Riparian Forest Restoration in the Pindorama Municipality, São Paulo State, Brazil.

Maria Teresa Vilela Nogueira Abdo (corresponding author: Polo Regional Centro Norte, APTA, SAA, PO Box 24, Pindorama, SP, 15-830.000, Brazil, mtvilela@terra.com.br), Sidney Rosa Vieira (IAC, Campinas, SP, Brazil), Antonio Lucio Mello Martins (Polo Regional Centro Norte, Pindorama, SP, Brazil) and Luis Cláudio Paterno Silveira (Lavras University, Lavras, MG, Brazil).

In Brazil, the use of mixed reforestation with native tree species is accepted as one of the most effective ways of promoting native revegetation in degraded areas. Restoration 'plantations' consist of native tree seedlings representing different floristic groups as determined by the seedlings' edaphic requirements and the conditions of the area. The expectation is that the growth of those first planted trees will result in a dynamic interaction between plants and animals that will induce natural regeneration processes in the area in subsequent years.

The vegetation structure of a forest remnant is composed by many native tree species from different floristic groups. Budowsky (1965) established some floristic groups of tropical forest species according to their behavior and shade tolerance during successional processes and regeneration dynamics. According to the author, tree colonization and growth in a remnant is due to stimulus from disturbances and tree-fall gaps inside the forest. The plants could be classified in three groups: pioneer (shade intolerant species with rapid growth); secondary (medium shade tolerant species with average growth speed); and climax (shade tolerant species and slow growth). According to Whitmore (1998), the opening of gaps in the forest drives tree colonization and growth, favoring the species that have a high demand for light such as the pioneers. Forest gaps cause disadvantages for the species that are shade tolerant, i.e., the secondary and climax species. Lugo and Brown (1990) define secondary forests as a forest resulting from human disturbance, and although they appear to accumulate woody plant species at a relatively rapid rate they are under very complex and unknown mechanisms. Natural

Color version of this article is available through online subscription at: http://er.uwpress.org

Figure 1. Overview of the restoration area at Polo Regional Centro Norte, Pindorama, São Paulo, Brazil. (A) before plantation (1997), (B) during the native riparian species planting with the hollows and drains opened (1998), (C) in 2008, and (D) 2015.

succession is one of these driving forces or mechanisms of change and suggests a predictable sequence of colonization events that guides restoration work today.

A successful restoration project will not only introduce appropriate plants that will flourish, but insect and animal biodiversity and soil and water balance of the area will also be restored or brought back to acceptable conditions. Barbosa et al. (2007) showed that planting native species can go beyond vegetation improvements alone; after eight years even the chemical and nutrient composition of the soil of a degraded area could be restored. In our experiment, we were attempting just that.

Our experimental area is located in the "Polo Regional Centro Norte" (Figure 1), a 532 hectare Agriculture Research Unit located in Pindorama Municipality, São Paulo State, Brazil. A 144 hectare portion of this research unit consists of natural forest remnants, classified by Abdo (2009) as seasonal, semi-deciduous, tropical forest of the Atlantic Forest biome. According to Lepsh and Valadares (1976), the local soils are classified as Kandiustalf and present sandy texture in the surface layer (A horizon) and clay loam in the subsurface layer (B horizon). This soil is highly susceptible to erosion processes because of differences in water infiltration velocity in the different horizons due to the soil textures (Lepsch and Valadares 1976, Rezende Mattos 1999). The problem of soil erosion is minimized by vegetative cover or buffers alongside nearby rivers, lakes, or dam edges. The 144 hectare fragments were declared a Biological Reserve by São Paulo state law 4960/86 on January 6th, 1986. It was classified as a conservation area because of its great diversity of regional endemic species, and as such, it needs special management and protection.

Although seasonal, semi-deciduous tropical forests still remain in isolated fragments and they are threatened by edge effects due to natural and human disturbance. Restoration work of the surrounding areas and edges has to be done in order to preserve the main forest area and the local biodiversity. In the Polo Regional Centro Norte Biological Reserve, there is a dam linking two important forest remnants and the area around the dam was lacking vegetation (Figure 1), essentially breaking the link between the remnant forests. Reforestation efforts using native vegetation at this dam was necessary to create a forest corridor encourage the movement and dispersal of animals and plants between fragments.

