FOREST RESTORATION AT DOGLEG BRANCH ON PHOSPHATE-MINED AND RECLAIMED LAND, FLORIDA

by

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Abstract. The central Florida phosphate mining industry is required to replace first-order streams removed by mining and restore their attendant forested wetlands. Mine pits are backfilled with tailings and overburden to their approximate original grade and elevation. Performance of most restoration projects is known only from limited data collected to satisfy compliance monitoring requirements prior to release from regulatory liability. To ascertain longer-term performance, we inventoried soils and vegetation along three belt transects in 1999 at the 8-ha Dogleg Branch Restoration project, which was initiated in 1983 at Lonesome Mine. Comparisons of transect data with baseline ecological data taken prior to mining documented the restoration of hydric forest in terms of soil development, plant species composition, and community structure. Mesic forest located on elevated side slopes has been rehabilitated in respect to community structure.

Additional Key Words: ecological restoration, hydric soil indicators.

Introduction

Dogleg Branch is a first-order, low-gradient stream located at Lonesome Mine in Section 20, T31S, R22E, Hillsborough County, Florida. This short, 1.1 km-long stream discharges into the South Prong Alafia River and ultimately Tampa Bay. In 1983 a centrally located 0.6 km reach of Dogleg Branch and 8.0 ha of adjacent riverine forest were removed as a consequence of surface mining for phosphate. Regulatory authorities required the replacement of the mined stream reach and restoration of the riverine forest. Stream replacement and forest restoration were accomplished on mined and reclaimed land. Design criteria were fulfilled, and the project site was released from regulatory liability in 1996. The reference ecosystem that served as the model for restoration design was riverine forest along the South Prong Alafia River and its tributaries at Lonesome Mine. This ecosystem was described at 27 locations by Clewell et al. (1982) and included the forest along original Dogleg Branch prior to mining.

Once released, reclamation projects such as this one are not monitored, and little opportunity exists to evaluate longer-term performance and development towards ecological maturity. An exception was Hall Branch Restoration at Lonesome Mine (Clewell 1999). The present article evaluates forest recovery 16 years after restoration commenced at Dogleg Branch. The rationale for this inventory was to document and evaluate forest development five years after the final mandatory monitoring event. This inventory was sponsored by the IMC-Agrico Company and was authorized by the Florida Division of Recreation and Parks which assumed title to the land in 1997. Dogleg Branch Restoration has since been incorporated into the Alafia River State Recreation Area.

Land Reclamation

The replacement stream was constructed in a contiguous mine cut that paralleled one edge of the riverine forest. Mining in this cut occurred in 1982. Early in 1983, the mine cut was backfilled with overburden materials consisting of sand and clay and was graded to match the elevations and topographic contours that existed in adjacent Dogleg Branch. The valley which was reconstructed for the replacement stream and restored forest averaged 120 m wide and 3.2 m deep with gentle side slopes and a broad, nearly flat bottom. The forest along original Dogleg Branch was removed. Scrapper pans excavated the forest topsoil to a depth of approximately 30 cm and deposited it at the reclamation site where it was spread with bulldozers. Bahiagrass *(Paspalum notatum)* was sown to stabilize slopes. The stream was allowed to cut its own channel. Piles of logs, called log jams, were placed at approximately 30 m intervals to induce sinuous flow.

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The new stream channel was tied back into undisturbed Dogleg Branch at either end. Discharge was intercepted temporarily by a mine re-circulation canal until 1993. Thereafter, water from reclaimed Dogleg Branch flowed to the Alafia River.

Forest Restoration

Mature cabbage palms *(Sabal palmetto)* were transplanted from the original forest to the restoration site concurrently with the transfer of topsoil. Beginning in June 1983, nursery-grown, year-old tree saplings were planted on approximately 1.5 m centers. The saplings were grown from seeds gathered from indigenous trees in central Florida. The restoration strategy was to assure reforestation by these plantings and to assume that forest undergrowth, consisting of shrubs, vines, and herbaceous species, would recover from seeds and rootstocks transferred in the topsoil.

