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Fruit color preference by birds and applications to ecological restoration

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Abstract

Ecological restoration aims to retrieve not only the structure but also the functionality of ecosystems. Frugivorous birds may play an important role in this process due to their efficiency in seed dispersal. Color perception in these animals is highly developed, and then the colors of fleshy fruits may provide important clues for choosing plant species for restoration plans. This study aims to integrate bird color preferences and restoration of degraded areas, with an objective to evaluate the potential attractiveness to birds by colored fruits. We carried out an experiment with 384 artificial fruits made of edible modeling clay with the following colors: black, blue, green and red, with 96 fruits of each color in six sites, including four restored areas and two second-growth forest fragments. We also tested the possible effect of light intensity on fruit consumption by color. A total of 120 (38.6%) were assumed to be consumed by birds, and the fruit consumption varied in response to the location and light incidence. Consumption of black and blue fruits was not related to site by chance. Notwithstanding, red and black fruits were consumed significantly more than any other colors, emphasizing bird preference to these colors, regardless of location. Enrichment with shade tolerant shrubs or forest species with black or red fruits may be an alternative way to manage established restorations. In recently established or new restorations, one may introduce pioneer shrubs or short-lived forest species which have blue fruits, but also those having black or red ones.

Keywords: artificial fruits, Atlantic Forest, frugivory, ecological succession, color perception.

Preferência de cor de frutos por aves e aplicações à restauração ecológica

Resumo

A restauração ecológica tem a finalidade de recuperar não apenas a estrutura, mas também a funcionalidade dos ecossistemas, e as aves frugívoras podem desempenhar um papel importante neste processo devido à sua eficiência na dispersão de sementes. Como a percepção da cor nestes animais é altamente desenvolvida, a cor dos frutos carnosos pode ser uma característica importante na escolha de espécies de plantas para os reflorestamentos. Este estudo tem como foco integrar a preferência de cor de frutos por aves e a recuperação de áreas degradadas, objetivando determinar a atratividade potencial de aves por frutos de cores diferentes. Foi realizado um experimento com 384 frutos artificiais feitos com massa de modelar comestível nas cores preta, azul, verde e vermelha, com um total de 96 frutos em cada cor em seis locais, incluindo quatro áreas restauradas e dois fragmentos de floresta secundária. Também foi testado o possível efeito da intensidade de luz sobre o consumo de frutos conforme as cores. Um total de 120 (38,6%) frutos foi considerado consumido pelas aves, e o consumo variou em resposta aos locais e incidência de luz. O consumo de frutos pretos e azuis foi significativamente relacionado com o local. Os frutos vermelhos e pretos foram significativamente mais consumidos do que as outras cores, enfatizando a preferência aves por essas cores, independentemente do local. O enriquecimento com espécies tolerantes à sombra com frutos pretos ou vermelhos pode ser uma alternativa para manejo de restaurações já estabelecidos; enquanto nos recentemente criados podem ser introduzidas espécies pioneiras ou florestais de vida curta com frutos azuis, pretos ou vermelhos.

Palavras-chave: frutos artificiais, Mata Atlântica, frugivoria, sucessão ecológica, percepção de cores.

1. Introduction

Humans have converted large areas of tropical, native vegetation into landscapes of mixed crops, pastureland, and frequently isolated remnants of native vegetation (Laurance and Bierregaard, 1997; Steffen et al., 2011). Such mosaics have led to an impoverishment in tropical biodiversity (Fahrig, 2003) and losses of functionality and ecosystem services, as pest and diseases control and plant recruitment (Classen et al., 2014; Gray and Lewis, 2014; Moleón et al., 2014).

Ecological restoration aims to assist the recovery of a degraded ecosystem (SER, 2004) within a functional perspective, allowing goals of increasing ecosystem sustainability and their services (Suding, 2011; Stanturf et al., 2014). These processes may be accelerated by enhancing plant-animal networks (Piña-Rodrigues et al., 2009). Plants and animals have multiple relationship levels, such as predation, pollination and seed dispersal (Menz et al., 2011; Nuismer et al., 2013), and these interactions represent opportunities to establish a continuous regeneration, since animals may be considered as natural "sowers" and "planters" (Cole et al., 2010; McConkey et al., 2012). Likewise, the maintenance of species diversity is considered an important regulating ecosystem service (Isbell et al., 2011).

Zoochory is the most common way of seed dispersal in tropical forests (Barcelos et al., 2012; Gonçalves et al., 2015 and references therein). Animal-dispersed fruits are usually fleshy berries or drupe, or dehiscent capsules that expose the seeds involved with an aril, which contains sources of carbohydrates and lipids (Fleming and John Kress, 2011).

Birds are the main frugivorous in the Neotropics and are efficient seed dispersers because they are very mobile and have high metabolism that requires constant energy consumption (Whelan et al., 2008; Gonçalves et al., 2015). They also show color sensitivity (Hart, 2001) and well developed brain and vision, which allow for learning (Martin, 1993). Color preferences and fidelity have been reported in previous studies (e.g. Puckey et al., 1996; Whitney, 2005); however, this may be transient and strongly depend upon the environment (Schmidt et al., 2004). Then, we may predict a non-random variation in fruit choice, based not only by colors but also due to the contrast that each color has in different background, which varies in areas having different luminosities.