In the restoration area, there was variation in soil humidity and vegetation due to the drainage system of the soil. Next to the water line, the vegetation was typical of heath and in the highest altitudes the vegetation was typical of dry areas. These soil and vegetation differences were perceived to be an obstacle to the reforestation work, but in fact contributed to the successful reforestation and preservation of local biodiversity. The success of this project was due to the meticulous choice of the appropriate native species planted in the area and their tolerance to flooding. Also, the planting techniques were different for the heath soil areas and the dry areas.

Table 1. List of the tree species that were left in the restored area at Polo Regional Centro Norte located in the Pindorama Municipality, São Paulo State, Brazil.

Species Name
Albizia niopoides
Anacardium sp.
Anacromia aculeate
Araucaria angustifolia
Carpotroche brasiliensis
Cassia sp.
Cecropia pachystachya
Ceiba speciosa
Cordia trichotoma.
Croton floribundus
Curatella americana
Guarea guidonia
Guazuma ulmifolia
Maclura tinctoria
Mangifera indica
Pantagonula americana
Persea americana
Psidium guajava
Pterogyne nitens
Spondias sp.
Syzygium cumini
Trema micrantha
Zanthoxylum rhoifolium

In an area approximately 50 m wide and 200 m long (1 ha), native forest and fruit species were planted from February 1998 to March 1999 with the purpose of establishing a forest corridor. The northwest edge of the dam had an incline varying from 2% to 10% that was not considered in the project. Before the planting took place weed control was done in the area with manual mowing and hoeing. Some species were left on site, these were natural recruits from the nearby forests and agricultural areas (Table 1).

Additional species were planted and consisted of forest species and native fruit species that are used to attract birds and other animals that would help in seed dispersion and consequently in the restoration process. There were two distinct planting zones in our restoration. The area by the dam had wet heath soils and was an area subject to flooding. Species planted in this zone, therefore, had to be resistant to periodic flooding. The upland zone was a permanent dry area, so those plant species had to be drought resistant. To guarantee that the plants could establish in the flood zone, provisory drains were constructed. Species selection was based on the work of Budowsky (1965) and the adaptability of the species to the dry and flood zone areas (Table 2). Plants were supplied by the CESP (Companhia Energética de São Paulo)-JUPIÁ nursery and the local nursery of the Polo Centro Norte–APTA research unit. Plants from the CESP-JUPIÁ nursery were approximately

Table 2. Tree species that were planted from the CESP (Companhia Energética de São Paulo), JUPIÁ nursery and the local nursery of the Polo Centro Norte, APTA research unit.

	Dry-zone species	Wet-zone species	Pioneer species	Secondary species	Climax species
Species from Jupiá nursery					
Acacia polyphylla		X	X		
Acrocomia aculeate	X			X	
Allophylus edulis		X	X		
Anadenanthera colubrine	X		X		
Aspidosperma cylindrocarpon	X				X
Aspidosperma parvifolium		X			X
Astronium graveolens	X			X	
Cariniana estrellensis				X	X
Casearia gossypiosperma	X			X	
Cassia sp.	X			X	
Cecropia pachystachya		X	X		
Cedrela fissilis		X		X	
Citharexylum myrianthum		X	X		
Colubrina glandulosa	X			X	
Cordia goeldiana	X			X	
Croton floribundus		X	X		
Croton urucurana		X	X		
Enterolobium sp.		X	X		
Esenbeckia leiocarpa	X				X
Ficus guaranitica	X		X		
Gallesia gorazema	X		X		
Genipa americana		X		X	
Guazuma ulmifolia	X		X		
Inga vera		X	X		
Jacaranda sp.	X			X	
Lithraea molleoides	X		X		
Luehea sp.		X		X	
Mabea fistulifera	X		X		
Maclura tinctoria		X	X		
Myrocarpus frondosus	X			X	
Nectandra megapotamica	X			X	
Ochroma pyramidale	X		X		
Ocotea velutina	X			X	
Peltophorum dubium	X			X	
Platypodium elegans	X			X	
Poecilante parviflora	X			X	
Pouteria ramiflora	X			X	
Pouteria torta		X		X	
Psidium sp.		X	X		
Pterocarpus rohrii		X	X		
Rapanea gardneriana		X	X		
Tabebuia sp.	X			X	
Trema micrantha		X	X		
Triplaris sp.		X		X	
Vitex polygama	X			X	

40 cm height and planted in small tubes. Seedlings from the local nursery were in 1 L and 2.5 L plastic containers; heights ranged from 0.5 cm to 2.0 m.

The planting was done at two different times. The pioneer species were planted in September 1998. The second planting started on February 2, 1999 and finished on March 22. During the second phase of planting, 1560 seedlings of secondary and climax species had been planted initially and 149 plants were replanted. In total, approximately 1700 seedlings of native species were planted. The distance

Table 2, continued.

