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Forest Health & Biosecurity Working Papers

Case Studies
on the Status of Invasive Woody Plant Species
in the Western Indian Ocean

3. Mauritius
(Islands of Mauritius and Rodrigues)

By

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Quantitative information regarding the status of forest resources has been compiled according to sources, methodologies and protocols identified and selected by the authors, for assessing the diversity and status of forest resources. For standardized methodologies and assessments on forest resources, please refer to FAO, 2003. *State of the World's Forests 2003*; and to FAO, 2001. *Global Forest Resources Assessment 2000 (FRA 2000)*. FAO Forestry Paper No 140.

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Comments and feedback are welcome.

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Kueffer, C., Vos, P., Lavergne, C. and Mauremootoo, J. 2004. *Case Studies on the Status of Invasive Woody Plant Species in the Western Indian Ocean. 1. Synthesis*. Forest Health and Biosecurity Working Papers FBS/4-1E. Forestry Department, Food and Agriculture Organization of the United Nations, Rome, Italy.

For detailed studies on individual countries and territories, please refer to:

Vos, P. 2004. *Case Studies on the Status of invasive Woody Plant Species in the Western Indian Ocean: 2. The Comoros Archipelago (Union of the Comoros and Mayotte).* Forest Health & Biosecurity Working Papers FBS/4-2E. Forestry Department, Food and Agriculture Organization of the United Nations, Rome, Italy.

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1. GENERAL BACKGROUND

The general background information given in this section is based on Blanchard (2000), Gade (1985) and Safford (2001).

Mauritius and Rodrigues form a political unit together with the Cargados Carajos shoals (total land area around 3 km^2, main island St Brandon) and the atoll of Agalega (21 km^2), which became independent in 1968. However, only the islands of Mauritius and Rodrigues and nearby small islets (of some 10 ha to some 100 ha) are considered in this report. Rodrigues, 570 km to the east of the island of Mauritius, has district status and is represented by a minister, a Chief Island Commissioner and a regional parliament. When the Republic of Mauritius is meant in this document, this is explicitly stated.

1.1. Island of Mauritius

The island of Mauritius (20°10' S, 57°30' E) lies 840 km from Madagascar, the nearest continental land mass, in the Western Indian Ocean. It has a total land mass of 1 865 km^2. A central plateau of 500–700 m above sea level (asl) peaks at a maximum altitude of 828 m asl. The age of the main island is estimated at more than 8 million years (Saddul 1995). It is surrounded by a reef and 49 small islets.

Mauritius has a population of 1.2 million inhabitants, i.e. it has one of the highest population densities in the Afrotropics (580 inhabitants per square kilometre). It has been inhabited since 1638. Sugar cane (*Saccharum officinarum*), the main agricultural product, covers 84 000 ha (93 percent of the cultivated area).

The plateau is humid, receiving around 3 000 mm of rainfall annually (locally 5 000 mm), and relatively cool (annual mean temperature around 20°C). The lowlands are drier and hotter (1 000–1 800 mm rainfall, annual mean temperature 24–25°C). December–April are the wettest, hottest months, September–November the driest and June–August the coolest. The heaviest rainfall is brought by cyclones and cyclonic weather systems.

Of the some 650 surviving native flowering plant species, 287 (45 percent) are endemic to Mauritius and a further 122 (19 percent) are Mascarene (Mauritius, Rodrigues and Réunion) endemic species. Historically, the native fauna included at least 68 native vertebrate species that bred on land (birds, mammals and reptiles). Of these, 32 (47 percent) are or were endemic to Mauritius.

The main altitudinal vegetation zones are lowland dry or semi-dry vegetation (palm-rich woodland, semi-dry ebony [*Diospyros* spp.] dominated forest), intermediate-altitude humid forest, and small patches of mountain cloud forest. In some instances, coastal vegetation, marshland vegetation, riverine vegetation, secondary forests and forest plantations and agricultural land are also considered in this report.

