Chapter 6.6
Monitoring of Biometric and Ecological Parameters Following Restoration of a *Lepironia mucronata* (Family Cyperaceae) Wetland in Mandena

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Abstract

Lepironia mucronata is a reed used for weaving by the local population and represents a substantial economic component. A considerable number of wetlands will need to be restored after mining. Restoration of *L. mucronata* was undertaken in a newly built swamp for the experiment. Rhizomes were mixed with soil from nearby natural swamps. The depth of the replaced soil measured 30 or 60 cm. Twenty-one months after the installation of the experimental plot, the planted *L. mucronata* reached heights of about 40–50 cm. After 33 months, they measured about 1 m and after 69 months, the plants were about 1.3 m high. In contrast, to the continuous growth in length, the diameter of plants changed little after 33 months. Initially plants grew faster on deeper soil, but the differences in length and diameters leveled by the time the plants were harvested. Some plant species from the natural ecosystem colonized the artificial swamp, which also contained five amphibian species. Only two of these frogs were forest species, which migrated to the swamp for breeding.

Résumé

Suivi des paramètres biométriques et écologiques après restauration d'un marécage à *Lepironia mucronata* (Famille Cyperaceae) à Mandena. *Lepironia mucronata* est un type de roseau employé par les gens de la région dans les activités artisanales de tissage et représente ainsi une composante économique substantielle. De nombreux marécages devront être restaurés après les activités minières. La restauration de *L. mucronata* a été réalisée à partir d'un marécage nouvellement construit pour l'expérimentation où les rhizomes avaient été mélangés dans du sol provenant de marécages naturels à proximité. Le sol a ainsi été ajouté sur une hauteur de 30 ou 60 cm. Vingt et un mois après installation de la parcelle expérimentale, les tiges de *L. mucronata* atteignaient près de 40-50 cm de haut. Après 33 mois, elles mesuraient près de 1 m de haut et après 69 mois, les plantes avaient atteint une hauteur de l'ordre de 1,3 m. Contrairement à la croissance en hauteur, le diamètre des plantes a peu changé après 33 mois. Au départ, les plantes poussaient plus rapidement dans les sols les plus profonds mais les différences de longueur et de diamètre ont été similaires au moment de la période de récolte des roseaux. Quelques espèces de plantes de l'écosystème naturel ont colonisé le marécage artificiel qui abritait également cinq espèces d'amphibiens. Seulement deux de ces espèces de grenouilles étaient des espèces forestières qui avaient migré vers le marais pour la reproduction.

Introduction

The ecological restoration work conducted within the context of the Mandena ilmenite mining project must re-establish the wetlands located along the extraction pathway. Locally, wetlands resting on a sand substrate make up about 15% of Mandena's surface area, and are important economically for human populations living near Mandena that harvest the reed species, *Lepironia mucronata* (Cyperaceae). This reed, known as *mahampy* in the local Malagasy dialect, is harvested and used to make different types of basketry, which is an indispensable activity in the local daily and cultural customs. Wetlands are also important for wildlife diversity, in particular for certain species of amphibians and waterbirds. The restoration of the mined sites is also a requirement of the Mining Code of Madagascar (Repoblikan'I Madagasikara 2000),

