimal ecological standards. Moreover, large environmental variation across the country, and even within the same region, represents a challenge to appropriately identify attainable ecological outcomes of these systems.

Although Brazil has a long history of scientific development of tropical forest restoration approaches (Rodrigues *et al.* 2009), the involvement of local communities in the process has been weak. This is, in part, because most of these approaches were developed in the context of mandatory restoration projects in large agricultural farms to comply with environmental laws and obtaining certification of agricultural commodities (Rodrigues *et al.* 2011), without incorporating the perspective of improving local livelihoods and food security through the exploitation of timber and non-timber forest products and crops in restoration sites (Brancalion *et al.* 2012a). We thus need a better scientific understanding of such systems to promote their inclusion in new restoration policies, as well to safeguard the socio-cultural heritage of traditional communities, which may be crucial to adapt to in a changing climate.

Here, we present a case study on the potential of community-managed agroforests and secondary forests to meet ecological, socio-economic and cultural needs/goals and to assist natural regeneration in the coastal Atlantic Forest of southeast Brazil. Based on field inventories along an altitudinal gradient and interviews in four local communities, we address the following questions: (1) how do community-managed secondary forests and agroforests resemble the structure and composition of unmanaged old growth forests? (2) What is the role of agroforests and managed secondary forests in supporting livelihoods? (3) Which are the most culturally important plants and how do they contribute to broad agroforestry systems?

We hypothesize that agroforests and managed secondary forests allow effective—but not complete—structural and floristic recovery of the coastal Atlantic Forest in fallow and agricultural lands and provide relevant benefits for livelihoods as a consequence of the exploitation of a large array of economically and culturally important plants for local communities. More specifically, we contend that the cultivation of some locally important native species could be responsible for most of the positive economic, social, cultural, and conservation outcomes of these systems. Our overreaching hypothesis is that active community management of fallows and agroforests could complement conservation strategies and assist natural regeneration where forest remnants or fragments persist together with human populations.

METHODS

Study Area.—This study was conducted in the coastal Atlantic Forest region of São Paulo state, Southeastern Brazil, specifically in four rural communities adjacent to *Santa Virgínia* and *Picinguaba* Stations of the *Serra do Mar* State Park (Fig. 1). Covering an area of 315,000 ha, it is the largest protected area of the Atlantic Forest biome, which is one of the top five global hotspot for biodiversity conservation (Myers *et al.* 2000, Laurance 2009). The study sites were located in three areas in respect to the distribution of protected areas (state park): (1) within protected areas, in a special zone where traditional communities are allowed to live and manage land and resources, subject to state park rules; (2) within protected areas, in restricted use zones where agriculture and forestry are not allowed, but still take place where farmers have not yet been formally evicted; and (3) in areas outside but

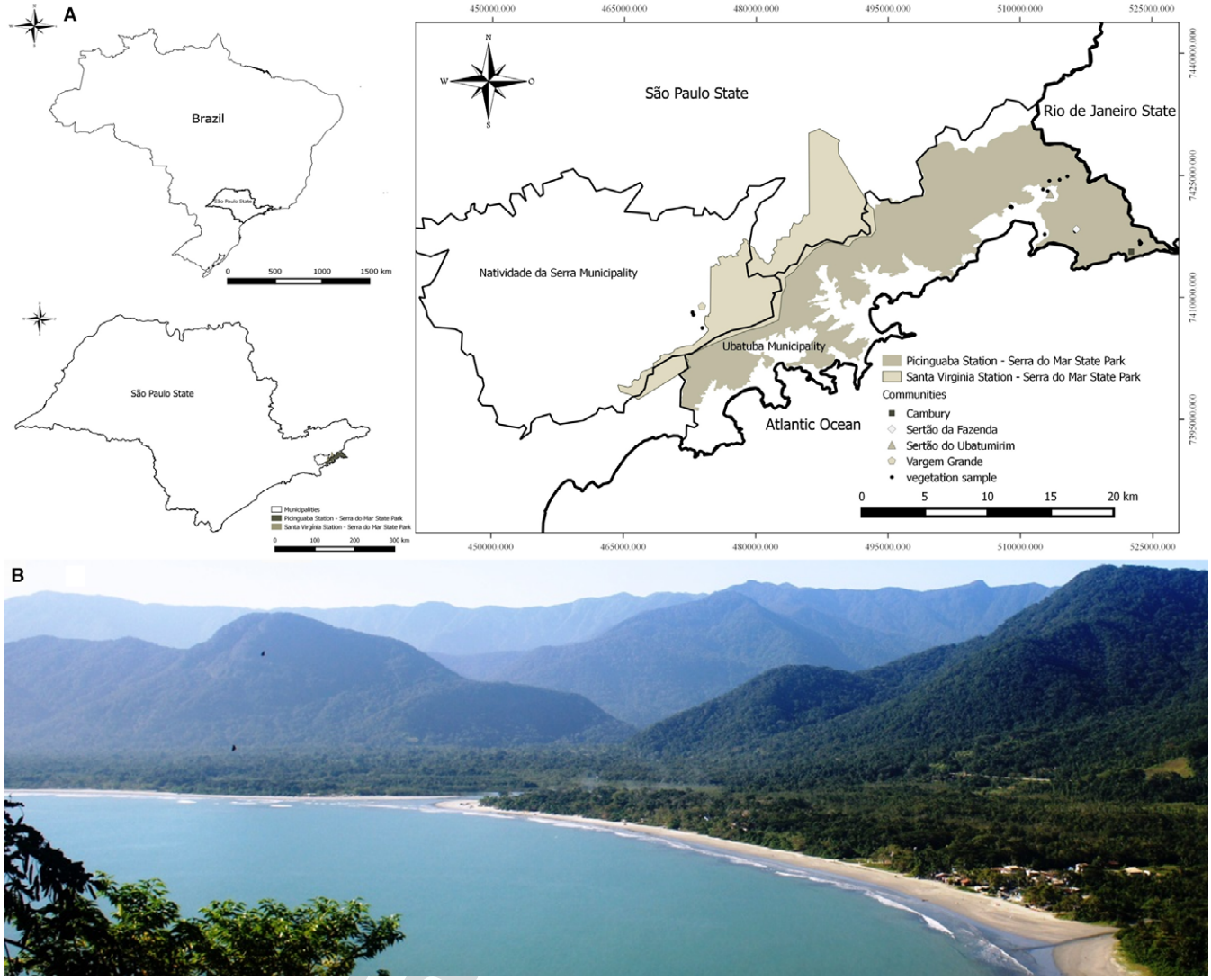

FIGURE 1. Study area and local communities (A), front view of the studied altitudinal range (B) in the coastal Atlantic Forest region of São Paulo state, southeastern Brazil.

adjacent to protected areas, in private landholdings with or without land title.

