Chapter 33
Reforestation and Natural Succession as Tools for Restoration on Abandoned Pastures in the Andes of South Ecuador

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Abstract Ecuador is one of the global hot spots of biodiversity. Nevertheless, it faces high deforestation rates and unsustainable land use resulting in a substantial and growing amount of degraded land, which needs to be rehabilitated for productivity and biodiversity purposes. We present the results of a reforestation experiment within a gradient of three successional phases after abandonment of pastoral use. Six native species were tested against two exotics. Furthermore, we analyzed the regeneration potential from the soil seed bank and monitored the development of the diversity of woody species in the natural succession at the different sites. Our results show that dependence on natural regeneration for forest recovery cannot be an acceptable solution for forest users, due to the low speed of recovery and the insufficient species composition of the regeneration. Planted seedlings of native species are able to cope with the harsh conditions if they are selected according to their adaptation to the environmental characteristics of the respective planting sites.

Keywords Biodiversity · Ecuador · Native species · Reforestation · Restoration

33.1 Introduction

Ecuador is part of the 17 mega-diverse countries of the planet and contains portions of two of the world's biodiversity "hot spots," the tropical Andes and the Tumbes-Choco-Magdalena (Mittermeier et al. 1997; Myers et al. 2000; Brummitt and

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Lughadha 2003). However, it also has the highest deforestation rate of South America (FAO 2006). As a result of high deforestation and nonsustainable land use, there now exists a substantial and growing reservoir of unproductive land in Ecuador, especially of previously over used, degraded, and abandoned fields and pastures (Weber et al. 2008). For instance, from 1972 to 1985, pastoral land in Ecuador increased from 2.2 to 4.4 million ha and by 1989 pastures covered an area of about 6 million ha (Wunder 2000; Mosandl et al. 2008).

Tree plantations play an important role in tropical forest restoration and rehabilitation as they can provide canopy cover within a short time (Parrotta 1992; Sampaio et al. 2007). Natural succession is also considered as a strategy to forest recovery providing further advantages such as enhancing floristic composition. Recovery of tropical forests in abandoned pastures is very complex and depends on many factors, including land use history (Pascarella et al. 2000; Chinea 2002), land use intensity (Guariguata and Ostertag 2001), the often limited availability of seeds (Wijdeven and Kuzee 2000), competition with introduced highly competitive pasture grasses (Holl et al. 2000), time since abandonment (Aide et al. 1995; Klanderud et al. 2009), and distance from the forest edge (Zimmermann et al. 2000; Günter et al. 2007).

In Ecuador, initiatives to develop sound concepts for assisting forest recovery are very limited. The few reforestation activities carried out to date are predominantly based on plantations with introduced species, such as *Pinus* and *Eucalyptus* spp. (Günter et al. 2007). Among the main reasons for the neglect of native species in reforestation activities is the lack of knowledge about their ecology and silvicultural characteristics (Alvarez-Aquino et al. 2004; Stimm et al. 2008). In fact, no national organizations exist in the country, which are capable of designing and implementing a structured national research and development program for the forest sector (IITO 2009).

Based on the two approaches mentioned above, and with the aim to identify ways to accelerate the restoration processes, an experiment was set up in 2003 along a gradient of three successional stages of abandoned pastures. The specific objectives of the study were (1) to explore the suitability of native species for reforestation of abandoned pastures, (2) to compare the performance of the native species with that of the commonly used exotics, (3) to identify species-specific reactions to different successional states of planting sites, and (4) to analyze the natural regeneration potential of different types of abandoned pastures.

33.2 Study Area

The study area is located in Southern Ecuador, in the province of Zamora Chinchipe. The test sites are located in the high valleys of the San Francisco River, on the flanks of the Andes, near the research station “Estacion Scientifica San Francisco” (ECSF) in the buffer zone of the Podocarpus National Park (Fig. 33.1).

