Assessing Restoration Outcomes in Light of Succession: Management Implications for Tropical Riparian Forest Restoration

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ABSTRACT

Today there is a wide variety of approaches on how to determine when a river restoration project can be considered ecologically successful. The limited information on river restoration responses renders this practice a subjective component of river management. We aimed to contribute to this issue by assessing the ecological outcomes of a restoration project conducted in Quebrada Chiclana, a first-order tropical stream located in the headwaters of the Rio Piedras in the city of San Juan, Puerto Rico. We focused on the reforestation component of the restoration project using current structure and composition of riparian vegetation as an indicator of restoration success. Recovery of riparian vegetation was studied eight years after restoration using a forest succession approach. We conducted a vegetation census and measured structural variables on vegetation at restored and nearby reference areas. We encountered a riparian vegetation community composed of 35 tree and 84 non-tree species. The non-native trees tall albizia (*Albizia procera*) and African tuliptree (*Spathodea campanulata*) were the most abundant tree species within the study area. We observed 11 out of the 16 woody species initially proposed in the reforestation plan but with lower tree density than proposed. Even though we demonstrate that the river restoration project has not yet met its reforestation objectives, our results show recovery of the vegetation community in the impacted area has occurred through natural succession.

Keywords: riparian vegetation, secondary forest, tropical streams, tropics

Restoration Recap

- Completion of the restoration project does not mean an ecologically successful project. Scientific methods implemented in pre- and post-monitoring programs are the best approach to evaluate the success of a restoration project.
- Species recovery has been known to be slow after a heavy impact. In the tropics, however, the high levels of precipitation and the amount of solar energy available could facilitate these processes when compared to temperate ecosystems.
- River restoration practices implemented can result in the recovery of a riparian forest that is not uniformly distributed across the restored area due to disproportional impacts.
- A reference site with desired vegetation characteristics should be chosen as a guide for restoration species selection. The quantity of species and stems proposed versus the observed denotes that the developer failed at the selection of species to be introduced in the restored area.
- In tropical degraded lands, some non-native species may serve to rehabilitate ecosystem properties on sites that natives may not be capable of colonizing immediately due to novel conditions at the site, potentially facilitating more opportunities for succession of native species as we observed under the canopy of reference sites.

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The global human population is increasing mainly in urban areas across the world (UN Population Division 2011). The responses to the needs and demands of this growing population have led to an increase in urban expansion, one of the major forces driving land cover change (Wu et al. 2006). These land-use changes are linked

Figure 1. Southern view upstream of Quebrada Chiclana (a headwater stream of the Rio Piedras Watershed, San Juan, Puerto Rico) during the restoration project, circa 2003. *Photo Credit: J. Cruz.*

to urban expansion, some with poor infrastructure planning, affecting natural ecosystems (Parés-Ramos et al. 2008). Urban expansion represents a particular threat to stream ecosystems (Paul and Meyer 2001). The process increases impervious surface cover which alters water discharge, urban runoff, stream habitat, and species community dynamics (Walsh et al. 2005). The humid tropics are not an exception. Islands, like Puerto Rico, have experienced significant land-use changes (Ramos 2001, López-Marrero 2003, López-Marrero et al. 2012) with concomitant alterations to streams networks. When land cover changes modify streams, and their associated riparian vegetation, valuable ecosystem services are compromised, as these are considered natural filters of nutrients and other pollutants, provide habitat for wildlife and are sources of clean freshwater (Naiman et al. 2005, Elmore and Kaushal 2008, Heartsill-Scalley 2012). Changes in land-use and in the natural hydrologic regime of rivers have altered ecosystem services and natural processes in river ecosystems.

In this scenario, ecological restoration becomes an option to help improve the functionality of impaired riverine landscapes (Seavey et al. 2009). However, gaps in scientific knowledge hinder the process of developing restoration successful strategies. We aimed to improve the understanding of these processes by assessing the state of a restored riparian landscape and analyzing outcomes using the approach of viewing the restoration project as a natural experiment. This approach aligned with the views of Wohl et al. (2005) who considered research on restored ecosystems as large-scale experiments and a scientific challenge that can improve our understanding of ecosystem processes. The assessed area comprises the riparian landscape of Quebrada Chiclana, a headwater stream localized in San Juan, Puerto Rico and buried in February of 2000 during the construction of a residential complex. In 2003, the Puerto Rico Department of Natural and Environmental Resources (DNER) ordered the restoration of the impacted area.