The island was almost entirely forested until human colonization. Today, five percent of the native vegetation (close to 100 km^2) remains, and all of this has been degraded by invasive exotic species to some degree (Safford 1997a). Forty-six percent (31 of 68) of the native vertebrate species (including more than half of the bird species) have been lost. At least 39 plant species and 17 vertebrate species have become globally extinct, while 40 percent of the native flora and 54 percent of the surviving vertebrate species have been reduced to globally threatened status. Besides exotic plants, exotic animals are today an equal threat to the native flora and fauna. Problematic introduced animals include birds (notably the red-whiskered bulbul, *Pycnonotus jocosus*), hares (*Lepus nigricollis*), deer (*Cervus timorensis*), pigs (*Sus scrofa*), monkeys (*Macaca fascicularis*), rats (*Rattus rattus* and *Rattus norvegicus*), and giant African landsnails (*Achatina* spp.).

1.2. Rodrigues

Rodrigues (19°40’ S, 63°25’ E) lies some 1 400 km from the nearest continental land mass, Madagascar, in the Western Indian Ocean. It covers a total land area of 109 km^2 that peaks at a maximum altitude of 393 m asl. The age of the main island is estimated at 1.8 million years. Rodrigues is surrounded by a reef and 18 small islets. It has been permanently inhabited since 1792 and now has a population of 37 000.

Annual temperatures are around 24°C and annual rainfall is generally in the range 1 000–1 700 mm, but the total is very variable and greatly influenced by the number of cyclones in the vicinity.

Historically, the native flora and fauna included 132 flowering plant species, and at least 39 vertebrate species that bred on land (birds, mammals and reptiles). Of these, 44 (33 percent) of the plants, and 20 (51 percent) of the vertebrates were endemic to Rodrigues, and an additional 18 percent of the plants were Mascarene endemic species. The native forest has now been entirely destroyed. Eight endemic plant species are known to have become extinct and all surviving native plant species are threatened. All native land vertebrates except three bird species (two of which are endemic), two reptile species (that are pantropical) and a single endemic fruit bat species have been exterminated.

2. INVASIVENESS AND DEGREE OF INVASION

In this section, the invasion history of the islands of Mauritius and Rodrigues, the invasiveness of exotic woody plant species, the main invasive non-woody plant species, and the degree of invasion in different habitats are discussed.

2.1. A brief history of invasions

The invasion of exotic species into the forests of the islands of Mauritius and Rodrigues occurred in parallel with the degradation and clearance of these forests.

2.1.1. Island of Mauritius

This short overview of the environmental history of the island of Mauritius is based on Cheke (1987) and Rouillard and Guého (1999).

- During the seventeenth century there were never more than 300 people on Mauritius. The biggest impact of invasive species during this period was from introduced animals (rats, cats, pigs, monkeys, cattle, goats, deer). Felling was confined to easily accessible forests.

- Many exotic plant species were introduced during the eighteenth century, mainly fruit trees and spice plants. In 1736, the botanical garden in Pamplemousses was opened by Mahé de Labourdonnais. Around 1770, Pierre Poivre, the foremost promoter of trials with introductions of exotic plant species on Mauritius, arrived on the island. Dispersed by introduced animals (notably monkeys and pigs), species such as *Psidium cattleianum* spread into natural forests. During the eighteenth century the lowland palm-rich woodland and semi-dry forests became badly degraded.

- At the end of eighteenth century 4 400 ha of sugar cane, 660 ha of indigo (*Indigofera* spp.), 2 900 ha of cotton (*Gossypium* spp.), 880 ha of coffee (*Coffea* spp.) and 110 ha of cloves (*Syzygium aromaticum*) were being cultivated. However, most of these plant species were not well adapted to the climate and the cyclones.

- Around 1825 the sugar cane industry started on a large scale and since then it has dominated the agricultural sector.

- In the mid 1830s some 65 percent of the island, essentially the uplands above the 200 m contour line, was still forested.

- All the current main invasive woody plant species, except *Clidemia hirta* and *Homolanthus populifolius*, were introduced 100–200 years ago.

- *Acacia nilotica*, *Leucaena leucocephala* and *Syzygium jambos* were showing a tendency to become naturalized by the early nineteenth century (Rouillard and Guého 1999).

- As a consequence of increased agriculture (especially sugar cane), the emancipation of slaves, population growth and the demand for wood for the railways, by 1880 the area of untouched forests had been reduced to about 6 500 ha (3.6 percent of total land area).

- It was not until the end of the nineteenth century that reforestation was undertaken on a large scale. Coastal zones were replanted with *Casuarina equisetifolia* and *Cocos nucifera*, and inland forests with *Pinus* spp., *Eucalyptus* spp. and *Casuarina equisetifolia.*

- At the end of the nineteenth century a tea (*Camellia sinensis*) industry developed over a number of decades, peaking at a total area of 6 000 ha in the 1970s.