Many frugivorous birds are able to use human-modified environments (such as crop fields and forest edges) and/or move across open areas and forest fragments (Gomes et al., 2008), thus increasing seed dispersal along their route and acting as "mobile links" (Lundberg and Moberg, 2003; Piña-Rodrigues et al., 2009). In this scenario, ecological restoration of degraded land also has the function of making this area more permeable and "bird-friendly", reestablishing links among isolated forest remnants and allowing gene flow and increasing biological and functional diversity (Cavallero et al., 2012). Thus, if appropriate species are used in a given restored area, forest enrichment with attractive species may increase functional processes such as seed dispersal.

Therefore, the aim of this study was to integrate fruit color preference by birds and restoration of degraded areas, in order to evaluate the potential attractiveness of birds by colored fruits in different sites. Our premise is that birds are generally attracted and consume fruits that are more conspicuous, considering that the choice of fruit also depends on the environment and light intensities. We predict that in recently restored areas, fruits would be more detected and consumed due to the high luminosity of these open areas. Then we discuss the use of plant species whose fruits would be more attractive in each situation, which would increase seed dispersal and accelerate the process of ecological succession.

2. Material and Methods

2.1. Study area

We performed fieldwork near the city of Itu in the **s**tate of São Paulo, **S**outheastern Brazil (see Figure 1a) in a 526-ha area (lat 23°14'15.18"S; long 47°24'3.29"W). The regional predominant physiognomy is the seasonal semidecidual Atlantic Forest with a transition to Cerrado, which is characterized by its climatic seasonality (Veloso et al., 1991). The climate is temperate humid with dry winters and hot summers. The average rainfall is 160mm for the rainy period and 56mm for dry season (Cepagri, 2015).

The area is a 400 ha of abandoned pasture and croplands inserted in a restoration program (Martins, 2011). We defined three habitat-types (recent, old-restored areas, and natural fragments), where we selected six study sites: two 3-year old areas (0.91 and 1.30-ha; from now RN1 and RN2), two 6-year-old restored sites (0.25 and 1.20-ha; from now RO1 and RO2) and two forest fragments with 9 and 23 ha (hereinafter F1 and F2). The study sites were mainly surrounded by pastures of *Urochloa decumbens* L. (Poaceae) (Figure 2).

The restorations were planted in 2005 (RO1 and RO2) and 2008 (RN1 and RN2), according to the "filling and diversity" methodology (Nave and Rodrigues, 2007). Fill species include those faster grow that provide shade to the others, and the "diversity" consists of those that increase the area diversity. The local seedling nursery produces 189 native tree species, mainly from initial (pioneers and early secondary) successional stages. About 49.2% of the species are abiotically dispersed and 50.8% of the species are animal-dispersed (Appendix A). Species were randomly planted in alternating rows of pioneers and non-pioneers species, keeping 2 x 3 m between rows. After three years, the dominant species were *Schinus terebinthifolius* Raddi, *Cytharexyllum myrianthum* Cham., *Guazuma ulmifolia* Lam., *Machaerium nyctitans* (Vell.) Benth, *Luehea divaricata* Mart. and *Cedrela fissilis* Vell.

2.2. Fruit color preference

We carried out an experiment in November 2011 with 384 artificial fruits made of odorless edible clay (Wennersten and Forsman, 2009). We made 2-cm spherical fruits, dyed in either black, blue, green or red, with 96 fruits of each