For the purpose of this study, our goal was to assess the reforestation component of the restoration project using the current structure and composition of the riparian vegetation as an indicator of restoration success. Numerous studies have described the patterns of forest succession in Puerto Rico (Aide et al. 1996, Aide et al. 2000, Chinea 2002, Chinea and Helmer 2003, Heartsill-Scalley and Aide 2003, Lugo and Helmer 2004) and across the tropics (Aide and Cavelier 1994, Ferreira et al. 2002, Bhuyan et al. 2003, De Souza and Batista 2004, Davies et al. 2005, Rodrigues et al. 2009, Lawrence et al. 2012). We aimed to improve and

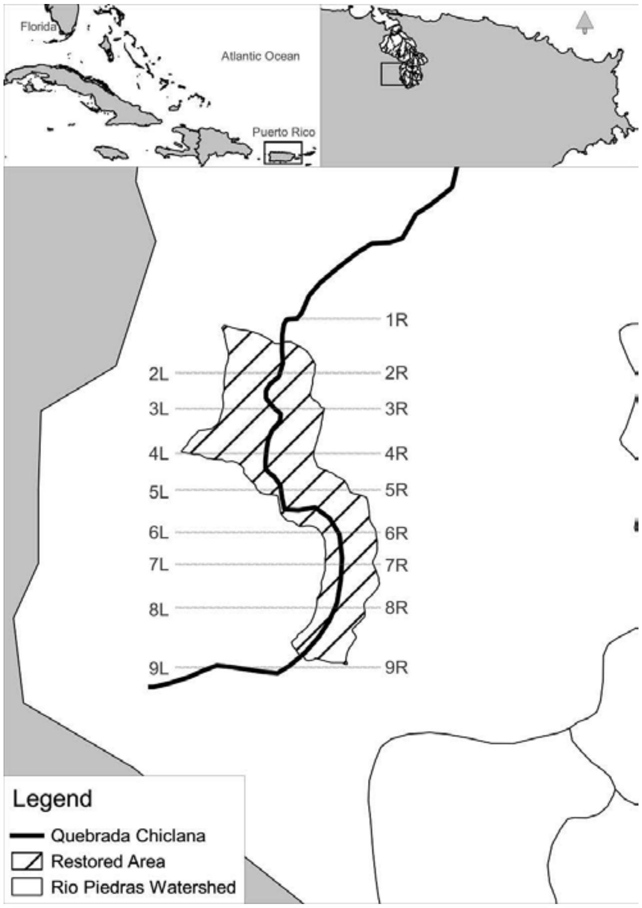

Figure 2. Location of Quebrada Chiclana restored area in the Rio Piedras Watershed, San Juan, Puerto Rico. Image also contains all right (R) and left (L) bank study plots.

supplement the findings in these studies due to the lack of information regarding vegetation evaluation on restored riparian areas in the tropics. Furthermore, we studied how forest recovery is taking place at the site from a natural succession approach.

Today, there is no protocol that defines how a restoration project can be considered ecologically successful, mostly due to the unique characteristics of each project (Whol et al. 2005). Our post-restoration findings were compared with the initial reforestation plan objectives to determine whether the reforestation plan implemented was ecologically successful. Based on these results, we outline a monitoring approach, which could result in better management practices for future restoration projects in the tropics.

Methods

In February of 2000, approximately 1km of a headwater stream and adjacent riparian area were buried and converted to a French drain placed over the stream and riparian area (Perez 2000). In 2005, the stream and riparian zones were restored to their original condition after the

Table 1. Study area variables at the Quebrada Chiclana restored area in the Rio Piedras Watershed, San Juan, Puerto Rico. The urban complex resides in the right bank of the creek, while only scattered houses are present on the left bank. Plots with an asterisk are reference plots. Plot 1L was private property inaccessible for this study.

Plots Left Bank (L)	Area (m^2)	Plots Right Bank (R)	Area (m^2)
—	—	1R*	300
2L	300	2R	150
3L	300	3R	250
4L	300	4R	250
5L	300	5R	340
6L	300	6R	200
7L	300	7R	200
8L	300	8R	175
9L*	300	9R*	200

2003 order by the government of Puerto Rico to the land developer (Figure 1). The river restoration order had three main components: (1) returning the stream channel to its original morphology, (2) the removal of the filling material, and (3) reforestation of riparian areas. The re-forestation plan for Quebrada Chiclana stated two goals: "Increase the ecological value of the area to be restored when compared with the conditions before the construction and conversion of the riparian vegetation to a flat fill" and "Achieve a native tree corridor of multiple habitats and give an advantage to native species over the exotics" (Ecosystems and Associates 2003). These goals were used as the basis to determine the success of the re-forestation component of the stream restoration.

Quebrada Chiclana is located in Caimito, a ward of the municipality of San Juan, Puerto Rico. In 2000, Caimito had more than 21,000 residents, in an area of 8 km² linked by 120 segments of rural roads. Chiclana is a headwater stream tributary of the Río Piedras, San Juan's main river (Figure 2). Its position in the Río Piedras Watershed (RPWS) places Chiclana in the humid northern foothills (> 100 meters above sea level) close to the coastal plains that characterize the north of the Island (Lugo et al. 2011). Quebrada Chiclana is also part of the San Juan Bay Estuary (SJBE) watershed and thus both systems are hydrologically connected (Lugo et al. 2011). The study area is located at 18°19′53.52″ N, 66°4′33.75″ W (NAD83). By 2010, the restored area (approximately 66,000 m²) was covered by forests (43.6%) and the remaining area (56.2%) was covered by pastures and shrubs (Manrique-Hernández 2013).