- *Lantana camara*, *Leucaena leucocephala*, *Psidium cattleianum* and *Rubus alceifolius* were invasive by the beginning of the twentieth century (Rouillard and Guého 1999).

- Clearance of natural forest continued until the mid 1970s (e.g. through a post-independence job-creation programme funded by the World Bank).

- Major cyclones during the second half of the twentieth century (1945, 1950, 1960) opened a pathway for new invasions (G. D'Argent, personal comunication).

- Today the total forested area is down to less than five percent of the original forested area, all of which is degraded to varying degrees. In total, native forests probably cover less than one percent of the area of Mauritius.

2.1.2. Rodrigues

This short overview of the environmental history of Rodrigues is based on Cheke (1987), Gade (1985) and Strahm (1989).

- Goats, sheep, cattle and pigs were introduced in the seventeenth century.

- At this time rats were probably already severely restricting tree regeneration because of seed predation.

- The human population increased within 180 years from about 100 in 1 800 to some 13 300 in 1950, and to some 35 000 in 1980 (350 inhabitants per square kilometre).

- At the end of the eighteenth century, the forests were still thick and difficult to penetrate. By 1825 the forest over much of the island was reduced to a savanna with scattered trees. By the mid 1800s, the forest cover had been largely removed through tree felling, wood burning, browsing (by goats), trampling (by cattle) and rooting (by pigs). Some tiny pockets of forest remained in remote valleys.

- Since the beginning of the eighteenth century, thicket-forming exotic plant species have dominated the landscape.

- Sporadic tree planting was carried out with *Albizia lebbeck* in the early nineteenth century.

- Deer were introduced to the island in 1862 but are no longer present.

- Naturalized *Leucaena leucocephala* and *Furcraea foetida* were already widespread in the middle of the eighteenth century. *Syzygium jambos* was introduced before the 1800s and, possibly planted for watershed protection, soon became invasive. In 1879 it was already very common in all valleys. *Mangifera indica, Tamarindus indica, Psidium cattleianum, Citrus limon* and *Citrus medica* were invasive by the 1940s.

- No major reforestation programme was initiated until 1922. Until the Second World War, *Syzygium jambos* was the main species for replanting schemes, but since then the list has expanded to include *Acacia nilotica, Casuarina equisetifolia, Eucalyptus tereticornis* and *Terminalia catappa*. In 1980, some 4 500 ha were planted with trees.

- *Lantana camara* was introduced in the 1930s and soon became invasive.

- *Litsea glutinosa* was still localized in 1941, but is now one of the main invasive species on Rodrigues.

- Today, maize (*Zea mays*) dominates agriculture (80 percent of cropland in the 1980s). Domesticated free-ranging cattle and goats graze on the hillsides and prevent any regeneration of native forest.

- Because of the vast deforestation, accelerated soil erosion affects 95 percent of the total area of the island. The hydrology of the island has been completely disrupted. Water is scarce for most of the year and almost all springs and streams have dried up.

2.2. Invasiveness

The native flora of the island of Mauritius includes some 650 flowering plant species. A recent review of the documented exotic species in the Mauritian herbarium (Heeroo 2000) found 1 675 non-native species, almost all collected prior to 1980. The introduced flora is thus at least three times larger than the native flora. A similar ratio has been estimated for Rodrigues (Gade 1985).

Although there is no quantitative evidence, it would appear likely that during the last two decades the introduction of new exotic species has accelerated with the vast increase in international traffic experienced by the Republic of Mauritius.

2.2.1. Main invasive woody plant species

Seventeen woody plant species are classified as main invasive species, i.e. they are widely accepted according to this study as very problematic, are widespread, are continuing to spread and have a negative impact or invade sensitive areas (Table 1).