The study region has a tropical, humid climate, with a lower average annual temperature (20°C) and rainfall (1200 mm) in Natividade da Serra compared to Ubatuba (24°C and 2500 mm, respectively; INMET 2014). The vegetation is predominantly dense, evergreen rain forest, composed of different forest types according to altitude (lowland forest: 0–50 m asl; submontane forest: 50–500 m asl; and montane forest: 500–1500 m asl; IBGE 2012). These forests grow on nutrients poor inceptisols soils with high concentrations of aluminum and low cation concentration (Sousa Neto *et al.* 2011, Brancalion *et al.* 2012b). Soil carbon and nitrogen content increases with altitude (Sousa Neto *et al.* 2011). Topographic factors strongly influenced the floristic patterns along this elevation gradient, together with disturbance and elevation related variables (Eisenlohr *et al.* 2013). In addition, soil characteristics were shown to affect the potential for NTFP sustainable management in the Atlantic Forest (Brancalion *et al.* 2012b).

Local Communities.—We performed vegetation assessments and interviews in Vargem Grande (VG) village, located at the plateau formed over the mountain top (700–1000 m asl) in Natividade da Serra, and in Cambury (CA), Sertão da Fazenda (SF) and Sertão do Ubatumirim (SU), located at the coastal plains and mountain slopes north of Ubatuba municipality (0–1000 m asl, Table 1; Fig. 1). VG comprises montane forests while the other villages comprise lowland and submontane formations. These communities were selected because of their active involvement in forest management and agroforestry systems, especially regarding fruit exploitation of the palm *Euterpe edulis* Mart. (*juçara*, Arecaceae), an endemic, threatened species traditionally harvested by

TABLE 1. *Local communities and number of interviewed people.*

Communities	Number of inhabitants	Number of families	Number of *E. edulis* managers	Number of *E. edulis* managers interviewed	Number of people participating in free listing of plants
Vargem Grande	285*	56	15	13	15
Cambury	308†	77	8	5	16
Sertão da Fazenda	105‡	44	13	8	10
Sertão do Ubatumirim	399†	132	42	19	20
Total	812	310	78	45	61

*Assuming five people in each family counted by Pilla and Amorozo (2009).
†Data from health care centers at each community (2014).
‡Data from Simões (2010).

cutting the plant to take the palm heart (Matos & Bovi 2002). Stimulated by local NGOs (IPEMA and Akarui), these communities started to manage fruits of *E. edulis* to produce a highly energetic and nutritional drink (Silva *et al.* 2011), similar to its worldwide known conspecific *Euterpe oleraceae* Mart. (*açaí*) from the Amazon region (Trevisan *et al.* 2015). Fruit production relies on the maintenance of well-developed stands of *E. edulis* and prevention of predatory harvesting by poachers, although harvesting palm hearts implies killing trees, because this single-stemmed palm cannot re-sprout after being cut (Brancalion *et al.* 2012b, Souza 2015, Trevisan *et al.* 2015).

The local communities comprise distinct cultural groups, considered as the main non-indigenous traditional communities of southeastern Brazil: *Caipiras*, *Caiçaras,* and *Quilombolas* (Diegues & Arruda 2001). *Caipiras* and *Caiçaras* are descendants of Amerindians and Europeans. The former live inland and the latter on the coast of Rio de Janeiro, São Paulo, and Paraná states (Begossi 2006, Pilla & Amorozo 2009). *Quilombolas* are afro-Brazilian communities, descendants of a large contingent of slaves brought to Brazil until late 19th Century to work in agriculture (Penna-firme & Brondízio 2007). The three groups traditionally lived on subsistence agriculture, fishing (especially *caiçaras*), extraction and handicrafts; however their economic activities have diversified, with increasing participation in the services sector (Pilla & Amorozo 2009, Hanazaki *et al.* 2013). Among the studied communities, land tenure is mostly private in VG and SU and communal in SF and CA, where *Quilombola* territories have been recognized, however land titles are still unclear (Instituto Florestal 2006).

Vegetation Assessment and Analysis.—Composition and structure of secondary forests (hereafter SecF) and agroforests (hereafter AgrF) managed by communities were investigated by assessing of large individuals (dbh ≥ 4.8 cm), including trees, tree ferns, palms, and banana plants (Fig. 2). These plants were sampled in circular subplots (0.031 ha), randomly established along 100-m transects systematically distributed in SecF and AgrF (Table 2). Secondary forests consisted of fallows of different regeneration ages (15–80 yr old) recovering from agricultural use,