Dogleg Branch Restoration was the first forested wetland mitigation project to be initiated under Florida's dredge and fill rule. Several techniques were attempted for the first time, at least in Florida wetland mitigation projects, including logjams, topsoil transfer, and cabbage palm transplanting. Other innovations were the installation of a small marsh at the distal end of the replacement stream to remove suspended solids, the introduction of emergent aquatic plants to stabilize the stream bottom, transplantation of hardwood tree stumps from the original forest to encourage re-sprouting, application of starch polymer gel to roots to enhance survival of planted nursery stock, direct seeding of acorns, intentional planting of wax myrtles *(Myrica cerifera)* as a nurse species for planted trees, mechanical removal of competitive brush from around young trees, application of pine straw to smother weeds, direct transplantation of undergrowth species from nearby forests, and the introduction of indigenous shrubs grown from stem cuttings.

Some of these techniques proved effective, such as the use of emergent plants to stabilize the stream bottom, direct seeding of acorns, use of wax myrtle as a nurse species, brush removal, and direct transplanting of undergrowth species. Other techniques were ineffective, such as logjams, stump transplanting, and use of starch polymer gel. The remaining techniques were qualified successes. For example, cabbage palm transplanting was effective only on better-drained slopes.

When design criteria were attained in 1994, 236 species of vascular plants were growing at the project site, including 3750 trees per ha of various size classes distributed among 28 tree species. Forty-five percent of the project site was covered by crowns of trees that ranged from 1.8 to 10.7 m tall with a density of 1143 trees per ha. At least 20 tree species and 65 non-arboreal species of the undergrowth were typical of the mature, undisturbed reference ecosystem. The stream flowed perennially with clear water. The macroinvertebrate fauna later met the Florida Department of Environmental Protection's Stream Condition Index thresholds in an inventory conducted by DEP personnel.

Lessons Learned

Since this was the first attempt at forest restoration in a mitigation context in Florida, it is not surprising that the project suffered from flaws in design and implementation. One flaw was the designation of all 8 ha as wetlands when nearly half of the site was mesic. To compensate, hydric trees had to be planted at elevations where their survival was jeopardized. Another flaw occurred when mining was conducted in the catchment that adjoined 85% of the periphery of the restoration site as restoration activities began. Groundwater seeped from the project site into adjacent mine pits. The soil in more elevated areas became desiccated during the spring and autumn dry seasons. This caused the seed bank to perish and organic matter to oxidize in the topsoil that was transferred in 1983. Upon drying, the clay hardened and inhibited tree root growth. A bahiagrass turf, weeds, and brush colonized the dry slopes and required repeated herbicidal applications to reduce competition with planted trees. Planted tree mortality was high. A 3-fold overplanting was needed over an eleven-year duration to attain the design density of 988 trees per ha that were $\geq$ 1.8 m tall. These and other flaws served as potent lessons that benefited subsequent restoration projects.

Methods

The inventory in 1999 was conducted in autumn along three parallel belt transects that spanned the project site perpendicular to the stream. The transects were centrally located along the reclaimed reach of Dogleg Branch and were spaced approximately 60 m apart. They duplicated transect locations that had been used previously for compliance monitoring. The belt transects were 20 feet wide (6.1 m) and were divided into 25 foot lengths (7.6 m) to form contiguous 20 by 25 foot quadrats in which data were recorded. The three transects were collectively 372 m long. The distinction between mesic and hydric portions of transects was determined using federal wetland delineation criteria. The delineation line was clearly evident as a zone of groundwater seepage along each slope.

Elevations were determined along one transect with a tripod-mounted dumpy level and leveling rod. Zero elevation was the bottom of the original stream channel immediately upstream from where the replacement stream connected.

Soils were examined at intervals along one transect. Two locations in hydric forest were selected for detailed characterization, one at 43 m interior from the outer edge of the restored forest near the base of the slope and the other at 66 m along the transect in nearly level bottomland near the stream. At each location the soil was described for texture, color (Munsell notation), abundance of fine roots, and distinctive features. Samples were returned to the laboratory for determinations of percent organic matter (loss on ignition at 400 C), percent sand and percent silt + clay (by destroying organic matter, defloculating with sodium hexametaphosphate, mixing, and wet sieving on a 270 mesh sieve), pH (glass electrode), and extractable P (dilute acetic acid-simplex).