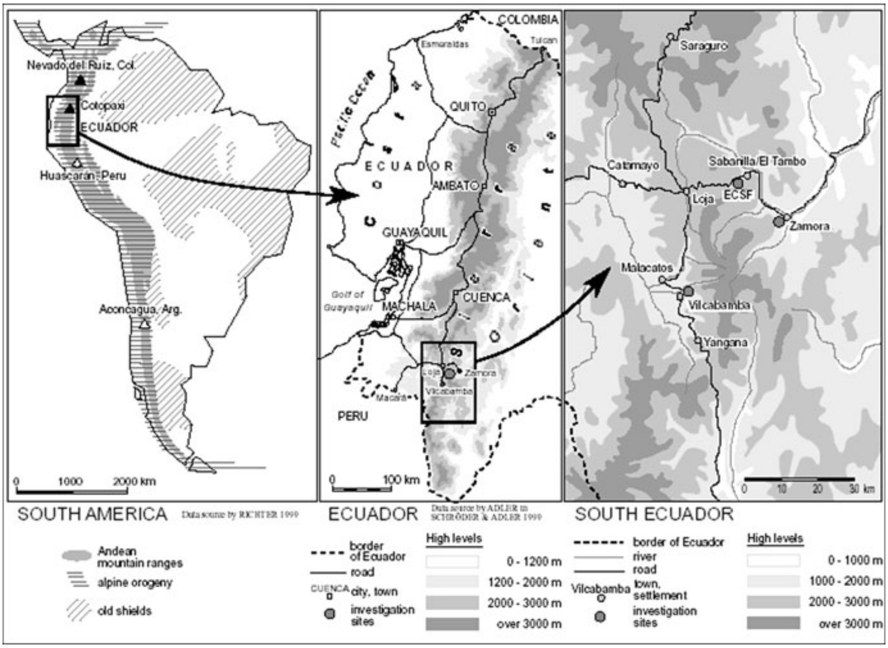

Fig. 33.1 Orientation map, showing the general location of Ecuador and the area under study (from Hagedorn 2001)

The study area occurs along an altitudinal range from 1,800 to 2,200 m asl (above sea level). The climate at ECSF is tropical humid and characterized by 11 humid months a year (Hilt and Fiedler 2005). The precipitation is strongly influenced by the altitude. At 1,950 m asl, mean annual rainfall amounts to 2,000 mm with an extremely wet season from April to July and a less humid period from September to December (Bendix et al. 2006). For the investigations of this study, three different stages of succession after abandonment of pastures have been selected (1) a most recently abandoned pasture used for livestock raising (hereafter: Pasture), (2) a shortly abandoned pasture actually covered by the invasive cosmopolitan fern *Pteridium arachnoideum* (hereafter: Fern), (3) an abandoned pasture where a young secondary forest with shrub vegetation could already become established (hereafter: Shrub).

33.3 Methods

33.3.1 Plantation Experiment

The reforestation experiment had been established in 2003 in a Generalized Randomized Block Factorial design with three successional stages of 4 ha each, six native and two exotic species, and two treatments of the competing herbaceous vegetation (removal only before planting vs. removal before planting and every 4 months after planting for 2 years). The experiment comprises a total of 480 plots with 25 seedlings each planted in pure and mixed species sets with a spacing of 1.8 m × 1.8 m, and eight replicates of each factor combination. A detailed description of the experimental design is given by Aguirre (2007). The species planted can be classified as follows:

- From the six native species, three (*Alnus acuminata*, *Heliocarpus americanus*, and *Morella pubescens*) are categorized as light-demanding species because they naturally regenerate especially in natural clearances and three as more shade tolerant species (*Cedrela montana*, *Juglans neotropica*, and *Tabebuia chrysantha*) due to their preference to regenerate under a closed canopy.
- The two exotic species (*Pinus patula* and *Eucalyptus saligna*) represent the species predominantly used for reforestation in the study area and more generally in the Andean region of Ecuador.