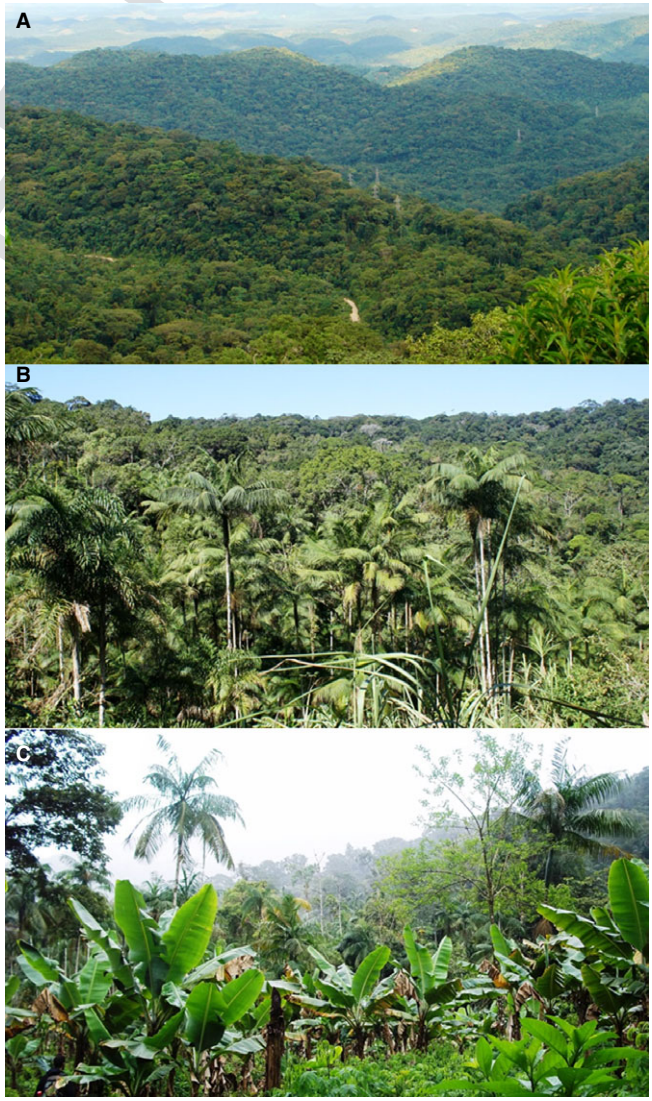

FIGURE 2. External view of examples of an old growth, reference forest (A), a managed secondary forest (B), and an agroforest (C) studied in the coastal Atlantic Forest of southeastern Brazil.

TABLE 2. *Sampling design of arboreal communities (≥4.8 cm dbh) managed by four local communities along the Atlantic Forest of Serra do Mar, Southeastern Brazil.*

Forest type (Communities)	Physiognomy	Altitude (m asl)	Time since regeneration or occupation (yr)	*N* samples	*N* subplots	Sampling area (ha)
Montane (VG)	Secondary forests	812–839	30–80	3	11	0.345
Submontane (CA and SU)	Secondary forests	178–232	30	3	9	0.282
	Agroforestry systems	90–281	15–45	4	13	0.408
Lowland (SU and SF)	Secondary forests	11–38	20–60	3	9	0.282
	Agroforestry systems	12–28	30–40	3	9	0.282
Total				16	51	1.602

mostly manioc and banana production (Table 2) and where local people harvest *E. edulis* fruits and implement enrichment plantings with this species, and eventually grow some crops in natural clearings (Macêdo 2014). Agroforests were represented by polyculture systems, consisted of traditional *bananal* in submontane formations (banana plantation in forest clearings without using fire, intercropped among useful native trees, where natural regeneration is managed), and homegardens in the lowland areas of the study region. Bananas are the main cash crops in submontane AgrF, while banana, manioc, peach palm, and other fruit trees are the main commercially grown species in homegardens (Souza 2015). Agroforests were not sampled in montane vegetation areas because there were not enough available areas.

Species were identified and classified according to their life form, biogeographic origin (native and exotic), and threatened status (Brasil 2008). Old growth, unmanaged forests were used as reference ecosystems in this study (hereafter RefF), and data were taken from studies of nearby forests in the same region and altitudinal range, using the same sampling scheme (Alves *et al.* 2010, Gomes *et al.* 2011, Padgurschi *et al.* 2011, Prata *et al.* 2011, Ramos *et al.* 2011). Field protocols and further results of these studies are found in Joly *et al.* (2012) and Eisenlohr *et al.* (2013). Excluding banana and standing dead trees, overall density per hectare was compared through Kruskall–Wallis test, followed by Wilcoxon rank-sum tests to identify if SecF and AgrF are different to RefF of the same elevation zone. Comparisons were also made irrespective to elevation zones. The same statistical procedure was used to analyze differences in densities of different life-forms. Basal area (m^2/ha) data were analyzed using ANOVA, preceded by Shapiro-Wilk and Bartlett tests to assess the assumptions of analysis of variance, and followed by Tukey HSD *post-hoc* test.

Individual based rarefaction analysis was performed to compare species richness among SecF, AgrF, and RefF (Magurran 2004). The rarefaction point for expected species richness comparisons was 79, which was the minimum number of individuals recorded in lowland AgrF plots. For assessing floristic similarity among sampled and reference sites, we used Chao-Jaccard abundance-based index, which can handle different sample sizes and take into account the number of unseen species pairs (Chao *et al.* 2005). These analyses were performed using the 'vegan' package (Oksanen *et al.* 2013) in R (R Core Team, 2014).

Socioeconomic Assessment and Analysis.—Between 2013 and 2014, we conducted semi-structured interviews with 45 people participating in the value chain of *E. edulis* fruit pulp (Table 1). This sample represents the groups of people engaged in the management of this NTFP in AgrF and SecF, which account for 3–14 percent of all the residents of each community (Table 1). Respondents averaged 38.1 ± 12.8 SD years old, 68 percent were men and 32 percent women. The majority of respondents (65%) have lived in the community since birth. We assessed the livelihood activities and the products cultivated or harvested from AgrF and SecF by counting the number of times a product was mentioned during the interviews. Each respondent working in agricultural, forestry and fishery sector mentioned important products in terms of income contribution, giving a total of 223 citations related to 44 products, being 15 primary and 29 secondary products. We also asked interviewees to provide an estimated annual income obtained from *E. edulis* fruit pulp production individually in the study systems.

Ethnobotanical Assessment and Analysis.—We used a free-listing method, in which participants were asked to spontaneously list names of plants they knew and report their related uses. The selection of participants was carried out using the 'snowball' method (Bailey 1994), which provided access to people considered plant experts within the community. In total, 61 people were interviewed (Table 1) with mean age of 58 (±15.5) years old and a high proportion of men (65%). In addition, five participants of the 61 guided walks across different local vegetation types for plant identification and association with plant names listed by the whole group. A total of 252 botanical samples were collected during guided walks, which was not enough to identify the scientific names of all quoted plants by each participant. To reduce mistakes due to different botanical identification by different participants, each ethnospecies was considered by grouping quoted ethnovarieties (plants with compound names) in accordance with their first name (Berlin 1992).