We assessed the current structure and composition of the riparian vegetation eight years after the stream restoration. Vegetation sampling was conducted at the restored area and nearby non-impacted areas hereafter referred to as "reference areas" (Figure 2). Located within the study site, the reference study area (800 m²) is four times smaller

Table 2. Tree species observed in the study area (reference and restored plots) after restoration and their structural variables values (NA was used for not available values). Origin: Native to the Americas (N), Non-native to the Americas (E).

Tree species	Common Name	Origin	Reference plots Frequency	Restored plots Frequency	Total Stems	Average Height (m)	Average Importance Values
Albizia procera	(tall albizia) Albicia	E	3	11	169	50.3 ± 10.6	46.3 ± 7.2
Andira inermis	Moca	N	1	0	1	2.21	1.1
Artocarpus affilen	Pana	E	1	1	2	12.75	1.3
Bursera siancaroba	Almacigo	N	0	2	3	5.5 ± 3.6	2.4 ± 0.6
Byrsonima spicata	Maricao	N	0	2	4	9.35	15.8
Calophyllum antillanum	Palo de maría	N	0	1	1	NA	1.6
Calophyllum inophyllum	María grande	E	0	1	1	7.8	1.9
Casearia aculeata	Rabo de ratón	N	0	1	1	—	—
Casearia guianensis	Cafetillo	N	3	1	31	5.7 ± 3.6	5.7 ± 3.6
Casearia sylvestris	Cafeíllo cimarrón	N	3	1	20	14.7 ± 4.	7.0 ± 6.0
Cecropia campanulata	Yagrumo	N	2	5	15	13.0 ± 2.6	8.6 ± 3.7
Chrysophyllum cainito	Caimito	N	0	1	2	—	1.5 ± 0.0
Cinnamomum elongatum	Avispillo	N	1	2	3	4.4 ± 0.7	18.2 ± 17.1
Citharexylum frutuosum	Péndula	N	0	1	4	7.2 ± 3.8	13.5
Citharexylum spinosum	Cambrón	N	2	5	14	7.4 ± 1.0	21.9 ± 19.5
Cocus nucifera	Palma de coco	E	1	2	21	27.2 ± 20.3	27.2 ± 20.3
Delonix regia	Flamboyan	E	0	1	1	10.2	53.8
Eugenia biflora	Pitangueira	N	0	2	2	—	—
Ficus sp.	Jagüey	N	0	2	3	23.8	2.6
Guarea guidonia	Guaraguao	N	2	5	41	13.4 ± 4.0	8.8 ± 1.1
Mangifera indica	Mango	E	1	0	14	36.5 ± 16.1	14.2
Miconia impetiolaris	Camasey	N	1	1	2	5.78	2.5
Miconia prasina	Camasey blanco	N	1	2	3	2.4 ± 0.9	1.5
Muntingia calabura	Capulin	N	0	2	7	82.3	11.9
Musa sp.		E	2	0	8	20.4	9.2
Myrcia splendens	Menuda	N	1	0	1	1.7	1.1
Persea americane	Aguacate	N	0	1	1	5.9	2.0
Platanus sp.		E	0	1	2	5.1	5.4
Spathodea campanulata	(African tulliptree) Tulipan africano	E	3	11	144	26.7 ± 4.0	36.4 ± 7.1
Syzygium jambos	Pomarrosa	E	2	1	3	8.2 ± 2.2	1.1 ± 0.0
Terminalia catapp	Almendro	E	0	2	4	26.3 ± 5.9	3.9 ± 0.3
Thespesia grandiflora	Maga	N	0	3	3	8.8 ± 2.4	2.1 ± 0.6
Thespesia populnea	Emajagüilla	E	0	1	1	6	2.0
Trema micranthum	Cabra	N	1	2	3	5.1	1.4
Zanthoxylum martinicense	Ayúa	N	3	0	3	14.8 ± 1.2	1.0 ± 0.1

than the restored area (3665 m^2), but representative of previous land cover conditions at the site (Table 1). Reference areas were located upstream and downstream from the restored area and are covered mostly by mature fragmented riparian forest land cover (Manrique-Hernandez 2013). Nine stream cross-sections were located inside the restoration project area (Figure 2). Cross-sections were divided into two sections, the right bank plot (R), which extended upslope to the residential complex, and the left bank plot (L). In the end, there were a total of 17 plots and not 18 because the left bank on the first cross-section had converted to residential land-use at the time of this study (Table 1). Plots composing the upstream restored area (9R and 9L) and the downstream restored area (1L) were classified as reference plots. All plots were perpendicular to the stream channel. All plots were five meters wide but plots varied in length depending on their location. Plots on the right bank were extended uphill to the border of the urban development (average of 45 m long) and all plots on the left bank were 60 m long.

We identified all grasses, shrubs, trees, ferns, vines, and herbs at each plot following Axelrod (2001) taxonomic checklist for Puerto Rico. For each plot we recorded the presence/absence of non-tree species and counted the number of individuals for each tree species. The diameter at 1.3 m from ground (DBH) was measured only for trees with a DBH > 2.5 cm. Data was used to calculate vegetation structural variables such as: Importance values, basal area (cm^2/m^2), tree density (stems/area), and species abundance at each plot. The importance value (IV) of each tree species within a plot was calculated for trees using the formula: [(Rb+Rd)/2)], where Rb is its relative basal area, and Rd is its relative density of each tree species (cf. Lugo et al. 2001).