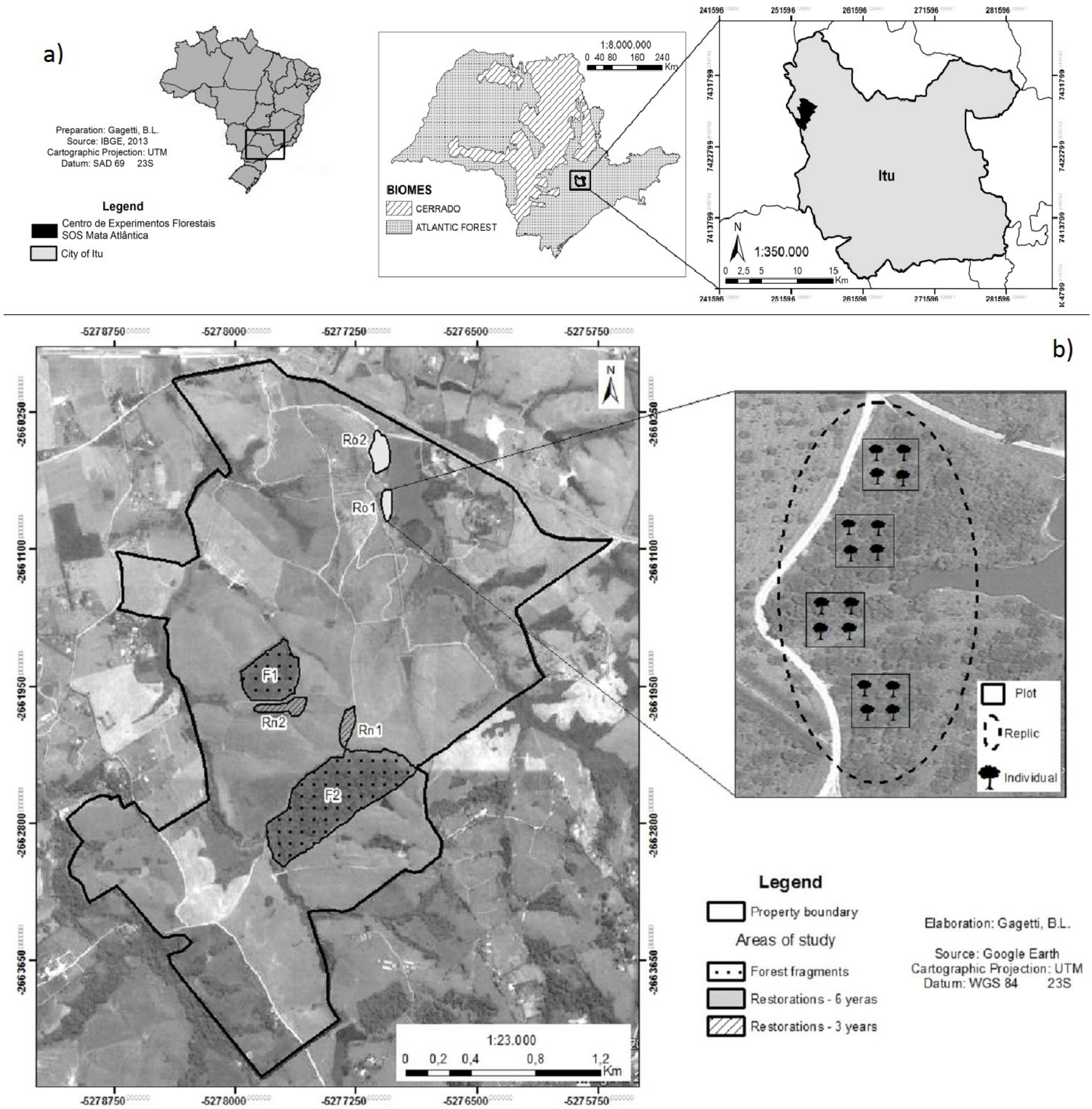

Figure 1. (a) Location of the study area in the state of São Paulo, Brazil; (b) Location of the study area and schematic illustration of the sampling design used in the experiment on the preference of fruit color. F1 and F2 = forest fragments; RO1 and RO2 = restoration of 6 year-old; RN1 and RN2 = restoration of 3-year old).

color. As the edible clay consisted of flour, butter and gelatin, we dyed the artificial fruits using food coloring.

These colors were selected because they are closer to those of naturally bird-dispersed fruits (Cazetta et al., 2009) and this technique controls variables as the number and size of fruits and position in vegetation (Alves-Costa and Lopes, 2001). In each site we set four groups of four fruits (one of each color), from now on called 'plots' in 16 trees (chosen at random), hanging in branches at about 1.5m high with approximately one meter between them, totaling 64 fruits per site (see Figure 1b). We checked the experiment two times, once after 24 and again after 48 hours.

Fruits that were removed or that had beak marks were considered as "consumed" (see Figure 2). We disregard of our analysis those fruits that were dropped and/or damaged by ants and/or mammals. We did not replace either predated or bird-consumed fruits. If mammals are mainly guided by the sense of smell (Munger et al., 2009), then they would prefer fruits having odor (Barcelos et al., 2012). Furthermore, tropical fruits are thought to have a strong dichotomy of colors; fruits consumed by mammals are often orange, yellow or brown, while bird-dispersed fruits would be predominantly red or black (Willson and Whelan, 1990). Thus, this set of characteristics may

Figure 2. Examples of artificial fruits having pecking marks.

support our decision to consider the removed fruits as consumed by birds.

We also tested the possible effect of light intensity on the fruit consumption by birds, assuming that the light intensity affect fruit conspicuousness (Schmidt et al., 2004). We measured each plot in the morning, choosing individual plants and taking photographs with the lens facing upward in the same place where the fruits were hung. Next, we calculated the luminosity (%) using the Adobe Photoshop CS5 software, following Engelbrecht and Herz (2001) with some adaptations. Each photo was converted to grayscale, dividing the image into two colors (black and white) and the percentage of white, which is equivalent to light intensity, was seen through the image histogram. In each area, we calculated the weighted average of the four plots.

2.3. Statistical analyses

The total fruit consumed (TFC) was calculated by adding the fruit consumed by color in the four plots at the six sites ($n = 24$). As the TFC did not show normality based on the Shapiro-Wilk Test ($p<0.01$), we transformed data using log ($x+0.5$), and log [$(x+0.5)/100$] to light intensity. We tested light intensity in the six sites using analysis of variance (AOV) followed by Tukey HSD to compare means, and a box-plot to assess the light homogeneity among them. Then, we performed a Spearman rank-correlation index using percentage of light intensity and mean of consumed fruits by plot in order to evaluate the relationship between light and color preference by birds; next, we carried out a Kruskall-Wallis One-way AOV and Dunn's all-pairwise comparisons to evaluate TFC by habitat-type.