The classification of the main invasive species was almost completely based on documents and experts from the island of Mauritius. There are, however, considerable differences between the behaviour of the invasive species there and on Rodrigues. Possible reasons for these differences are the drier climate and the lack of exotic monkeys (*Macaca fascicularis*) and bulbuls (*Pycnonotus jocosus*) as seed dispersers on Rodrigues (e.g. *Psidium cattleianum*) (Strahm 1989), or the difference in the timing and scale of introductions (e.g. *Acacia nilotica, Ligustrum robustum* subsp. *walkeri, Ravenala madagascariensis, Tabebuia pallida*). In the case of *Lantana camara* the lack of biological control agents on Rodrigues most probably accounts for the difference (see Section 4.1.1. Biological Control). *Acacia nilotica* and *Lantana camara* are more problematic on Rodrigues, while *Ligustrum robustum* subsp. *walkeri, Psidium cattleianum, Ravenala madagascariensis* and *Tabebuia pallida* are more problematic on the island of Mauritius. *Litsea monopetala*, which is very problematic on the island of Mauritius, is not present on Rodrigues but *Litsea glutinosa* poses a similar problem there (Strahm 1989, Strahm 1999).

TABLE 1: MAIN INVASIVE WOODY PLANT SPECIES OF MAURITIUS AND RODRIGUES
The most problematic species are in bold type

Species	Reference[a]	Habitat[b]	Island[c]	Introduction date[c,d]
Acacia nilotica	3, 4	L	M, R	M: 1816 or before; R: 1945 or before (Gade 1985)
Ardisia crenata	1, 2, 3, 4	U	M	Around 1800
Clidemia hirta	2, (3), 4	U, P	M	1990s(?); or 1940–1950 (G. D'Argent, pers. comm.)
Flacourtia indica	1, 3, (4)	C, L	M	1772 or before
Hiptage benghalensis	1, 3, 4	L, P, R	M	Before 1785
Homalanthus populifolius	2, 3, 4	P, (U)	M	1960–70 (G. D'Argent, pers. comm.)
Lantana camara	1, 2, 3, 4	C, L, P	(M), R	M: Before 1837; R: 1930 or before
Leucaena leucocephala	3, 4	C, L	M, R	M: 1810 or before; R: 1850 or before
Ligustrum robustum* subsp. *walkeri	1, 2, 3, 4	U	M, R	M: Around 1900 (?); R: Recent
Litsea monopetala	1, 2, 3, (4)	U	M	1815
Livistona chinensis	1, 3, 4	R	M	Before 1835
Psidium cattleianum	1, 2, 3, 4	U, P	M, R	M: 1763 or before (non-invasive variety), 1836 or before (invasive red-fruit variety), 20th century (invasive yellow-fruit variety) (V. Florens, pers. comm.); R: 1879 or before (yellow-fruit variety)
Ravenala madagascariensis	1, 2, 3, 4	U	M, R	M: 1751; R: 1845 or before
Rubus alceifolius	1, 2, 3, 4	U, P	M	1752 or before;
Schinus terebinthifolius	1, 3, 4	L	M	1863 or before
Syzygium jambos	1, 2, 3, 4	U, R	M, R	M: 1677 or before; R: 1795 or before
Tabebuia pallida	1, 3, 4	C, L	M, R	M: 1860s; R: 1955 or before

[a] 1: Page and D'Argent (1997); 2: Mungroo (1997); 3: Strahm (1999); 4: Interview this study.
[b] C: Coastal zone; L: Dry lowland; P: Production land; R: Riverine forest; U: Upland forest.
[c] M: island of Mauritius; R: Rodrigues.
[d] Data for the island of Mauritius from Rouillard and Gueho (1999), data for Rodrigues from Strahm (1989), except where noted otherwise.

Among the main invasive species are four forestry trees (*Acacia nilotica, Ligustrum robustum* subsp. *walkeri, Litsea monopetala, Tabebuia pallida),* four fruit trees and spice plants (*Flacourtia indica, Psidium cattleianum, Schinus terebinthifolius, Syzygium jambos*), six ornamentals (or introductions to the Botanical Garden in Pamplemousses) (*Ardisia crenata, Hiptage benghalensis, Homalanthus populifolius, Lantana camara, Livistona chinensis, Ravenala madagascariensis),* one fodder plant (*Leucaena leucocephala*), and two accidental introductions (*Clidemia hirta, Rubus alceifolius*).