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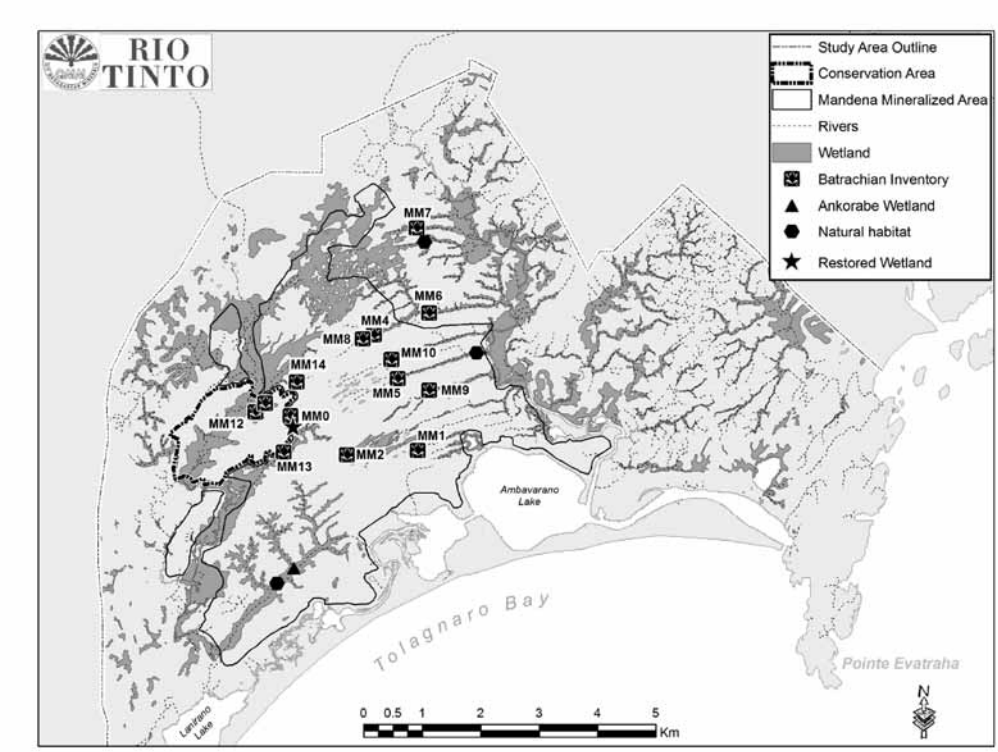

Figure 1. Map of the Mandena wetlands and location of inventory parcels (MM = natural wetlands).

which stipulates that all mining corporations must undertake environmental restoration once exploitation is completed. The environmental license issued and the Project Environmental Management Plan (QMM 2001) that accompanies it lists the restoration as a QIT Madagascar Minerals commitment.

Over 800 women in the Mandena area harvest, braid, weave, and sell basketry products made from *Lepironia* reeds. A great deal of reluctance was expressed by these women with respect to the viability of rehabilitating the *Lepironia* reed beds, which in their belief were offered by God and could not be cultivated. With this in mind, a research program was initiated to assess the viability of restoring these reed beds. Starting in 1999, 50 local women from various villages (Mandromondromotra, Ampasy, Mangaiky, etc.) were integrated into this experiment and contributed directly through their knowledge of this plant. Herein we report on the progress made in restoring *Lepironia* wetlands after five years of monitoring.

Methods

Site and experiment preparation

The site is characterized by an undulating terrain of sand dunes and interdune depressions. In these low-lying areas, the ground water table rises to the surface and provides the source for the wetlands. The littoral forests are restricted to slightly higher elevations. The experimental, restored wetland site was established some 20 m east of the edge of the M15 conservation zone, which was established in 2000 to monitor the evolution of certain biological parameters. The next naturally occurring wetland is 270 m away (Fig. 1).

The experimental design, which took place in September and October of 1999, included digging a 20 x 20 x 2 m hole (800 m^3 of excavated sand) manually in order to reach the water table (Fig. 2). The next operation consisted of adding a layer of clay on the edge, and a layer of topsoil from a locally occurring natural wetland at the bottom of the excavation in order to

stimulate the restoration process. The type of soil identified in such marshy depressions is an organic, hydromorphic soil with semi-fibrous peat on sand (Rabeson 1992). The local wetlands show differences in soils particularly soil thickness, which according to the local women, influences the growth of *L. mucronata*. With this in mind, we decided to adapt the design by digging half of the excavated surface another 30 cm deeper (10 x 20 x 0.30 m) resulting in 860 m^3 of excavated sand.

A volume of 140 m^3 of soil was deposited evenly at the bottom of the excavation. Thus, half of the hole received a 50 cm thickness of soil, and the more deeply excavated half received an additional 20 cm. In January 2000, once the level of water and topsoil set down in October 1999 was well stabilized and solid, an additional 10 cm layer of organic soil mixed with *Lepironia* rhizomes was added. This resulted in two treatments of soil depths: 30 cm and 60 cm. Flakes of rhizomes were gathered by the village women and mixed with the soil. They were preserved in single mound layers, mixed with sand, kept moist, and not directly exposed to the sun.