We used a general analysis of variance (General-AOV) to check for the simultaneous effects of light incidence and fruit color consumption by site, with light as the covariate and colors as dependent variables ($n= 4$) and sites ($n= 6$) as a model statement. In order to compare means, we applied a pairwise comparison using LSD to report homogeneous sites by fruit color and T-paired for each color using the fruit consumption by plot. All statistical analyses were performed in Statistix 10.0 (Analytical Software, 2013).

3. Results

A total of 73 (19%) of the 384 exposed fruits were found fallen ($n=31$) and/or were predated by mammals ($n=27$) and/or ants ($n=15$), and were not included in our analyses. From the 311 remaining fruits, 120 (38.6% of the total) were assumed to be consumed by birds (Table 1).

The incidence of light was heterogeneous within the study area; sites F1 and RN1 were the most homogeneous in terms of the plot´s light incidence, while RN2 and RO2 had the highest heterogeneity (as shown in Table 1; see Figure 3). Across sites, only F1 was different from the others, and probably due to this, the habitat-types diverge in light intensity (F= 5.74; p=0.0103). Although new and old restorations did not differ between themselves ($\overline{X}_{new}$ = 52.5±12.6%; $\overline{X}_{old}$ = 40.6±15.0%), the new-restorations were significantly different and more open than fragments ($\overline{X}_{fragment}$ = 25.5±14.3%).

Only the general consumption of red fruits was slightly correlated (r= 0.59; p <0.05) to light intensity. Despite this, when we evaluate each site, the light did not influence fruit consumption of red (F_{red} = 0.96; p>0.05), probably due to the high variation of light between plots (see Figure 3). The light incidence also did not affect fruit consumption of the other colors (F_{black} = 1.40; F_{blue} = 1.11; F_{green} = 1.02; p>0.05).

Table 1. Study sites, light intensity (%) and total of fruit consumed by color near the city of Itu in the state of São Paulo, Brazil.

Areas	Light intensity (%)		Fruit color					Total TFC
	Sites	Habitat type	Black	Blue	Green	Red	$\overline{X}$	
F1	12 (± 4.3)^{B}	30^{B}	1^{B}	0^{C}	3	7	3±1.71	11^{BC}
F2	39 (±20.2)^{A}		5^{AB}	3^{B}	5	6	5±2.21	19^{AB}
RO1	44 (±30.0)^{A}	42^{AB}	6^{A}	8^{A}	1	6	5±2.99	21^{ABC}
RO2	37 (±14.4)^{A}		6^{AB}	4^{B}	6	5	5±0.96	21^{BC}
RN1	54 (±8.8)^{A}	48^{A}	12^{A}	10^{A}	10	13	11±2.7	45^{A}
RN2	51 (±48)^{A}		1^{B}	0^{C}	1	1	1±0.95	3^{C}
Total (TFC)	-	-	31^{ab}	25^{b}	26^{b}	38^{a}		120
F_{value}	5.96	0.11	3.50	11.51	2.19	2.53		2.85
P	0.0020	Z=2.34	0.0219	0.000	0.1010	0.066		0.0455

[a]Values are replicate plot means (±SD) n =64 for each study site. Means with the same capital letter (A, B, C) are not significantly different across study sites (mean differentiation using LSD, α= 0.05, and habitat-types by Dunn´s z value). Means with the same lower case letter (a, b) are not significantly different across fruit colors (mean differentiation using T-paired α= 0.05). F1 and F2 = forest fragments; RO1 and RO2 = restoration of 6 years-old; RN1 and RN2 = restoration of 3-years old. TFC= total of fruit consumption.