Data Analysis

Vegetation structural variables were analyzed using a one-way analysis of variance (ANOVA) test for all plots which includes the descriptive variable: restored or reference (impacted or non-impacted). All data were checked (and transformed if necessary) for normality and variance heteroscedasticity. Variation of community composition was explored with a non-metric multidimensional scaling analysis and tested using an Analysis of Similarity (one-way ANOSIM) with Bray-Curtis as a distance measure (Clarke 1993). For tree species, we assessed community composition using basal area, individual stems and species abundance. For non-tree species, we assessed community composition using species abundance.

Species diversity was calculated with the Shannon-Weiner index (H′) using frequency per plot as a measure of species abundance. The distribution of diversity was assessed using species evenness ($e^{H/S}$) per plot. Our research area is composed of plots originating from cross-sections with different areas, which required sampling areas of different sizes. In order to compare taxonomical richness among plots with different areas, we used species rarefaction analysis (Gotelli and Colwell 2010). Difference in diversity index values, species evenness, and the rarefaction-based species richness values were assessed using one-way ANOVA. We executed all the analyses using Minitab statistical software v15 (Minitab Inc. 2010, State College, PA) and PAST statistical software 2.15 (Hammer et al. 2001, University of Oslo, Oslo, NO). Diversity index (H′) and evenness were calculated using Estimates v5.0 (Colwell 1997, University of Connecticut, CT).

Results

Riparian Vegetation Structure and Composition

We identified a total of 119 species in the 17 study plots. Out of those, 35 were tree species represented in 538 stems. The most abundant tree in the study area was tall albizia (*Albizia procera*), a non-native species, with a total of 169 stems distributed across 14 plots (Table 2). Average height of tall albizia was 14.9 m and average basal area was 2,116 cm^2/m^2, the highest recorded for trees in this study. Tall albizia was also the dominant species in eight out of the 14 plots followed by another non-native species, African tulip tree (*Spathodea campanulata*) with 144 stems and was the dominant species in six out of 14 plots. Both species where present in all 3 reference plots. The third most abundant tree was the native species American muskwood (*Guarea guidonia*) with 41 individuals present in only three plots. We found a total of 84 non-tree species distributed as follows: shrubs (n = 14), ferns (n = 10), herbs (n = 35), and vines (n = 25). Of these, only 3 species were observed in 16 of the 17 plots: Mexican crowngrass (*Paspalum fasciculatum*), tropical kudzu (*Pueraria phaseoloides*) and blackeyed Susan vine (*Thunbergia alata*) (Table 3).

Reference and restored plots were significantly different in tree structure. Tree species abundance (One-way ANOVA, $F_{16,544} = 6.1$, $p = 0.03$) was higher in the reference plots (Table 4). Out of the overall 35 tree species found in our study area, 23 were native and showed a higher abundance in restored than reference plots (One-way ANOVA, $F_{16,544} = 5.77$, $p = 0.021$). Basal area on the reference plots was significantly higher relative to plots within the restored area (One-way ANOVA; $F_{16,544} = 12.44$, $p < 0.001$). Tree stem density (One-way ANOVA, $F_{16,544} = 12.33$, $p < 0.001$) values for the reference plots were also higher compared to the restored plots, however. All tree species structural variables in reference plots showed higher values when compared to restored plots. The restored area was previously completed bulldozed, therefore, the tree community is young and the species abundance of non-tree species was higher (222 species) relative to reference (77 species) plots (One-way ANOVA, $F_{16,544} = 4.51$, $p = 0.05$; Table 4). The pooled species abundance (trees and non-trees) was significantly higher on the reference plots than on the restored plots (One-way ANOVA, $F_{16,1888} = 7.7$, $p < 0.01$). The combined tree and non-tree species composition differed between reference plots and restored plots (One-way ANOSIM, $R_{87} = 0.510$, $p = 0.001$). An exploratory NMDS plot arranged the reference plots together and clearly separated them from the restored plots based on tree and non-tree species composition (Figure 3). However, tree species composition in the reference plots was not different from restored plots (One-way ANOSIM, $R_{42} = 0.082$, $p = 0.309$).

Diversity and Species Richness

Species diversity values were significantly higher in reference plots than in restored plots (One-way ANOVA, $F_{16,1888} = 4.89$, $p = 0.04$). Therefore, even though the number of species observed in the restored area (240) was higher than the reference area (112), the restored plots didn't differ much from each other. The rarefaction analysis, used to account for unequal areas, showed a significant difference in species richness among reference and restored plots (One-way ANOVA, $F_{16,1888} = 111.8$, $p = 0.001$).

Table 3. Non-tree species observed in the study area (— was used for not available values). Origin: Native to the Americas (N), Non-native to the Americas (E), only cultivated (OC) and ornamental (OR).