Ethnospecies were classified according to life form (*e.g.*, herbs, vines, shrubs, palms, and trees), biogeographic origin (native and exotic to the Atlantic Forest) and use category (food, medicine, construction, manufacturing, and other). Different forms of use in the same category were deemed to be one quote from use. The

'manufacturing' category included ethnospecies used for making handicrafts, household items, tools and work equipment such as canoes. The 'other' category included ethnospecies used for purposes not covered by other categories such as: firewood, wildlife food, and for veterinary, religious, mystical, and recreation uses. To identify the use value of each ethnospecies we used the Cultural Importance Index (CI), which is the sum of the proportion of respondents who mentioned each use category for an ethnospecies (Tardio & Pardo-De-Santayana 2008). Thus, each ethnospecies' CI could reach the maximum value of five. In this article we only reported scientific names and other relevant information of ethnospecies with CI higher than one.

RESULTS

Ecological Importance of Agroforests and Managed Secondary Forests.—A total of 2543 tree-sized plants (dbh ≥ 4.8 cm) were recorded in community-managed areas. Average number of individuals/ha, excluding bananas (*Musa paradisiaca*), ranged from approximately 1000 in AgrF to over 2000 in SecF (Fig. 3A), being higher in SecF and RefF compared to AgrF (Kruskal–Wallis $\chi^2 = 17.56$, df = 7, $P = 0.0141$). However, further paired comparisons in each altitudinal range did not identify significant differences between managed areas (AgrF and SecF) and RefF (Fig. 3A), or between AgrF and SecF (Wilcoxon rank sum test, $P > 0.05$); only the density of individuals from submontane SecF was higher than that of lowland RefF (W = 15, $P = 0.0357$). Overall, basal area was higher in RefF forests than in managed forests ($F = 3.475$, df = 7, $P = 0.0185$; Fig. 3B); however, when comparisons were restricted to the same altitudinal range, basal area was only higher in RefF compared to AgrF in submontane forests (Tukey HSD, $P = 0.0099$; Fig. 3B).

In general, 54 percent of surveyed plants in SecF and AgrF were palms, 34 percent trees, 9 percent bananas, and 4 percent tree ferns. The most abundant species was the palm *E. edulis*, which accounted for 30–62 percent of tree-sized plants in SecF and 47–61 percent in AgrF. Agroforests and SecF had lower density of trees (Kruskal–Wallis $\chi^2 = 25.499$, df = 7, $P = 0.0006$) and higher density of palms (Kruskal–Wallis $\chi^2 = 23.441$, df = 7, $P = 0.0014$) than RefF, except for the montane altitudinal range, where results did not differ (Fig. 4). Palm density did not differ between AgrF and SecF ($P < 0.05$). Bananas were unique elements of managed areas, predominating in AgrF, but were also found in SecF; however, their density was only higher in submontane AgrF compared to montane SecF (W = 12, $P = 0.0497$; Fig. 4). Tree fern density was lower in RefF compared to AgrF and SecF (Kruskall–Wallis $\chi^2 = 20.457$, df = 7, $P = 0.0046$); however, paired tests performed in each altitudinal range indicated that tree fern density only differed in submontane forests, being higher in AgrF than in RefF (W = 0.5, $P = 0.0359$; Fig. 3). When AgrF and SecF were compared, tree fern density was only higher in montane SecF compared to submontane AgrF (W = 0, $P = 0.0436$).

We identified 184 species (including 46 morphospecies) in SecF (62–109 spp.) and AgrF (24–39 spp.), from 47 families

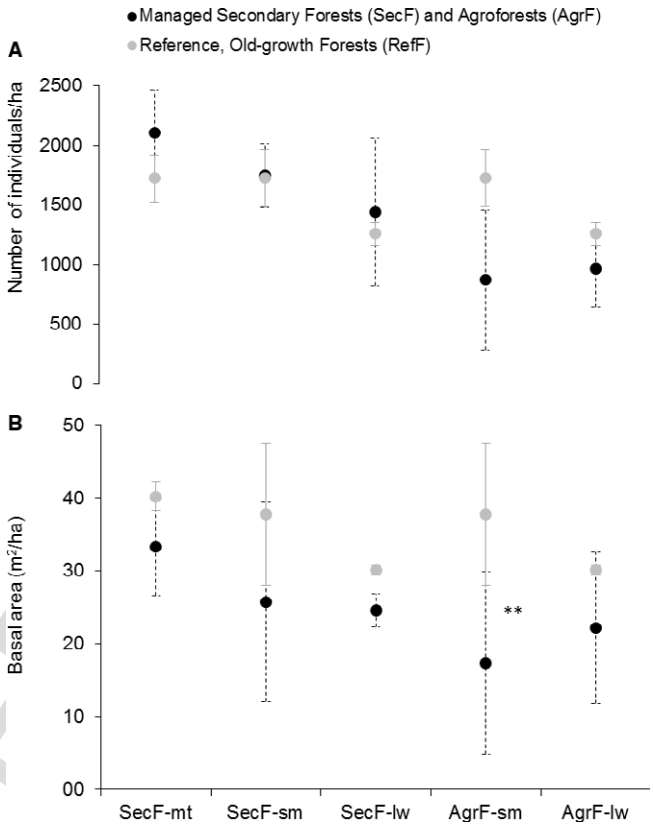

FIGURE 3. Comparison of absolute density (A) and basal area (B) of tree-sized individuals (dbh ≥ 4.8 cm), within different altitude levels (mt = montane, sm = submontane and lw = lowland), between managed secondary forests (SecF) or Agroforests (AgrF) and reference, old growth unmanaged forests (RefF) in the coastal Atlantic Forest region of São Paulo state, southeastern Brazil. Statistical difference according to Tukey HSD post-hoc test: ** for $P \leq 1\%$.

(Table S1). Myrtaceae, Rubiaceae, and Fabaceae were the richest botanical families accounting to 24, 16, and 15 species respectively. Among these species, five are listed as endangered: *Euterpe edulis* (Arecaceae), *Ocotea odorifera* (Lauraceae), *Cariniana legalis* (Lecythidaceae), *Miconia picinguabensis* (Melastomataceae), and *Cordia trichoclada* (Boraginaceae). Overall, species richness was lower in AgrF and higher in RefF, with SecF at an intermediate level (Fig. 5). However, SecF showed similar species richness than RefF in the montane range (Fig. 5). Chao-Jaccard similarity index was highest between SecF and AgrF (0.39–0.94), intermediate between SecF and RefF (0.33–0.76) and lowest between AgrF and RefF (0.12–0.39, Table S2).