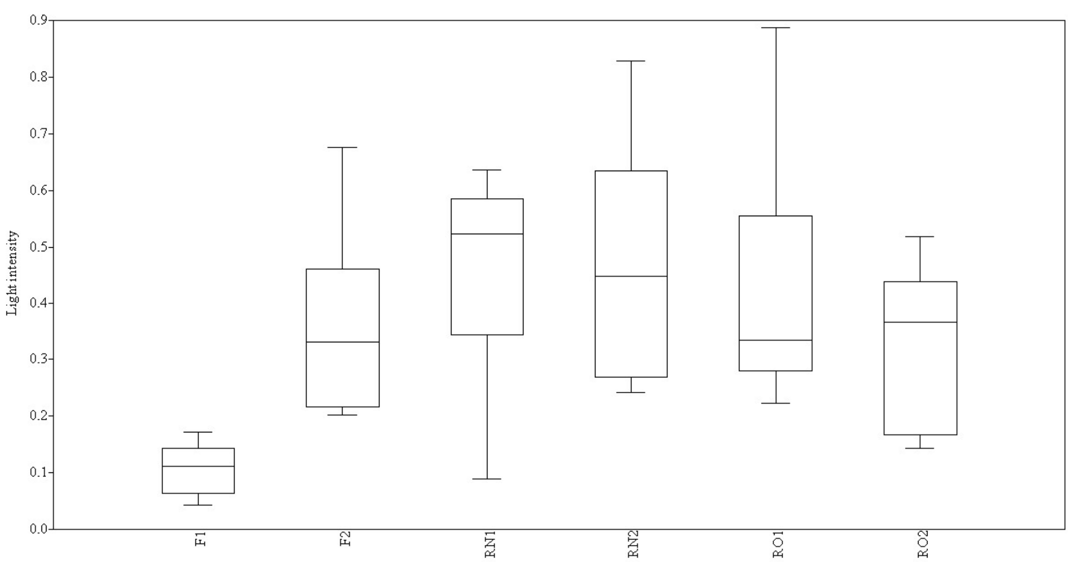

Figure 3. Box plot - median and quartiles (quartile method interpolation) - for light intensity in six studied sites in the state of São Paulo, Brazil. F1 and F2 = forest fragments; RN1 and RN2 = restoration of 3-years old, and RO1 and RO2 = restoration of 6 years-old.

The habitat-types did not affect the overall consumption of fruits (TFC) ($F= 0.11$; $p>0.05$); and the variation within each site was higher than between them ($F= 1.08$; $p< 0.05$), suggesting that sites, not habitat-types, influenced fruit consumption. Indeed, fruit consumption was significantly higher in RN1 and differed across sites (Table 1). The two newer restorations (RN1 and RN2) differed in relation to fruit consumption, which did not occur when comparing the older restorations (RO1 and RO2).

The consumption of black and blue fruits was related significantly to sites, but not for red ($F= 2.53$; $p> 0.05$) or green ($F= 2.19$; $p> 0.05$). Notwithstanding, the red fruits were consumed significantly more than other colors regardless the site, with black being the only exception. However, the consumption of black and blue fruits differed between the two new-restorations and they were intensively pecked in RN1. Although black (31 fruits) and blue (25 fruits) did not differ in relation to the total amount of fruit consumed, only few black and none of the blue fruits were pecked by birds in the sites F1 and RN2.

4. Discussion

We found no influence of light exposition on fruit consumption by birds, even though this may affect color conspicuousness (e.g. Cazetta et al., 2009). This is probably due to the light heterogeneity within each site. This heterogeneity in the recovered sites is probably a consequence of the filling and diversity methodology, which mix species with wider and sparser canopies used to foster sucessional processes (Rodrigues et al., 2009).

Species composition and arrangement affected light heterogeneity only for new restorations, that also differed in fruit consumption. This suggests that fruit consumption by birds may be more affected by sites mainly in their early stages. Confirming that, in the forest fragments fruit consumption was not affected, and the spatial heterogeneity of light incidence may be explained both by the expected stratification in understories of semidecidual forests, and by their relatively small size (see study area) and the consequent degradation process.

In general, we observed a higher consumption of blue and black fruits in the restored areas than in the fragments, and the consumption of red and green were site-independent (Table 1). Color conspicuousness may be relative and influenced by factors such as the type of environment and luminosity (Arruda et al., 2008), and the contrast between the fruit and the foliage in the background (Schmidt et al., 2004; Cazetta et al., 2009). Thus, different colors may be more or be less conspicuous depending on the conditions of a given area. Galetti et al. (2003) observed a strong trend towards a higher consumption of red and black fruits in relation to white ones in large fragments, whereas this difference was less pronounced in smaller and more fragmented areas.

Our study is consistent with the premise that red and black fruit displays are an evolutionary trait associated with the reported preference of tropical birds to these colors (e.g. Wheelwright and Janson, 1985). For black and blue fruits there was a potential site preference by birds to these fruit colors, independent of habitat type.

In our restored areas few species had black (n=22; ~11%) or red (n=22; ~11%) fruits, while none were blue, and about 93 (~49%) species were unattractive to birds (mainly wind-dispersed) (see Appendix A), which are diverging to tropical forests, where red and black fruits represent 50~70% of all fleshy fruits (Wheelwright and Janson, 1985).

In restored areas, animal seed dispersion is an ecosystem ecological functionality that is expected to be recovered and managed (SER, 2002). For attracting birds, an appropriate species selection and management of the area is required. Adaptive management is a challenge for restorers as it depends on research and science as key elements for restoration decisions (Failing et al., 2013), and interference in a restoration process is necessary to establish objectives and to adjust future management actions (LoSchiavo et al., 2013).

In our study, new restored sites were potentially more attractive to birds than fragments, especially for blue and black fruits, suggesting that plant species selection needs to consider these fruit colors. The re-establishment of ecosystem functionality and services is one of the most important goals in restoration ecology and often exhibits divergent and unpredictable pathways (Chazdon, 2008). Enrichment with shade tolerant shrubs or forest species with black and/or red fruits may be an alternative way to manage established restorations. On the other hand, in recently established or new restorations, the introduction of pioneer shrubs or short-lived forest species having blue fruits would be more appropriate, but also those having black or red ones might be considered.