Species	Common name	Type	Reference Plots Observed	Restored plots Observed
Adiantum sp.	—	Fern[N]	1	1
Alpinia sp.	—	Herb[E]	1	0
Astraea lobata	Croton lobulado	Shrub[N]	0	1
Bidens alba	Margarita	Herb[N]	1	3
Bromelia pinguin	Maya	Herb[N]	0	4
Campyloneurum phyllitidis	—	Fern[N]	0	1
Canna indica	Maraca	Herb[E]	0	0
Cayaponia sp.	—	Vine[N]	0	2
Centrosema sp.	—	Vine[N]	0	2
Chamaecrista nictitans	—	Herb[N]	0	3
Chromolaena odorata	Santa María	Shrub[N]	1	4
Cissumpelos pareira	Bejuco de mona	Vine[N]	2	4
Cissus verticillata	Caro	Vine[N]	2	4
Clidemia hirta	Camasey	Shrub[N]	2	3
Codiaeum variegatum	—	Shrub[OR]	1	0
Commelina diffuse	Cohitre	Herb[E]	3	8
Cuphea strigulosa	—	Herb[N]	1	2
Cyanthillium cinereum	Rabo de buey	Herb[E]	0	2
Cyperus odoratus	—	Herb[E]	0	3
Dieffenbachia seguine	Rábano	Herb[N]	1	0
Dioscorea alata	Ñame	Vine[E]	1	1
Elephantopus mollis	Lengua de vaca	Herb[N]	0	2
Emilia sp.	—	Herb[E]	0	1
Epipremnum pinnatum	Amapolo amarillo	Vine[OC]	1	0
Epipremnum sp.	—	Vine[E]	2	0
Euphorbia heterophylla	Lechecillo	Herb[E]	0	3
Euphorbia hyssopifolia	Lechera	Herb[N]	0	1
Euphorbia sp.	—	Herb[E]	0	1
Galactia sp.	—	Vine[N]	0	1
Gonzalagunia spicata	Mata de mariposa	Shrub[N]	1	1
Heteropterys sp.	—	Vine[N]	0	2
Heterotis rotundifolia	—	Herb[E]	1	3
Hibiscus bifurcatus	Buenas tardes	Shrub[N]	0	3
Hippocratea volubilis	Bejuco prieto	Vine[N]	1	0
Hyptis capitata	Botoncillo negro	Herb[N]	1	1
Ichnanthus pallens	Carrucillo	Herb[N]	3	1
Ipomoea sp.	—	Vine[E]	3	14
Lantarca camara	Cariaquillo	Shrub[N]	0	2
Lasiacis divaricata	Pito	Herb[N]	1	0
Lasiacis sp.	—	Vine[N]	0	1
Ludwigia octovalvis	Cangá	Herb[E]	1	1
Lygodium japonicum	—	Fern[E]	1	2
Macfadyena unguis-cati	Bejuco de gato	Vine[N]	1	0
Megathyrsus maximus	Guinea	Herb[E]	0	1
Melanthera nimer	Cariaquillo blanco	Herb[N]	2	5
Melothria pendula	Pepinillo cimarrón	Vine[N]	0	3
Merremia quinquefolia	Batatilla blanca	Vine[N]	0	1
Mimosa casta	Zarza	Shrub[N]	1	12
Mimosa pigra	—	Shrub[N]	1	11
Momordica charantia	Cundeamor	Vine[E]	0	5
Nephrolepis brownii	—	Fern[E]	3	9
Odontosoria aculeata	Helecho espinoso	Fern[N]	0	1

(***continued***)

Table 3. (*Continued*)

Species	Common name	Type	Reference Plots Observed	Restored plots Observed
Oeceoclades maculata	—	Herb[E]	1	0
Oplismenus hirtellus	Carruzo	Herb[N]	1	0
Oxalis barrelieri	—	Herb[N]	0	2
Paspalum fasciculatum	(Mexican crowngrass) Venezolana	Herb[N]	1	14
Paullinia pinnata	Bejuco de costilla	Vine[N]	3	2
Philodendron sp.	—	Vine[N]	1	0
Phymatosorus grossus	—	Fern[E]	1	0
Piper aduncum	Higuillo	Shrub[N]	0	4
Piper hispidum	Higuillo	Shrub[N]	2	1
Piper peltatum	Baquiña	Herb[N]	1	1
Pityrogramma calomelanos	Helecho blanco	Fern[N]	1	4
Pueraria phaseoloides	(tropical kudzu) Kudzu	Vine[E]	3	13
Rhynchospora ciliata	Botoncillo	Herb[N]	1	0
Roystonea borinquena	—	Herb[N]	1	1
Securidaca diversifolia	—	Vine[N]	0	1
Sida acuta	Escoba blanca	Herb[E]	0	1
Sida urens	—	Herb[N]	0	1
Solanum torvum	Berenjena cimarrona	Shrub[N]	1	5
Syngonium podophyllum	Malanga trepadora	Vine[N]	3	2
Tectaria incisa	—	Fern[N]	1	0
Thelypteris dentata	—	Herb[E]	0	1
Thelypteris hispidula	—	Fern[N]	1	0
Thunbergia alata	(blackeyed Susan vine) Culo de poeta	Vine[E]	3	13
Tournefortia hirsutissima	Nigua	Shrub[N]	1	0
Trichostigma octandrum	Bejuco de nasa	Herb[N]	1	3
Triumfetta sp.	—	Shrub[N]	1	1
Urena lobata	Cadillo	Herb[E]	1	3
Urochloa brizanthu	Yerba signal	Herb[E]	2	8
Vigna adenantha	Habichuela cimarrona	Vine[N]	1	0
Vigna hosei	Frijol de abisinia	Vine[E]	1	0
Vigna luteola	—	Vine[E]	1	3