The data presented here refer to the situation of the control and pure plantations plots 48 months after planting. For the height analysis, the top height (best 20% of individuals in each successional stage) was used.

33.3.2 Soil Seed Bank

At each of the three sites of the reforestation experiment, ten plots were randomly selected for an analysis of the soil seed bank. In addition to these samples, ten plots were also selected in the natural forest of the ECSF to enable a comparison between the seed bank at the disturbed reforestation sites and that of an undisturbed forest. In each of these 40 plots, five soil subsamples were collected with a metallic cylinder of 10 cm^3. The 200 samples were placed in receptacles under controlled conditions of the greenhouse in the project nursery and the germination of all woody species was evaluated over a period of 210 days.

33.3.3 Monitoring of Natural Succession

In addition to the reforestation experiment, 16 randomly chosen plots for each successional stage were established to monitor the natural succession of woody species. In each plot, species richness and abundance were recorded every 2 years from 2003 to 2007. To test whether a reduction of the strong competition by the ground vegetation can accelerate the restoration processes, the herbaceous vegetation was removed in 50% of the plots, while the rest remained untreated. However, since the treatment effect was not significant, the corresponding results are presented as a single group.

33.4 Results and Discussion

33.4.1 Survival and Growth of the Native and Exotic Species Plantations

The results of the plantation experiment revealed species-specific patterns of behavior corresponding to their variable ecological needs. Forty-eight months after planting, the exotic species were more successfully established in terms of survival and growth performance in all successional stages than the native species (Fig. 33.2). Only *T. chrysantha* also showed excellent survival with a total mean of 91.1% over all three sites. This indicates that the species is able to cope with the harsh conditions on abandoned land and can tolerate a wide range of environmental conditions. However, the accumulative growth in height (cm), especially at the Pasture was very low, which is a typical behavior for late successional species.

At the Pasture, the native species *A. acuminata* showed the best growth of all species, including *P. patula* and *E. saligna*. This is considered to be an effect of its high demand for light and the ability to fix nitrogen making the species more competitive, while all other native species in this area suffer under the strong competition of the pasture grass *Setaria sphacelata*, which is known to reduce soil nitrogen and thus resists re-colonization of forest species (Rhoades et al. 1998). Surprisingly, the light demanding pioneer species *H. americanus* showed the lowest survival at the open Pasture and the highest at the Shrub site, but the height development of the species was low on all sites. This is in contrast to the observations in gaps of the natural forest of the ECSF where height growth of 2 m per year is observed. *J. neotropica* showed the poorest establishment of all natives in terms of survival and growth development at all successional sites. At the Fern site, *M. pubescens* showed excellent survival almost reaching that of *T. chrysantha* and the growth performance within the first 4 years was also good compared to

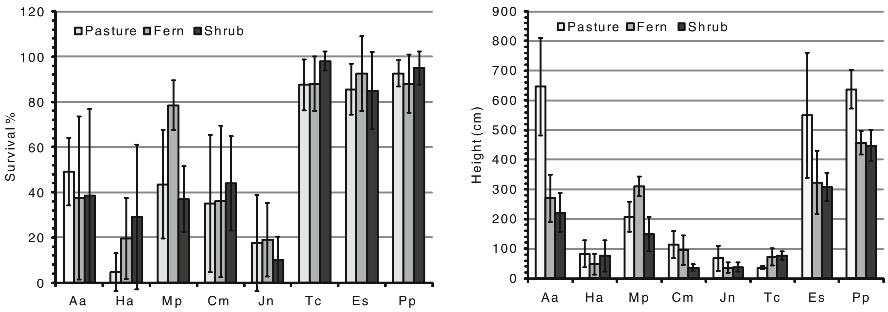

Fig. 33.2 Survival (%) and total height (cm) of seedlings at three different successional stages, 48 months after planting (means and standard deviation); *Aa Alnus acuminata*, *Ha Heliocarpus americanus*, *Mp Morella pubescens*, *Cm Cedrela montana*, *Jn Juglans neotropica*, *Tc Tabebuia chrysantha*, *Es Eucalyptus saligna*, *Pp Pinus patula*

other natives. At the Shrub site, survival of *C. montana* and *T. chrysantha* was higher than at the Pasture, but height growth of both species was quite low compared to *A. acuminata* and the two exotics and can hardly be considered sufficient for large-scale reforestation projects.