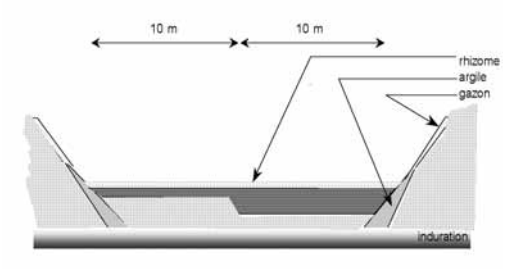

Figure 2. Schema of the excavation and preparation of the experimental wetland.

Lepironia mucronata in natural wetlands

In order to compare the *Lepironia mucronata* growing in the restored wetland with those growing in more natural conditions, reeds were measured in natural swamps dominated by *Ravenala madagascariensis*, *Pandanus* sp., or *L. mucronata* for a combined surface area of 225 m^2 (3 x 5 x 15 m^2). These sites had been identified by participating women as locations where they regularly collected reeds. The *L. mucronata* measured at this site were comparable to the plants in the experimental wetland collected in September 2002 at an age of 33 months.

Measurements

Within the restored wetland, *L. mucronata* plants were measured in 10 x 10 cm plots spaced at 1 m intervals along transects (Fig. 3). Transects began about 4 m inside the edge of the wetland. Twelve plots within each of the 30 and 60 cm deep sections of the restoration plot were measured at 21, 33, and 69 months after plantation. The diameter of each individual plant was measured at the water level. The height of the plant was measured from the collar to the tip. Each plant was considered an independent unit in the analyses, and statistical tests were run with SPSS (1999).

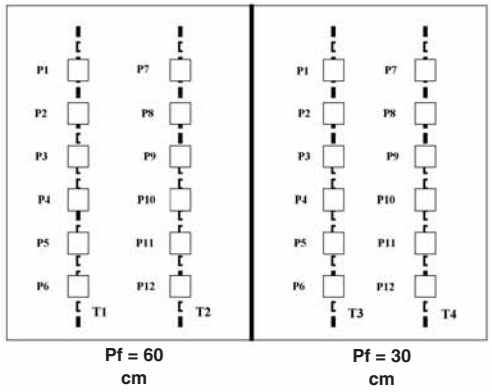

Figure 3. Experimental design survey of the restored wetland; P = Parcel, T = Transect, Pf = Depth.

Natural succession

The presence of plants other than *L. mucronata* was inventoried five years after the installation of the restored wetland in the 20 x 20 m area. The presence was compared to that of a natural habitat of the same area (flora and vegetation composition).

Amphibian survey on natural and restored wetlands

Amphibians have been inventoried in the wetlands and forests of Mandena since 1998 (see Ramanamanjato Chapter 4.4). In order to understand the recolonization of a newly restored area by amphibians and the importance of this habitat for the reproduction of this group of animals, an intense inventory

of 14 largely natural wetlands and one newly created wetland was conducted starting in 2003 (Fig. 1). We adopted the following inventory techniques.

Direct Observation

The transects used for diurnal and nocturnal surveys should randomly cross habitats representative of natural wetlands and document the species present (Raxworthy and Nussbaum 1994, Nussbaum *et al*. 1999). At night, the observer used a headlamp to locate animals by their movement and eye shine (for nocturnal animals) or by the outline of their body (for diurnal animals). If possible, the observed amphibians were identified on site; otherwise, specimens were retained to verify the preliminary identification.

Biotope Search

Certain species have a very specific biotope, such as *Pandanus* and *Ravenala* or rock crevices (Lehtinen 2005, see Ramanamanjato Chapter 4.4). Depending on the appropriateness, a search of these specific biotopes was conducted. Collected species were preserved using standard herpetological procedures (Ramanamanjato 1993, Raselimanana 1993) and were deposited in the Département de Biologie Animale, Université d'Antananarivo.

Results

Description of *Lepironia mucronata*

According to Chermezon (1931) and data extracted from the TROPICOS database (http://mobot.mobot.org/W3T/Search/vast.html), *L. mucronata* occurs in Madagascar between sea level and 800 m, and is distributed from Fenoarivo-Antsinanana, which is north of Toamasina, south to Mandena. It is also found on Nosy Be. This species occurs in hot and tropical climates, generally in peat fens with acidic soils, and tends to occur in areas with little drainage that may or may not be permanently flooded. It is often found with other wetland plants, particularly of the families Cyperaceae and Pandanaceae.