Table 4. Sum of all vegetation structural values for reference and restored plots.

	Variables	Reference	Restored
Tree species	Total Species	35	18
	Basal Area (cm^2/m^2)	4896.6	1183.0
	Total Tree stems	200	58
	Tree densities (Tree/m^2)	0.80	0.28
	Total species/area (m^2)	0.04	0.01
Non-tree Species	Total Vines species	30	74
	Total Herb species	26	81
	Total Fern species	9	19
	Total Shrubs species	12	48
	Total Species	77	222
	Species/area (m^2)	0.1	0.1

Discussion

Eight years after the Quebrada Chiclana stream restoration project, we found a sparsely forested riparian vegetation community compared to reference plots (Manrique-Hernández 2013). Pioneer non-native species such as tall albizia and African tulliptree were the most abundant trees in the study area. The tree tall albizia is characteristic of bulldozed sites, while African tulliptree is typical of post-agricultural abandoned zones (Aide et al. 2000, Chinea 2002, Chinea and Helmer 2003). Our findings capitulate these patterns showing tall albizia as the most important tree species at the previously bulldozed Quebrada Chiclana (IV = 52%) and African tulliptree the most important on reference areas (IV = 49%).

Assessing Restoration Success: Reference vs. Restored areas

The reforestation plan stated that one of its objectives was to increase the ecological value of the area to be restored when compared with the conditions before the construction and conversion of the riparian vegetation to a flat fill (Ecosystems and Associates 2003). We assumed that our reference areas were a representation of the riparian structure and composition prior to the conversion (Manrique-Hernández 2013). Tree structural values are all higher in reference plots when compared to restored plots (Figure 4). Non-tree species abundance also showed higher values in the reference plots when compared to restored plots. In tropical headwaters of an Australian study site, Davies et al. (2005) concluded that differences in structure and species composition could still be evident 15 years after site clearing. In addition, species diversity on reference plots was higher. Environmental factors such as environmental heterogeneity (Scheiner et al. 2000), usually influence differences among plots, in addition to the presence of less abundant species (Gotelli and Colwell 2010), both of which were present in our study area. Environmental heterogeneity caused a disproportional effect that resulted in a recovering species composition that is not uniformly distributed across our study area.

Our results showed that eight years after the restoration project ended, species abundance and composition was considerably different between reference and restored plots. We can conclude that, to date, the reforestation plan has not fully met the goal of improving the ecological value of the riparian zone from its pre-impact conditions.

Assessing Restoration Success: Native Vegetation

The reforestation plan was very clear about its objectives: "Achieve a native tree corridor of multiple habitats and give an advantage to native species over the exotics" (Ecosystems and Associates 2003). In order to assess the proposed reforestation plan objective we considered only the location and abundance of native species listed on the plan. The plan proposed the introduction of 16 species composed of 12 native and four non-natives. At the time of this study, there were only 11 of the proposed species in the restoration plan at the restored area (7 native, 4 non-native). The number of stems proposed versus the observed clearly denotes that the developer could not attain the survival of the planted species and therefore, did not fulfill the proposed corridor of native species (Table 5).

Tree recovery on the restored area seems favorable for other non-proposed native tree species. Native species showed a higher abundance in reference than restored plots. Of the present 23 native species, three were introduced by Chiclana's local community efforts. Tree species composition in the reference plots didn't differ when compared to restored plots even though the abundance of native tree species in restored plots was higher than those in the reference plots. This means that the lack of difference in tree species composition was influenced only by non-native tree species abundance which did not show significant differences between restored and referenced plots. The riparian community is mainly dominated by species that were not proposed in the reforestation plan.