Trees of potential canopy-forming species with diameters at breast height (dbh, 1.37 m) of ≥ 10 cm were tallied for density (number of trees per ha) and their diameters measured for the calculation of basal area (m^2/ha). Density (number of trees & shrubs per ha) was calculated for trees and shrubs with diameters < 10 cm in dbh and ≥ 1.8 m tall. Percent canopy cover of trees and shrubs ≥ 1.8 m tall was determined from measurements of line interception along a tape measure that extended the length of each transect line. Crowns of different species overlapped, and the sum of species cover values inflated total canopy cover. Therefore, total canopy cover was calculated as the percentage of transect line that intercepted canopy vegetation.

Percent cover was determined for undergrowth species (all vegetation except trees) by point interception at 2.0 foot intervals (61 cm) along each transect line. Each species of plant was recorded that touched a thin rod held vertically at each interception interval, including vines in the canopy. The percentage of intervals touched by a species was considered equivalent to percent cover. Total undergrowth vegetation cover was calculated from the number of interception intervals at which at least one species touched the rod.

Results

The distance in elevation above the bottom of the stream channel of Dogleg Branch to the upper limit of hydric forest was 3.7 m. Mesic restored forest occupied elevations from 3.7 to 5.5 m above the bottom of the stream channel. The stream channel was entrenched 0.7 m. The seepage line that separated mesic from hydric forest lay 38 m interior to the outer edge of the restored forest.

Soil descriptions at two locations in hydric forest are presented in Table 1. The soil taken from the slope at 43 m along the transect contained annelid worms, Coleoptera grubs, and unidentified eggs within the upper 28 cm of the soil profile. Soil was also examined in mesic forest at 36 m along the transect. The upper 13 cm consisted of a light gray "salt and pepper" sand that originated from topsoil which was transferred from the original forest in 1983. Clayey overburden backfill underlay this sand. Some sand had eroded from the slope, as evidenced by a low, step-like ridge of deposition at its base.

Tables 2-4 present vegetation data that were pooled from all three transects. Table 2 gives tree density and basal area for trees ≥ 10 cm in dbh, density for smaller trees and shrubs that were ≥ 1.8 m tall, and tree/shrub cover in mesic forest. Table 3 gives comparable tree data for hydric forest. Total canopy cover was 79% in mesic forest and 95% in hydric forest. Table 4 lists undergrowth species and their percent cover as determined by point-interception. Total undergrowth cover was 85% in mesic forest and 80% in hydric forest. Numerous seedlings and young saplings were observed, particularly in hydric forest, including species of *Acer, Ilex, Liquidambar, Nyssa, Quercus, Sabal, Taxodium,* and *Ulmus* listed in Table 3. Larger trees of those species that had been planted in the mid 1980's were copiously producing seeds. Apparently the seedlings arose from seeds produced by those trees.

Table 5 compares soil and vegetation parameters from the present study with those same parameters calculated with data from the reference forest ecosystem. Comparisons of undergrowth species were based on the entire reference ecosystem. Comparisons of all other parameters were based solely on inventory data from Dogleg Branch prior to mining.

Discussion

Soils. Soil in mesic forest consisted of sand that was transferred in 1983 from along original Dogleg Branch and deposited on backfill consisting of clayey overburden. The transferred sand stratum subsequently lost half of its thickness from erosion. Soil profile differentiation was absent, except for the formation of a dark-colored A horizon.

Soil in hydric forest exhibited no evidence of erosion and was as thick as when it was deposited in 1983. Overburden backfill began at a depth of 28 cm.

Table 1. Hydric soil descriptions at two transect locations in hydric forest.