33.4.2 Regeneration Potential from the Soil Seed Bank

The results of the analysis of the soil seed bank showed that the number of germinated seeds as well as the species composition differed clearly among the four sites (Table 33.1). The number of germinated seeds increased gradually with each advanced successional site corresponding to about 38,000 N/ha at the pasture and more than 430,000 N/ha in the natural forest. In total, seeds of 15 species from 11 families germinated in the greenhouse. However, compared to the natural forest (=100%) the potential number of seedlings at the disturbed sites was much lower (Pasture = 9%, Fern = 17%, Shrub 35%).

The dominant families were Asteraceae and Melastomataceae, which comprised 54% of all individuals. Only two species (*Brachyotum and Rubus*) were present at all three sites of the plantation experiment. As expected, the proportion of tree species was highest in the samples from the natural forest in terms of individuals (422,100 N/ha) as well as of number of species. However, from the samples of the Shrub site, seeds of five tree species germinated, while at the Pasture and Fern, it was only one in each case (*H. americanus Miconia*). It was surprising that despite the high number of *Heliocarpus* that germinated from the samples of the Pasture

Table 33.1 Number of seedlings ($N \times 10^3$/ha) germinated in the nursery from soil samples of four different sites (Life form: *S* shrub, *T* tree; *N* = 200)

Family	Species	Life form	Pasture	Fern	Shrub	Natural forest
Asteraceae	*Ageratina dendroides*	S		11.5	35.7	
	Baccharis latifolia	S		17.8	40.7	
	Piptocoma discolor	T				15.3
Caprifoliaceae	*Viburnum pichinchensis*	T			10.2	
Clethraceae	*Clethra revoluta*	T			6.8	
Clusiaceae	*Vismia* sp.	T				10.2
Euphorbiaceae	*Hyeronima* sp.	T				10.2
Melastomataceae	*Brachyotum campanulare*	S	10.2	10.2	11.9	
	Meriania sp.	S				10.2
	Miconia sp.	T		10.2	10.2	50.9
Meliaceae	*Cedrela* sp.	T				5.1
Moraceae	*Rubus* sp.	S	10.2	25.5	25.5	
Rosaceae	*Hesperomeles* sp.	T			5.1	
Rubiaceae	*Palicourea* sp.	T			5.1	
Tiliacaeae	*Heliocarpus americanus*	T	18.3			330.4
Total shrubs			20.4	64.9	113.7	10.2
Total trees			18.3	10.2	37.3	422.1
Total			38.7	75.1	151.1	432.3

and the natural forest, no individuals of this species were present in the Fern and Shrub samples.

33.4.3 Development of Natural Succession

The monitoring of the natural succession plots revealed clearly that time since abandonment is an important driver of development of species richness and abundance at all successional sites. However, while species richness increased during the whole observation period at all sites, abundance at Pasture stagnated since 2005. This coincides with the findings of Holl et al. (2000) and Aide et al. (1995) that the dense growth and strong competition of grasses can inhibit the establishment of seedlings in abandoned pastures.