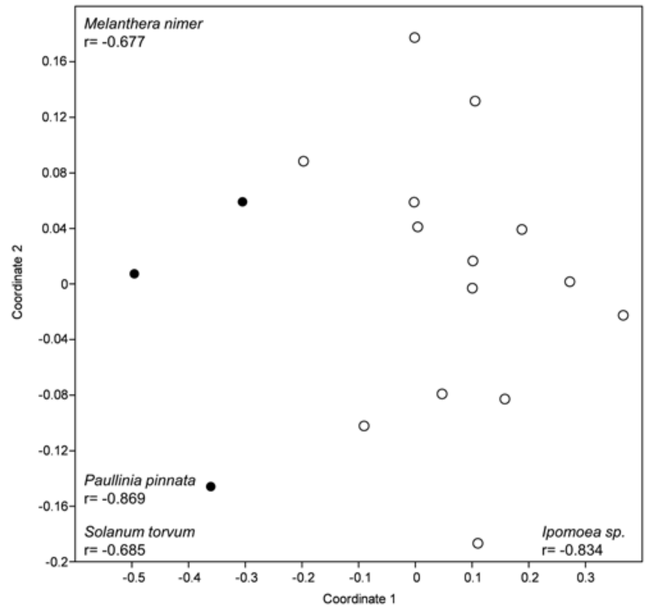

Figure 3. Non-Metric Multidimensional Scaling (NMDS) plot of overall species composition based on trees and non-tree species presence. Closed circles are reference plots, open circles are restored plots. Stress: 0.2033. Axis (coordinate) 1: 0.6587. Axis (coordinate) 2: 0.1802.

An Open-ended Restoration Approach

We have shown evidence that, after eight years, the river restoration project has not fully met its reforestation objectives, however, the present riparian forest ecosystem had recovery through succession and recovered ecological value. Hughes et al. (2012) described open ended restoration as a practice were human influence is reduced or removed, and the habitats are allowed to recover naturally. Natural regeneration has been proven as an effective strategy for restoration of abandoned tropical fields to obtain secondary forests (Aide et al. 2000). In tropical degraded lands, fast growing species may serve to rehabilitate ecosystem properties on sites that natives may not be capable of colonizing immediately (Chinea 2002). These species reduce grass cover and facilitate the increase of stem density, basal area and species diversity; this process continues to occur 10 to 15 years post-abandonment (Aide et al. 1996). For example, African tulliptree, one of the most abundant species in our study area, lives 30 to 40 years, and once it dies out, is replaced almost exclusively by native species that are present in the understory and have dispersed into the site (Aide et al. 2000, Chinea and

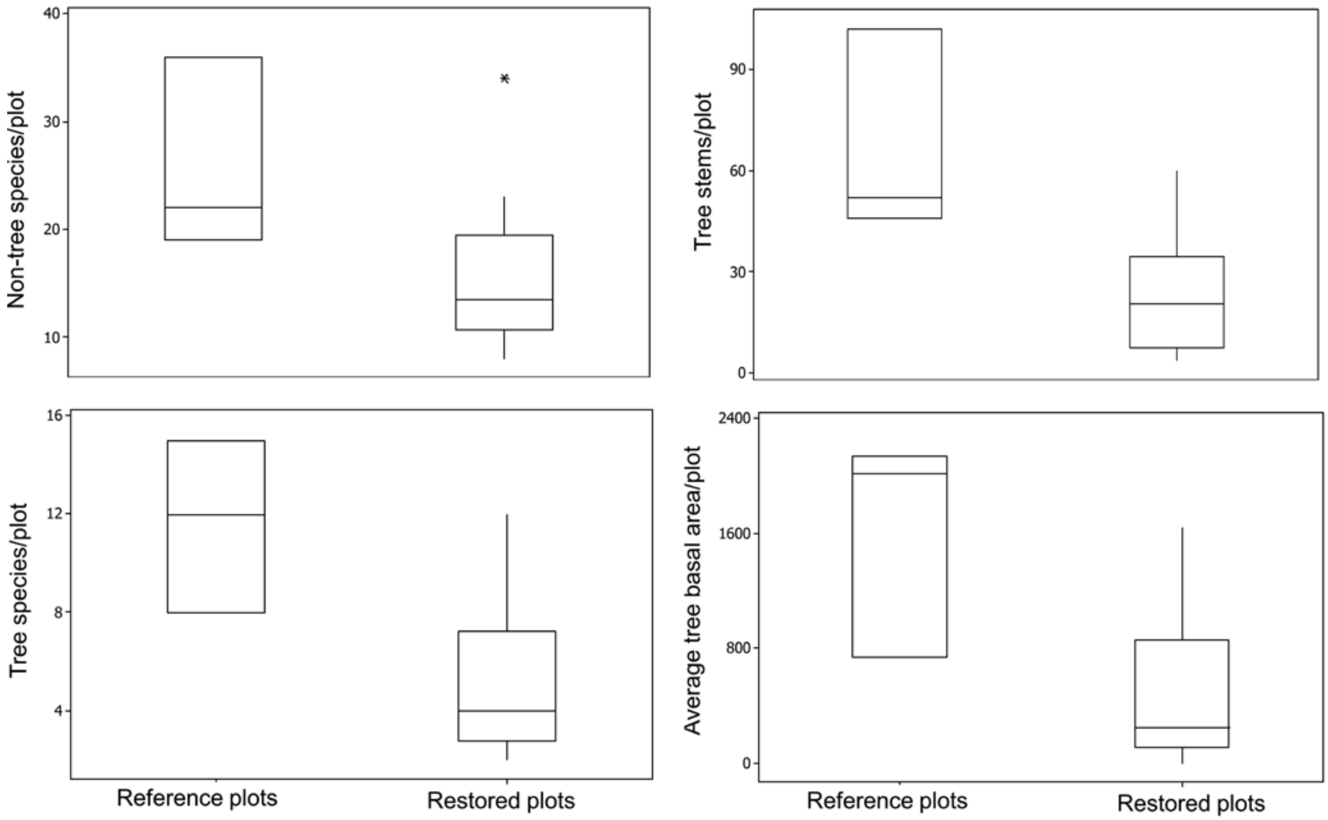

Figure 4. Box plots of tree species structural variables and non-tree species for reference (area = 800 m^2) and restored (area = 3665 m^2) plots.