	SOIL ON SLOPE AT 43 METERS				BOTTOMLAND SOIL AT 66 METERS			
Depth (cm):	0-10	10-20	20-28	>28	0-8	8-18	18-28	>28
Texture	sandy loam	loamy sand	loamy sand	sandy clay-loam	sandy loam	sand	sand	sandy clay-loam
Color	10YR 3/1	10YR 5/1	10YR 3/1	10YR 6/2	10YR 3/3	10YR 7/2	10YR 3/1	10YR 6/1
Fine roots	abundant	frequent	occa-sional	none	very abundant	occa-sional	occa-sional	none
Characteristics	occa-sional white spots; weak finely granular	abundant dark red-brown mottles	occa-sional gray-brown spots	abundant red mottles occa-sional hard concretions	abundant grayish-brown spots	occa-sional dark & very dark gray spots	Light gray streaks; abrupt boundary	
Organic matter (%)	7.5	3.7			8.3	1.1		
Sand (%)	80.8	96.2			76.9	95.4		
Silt + Clay (%)	19.2	3.8			23.1	4.6		
pH	4.5	4.7			5.3	4.9		
Extractable P	low	very low			none	low		

The light gray sands that were transferred in 1983 have darkened with organic matter. Downward movement of organic matter was evident. The soil that was described at 66 m along the transect became darker with increasing depth and exhibited vertical streaking. This accumulation of organic matter and its downward movement were indicators of hydric soil which have developed within the past 16 years. The soil at 43 m along the transect came from sloping land near the boundary with mesic forest. White spots in the upper 10 cm of the profile were evidence of striping of organic matter by percolation. This feature allowed the soil to be designated as hydric, albeit weakly so.

Mesic Vegetation. Tree species composition in mesic forest consisted largely of facultative wetland species that sometimes colonize upland sites in central Florida in the absence of fire. Undergrowth species consisted largely of weedy generalists and few that were characteristic of mature forest (Table 4). Approximately one-third of the species were exotic introductions, including species of *Paspalum, Urena, Lygodium, Cynodon, Imperata, Sporobolus, Hyptis, Indigofera,* and *Phyllanthus*. The formerly dense turf of bahaiagrass has suffered reduced cover and vigor from the shade of woody species. Cogongrass (*Imperata cylindrica*) was aggressively colonizing beneath some trees. Mesic forest community structure was developing slowly, but its species composition was disappointing.

Hydric Vegetation. Species composition and community structure were impressive for both the canopy (Table 3) and undergrowth (Table 4). Many undergrowth species were typical of mature, undisturbed stands of the reference ecosystem (Table 4).

Table 2. In mesic forest: density (trees per ha) & basal area (m^2/ha) of trees ≥ 10 cm in dbh; density of trees/shrubs ≥ 1.8 m tall & < 10 cm in dbh; and percent cover of trees/shrubs ≥ 1.8 m tall.

		Trees ≥ 10 cm in dbh		Tree/shrub ≥ 1.8 m	
Species	Common Name	Density	Basal Area	Density	Cover
Acer rubrum	red maple	47	0.6	57	6
Carya aquatica	water hickory	10	0.2	0	2
Juniperus virginiana	southern red cedar	0	0.0	20	0
Liquidambar styraciflua	sweetgum	104	1.9	215	11
Quercus laurifolia	swamp laurel oak	94	2.5	121	18
Quercus nigra	water oak	151	3.2	215	29
Quercus virginiana	live oak	121	3.0	141	19
Sabal palmetto	cabbage palm	10	1.1	141	2
Ulmus americana	American elm	27	0.4	0	3
Total		564	12.9	910	90

Table 3. In hydric forest: density (trees per ha) & basal area (m^2/ha) of trees ≥ 10 cm in dbh; density of trees/shrubs ≥ 1.8 m tall & < 10 cm in dbh; and percent cover of trees/shrubs ≥ 1.8 m tall.

		Trees ≥ 10 cm in dbh		Tree/shrub ≥ 1.8 m	
Species	Common Name	Density	Basal Area	Density	Cover
Acer rubrum	red maple	151	2.6	479	23
Carya aquatica	water hickory	7	0.1	0	0
Carya glabra	pignut hickory	0	0	7	0
Cornus foemina	swamp dogwood	0	0	119	3
Fraxinus caroliniana	popash	7	0.1	109	3
Fraxinus profunda	pumpkin ash	0	0	0	1
Gleditsia aquatica	water locust	0	0	7	<1
Ilex cassine	dahoon holly	0	0	77	<1
Liquidambar styraciflua	sweetgum	126	2.7	427	16
Magnolia virginiana	sweetbay	25	0.8	84	6
Myrica cerifera	wax myrtle	0	0	0	24
Nyssa biflora	swamp tupelo	25	0.2	77	2
Quercus laurifolia	swamp laurel oak	143	3.3	126	27
Quercus nigra	water oak	35	0.5	35	5
Quercus virginiana	live oak	7	0.1	25	0
Sabal palmetto	cabbage palm	0	0	0	1
Salix caroliniana	Carolina willow	77	0.8	252	11
Taxodium ascendens	pond-cypress	7	0.1	7	1
Taxodium distichum	bald-cypress	25	0.3	42	2
Ulmus americana	American elm	7	0.3	101	5
Total		642	11.9	1974	128