	Dry-zone species	Wet-zone species	Pioneer species	Secondary species	Climax species
Species from Polo Centro Norte nursery					
Anadenanthera macrocarpa	X			X	
Bauhinia forficata	X		X		
Calycophyllum spruceanum		X		X	
Cassia ferruginea	X			X	
Citharexylum myrianthum		X	X		
Couroupita guianensis		X			
Cybistax antisyphilitica	X		X		
Enterolobium contortisiliquum		X		X	
Eugenia uniflora	X				X
Gallesia gorazema	X		X		
Genipa americana		X		X	
Jacaratia spinosa		X	X		
Lecythis pisonis		X		X	
Maclura tinctoria		X	X		
Musa sp.	X			X	
Myrciaria cauliflora	X				X
Nectandra megapotamica	X			X	
Psidium cattleianum		X	X		
Pterogyne nitens	X		X		
Rollinia sylvatica	X			X	
Syagrus romanzoffiana		X			X
Tabebuia sp.	X			X	
Talauma ovata		X		X	
Triplaris americana		X		X	

between the rows was 3.0 m and 2.5 meters between plants in each row. To make colonization in the wet area possible for tree species, some drainage trenches were dug. They were approximately 30 cm deep and 10 m apart from each other. Drainage ditches were created in the shape in a "fish spine" in this zone as needed (Figure 1). In the dry area the seedlings had been planted in conventional hollows, but in the wet area they have been planted on small soil elevations to prevent rotting stems (Figure 2). Each seedling hollow received 1.5 kg of calcareous rock, 200 g of simple superphosphate, mulching and manual irrigation. Weed control was carried out with chemical control and manual mowing and was done up to 150 days after the planting. The percentages of seedlings planted for each floristic group were: 60% Pioneer (P), 30% Secondary (S), and 10% Climax (C).

In seventeen years, we can observe that there was riparian vegetation recovery (Figure 1), which has allowed the dispersal of flora and fauna between the remnant forests. The tree seedlings grew and the community structure developed well despite the soil and water differences of the site. We did not have any death due to rotten stems. The different species chosen and the appropriated handling of the planting and drainage made the recovery of the heath forest possible. Intensive use of the restored forest corridor by native fauna has been observed. Otaviano and Barros (2012) performed a bird survey in the area and registered 85 different species during the months of May, June, and July in 2012 (Figure 3). The species *Tapera naevia* (Striped cuckoo), *Sporophila caerulescens* (Double-collared seed-eater), *Automolus leucophthalmus* (White-eyed foliage-gleaner), *Galbula ruficauda* (Rufous-tailed jacamar), *Tachycineta albiventer* (White-winged swallow), *Myiothlypis flaveola* (Flavescent warbler), and *Thamnophilus doliatus*

Figure 2. "Inverted hollows" for seedlings in soaked areas. Pictured here is Canelinha (*Nectandra megapotamica*).