Socioeconomic Importance of Local Productive Systems.—Regarding to different major livelihood activities, agriculture was by far the most frequent (34%) among respondents, followed by forestry (production of seeds and seedlings of native forest species, 6%). Thirteen other different major livelihood activities were cited and 73 percent of respondents also cited complementary activities. Most commercially important products for local

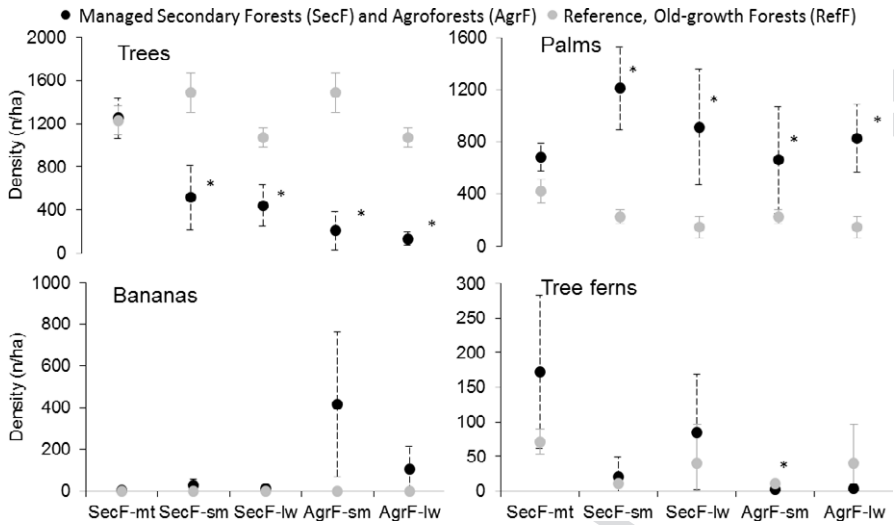

FIGURE 4. Density (n/ha) of different life forms in arboreal communities of managed areas (secondary forests – SecF, and or Agroforests – AgrF) within different forest types (mt = montane, sm = submontane and lw = lowland) contrasted to its reference, old growth unmanaged forests (RefF) (Alves *et al.* 2010) in the coastal Atlantic Forest region of São Paulo state, southeastern Brazil. Statistical difference according to chi-square test: * for $P \leq 5\%$ and ** for $P \leq 1\%$.

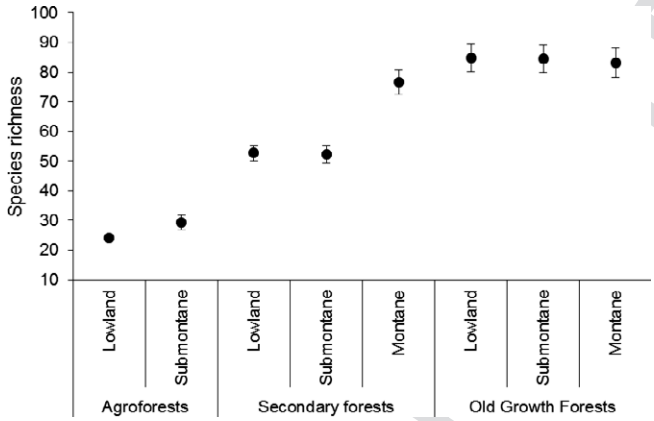

FIGURE 5. Comparison of rarefied species richness among agroforests, managed secondary forests and reference, unmanaged old growth forests along the Atlantic Forest of Serra do Mar (SE Brazil) at the point of equal number of individuals. Bars indicate standard error.

livelihoods are obtained from SecF and AgrF, being the production from shifting cultivation or permanent crop fields, pastures and sea less prominent (Table 3). In descending order, the three most frequently cited products were banana, *E. edulis* fruit pulp and manioc; however, manioc flour was the only product quoted across all communities (Table 3). While *E. edulis* fruits were harvested in SecF and AgrF, bananas were predominantly grown in AgrF, and manioc in opened areas in the traditional shifting cultivation system, homegardens and other more permanent cultivation fields. In addition to the main products in Table 3, respondents also listed 33 products of secondary economic importance (Table S3). Income from the *E. edulis* fruit pulp production has been complementary and its economic importance differs among communities. In both communities where it was considered among the main products (VG and SU, Table 3), the estimated economic contribution for their individual annual income was 3.5 and 20.2 percent on average respectively. SF and CA respondents reported very low contribution of *E. edulis* fruit pulp to their annual income (below 1%). Between 2012 and 2014, annual individual income from *E. edulis* pulp production ranged between US 135.14 and US 2,252.25 (1 US = R 2.22 on 2 May, 2014).

Cultural Importance of Locally Used Plants.—Considering the aggregated results of the ethnobotanical assessment in the four communities, a total of 4573 use citations about 442 plant ethnospecies were recorded, of which, 231 were native Atlantic Forest species. 'Native' ethnospecies, 'food' use category, and 'tree' life form were the most cited categories (Fig. 6). Part of the cited ethnospecies (40.5%) could be obtained from cultivation or bought from local or regional markets, while the majority (59.5%) could be obtained through harvesting from managed or wild plant populations found in different production systems (SecF, AgrF, pasturelands, and crop fields), or in other local ecosystems. Only 13 native ethnospecies (3%), with different degrees of domestication, were reported as being deliberately cultivated, as *E. edulis*, the ethnospecies with the highest index of cultural importance. Among the plants of highest cultural importance, most are native to the Atlantic Forest and used predominantly for food (Table 4). These plants were considered widely versatile, used in various ways for various purposes, and obtained mainly through harvesting from SecF and AgrF (Table 4). Most of the ethnospecies listed in Table 4 encompasses numerous ethnovarieties. For instance, *canela* (Lauraceae spp.), *ingá* (*Inga* spp., Fabaceae), and *mandioca* (*Manihot esculenta*, Euphorbiaceae) ethnospecies comprise 22, 19, and 51 distinct ethnovarieties respectively.