The full-grown stem is a thin, cylindrical shape, notably smooth, and between 40 and 150 cm in length and 2 to 5 mm in diameter. The leaves are limbless sheaths that are generally green, but turn brownish red under water shortage conditions. The inflorescences have a pseudoterminal position, are oblong, elliptical-spike shaped, and are 12 to 20 mm in length and 6 to 8 mm in width. The seeds are about 1 mm in diameter. The root system of the plant is formed by underground or rhizome stems. *Lepironia mucronata* is a perennial plant that multiplies from the rhizomes. Plant propagation by

Table 1. Height (cm) and diameter (cm) characteristics of *Lepironia mucronata* growing on 30 or 60 cm of soil. Age = Number of months since the construction of the wetland study site. Values are means ± standard deviations. N = sample size. Asterisks mark significance levels according to F-tests to test for differences in variance, and t-tests to test for differences in means between plants growing on 30 or 60 cm of soil: * $p \leq 0.05$, ** $p \leq 0.01$, *** $p \leq 0.001$.

Date of survey	Age of the rhizome (months)		30 cm	60 cm	F	t
December 1999	21	Height	40.7 ± 10.8 n = 221	53.6 ± 16.1 n = 271	38.3***	10.58***
December 1999	21	Diameter	2.1 ± 0.5 n = 213	2.1 ± 0.6 n = 267	13.3***	1.23
September 2002	33	Height	94.1 ± 25.4 n = 190	93.6 ± 17.3 n = 235	34.8***	0.26
September 2002	33	Diameter	4.3 ± 1.3 n = 190	3.9 ± 0.8 n = 235	37.3***	4.04***
August 2005	69	Height	127.1 ± 36.7 n = 448	130.2 ± 31.1 n = 374	10.9***	1.28
August 2005	69	Diameter	3.9 ± 0.9 n = 448	4.1 ± 1.2 n = 374	19.5***	2.27*

cuttings is possible, based on rhizome splinting. Rhizomes were preserved in single mound layers, mixed with sand, kept moist, and not directly exposed to the sun.

Growth parameters

Twenty-one months after the installation of the experimental plot, the planted *L. mucronata* had reached heights of about 40 - 50 cm. After 33 months, they measured about 1 m, and after 69 months, the plants were about 1.3 m tall (Table 1, Fig. 4). In contrast to the continuous growth in height, the diameter of plants changed little after 33 months (Table 1).

Comparison of natural and restored wetlands

The comparison between the experimental and the largely natural wetlands is hampered by the fact that the natural wetlands were not controlled for impacts (such as collection of reeds). Therefore it was impossible to assign an age to the measured plants, and analyses were restricted to a comparison between the length and the diameter of "natural" versus "replanted" individuals. Plants in the natural wetlands measured 64.5 ± 13.8 cm height with diameters of 2.6 ± 0.8 cm. These dimensions are comparable to the size of plants from the restored wetland between the age of 21 and 33 months. For this time interval, the height of plants in the replanted site is related to the diameter of the plant as: height = 16.53 x diameter + 19.44 ($r = 0.73$; $p < 0.001$). If the average diameter of the plants from the natural sites (= 2.6 cm) is used to predict their height, they should be on average 62.4 cm tall. This matches closely the actual value, which is 64.5 cm. Thus, plants in the restored wetland do not seem to differ from plants growing in natural areas in the relationship between height and diameter.

Natural succession

Apart from *L. mucronata*, natural wetlands in the Mandena area contain a number of different plant species (Table 2). None of these was directly planted at the restored site, but could have been brought in with the soil collected from natural wetlands and deposited at the restored site.

Twelve species of amphibians are known from natural wetlands in the area (see Ramanamanjato Chapter 4.4). Six out of these 12 amphibians are forest species and migrate during the rainy season to water holes to reproduce. In total, five amphibian species were identified in the replanted wetland (Table 3). Only two of them are forest species that migrated to the restored wetland during the rainy season, although it is only 20 m from the littoral forest edge.