The Shrub site was the most diverse in terms of species richness and abundance followed by the Fern site (Fig. 33.3). Surprisingly, in the last 2 years of the monitoring, the Fern site was the most dynamic. This may be assigned to the fact that the shelter of the fern became stronger with time and provided more shade and protection against high irradiation, strong winds, and the resulting drought stress at the site. Although bracken fern is usually considered a weed species (Marrs et al. 2000) with phytotoxic effects (Dolling 1996; Marrs et al. 2000) that suppresses upcoming seedlings of other plants (Beck et al. 2008), this is not confirmed by our results. Our findings are in line with the results of Günter et al. (2009), who identified a facilitative effect of bracken on the development of planted seedlings of *C. montana* in our study area and Douterlungne et al. (2008), who revealed that *Ochroma pyramidale* (Cav. ex lam.) (Balsa) can also establish well in areas dominated by bracken fern. Consequently, we conclude that under certain conditions, bracken can mitigate extreme environmental factors and thus act as a facilitator for the development of natural succession and biodiversity.

The most dominant family at the Pasture and the Fern sites through time was Asteraceae (Table 33.2), which indicates the presence of many wind dispersed pioneer species. Table 33.3 shows that wind dispersed individuals clearly represent

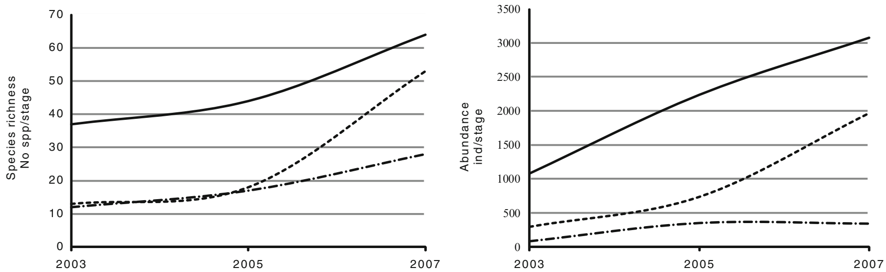

Fig. 33.3 Comparison of species richness (**a**) and abundance (**b**) of woody species at the different successional sites over time (sample area per site: 1,866 m^2)

Table 33.2 List of dominant woody species at the different successional sites (only species with >20 individuals/site), 0 and 48 months of monitoring (*P* pasture, *F* fern, *S* shrub)

Family	Species	Mode of dispersal	Life form	0 Months			48 Months		
				P	F	S	P	F	S
Asteraceae	*Ageratina dendroides* (Spreng) RM	Wind	Shrub	12	203	241	54	673	817
	Baccharis latifolia (R&P) Pers.	Wind	Shrub	20	3	1	55	6	1
	Baccharis tricuneata (L. f.) Pers.	Wind	Shrub				2	40	1
	Baccharis sp.	Wind	Shrub					379	
Caprifoliaceae	*Viburnum pichinchensis* Benth	Bird	Tree			5	4	1	92
Clethraceae	*Clethra fagifolia* Kunth	Wind	Tree					10	57
Cyatheaceae	*Cyathea* sp.	Wind	Treelet			20		1	69
Ericaceae	*Bejaria aestuans* L.	Bird	Shrub				1	74	4
	Bejaria resinosa Mutis ex L.F.	Bird	Shrub		23				
	Gaultheria erecta Vent.	Bird	Shrub				11	168	137
	Vaccinium floribundum H.B.K	Bird	Shrub			2			22
Gentianaceae	*Macrocarpaea* sp.	Bird and bats	Treelet					1	21
Grosilariaceae	*Escallonia paniculata* (Ruiz & Pav.) Roem. & Schult	Wind	Treelet				1	51	2
Melastomataceae	*Axinaea* sp.	Wind	Shrub					2	30
	Monochaetum lineatum (D. Don) Naudin.	Wind	Shrub		2	4	29	240	25
	Tibouchina laxa (Desv.) Cogn	Wind	Shrub	7	3	54	36	27	95
	Brachyotum campanulare (Bonpl) Triana	Bird	Shrub	34	4	16	48	34	394
Myrsinaceae	*Myrsine coriacea* (Sw.) R. Br. Ex Roem. & Schult.	Bird	Tree		36	581	2	142	1,016
Rosaceae	*Hesperomeles obtusifolia* Pers.	Bird	Tree			8		3	25
	Rubus floribundun HBK	Bird	Shrub	1	2	7	29	3	54
Rubiaceae	*Palicourea* sp. 1	Bird	Treelet						32
	Palicourea anceps Standl.	Bird	Treelet					1	54
	Palicourea sp. 2	Bird	Treelet			43			