TABLE 3. *Citation frequency (%) of main commercial products declared by smallholders from four local communities in the coastal Atlantic Forest region of São Paulo state, southeastern Brazil. VG = Vargem Grande (800–1100 m asl,* N = *13); SU = Sertão do Ubatumirim (10–600 m asl,* N = *19); SF = Sertão da Fazenda (5–150 m asl,* N = *8); CA = Ubatumirim (0–300 m asl,* N = *5).*

	Local communities				
Production systems and main products	VG	SU	SF	CA	General
Secondary forests and agroforests					
Craftwork (mostly made from wood of dead trees and climbers stems)			1.7	3.3	5.0
Juçara fruit pulp (mostly frozen fruit pulp from the endemic palm *Euterpe edulis* – Arecaceae)	6.7	10.0			16.7
Seeds and locally grown seedlings from approximately 50 species of native trees	8.3				8.3
Total	15.0	10.0	1.7	3.3	30.0
Agroforests					–
Bananas (*in natura*)		25.0	1.7		26.7
Cambuci (frozen fruits and pulp from the endemic tree *Campomanesia phaea* – Myrtaceae)		1.7	1.7		3.4
Palm heart (*in natura* from peach palm – *Bactris gasipaes* – Arecaceae)			1.7		1.7
Total	–	26.7	5.1	–	31.8
Shifting cultivation or permanent crop fields					–
Cassava (*in natura* or semi-processed)		11.7	1.7		13.4
Cassava flour (processed with traditional technology)	1.7	5.0	1.7	1.7	10.1
Greenery	3.3				3.3
Total	5.0	16.7	3.4	1.7	26.8
Pastures					–
Dairy cattle (calves)	1.7				1.7
Cheese	1.7				1.7
Milk	3.3				3.3
Total	6.7	–	–	–	6.7
Sea					–
Fish		1.7			1.7
Shrimp		1.7			1.7
Squid		1.7			1.7
Total	–	5.1	–	–	5.1

DISCUSSION

Agroforests and SecF showed remarkable potential to contribute to the overall goals of FLR programs, since these production systems (1) re-established a well-developed forest structure, with evident benefits for carbon sequestration, soil protection, water infiltration, and habitat provision for wildlife; (2) are composed by a rich array of native species, including many threatened, complementing biodiversity conservation in adjacent protected areas and serving as buffer zones; and (3) improved local livelihoods by supplying market valuable and culturally important plants, reducing the pressure upon protected areas. Therefore, the adoption of these production systems may allow for the achievement of the idealist win-win-win scenario promoted by FLR in terms of ecosystem services provisioning, biodiversity conservation, and human well-being. Although such land-sharing approaches should be seen as complementary to land-sparing perspectives for maximizing food, fuel, and fiber production per unit of area and biodiversity conservation in reserves, it may represent the best solution for engaging smallholders of developing tropical countries in FLR programs.

Overall, AgrF and SecF showed a great potential to assist natural regeneration in the Atlantic Forest, supporting the reestablishment of a well-developed, species-rich forest structure in the short term. In spite of the differences in precipitation, temperature, and soil, we did not find a clear pattern of variation in density of individuals and basal area across the altitudinal range, which demonstrates the viability of these community-managed systems under a large array of environmental conditions. Managed secondary forests, in particular, exhibited higher species richness than AgrF and, in the case of the 30–80 yr old montane SecF, similar species richness than RefF, indicating the role of second growth forests in fostering biodiversity conservation in forested landscapes. Although the resilience of tropical forests depend upon several factors (Holl & Aide 2011), these ecosystems often exhibit high ecological resilience in landscapes with forested matrices (Letcher & Chazdon 2009, Norden *et al.* 2009), as observed in our study region.

When conserved old growth forest remnants are found within less fragmented landscapes, secondary forests may play a valuable role for biodiversity conservation and ecosystem functioning (Dent & Joseph Wright 2009, Pinotti *et al.* 2015). The

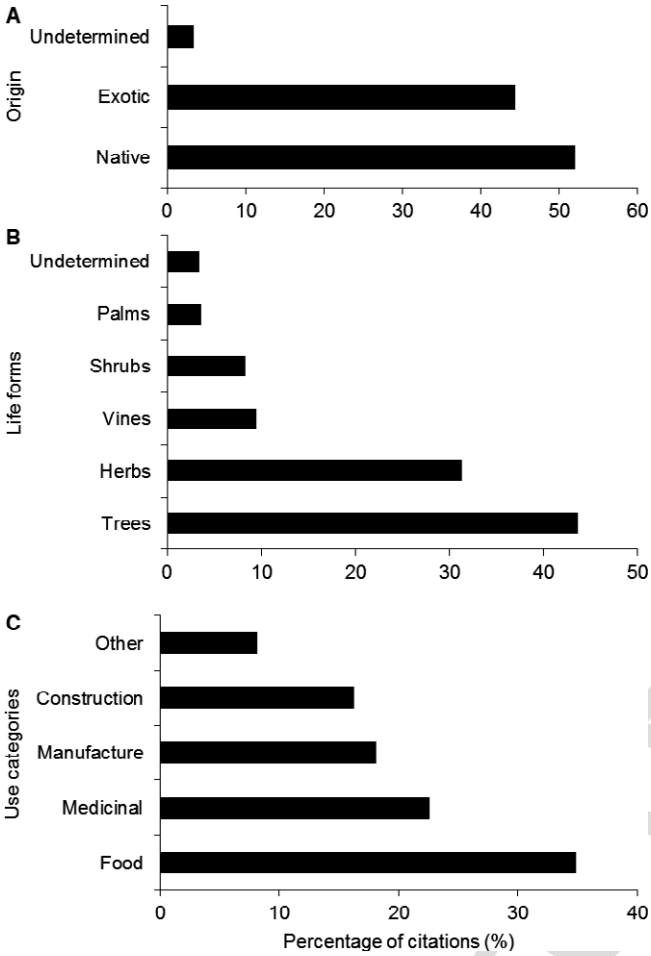

FIGURE 6. Percentage of ethnospecies citations according to biogeographic origin (A), life forms (B) and use category (C). Aggregated data from four local communities (N = 61) of the coastal Atlantic Forest region of São Paulo state, southeastern Brazil.