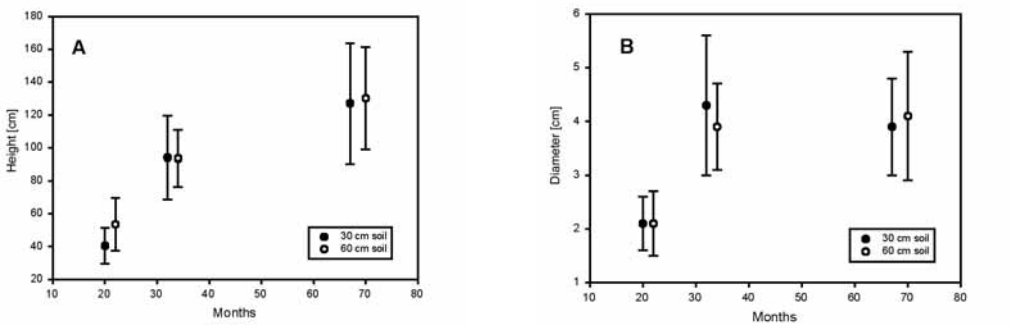

Figure 4. Height (A) and diameter (B) of *Lepironia mucronata* growing on 30 or 60 cm of soil, in relation to the time since the installation of the experimental restoration. Values are means and standard deviations.

Table 2. Plant species found in natural and restored wetlands five years after installation of the experiment. Growth forms: F = fern, G = grass, T = tree, and L= liana.

Vernacular name	Scientific name	Family	Growth form	Natural wetland	Replanted wetland
Not available	*Antirrhinum* sp.	Scrophulariaceae		+	+
lendemy	*Anthocleista madagascariensis*	Loganiaceae	T	+	
fotadrano	*Barringtonia racemosa*	Lecythidaceae	T	+	
varikanda	*Breonia* sp.	Rubiaceae	T	+	
tavolohazo	*Cryptocarya* sp.	Lauraceae	T	+	
voantsilana	*Cuphocarpus aculeatus*	Araliaceae	T	+	
beloha	*Cyperus* sp.	Cyperaceae	G	+	+
forimbato	*Xyris semifiscatus*	Xyridaceae	G	+	+
voatrotroka	*Dichaetanthera* sp.	Melastomaceae	G	+	
metitsilo	*Dicranopteris* sp.	Polypodiaceae	F		+
valahivoky	*Dicranopteris* sp.	Polypodiaceae	F	+	+
helana	*Eliea articulata*	Clusiaceae	T	+	
taratasy	*Embelia* sp.	Myrsinaceae	L	+	
tsiotsio	*Emilia citrine*	Asteraceae	G	+	
remaintso	*Exacum* sp.	Gentianaceae	G	+	+
Not available	*Fimbristylis* sp.	Cyperaceae	G	+	+
Not available	*Helichrysum* sp.	Asteraceae	G		+
marankoditra	*Homalium brevipeducelatum*	Salicaceae	T	+	
anjavidilahy	*Hibbertia coriacea*	Dilleniaceae	T	+	+
tranompiha	*Hyparrhenia* sp.	Poaceae	G	+	
andrasiriky	*Hyparrhenia* sp.	Poaceae	G	+	
mamoatelo	*Kyllinga* sp.	Cyperaceae	G	+	+
mahampy	*Lepironia mucronata*	Cyperaceae	G	+	+
mokaragna	*Macaranga obovata*	Euphorbiaceae	T	+	
tsilondrano	*Mascarenhasia arborescens*	Apocynaceae	T	+	
hazondrano	*Mascarhenasia arborescens*	Apocynaceae	T	+	
kinibonaky	*Melaleuca quinquenervia*	Myrtaceae	T	+	+
vahilengo	*Morinda* sp.	Rubiaceae	L	+	
voalaka	*Myrica spathulata*	Myricaceae	T	+	
takotra	*Nepenthes madagascariensis*	Nepenthaceae	G	+	+
tatamo	*Nymphaea stellata*	Nymphaeaceae	G	+	+
fandramamy	*Pandanus platyphyllus*	Pandanaceae	T	+	
fandranabo	*Pandanus rollotii*	Pandanaceae	T	+	
sahanalaotry	*Pandanus* sp.	Pandanaceae	T	+	
fandriampogny	*Panicum parvifolium*	Poaceae	G	+	+
goavy	*Psidium guajava*	Myrtaceae	T	+	
tsipangapanga	*Pteridium aquilinum*	Polypodiaceae	F	+	+
fontsy, ravinala	*Ravenala madagascariensis*	Strelitziaceae	T	+	
beloha	*Senecio* sp. 1	Asteraceae	G	+	
reso	*Senecio* sp. 2	Asteraceae	G	+	+
vendranoroko	*Setaria* sp.	Poaceae	G	+	
fengalala	*Spermacoce verticillata*	Rubiaceae	G	+	+
lomodrano	*Sphagnus* sp.	Sphagnaceae	G	+	
rotra	*Syzygium* sp.	Myrtaceae	T	+	
ambora	*Tambourissa* sp.	Monimiaceae	T	+	
tsipangalamalona	*Thelipteris* sp.	Polypodiaceae	F	+	
tsilanintria	*Vaccinium emirnense*	Ericaceae	T	+	
lalona	*Weinmannia bojeriana*	Cunoniaceae	T	+	
betratra	*Xyris semifuscatus*	Cyperaceae	G	+	+
tsiboraky	*Scrophularia* sp.	Scrophulariaceae	G	+	+
total number of species			**48**	**20**	