Table 4. Percent cover of plant species in the undergrowth. Species in bold face are typical of mature, undisturbed stands of the riverine forest reference ecosystem.

MESIC FOREST		HYDRIC FOREST	
	SHRUBS		
Myrica cerifera	2	*Myrica cerifera*	37
Baccharis halimifolia	1	***Viburnum nudum***	2
Ludwigia peruviana	1	***Itea virginica***	1
Rhus copallina	1	*Ludwigia peruviana*	1
Sambucus canadensis	1	*Rubus betulifolius*	1
Callicarpa americana	<1	*Rubus trivialis*	1
		Sambucus canadensis	<1
	CLIMBING VINES		
Smilax bona-nox	13	***Toxicodendron radicans***	6
Clematis virginiana	6	***Smilax bona-nox***	4
Lygodium japaonicum	5	***Ampelopsis arborea***	2
Ampelopsis arborea	1	***Clematis virginiana***	2
Parthenocissus quinquefolia	1	***Apios americana***	1
		Gelsemium sempervirens	1
		Clematis crispa	<1
		Vitis rotundifolia	<1
	GRAMINOIDS		
Paspalum notatum	35	*Juncus effusus*	9
Imperata cylindrica	4	***Paspalum conjugatum***	8
Sporobolus indicus	2	***Carex bromoides***	2
Andropogon glomeratus	1	***Rhynchospora caduca***	2
Cynodon dactylon	1	***Rhynchospora fascicularis***	2
Dichanthelium 4 spp., each	1	***Chasmanthimum laxum***	1
Paspalum conjugatum	1	*Dichanthelium* 3 spp., each	1
Andropogon virginicus	<1	***Oplismenus setarius***	1
Cyperus globulosus	<1	***Carex howei***	<1
3 species, each	<1	4 species, each	<1
	FORBS		
Bidens alba	9	***Thelypteris interrupta***	6
Hyptis verticillata	8	*Centella asiatica*	4
Urena lobata	7	*Urena lobata*	4
Drymaria cordata	5	***Saururus cernuus***	3
Salvia lyrata	5	*Hydrocotyle umbellata*	2
Commelina diffusa	1	***Lycopus rubellus***	2
Euthamia minor	1	***Boehmeria cylindrica***	1
Galactia elliottii	1	***Osmunda cinnamomea***	1
Hydrocotyle umbellata	1	***Osmunda regalis***	1
Indigofera hirsuta	1	***Psilotum nudum***	1
Phyllanthus urinaria	1	***Thelypteris palustris***	1
4 species, each	<1	***Woodwardia aerolata***	1
		Woodwardia virginica	1
		4 species, each	<1

Table 5. Comparisons between Dogleg Branch Restoration site and its reference ecosystem.

ITEM		RESTORATION SITE	REFERENCE ECOSYSTEM
1.	Elevation (m) above the stream bottom of the seepage line that separates hydric forest from mesic forest	3.7	3.4
2.	Silt + clay (%) in **mesic** forest topsoil	19.2	3.3
3.	Organic matter content (%) in **mesic** forest topsoil	3.7	4.6
4.	pH of **mesic** forest soil	4.5	4.7
5.	Extractable P in the soil	low	high
6.	Number of trees $\geq$ 10 cm dbh per ha in **mesic** forest	564	522
7.	Basal area (m^2/ha) of trees $\geq$ 10 cm in **mesic** forest	12.9	27.6
8.	Mean **mesic** forest canopy height (m)	11.7	19.9
9.	Number of shrubs per ha in **mesic** forest	910	1259
10.	Number of **mesic** forest undergrowth species that also occurred in the reference system	28 of 41	
11.	Silt + clay (%) in **hydric** forest topsoil	23.1	3.3
12.	Organic matter content (%) in **hydric** forest topsoil	8.3	19.0
13.	pH of **hydric** forest soil	5.3	5.6
14.	Number of trees $\geq$ 10 cm dbh per ha in **hydric** forest	642	750
15.	Basal area (m^2/ha) of trees $\geq$ 10 cm in **hydric** forest	11.9	43.0
16.	Mean **hydric** forest canopy height (m)	11.3	20.5
17.	Number of shrubs per ha in **hydric** forest	1974	1819
18.	Number of **hydric** forest undergrowth species that also occurred in the reference system	44 of 49	