Adaptive practices may be used to manage forest restoration, by selecting pioneers with blue (e.g. *Psychotria suterella* Müll. Arg. and *Miconia affinis* DC) or black (e.g. *Myrsine coriacea* (Sw.) R.Br. ex Roem. & Schult. and *Dendropanax cuneatus* (DC.) Decne. & Planch.) fruits and secondary or climax species with more conspicuous fruits such as red (e.g. *Cabralea canjerana* (Vell.) Mart. and *Cordia ecalyculata* Vell.) or black (e.g. *Cupania vernalis* Cambess. and *Nectandra megapotamica* (Spreng.) Mez).

Our results suggest that fruit color should be taken into account when selecting the species to be used in reforestation programs, whether planting or enrichment. This could speed up the process of ecological succession and optimize the recovery of degraded areas.

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Appendix A. Plant species available in the nursery or planted in the Centro de Experimentos Florestais, in the region of Itu, state of São Paulo, with colors of fruits/diasporas and dispersal syndrome (biotic or abiotic).

Taxon	Fruit/diaspore color	Seed dispersal*
Acacia caven Molina	Brown	Abiotic
Acacia polyphylla DC.	Black/Yellow	Abiotic
Aegiphila sellowiana Cham.	Orange	Biotic
Albizia polyphylla E. Fourn.	Brown	Abiotic
Allophylus edulis (A. St.-Hil., A. Juss. & Cambess.) Hieron. ex Niederl.	Red	Biotic
Allophylus petiolulatus Radlk.	Red	Biotic
Aloysia virgate (Ruiz & Pav.) Pers.	White	Abiotic
Anadenanthera falcate (Benth.) Speg.	Brown	Abiotic
Anadenanthera macrocarpa (Benth.) Brenan	Brown	Abiotic
Anadenanthera peregrina (L.) Speg.	Brown	Abiotic
Annona cacans Warm.	Green	Biotic
Annona coriácea Mart.	Green	Biotic
Apeiba tibourbou Aubl.	Green	Abiotic
Aspidosperma parvifolium A.DC.	Beige	Abiotic
Aspidosperma cylindrocarpon Müll. Arg.	Brown	Abiotic
Aspidosperma ramiflorum Müll. Arg.	Brown	Abiotic
Astronium graveolens Jacq.	Brown	Abiotic
Balfourodendron riedelianum (Engl.) Engl.	Yellow	Abiotic
Bastardiopsis densiflora (Hook. & Arn.) Hassl.	Green	Abiotic
Bauhinia forficata Link	Brown	Abiotic
Byrsonima sericea DC.	Yellow	Biotic
Cabralea canjerana (Vell.) Mart.	Red	Biotic
Calophyllum brasiliensis Camb.	Green	Biotic
Campomanesia eugenioides (Cambess.) D. Legrand ex L.R. Landrum	Green	Biotic
Campomanesia neriiflora (O. Berg) Nied.	Green	Biotic
Campomanesia xanthocarpa Mart. Ex O. Berg	Yellow	Biotic
Capsicodendron dinisii (Schwacke) Occhioni	Red	Biotic
Cariniana estrellensis (Raddi) Kuntze	Beige	Abiotic
Cariniana legalis (Mart.) Kuntze	Beige	Abiotic
Casearia gossypiosperma Briq.	Yellow/Green	Biotic
Casearia sylvestris Sw.	Red/Black	Biotic
Cassia ferruginea (Schrad.) Schrader ex DC.	Brown	Abiotic
Cassia leptophylla Vogel	Brown	Abiotic
Cecropia hololeuca Miq.	Brown	Biotic
Cecropia pachystachya Trécul	Green	Biotic
Cedrela fissilis Vell.	Brown	Abiotic
Cedrela odorata L.	Brown	Abiotic
Ceiba speciosa (A. St.-Hil.) Ravenna	Green	Abiotic
Centrolobium tomentosum Guillemin ex Benth.	Brown	Abiotic
Chorisia glaziovii (Kuntze) E. Santos	Green	Abiotic
Chorisia speciose A. St.-Hil.	Green	Abiotic
Chrysophyllum gonocarpum (Mart. & Eichler ex Miq.) Engl.	Yellow	Biotic
Citharexylum mirianthum Cham.	Red	Biotic
Citharexylum solanaceum Cham.	Orange	Biotic
Colubrina glandulosa Perkins	Black	Biotic
Copaifera langsdorffii Desf.	Orange/Black	Biotic
Cordia americana (L.) Gottschling & J.S. Mill.	Brown	Abiotic
Cordia ecalyculata Vell.	Red	Biotic

Source: *Resolução SMA - 8/2008 (São Paulo, 2008). **unknown.

Appendix 1. Continued...