Table 3. Amphibian species found at Mandena in natural and replanted wetlands 4, 5, and 6 years after installation of the experiment.

Species	Natural wetland	Replanted wetland		
		2003	2004	2005
Aglyptodactylus madagascariensis	+		+[1]	
Heterixalus boettgeri	+	+	+	+
Mantidactylus wittei	+		+[1]	
Boophis opistodon	+			
Mantidactylus bilcalcaratus	+			
Mantidactylus ulcerosus	+	+	+	+
Mantidactylus decaryi	+			
Mantidactylus depressiceps	+			
Mantidactylus punctatus	+			
Mantidactylus sp.	+			
Plethodontohyla bipunctata	+			
Ptychadena mascareniensis	+	+	+	+
Total number of species	**12**	**3**	**5**	**3**

[1] During the reproduction season only (between March and May).

Discussion

Reconstructing a wetland means reconstituting aspects of the natural topographical, pedological, and biological environmental conditions. Once the mining project is completed, a serious effort will be made to reconstruct certain aspects of the topography of the site to pre-mining condition, based on detailed, pre-exploitation land surveys. Herein, we provide some further steps that need to be taken to aid the rehabilitation processed.

Flora

Monitoring of the replanted marshland should be continued in order to follow its evolution over time. It is also important to continue cooperating with the village women in order to catalyze their impressions and traditional knowledge of *L. mucronata*. With the commencement of mining, the monitoring of the hydrology of Mandena and associated water quality, vegetation dynamics, and other ecological processes will be important for problem mitigation. Invasive species such as *Melaleuca quinquenervia* should be monitored and managed to prevent their rapid expansion.

Fauna

The distribution of amphibian species in the wetlands outside the forest is uneven. In addition to the distance of the wetlands from the remaining forests, sun exposure is a determining factor because these animals are sensitive to drought. It should be noted that the restored wetland, with its constant presence of water, provided shelter for three species by its fourth year, and five species the fifth year. This is less than 50% of the species known to occur in the natural marshlands of Mandena. Movements of frogs from the forest to external wetlands associated with egg-laying are closely related to the level of rainfall during the breeding season of any given year. *Aglyptodactylus madagascariensis* and *Mantidactylus wittei* migrated from the littoral forest block M15 to the replanted marshland to reproduce in 2004, although they were still absent in 2003. A drought in 2005 may explain their absence from the replanted site in that year, as it did not have standing water.

Conclusion

The restoration of the Mandena wetlands following mining will be a considerable operation. The experiments described in this chapter, which started in 1999, will form the basis of further research and the initial steps in the process of reclaiming former wetlands. The creation of forested corridors between the wetlands and forests could improve the recolonization capacity of certain taxa that use wetland habitats, such as amphibians. It should not be forgotten that an important objective of restoring this ecosystem is economic-based for the local villagers, and hence, their role in the research program should be maintained.

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