Table 33.3 Number of individuals of woody species dispersed by animals and wind per successional stage (1,866 m^2) at 0 and 48 months (*P* pasture, *F* bracken, *S* shrub)

Dispersal mechanism	0 months			48 months		
	P N (%)	F N (%)	S N (%)	P N (%)	F N (%)	S N (%)
Animal	7 (8)	71 (24)	87 (20)	76 (22)	453 (23)	1,566 (51)
Wind	77 (92)	226 (76)	347 (80)	268 (78)	1,511 (77)	1,488 (49)
Total	84 (100)	297 (100)	434 (100)	344 (100)	1,964 (100)	3,054 (100)

the prevailing fraction at the Pasture and Fern, although the proportion of animal dispersed individuals at the Pasture increased from 8 to 22% within the observation period, a level which is equivalent to that of the Fern. In contrast, at 48 months of monitoring, the Shrub site was dominated by animal dispersed individuals (51%). The dominant family here was the Myrsinaceae with one single predominant species (*Myrsine coriacea*) whose life form is that of a small tree and whose seeds are dispersed by birds.

At all three sites, only a few species of late successional status were found, presumably due to the distance of the areas to a mature forest, which limits seed input. These results support also the findings of Günter et al. (2007) that the speed of the natural regeneration of abandoned pastures as well as its species composition is not satisfying from a user's point of view.

33.5 Conclusions

In conventional reforestation activities, trees are usually planted directly in open areas. In fact, areas where shrubs or bushes have already established are even manually or chemically cleared or burned before planting. Such conditions may be acceptable for pioneer species and many exotic species, but not for mid and late successional species, such as *C. montana*, *J. neotropica*, or *T. chrysantha*, that require slight shelter. However, it is not yet a well-established procedure in reforestation measures in the tropics to adapt tree species to the successional stage of the dominating vegetation at the reforestation site (Dobson et al. 1997; Lamb et al. 2005; Wishnie et al. 2007).

Our study confirms the well-known qualification of the exotic species Pinus and Eucalyptus in the reforestation of degraded land. However, as several studies revealed, these species have negative effects on the hydrological balance (Farley and Kelly 2004; Buytaert et al. 2007; Vanacker et al. 2007) and on biodiversity (van Wesenbeeck et al. 2003). Therefore, it is necessary to identify native species that are better adapted to the local environment. Our results show that native species, such as *A. acuminata*, *T. chrysantha*, or *C. montana*, are able to cope with the harsh conditions of degraded land. To ensure good survival and growth, it is necessary to choose the species according to their adaptation to the environmental characteristics at the respective planting site. For instance, in the Andean region of South Ecuador, *A. acuminata* could be a promising option for the reforestation of recently abandoned pastures, not only because of its good survival and growth rate but also its ability to improve the nitrogen status of the soil. *C. montana*, *T. chrysantha*, and *M. pubescens* could be valuable species for the reforestation of areas of advanced successional status or land dominated by *P. arachnoideum*. According to our results, the unilateral evaluation of bracken fern as a hindrance for tree seedling establishment has to be reassessed as well. Planting valuable tree species into areas of advanced natural succession (enrichment planting) could also provide a facilitating effect for the establishment of other plants (Vandermeer 1989; Carpenter et al. 2004), a more effective recovery of soil properties (Zheng et al. 2005), and a contribution to faster rehabilitation of biodiversity.

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