Nearly all species were native. Some individual trees exceeded 30 cm in dbh and 15 m tall. The replacement stream had become more sinuous from trees growing on its banks that were redirecting flow and from the recent appearance of side streams that carried groundwater seepage from the bases of slopes. Bank undercutting was beginning. A dense stand of primrose willow *(Ludwigia peruviana),* which had been observed in previous monitoring events, had nearly disappeared. Volunteer willows *(Salix caroliniana),* which were once common, were undergoing senescence and literally falling apart. Wax myrtles *(Myrica cerifera)* were common, although many individuals were displaying initial signs of senescence. Primrose willow, willow, and wax myrtle are common species of forest gaps and exposed stream banks. Their reduction in abundance served as evidence of forest maturation. Comparable maturation was evident among herbaceous species. Forest sedges and ferns had largely replaced formerly common herbs that were more typical of open marshes.

Comparison with the Reference Ecosystem. Table 5 lists 18 items, each comparing Dogleg Branch Restoration with its reference ecosystem for specific parameters. The first item showed that the elevations of the seepage lines were nearly identical, relative to the stream elevation. The difference of 0.3 m was expected, because the reference elevation was recorded shortly downstream of our transects. This comparison was significant, because it documented that the original hydrology was restored with respect to lateral seepage.

Items 2 and 11 in Table 5 revealed that soils of the restoration had a much higher silt + clay content (mostly clay) than did the reference ecosystem. This has apparently not affected the hydric forest, but it caused the induration of mesic forest soil in dry seasons. Items 3 and 12 showed that the organic matter content of the soil was greater in the reference than in the restoration. Nonetheless, both mesic and hydric forest soils contained a substantial element of organic matter. Some of it was imported when topsoil was transferred in 1983; however, a large increment likely developed in situ.

Items 4 and 13 showed that soil reaction was nearly identical in the restoration and reference sites. Extractable phosphorus (item 5) was high in native soil and low in the restoration area where phosphate was mined. Low levels of phosphorus are normal in most regional soils, although there was indication that apatite occurred in the original soil profile, which would explain this anomaly. High levels of P may be inconsequential ecologically in light of the generally low levels of some other essential nutrients in regional soils.

Items 6 and 14 showed that tree density was nearly equivalent between restored and reference forests. This comparison lent credence to the assertion that community structure was similar between the restoration and its reference. Items 7 and 15 demonstrated that tree girth was not as great in the restoration as in the reference, nor were the trees as tall (items 8, 16). However, the growth amassed in only 16 years was substantial, and continued growth is fully anticipated. Items 9 and 17 showed that shrub density was reasonably similar between the restoration and the reference, which provided additional evidence for comparability in community structure.

Only 28 of the 41 undergrowth species in restored mesic forest were known to occur in the reference (item 10), emphasizing dissimilarity in species composition. In contrast, 44 of 49 undergrowth species in restored hydric forest were recorded in the reference ecosystem (item 18).

Conclusion

Hydric forest has been restored in terms of its hydrology, soil development, tree species composition undergrowth species composition, and community structure. In addition, the benthic invertebrate fauna of the replacement stream has been restored, according to the aforementioned study by the Florida DEP. The hydric forest represents a relatively young stage of ecological development. It is expected to continue its maturation entirely by natural processes and to become essentially indistinguishable from undisturbed forests of the reference ecosystem.

The mesic forest has been partially restored in terms of structure. Soils remain relatively undifferentiated, and species composition is novel. A restoration trajectory leading towards the reference ecosystem is not apparent. In this respect, the mesic forest is better designated as representing rehabilitation rather than restoration.

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