Serra do Mar biogeographic region is, by far, the most conserved of the Atlantic Forest biome, with 32 percent of remaining forest cover (Ribeiro *et al.* 2009), and the study region is located on the periphery of the largest remnants of this biogeographic region. The *Serra do Mar* harbors some of the richest forests of Neotropics, comprising over 200 tree species per hectare (Eisenlohr *et al.* 2013). Thus, the positive results of community management to assist forest regeneration were certainly favored by this biodiversity-friendly context. Otherwise, in less forested areas and more degraded sites the ecological outcomes would be less pronounced, demanding higher efforts to increase biodiversity and recover ecosystem functions through other management approaches (Chazdon *et al.* 2008). However, as expected, AgrF and SecF showed a number of compositional and structural differences compared to old growth, reference ecosystems.

The first difference was related to the proportion of trees and palms in the study sites, which was mostly driven by the abundance of *E. edulis*, one of the most common species (dbh > 4.8 cm) in Atlantic rainforests, with over 200 individuals per hectare in conserved areas (Brancalion *et al.* 2012b). Besides the architecture of palms that enables a higher number of individuals per unit area compared to trees, the higher proportion of palms in AgrF and SecF can be explained by both illegal palm-cutting in the RefF, a common problem even inside protected areas (Galetti & Chivers 1995, Muler *et al.* 2014), and assisted regeneration of *E. edulis* in AgrF and SecF to support fruit pulp production. In fact, field assessments with the same inventory procedures inside the state park, adjacent to the studied AgrF and SecF plots, showed a very low density of reproductive *E. edulis* individuals (34 individuals/ha) as a consequence of illegal heart of palm harvesting (Chagas 2015). A similar result was observed in another protected area of São Paulo state, in which illegal *E. edulis* harvesting reduced density of individuals dbh > 4.8 cm in permanent plots from 202 to 26 individuals/ha (Muler *et al.* 2014).

The very high density of this threatened palm species within community-managed systems provides sound evidence that social and governance norms established by local communities were more effective than those established by environmental agencies to protect *E. edulis* from illegal harvesting. Social strengthening of traditional communities and promotion of sustainable use of *E. edulis* through palm fruit exploitation, rather than its heart, have been the focus of *Rede Juçara* (*Juçara Network*), including more than 500 families from South and Southeast Brazil (Rede Juçara 2012). Outcomes reported here for *E. edulis* conservation demonstrate that their strategy has, at a first glance, succeeded. However, some relevant governance challenges have limited the success of *E. edulis* fruit pulp management in the southern coast of São Paulo state, including policy barriers for cultivating threatened species, sanitary rules for commercialization, access to markets and equipment, and limitations of the most disadvantaged members of communities to benefit from this activity (Ball & Brancalion 2016).

Forest structure usually recovers more rapidly than species composition in unmanaged secondary forests (Aide *et al.* 2000, Martin *et al.* 2014), but little is known on how this trend shifts in managed stands. For instance, management practices were found to shape both the structure and floristic diversity of managed stands, favoring useful species in Central America and Africa (Asase & Tetteh 2010, López-Acosta *et al.* 2014). Our results showed less prominent alterations of tree density and basal area in managed areas compared to unmanaged old growth forests than species richness. Palm density increase due to cultivation and protection of natural regeneration help to explain these results; however the basal area results were mostly attributed to other large trees present in these systems, especially pioneers, residual and useful species, such as *Alchornea triplinervia* (Euphorbiaceae), *Cabralea canjerana* (Meliaceae), *Ficus adhatodifolia* (Moraceae), *Hyeronima alchorneoides* (Phyllantaceae), *Piptadaenia gonoachanta* (Fabaceae), *Tibouchina mutabilis* (Melastomataceae), and *Virola bicuhyba* (Myristicaceae), among others. In addition, there is a naturally high density of individuals in the initial phases of succession, with a peak in the 'understory reinitiating' phase, before the 'stem exclusion' phase of forest succession, which occurs after 40–70 yr (Oliver & Larson 1996).

TABLE 4. *Most culturally important plant ethnospecies (Cultural Importance Index > 1) at four local communities in the coastal Atlantic Forest region of São Paulo state, southeastern Brazil. N = Native; E = Exotic; H = Harvested; C = Cultivated; M = Obtained in the market.*

Life form/Ethnospecies	Species	Botanical family	Origin	Management	Environment	Cultural importance index	Main use categories
Trees							
Canela	*Cryptocaria* sp. pl.; *Endlicheria paniculata* (Spreng.) Macbride; *Nectandra* sp. pl.; *Ocotea* sp. pl.	Lauraceae	Native	H	Forest and agroforest	1.69	Construction and medicinal
inga	*Inga* sp. pl.	Fabaceae	Native	H/C	Forest and agroforest	1.38	Food, construction and manufacture
ipê	*Handroanthus* sp. pl.	Bignoniaceae	Native	H	Forest	1.36	Medicinal and construction
jatobá/jataí	*Hymenaea courbaril* L.	Fabaceae	Native	H	Forest	1.26	Medicinal and construction
cedro	*Cedrela* sp. pl.	Meliaceae	Native	H	Forest and agroforest	1.11	Construction and manufacture
laranjeira	*Citrus sinensis* (L.) Osbeck	Rutaceae	Exotic	C	Agroforest	1.00	Food and medicinal
Shrubs							
mandioca/ipi/ aipim	*Manihot esculenta* L.	Euphorbiaceae	Exotic	C	Orchard	1.05	Food
Palms							
juçara/jiçara/ palmito	*Euterpe edulis* Mart.	Arecaceae	Native	H/C	Forest and agroforest	1.95	Food and construction
patiero	*Syagrus pseudococus* (Raddi) Glassman	Arecaceae	Native	H	Forest and agroforest	1.46	Food and construction

Although the studied community managed systems showed high levels of species richness, including threatened species, RefF had three and 1.5 more species than AgrF and SecF respectively. This is an expected result given the young age of AgrF and SecF, which limits the time required to accumulate the full number of species they can potentially host, including late successional species that take longer to establish along succession (Chazdon 2014, Gilman *et al.* 2016). In the older (30–80 yr old) SecF of the montane region, species richness was similar to that of RefF. The same observations apply to the results on floristic similarity, which was lower between managed systems and RefF. Each stage of tropical forest succession is characterized by particular group of species, with functional traits adapted to the ecological conditions of each stage; however, even forests at the same successional stage may have distinct floristic composition, as consequence of a myriad of different pre-established and stochastic environmental factors driven succession (Arroyo-Rodríguez *et al.* 2015).