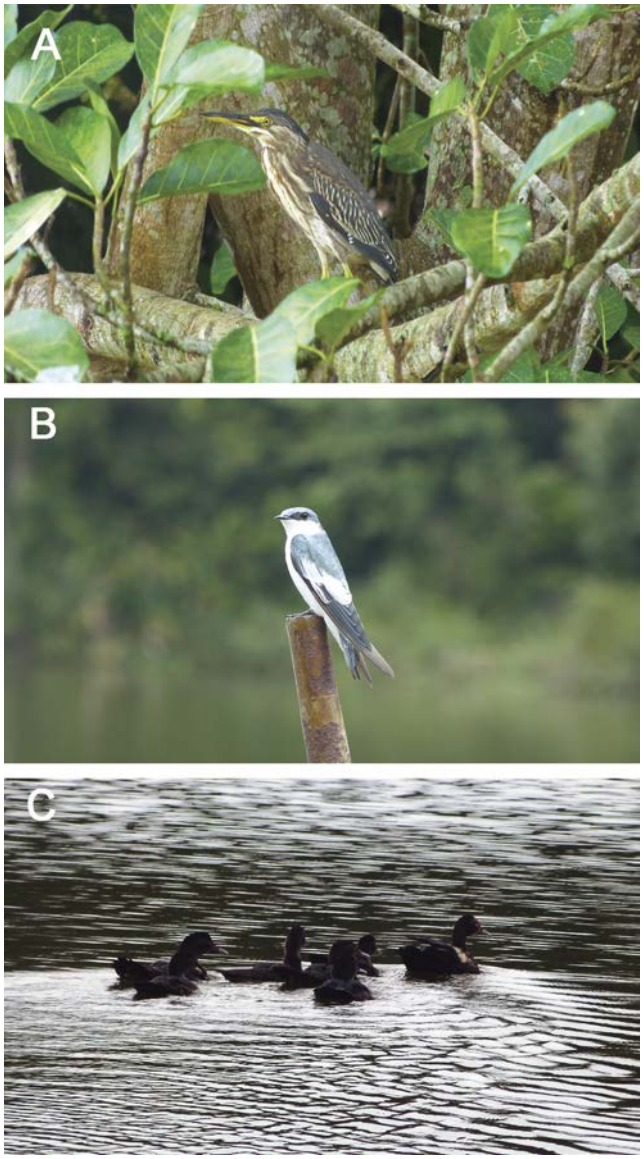

Figure 3. Bird species that visited the restoration area in 2012. (A) Striated Heron (*Butorides striata*), (B) White-winged swallow (*Tachycineta albiventer*), and (C) Muscovy duck (*Cairina moschata*).

(Barred antshrike) were the most frequent species observed and their occurrence was observed during all the three months of the survey in the area of the reforestation. Other animal species have also been observed in the area, such as monkeys, particularly Macaco prego (*Sapajus libidinosus*).

Many obstacles occur during restoration, nonetheless each area should be seen as unique and the recovery of its vegetation should preserve or restore plant and animal biodiversity. In Brazil, in the São Paulo State, there is an official list of native species that should be planted according to their occurrence area. Producers that intend to restore the native vegetation should follow the State Environmental Secretary protocols that require at least 80 different species be planted. This practice contributes to the reestablishment of the biodiversity in the area. The drainage of the soil, as well as the vegetation variation, requires different and meticulous work strategies at each site. Although some species tolerate flooding when they are mature, not all can establish and grow in totally inundated areas. This should be of concern when planting in flood zones. We consider this project to be a restoration success. The different soil zones at this site and the slope of the hill presented challenges in reestablishing native forest, and not just creating a grassy heath area that can dominate such areas. The drainage ditches were criticized initially, but they proved functional, favoring wetland species in a way that did not cause erosion as was expected with these successful results, we can conclude that the possibility of heath and riparian vegetation recovery is viable and desirable. Adjustments should be done in order to overcome the obstacles. Planting techniques, the choice of adequate species, as well as the drainage handling are some of the points that should receive special attention.

Acknowledgements

The authors would like to thank the FAPESP for the finance support that made this project possible and the director of Polo Regional Centro Norte–APTA that made possible the activities of the project in the area.

References

Abdo, M.T.V.N. 2009. Caracterização da vegetação arbórea e atributos do solo da Reserva Biológica de Pindorama, SP. PhD dissertation, Universidade Estadual Paulista.

Barbosa, L.M., K.C. Barbosa, J.M. Barbosa, E.C.M. Neuenhaus and T.C. Barbosa. 2007. Diagnóstico sobre os projetos de Recuperação de Áreas Degradadas (RAD) no estado de São Paulo: subsídios para aprimoramento das técnicas de implantação de reflorestamentos heterogêneos com espécies arbóreas nativas. Pages 63–72 in Pereira T.S., M.L.M.N. Costa and P. Wyse Jackson (eds), *Recuperando o Verde para as Cidades: a Experiência dos Jardins Botânicos Brasileiros*. Rio de Janeiro, Brazil: HSBC, Investing in Nature, BGCI Rede Brasileira de Jardins Botânicos and Jardim Botânico do Rio de Janeiro.

Budowsky, G.1965. Distribution of tropical American rain forest species in the light of sucessional processes. *Turrialba* 15:40–42.

Lepsch, I.F.E. and J.M.A.S. Valadares. 1976. Levantamento pedológico detalhado da Estação Experimental de Pindorama. *Bragantia* 35:13–40.

Lugo, A.E. and S. Brown. 1990. Tropical secondary forests. *Journal of Tropical Ecology* 6:1–32.

Otaviano, J. and D.R. Barros. 2012. Aves da Reserva Biológica de Pindorama, SP.APTA, Pindorama.

Rezende Mattos J. (ed). 1999. *Sistema Brasileiro de Classificação de Solos*. Rio de Janeiro, Brazil: Embrapa.

Whitmore, T.C. 1998. *An Introduction to Tropical Rain Forests,* 2nd Edition. New York, NY: Oxford University Press.