Table 5. Species proposed (#) to be planted in the reforestation plan and observed (#) in the study area eight years later (— was used for not available values). Species with asterisk were not all necessarily planted by the developer. For example, *S. jambos* and *M. indica* were observed in control plots, while *A. inermis* and *A. squamosa* were planted by the community members from the Caimito area. N = Native to the Americas, E = Non-native to the Americas.

Scientific name	Common name	Origin	Proposed	Observed
Cecropia schreberiana	*Yagrumo*	N	75	15
Thespesia grandiflora	*Maga*	N	85	10*
Syzygium jambos	*Pomarrosa*	E	100	6*
Roystonea borinquena	*Palma real*	N	10	4
Magnifera indica	*Mangó*	E	20	3*
Annona glabra	*Anón cimarrón*	N	100	3
Andira inermis	*Moca*	N	5	2*
Ficus citrifolia	*Higo ó jaguey*	N	—	2
Annona squamosa	*Anón*	N	100	1*
Clusia rosea	*Cupey*	N	20	1
Thespesia populnea	*Emajaguilla*	E	15	1
Delonix regia	*Flamboyán*	E	—	1
Burcera simaruba	*Almácigo*	N	20	0
Ceiba petandra	*Ceiba*	N	4	0
Cordia sebestena	*Vomitel colorado*	N	—	0
Tabebuia heterophylla	*Roble blanco*	N	10	0

Figure 5. Forest succession in plot 3L, view from plot 3R. Top photo 2006, below 2010. A pluvial structure is marked at the right of each photo for reference.

Helmer 2002, Abelleira 2010). Chinea (2002) concluded that early successional species may serve to rehabilitate ecosystems on sites that natives may not be capable of colonizing immediately, such as heavily impacted sites like ours. N-fixing species, such as African tulliptree and Indian albizia (*Albizia lebbek*) may improve recruitment of native woody species in degraded tropical sites (Cusak and McCleery 2014, Abelleira et al. 2015).

The concept presented by Hughes et al. (2012) of natural regeneration can be observed in the Quebrada Chiclana restored area (Figure 5). Our results present favorable natural succession after the restoration project ended. For example, the vegetation community in our study area is not as species-poor as expected, even after determining that the reforestation plan was not fully successful. Furthermore, we found no significant difference in tree species composition when comparing the restored area with reference areas. This implies that the riparian community growing in the restored area is recovering at a rate that is already showing similar structural characteristics present in the vegetation growing in reference non-impacted areas. In tropical areas, it may take up to 40 years for a recovering forest to become similar to 80 year-old mature secondary forests (Aide et al. 2000), and in an area with highly compacted soil such as the ones studied, this process can be delayed significantly (Aide et al. 2000, Chinea 2002).

In addition, even though non-natives showed a higher number of stems, 90% of all species present in our study area are native. Although the most important trees species are non-native, with the evidence provided by the previous studies we can expect a transition from non-native to native species in the coming years. Considering the magnitude of the events that affected the area (Ortiz-Zayas et al. 2011), the diversity values observed are similar to other early successional secondary forest sites (Aide et al. 1996, Thompson et al. 2002, Chinea and Helmer 2002, Heartsill-Scalley et al. 2002). The number of tree species observed in our restored area (29) is similar to those on an urban forest (33), reverted moist forest (31) and a lower montane wet forest (30) (Island-wide data from the year 2002, presented in Lugo 2004). Still, Hughes et al. (2012) clarify that open-ended restoration should not be used as an excuse to replace targeted driven restoration.

The variable dynamics in the humid tropics due to climate events and available energy makes it harder to predict restoration results in the area and further more in instances of restoration of heavily impacted systems. Through a vegetation census based on study plots, we determined which species are able to grow favorably on a heavily impacted area. Due to their fast growth and resilience, non-native species appeared to be the best option (Chinea 2002, Cusak and McCleery 2014, Abelleira et al. 2015). These species are ideal to use during targeted driven restorations for projects aiming for habitat restoration over a restoration focused immediately on species richness. Nearby patches of forest will also contribute to dispersal and facilitate succession from non-native to native species (Norden et al. 2009). The species listed in this study can be used as a tool for seeding programs in heavily impacted tropical soils. The low values for structural variables of native species presented in our study is an indicator that the community is not resilient enough and might need human intervention in order to reach a successful recovery. This is a result of a management approach in which scientific methods weren't adequately incorporated during the pre-restoring planning. Incorporating assessments of reference area species composition and environmental variables when setting restoration objectives would lead to a more ecologically successful restoration.

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