Taxon	Fruit/diaspore color	Seed dispersal*
Cordia sellowiana Cham.	Yellow	Biotic
Cordia superba Cham.	White	Biotic
Cordia trichotoma (Vell.) Arráb. Ex Steud.	Green	Abiotic
Couroupita guianensis Aubl.	Yellow	Biotic
Coutarea hexandra (Jacq.) K. Schum.	Green	Abiotic
Croton floribundus Spreng.	Green	Abiotic
Croton urucurana Baill.	Green	Abiotic
Cryptocarya aschersoniana Mez	Yellow	Biotic
Cupania vernalis Cambess.	Black/Red	Biotic
Curatella americana L.	Red	Biotic
Cyclolobium vecchi A. Samp. Ex Hoehne	Beige	Abiotic
Dendropanax cuneatum Decne. & Planch.	Green	Biotic
Dictyoloma vandellianum A. Juss.	Beige	Abiotic
Dilodendron bipinnatum Radlk.	Black	Biotic
Diospyros inconstans Jacq.	Purple	Biotic
Diplokeleba floribunda N.E. Br.	Brown	Abiotic
Enterolobium contortisiliquum (Vell.) Morong	Black	Abiotic
Enterolobium timbouva Mart.	Black	Abiotic
Eriotheca gracilipes (K. Schum.) A. Robyns	Green	Abiotic
Erythrina speciosa Andrews	Brown	Abiotic
Erythrina crista-galli L.	Brown	Abiotic
Erythrina falcate Benth.	Brown	Abiotic
Erythrina velutina Willd.	Green	Abiotic
Erythroxylum deciduum A. St.-Hil.	Red	Biotic
Erythrina verna Vell.	Brown	Abiotic
Esenbeckia leiocarpa Engl.	Green	Abiotic
Eugenia brasiliensis Lam.	Red/Black	Biotic
Eugenia cerasiflora Miq.	Red	Biotic
Eugenia candolleana DC.	Black	Biotic
Eugenia dysenterica DC.	Yellow	Biotic
Eugenia glazioviana (Kiaersk.) D. Legrand	Yellow	Biotic
Eugenia involucrata DC.	Red/Black	Biotic
Eugenia luschnathiana (O. Berg) Klotzsch ex B.D. Jacks.	Yellow	Biotic
Eugenia pyriformis Cambess.	Yellow	Biotic
Eugenia uniflora L.	Orange/Red	Biotic
Ficus enormis (Mart. Ex Miq.) Mart.	Red/Purple	Biotic
Ficus guaranítica (Chodat)	Green	Biotic
Ficus insipida Willd.	Green	Biotic
Ficus luschnathiana (Miq.) Miq.	Red/Purple	Biotic
Ficus obtusifolia Kunth	Yellow/Orange	Biotic
Gallesia integrifólia (Spreng.) Harms	Beige	Abiotic
Garcinia gardneriana (Planch. & Triana) Zappi	Yellow	Biotic
Genipa Americana L.	Green/Brown	Biotic
Gochnatia polymorpha (Less.) Cabrera	White	Abiotic
Guapira graciliflora (Mart. Ex J.A. Schmidt) Lundell	Black	Biotic
Guarea kunthiana A. Juss.	Brown	Biotic
Guazuma ulmifolia Lam.	Black	Biotic
Handroanthus chrysotrichus (Mart. ex A. DC.) Mattos	Green	Abiotic
Handroanthus heptaphyllus (Vell.) Mattos	Brown	Abiotic

Source: *Resolução SMA - 8/2008 (São Paulo, 2008). **unknown.

Appendix 1. Continued...

Taxon	Fruit/diaspore color	Seed dispersal*
Handroanthus impetiginosus (Mart. ex DC.) Mattos	Brown	Abiotic
Heliocarpus popayanensis Kunth	Beige	Abiotic
Hexachlamys edulis (O. Berg) Kausel & D. Legrand	Yellow	Biotic
Hymenaea courbaril L.	Green	Biotic
Inga laurina (Sw.) Willd.	Green	Biotic
Inga marginata Willd.	Green	Biotic
Inga uruguensis Hook. & Arn.	Green	Biotic
Inga vera Willd.	Green	Biotic
Jacaranda micranta Cham.	Black	Abiotic
Jacaratia spinosa (Aubl.) A. DC.	Yellow	Biotic
Lafoensia glyptocarpa Koehne	Green	Abiotic
Lafoensia pacari A. St.-Hil.	Brown	Abiotic
Leucochloron incuriale (Vell.) Barneby & J.W. Grimes	Yellow	Abiotic
Lonchocarpus campestres Mart. ex Benth.	Green	Abiotic
Lonchocarpus cultratus (Vell.) A.M.G. Azevedo & H.C. Lima	Green	Abiotic
Lonchocarpus muehlbergianus Hassl.	Brown	Abiotic
Luehea divaricata Mart.	Green	Abiotic
Luehea grandiflora Mart.	Green	Abiotic
Mabea fistulifera Mart.	Green	Abiotic
Machaerium hirtum (Vell.) Stellfeld	Brown	Abiotic
Machaerium stipitatum (DC.) Vogel	Brown	Abiotic
Machaerium villosum Vogel	Brown	Abiotic
Machaerium brasiliense Vogel	Green	Abiotic
Maclura tinctoria (L.) D. Don ex Steud.	Green	Biotic
Miconia cabucu Hoehne	Yellow	Biotic
Mimosa bimucronata (DC.) Kuntze	Brown	Abiotic
Mimosa scabrella Benth.	Brown	Abiotic
Myracrodruon urundeuva Allemão	Black	Abiotic
Myrciaria floribunda (H. West ex Willd.) O. Berg	Red	Biotic
Myrciaria glazioviana (Kiaersk.) G.M. Barroso ex Sobral	Yellow	Biotic
Myroxylon peruiferum L.f.	Beige	Abiotic
Myrsine umbellata Mart.	Black	Biotic
Nectandra megapotamica (Spreng.) Mez	Black	Biotic
Ocotea puberula (Rich.) Nees	Black/Red	Biotic
Ormosia arborea (Vell.) Harms	Orange/Black	Abiotic
Parapiptadenia rígida (Benth.) Brenan	Brown	Abiotic
Peltophorum dubium (Spreng.) Taub.	Beige	Abiotic
Persea pyrifolia (D. Don) Spreng.	Green	Biotic
Phytolacca dioica L.	Yellow	Abiotic
Piptadenia gonoacantha (Mart.) J.F. Macbr.	Green	Abiotic
Piptocarpha axillaris (Less.) Baker	**	Abiotic
Piptocarpha rotundifolia (Less.) Baker	**	Abiotic
Platypodium elegans Vogel	Beige	Abiotic
Plinia edulis (Vell.) Sobral	Yellow	Biotic
Poecilanthe parviflora Benth.	Brown	Abiotic
Posoqueria acutifolia Mart.	Yellow	Abiotic
Pouteria torta (Mart.) Radlk.	Yellow	Abiotic
Prunus sellowii Koehne	Purple	Biotic
Psidium cattleianum Sabine	Yellow	Biotic