Regarding socioeconomic outcomes, AgrF and SecF play an important role, providing a significant share of economic activity of interviewed farmers. Two endemic species to the Atlantic Forest (*E. edulis* and *Campomanesia phaea*) demonstrated the high economic importance of these production systems for smallholders. Interestingly, forest and agroforest management were more common among respondents than that of cattle ranching activity, recognized as the main driver of deforestation in the Neotropics (Aide *et al.* 2013). In spite of these promising results, the pressure to reconvert these systems to crop fields and pastures, or to shorten fallow periods, are high in tropical regions (van Vliet *et al.* 2012, Magnuszewski *et al.* 2015). Strengthening community management systems may therefore be a vital key to sustain increasing and permanent levels of tree cover in tropical regions.

Constraints on the maintenance and expansion of protected areas coupled with the need to augment landscape permeability through biodiversity friendly production systems (Sayer *et al.* 2013, Juffe-Bignoli *et al.* 2014) highlight the important role SecF and AgrF can play toward the conservation of threatened species. Even with reduced species richness, we found five threatened species, *E. edulis* being the most prominent, reaching a six-fold density increase in relation to the populations in protected areas. When a plant is threatened by overexploitation, a feasible conservation strategy could be to stimulate agroforestry production that potentially reduces pressure on wild populations and takes advantage of the socioeconomic and ecological features that makes the species desirable. Nevertheless, although other community production systems across the tropics might not host economically important threatened species as our study area, fallows and complex agroforests could still play important roles for biodiversity conservation in other human-dominated landscapes, providing habitat to a diverse array of taxa, favoring genetic flow and acting as biological corridors and 'stepping stones' (Bhagwat *et al.* 2008). Additionally, in contrast with intense commodities` agriculture,

community production systems may raise local food security and nutrition (Chappell & LaValle 2011, Tscharntke *et al.* 2012), improve soil characteristics and offer protection against widespread pests (Ewel 1986).

The new economic cycle of *juçara* palm based on its fruits instead of palm heart has been of great importance in reversing the threat status of the species, since increasing survival of adult palms can promote further recruitment of seedlings (de Souza 2015). As soon as local producers realize that yearly fruit yield exceeds that of a single cut of each palm, it increases the protection level of remnant populations and interest for planting, which, in turn, favor its conservation status while offering an excellent opportunity to boost agroforestry production across the Atlantic Forest (Trevisan, 2015). In our study sites, total frozen pulp production increased from one ton in 2009 to more than 11 in 2014 (de Souza 2015). With proper fruit processing, each kilo of pulp could yield another kilo of good quality seeds, which accounts to 800–1000 seeds that have been planted, donated, or marketed (Rede Juçara 2012, de Souza 2015, Trevisan, 2015). Although the monetary income from *juçara* was just complementary, and even insignificant in some communities, the consumption of its multiple products and the high cultural value attributed to the species have encouraged its management. However, policy restrictions to manage native and endangered species, sanitary legislation requirements not applicable to smallholders and subsidies favoring non-native species products are amongst the barriers to improve *E. edulis* fruit pulp supply chain (Rede Juçara 2012, Ball & Brancalion 2016). Besides, planting and managing trees require a long-term perspective of land rights, which is somehow threatened across the study area because of strong real estate speculation and weak land tenure of communities inside protected areas.

The prominent importance of forest products for household income is not a result restricted to this study. In an extensive inventory of over eight thousand households located in 33 countries in Africa, Asia and Latin America, income obtained from forest products contributed, on average, to 21 percent of household income; coupled with the income from non-forest ecosystems and that from agriculture, including agroforestry, the participation raised to almost 60 percent (Angelsen *et al.* 2014). Therefore, it is imperative to consider in the implementation of FLR the socio-economic needs of smallholders and family farmers, which manage more than one billion hectares of the global agricultural land and 98 percent of farms (Graeub *et al.* 2015, Adams *et al.* 2016). However, the importance of AgrF and SecF for local livelihoods should not be restricted to income generation, since many locally used species are also culturally important. Our results reinforced the key role of spontaneous and assisted regeneration for providing ethnospecies with high cultural value.

Thus, assisted natural regeneration by local communities may promote diversified forest regrowth in tropical regions, and constitute solid foundation for a long-term mode of reforestation at the landscape scale that is beneficial to humans and the planet (Chazdon 2012). Traditional forest-based community systems of management have overcome the test of time as effective approaches to take advantage of ecological resilience, to enhance local livelihoods and maintain high levels of forest cover in forested landscapes, in spite of the lack of supportive policies and financial mechanisms from modern economies. Thus, these production systems may ease community involvement in FLR programs, fostering reforestation of degraded landscapes and providing economic benefits and food security to farmers and local communities who cannot afford to allow forest regrowth without receiving some form of material benefit (Chappell & LaValle 2011). To foster FLR in developing countries of tropical regions, we advocate the promotion of these systems as effective approaches in national and international programs and policies, the valuation of their positive environmental outcomes through payments for ecosystem services, and the development of the market chain of commercially valuable native forest species.

ACKNOWLEDGMENTS

We are grateful for the inhabitants of Vargem Grande, Sertão do Ubatumirim, Sertão da Fazenda, and Cambury for their collaboration with this study. We thank local NGOs (IPEMA and Akarui), graduate and undergraduate students associated with LASTROP for their field assistance, and Fundação Florestal and IBAMA for research permits. We also thank Thiago Flores, Marcelo Ferreira, and Renato Lima for support in plant identification. S.E.X.F.S thanks São Paulo Research Foundation (FAPESP # 2011/02941-5) and National Council for Scientific and Technological Development (CNPq) for financial support, and PHSB thanks CNPq for a productivity grant (#304817/2015-5).

SUPPORTING INFORMATION

Additional Supporting Information may be found online in the supporting information tab for this article:

TABLE S1. *List of tree-sized species (dbh ≥ 4.8 cm) found in community-managed agroforests and secondary forest in the costal Atlantic Forest of Southeastern Brazil.*

TABLE S2. *Chao-Jaccard similarity index of different forest and agroforest types, along an altitudinal gradient in the costal Atlantic Forest of Southeastern Brazil.*

TABLE S3. *Citation frequency of secondary products of agricultural and silvicultural production of four communities in the coastal Atlantic Forest region, southeastern Brazil.*

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