Source: *Resolução SMA - 8/2008 (São Paulo, 2008). **unknown.

Appendix 1. Continued...

Taxon	Fruit/diaspore color	Seed dispersal*
Psidium guajava L.	Green/Red	Biotic
Psidium longipetiolatum D. Legrand	Purple	Biotic
Psidium rufum DC.	Green	Biotic
Psychotria carthagenensis Jacq.	Red	Biotic
Pterocarpus violaceus Vogel	Beige	Abiotic
Pterogyne nitens Tul.	Beige	Abiotic
Rapanea ferrugínea (Ruiz & Pav.) Mez	Black	Biotic
Rapanea gardneriana (A. DC.) Mez	Black	Biotic
Rauvolfia sellowii Müll. Arg.	Black	Biotic
Rhamnidium elaeocarpum Reissek	Red	Biotic
Sapium glandulatum (Vell.) Pax	Red	Biotic
Schefflera morototoni (Aubl.) Maguire, Steyerm. & Frodin	Brown	Biotic
Schinus molle L.	Red	Biotic
Schinus terebinthifolius Raddi	Red	Biotic
Schizolobium parahyba (Vell.) S.F. Blake	Beige	Abiotic
Seguieria langsdorffii Moq.	Black	Abiotic
Senna alata (L.) Roxb.	Black	Abiotic
Senna macranthera (DC. ex Collad.) H.S. Irwin & Barneby	Black	Abiotic
Senna multijuga (Rich.) H.S. Irwin & Barneby	Brown	Biotic
Senna pendula (Humb. & Bonpl. ex Willd.) H.S. Irwin & Barneby	Green	Abiotic
Simira sampaiona (Standl.) Steyerm.	Green	Abiotic
Solanum erianthum D. Don	Yellow	Biotic
Solanum granuloso-leprosum Dunal	**	Biotic
Solanum lycocarpum A. St.-Hil.	Green/Yellow	Biotic
Solanum pseudoquina A. St.-Hil.	Yellow	Biotic
Sparattosperma leucanthum (Vell.) K. Schum.	Beige	Abiotic
Strychnos brasiliensis (Spreng.) Mart.	Yellow	Biotic
Styrax pohlii A. DC.	Black	Biotic
Syagrus romanzoffiana (Cham.) Glassman	Yellow	Biotic
Tabebuia avellanedae Lorentz ex Griseb.	Green	Abiotic
Tabebuia ochracea A.H. Gentry	Green	Abiotic
Tabebuia roseo alba (Ridl.) Sand.	Green	Abiotic
Tabernaemontana hystrix Steud.	Red	Biotic
Terminalia argentea Mart.	Beige	Abiotic
Terminalia brasiliensis Spreng.	Yellow	Abiotic
Trema micranta (L.) Blume	Red	Biotic
Vantanea compacta (Schnizl.) Cuatrec.	Yellow	Biotic
Vitex montevidensis Cham.	Black	Biotic
Vochysia tucanorum Mart.	Green	Abiotic
Xylosma glaberrima Sleumer	**	Biotic
Zanthoxylum caribaeum Lam.	Purple	Biotic
Zanthoxylum rhoifolium Lam.	Purple	Biotic
Zeyheria tuberculosa (Vell.) Bureau ex Verl.	Brown	Abiotic

Source: *Resolução SMA - 8/2008 (São Paulo, 2008). **unknown.