Nine species are listed as most problematic species (*Ardisia crenata, Hiptage benghalensis, Lantana camara, Ligustrum robustum* subsp. *walkeri, Psidium cattleianum, Ravenala madagascariensis, Rubus alceifolius, Schinus terebinthifolius, Syzygium jambos*; these are shown in bold type in Table 1), i.e. there was general agreement that they are very problematic. Seven of these were probably introduced before the beginning of the eighteenth century, one (*Schinus terebinthifolius*) in the middle of the nineteenth century, and one (*Ligustrum robustum* subsp. *walkeri*) probably around 1900.

2.2.2. Non-consensus woody plant species

Some experts suggested additional invasive woody plant species for Mauritius and Rodrigues. These species have been categorized as non-consensus species (Table 2). They should be monitored carefully.

Rouillard and Guého (1999) is an extensive source of expert knowledge about invasive and potentially invasive species in Mauritius. It was not possible to consult this document in detail within the scope of this study. However, additional information has been gathered for the species in Table 2. *Acacia concinna* is invasive in the dry lowland. *Acacia farnesiana* is naturalized, especially in the west of Mauritius, e.g. around Tamarin and Yemen, and it was already naturalized by about 1800. *Albizia lebbeck* is naturalized around Port Louis and Bois Rouge. *Ardisia elliptica* is invasive in Flacq. *Cinnamomum verum* is naturalized in the south of Mauritius. *Cordia dichotoma* (syn. *C. myxa*) is naturalized in the coastal zone and along roads. *Cyathea cooperi* (syn. *Sphaeropteris cooperi*) is naturalized. *Eugenia uniflora* is widely naturalized, especially in the lowlands (it was becoming naturalized during the early eighteenth century). *Eupatorium pallescens* (syn. *Clibadium surinamense*) is naturalized particularly in the humid areas of Mauritius. *Litsea glutinosa* is widely naturalized, especially in the lowlands. *Flacourtia jangomas* is naturalized in forests. *Haematoxylum campechianum* has been naturalized since the beginning of the nineteenth century, especially in the dry lowland. *Michelia champaca* is quite widely naturalized, i.e. in the Black River Gorges. *Mimusops coriacea* is often naturalized in the coastal zone. *Murraya paniculata* is naturalized in some lowland forests. *Pithecellobium dulce* is naturalized in the dry lowland. *Pongamia pinnata* is naturalized in estuaries. *Rhamnus nepalensis* is invasive along the slopes of the hills in Moka, and in Piton du Milieu region, and was naturalized by 1837. *Santalum album* is naturalized in lowland secondary vegetation. *Tamarindus indica* is naturalized. *Terminalia arjuna* has a tendency to naturalize. *Tibouchina viminea* was not naturalized in 1937, yet today forms dense thickets at higher altitudes (e.g. Montagne Cocotte). *Ziziphus mauritiana* is naturalized in the dry lowland and the coastal zone.

2.2.3. Potentially new invasive woody plant species

Some species were identified that might become invasive in the near future, and that are already naturalized in some restricted areas: *Averrhoa carambola, Casuarina equisetifolia, Eucalyptus* spp., *Melaleuca quinquenervia, Pinus* spp., *Prosopis juliflora, Raphia farinifera, Schefflera actinophylla, Sesbania punicea, Spathodea campanulata* and *Ulex europaeus.*

TABLE 2: NON-CONSENSUS WOODY PLANT SPECIES OF MAURITIUS AND RODRIGUES

Species	Refs.[a]	Habitats[b]	Islands[c]	Introduction date[c,d]
Acacia concinna	3	L, R	M	18th century
Acacia farnesiana	2		M	1800 or before
Albizia lebbeck	3	L	M	1767
Ardisia elliptica	2		M	1835 or before
Camellia sinensis	1		M	1765
Cinnamomum verum	1, 2, 3		M	Around 1750
Cordia dichotoma (syn. *C. myxa*)	3	C, L	M	1837 or before
Cyathea cooperi (syn. *Sphaeropteris cooperi*)	3	U	M	?
Eugenia uniflora	1, 3		M	1785 or before
Eupatorium pallescens	1		M	1936
Flacourtia jangomas	3	R	M	1750 or before
Haematoxylum campechianum	3	L	M	1785 or before
Litsea glutinosa	1, (3)	R, L	M, R	M: 1775 or before; R: 1879 or before
Michelia champaca	1		M	1785 or before
Mimusops coriacea	1	C	R	1785 or before (?)
Murraya paniculata	2		M	1764
Pithecellobium dulce	3	L	M	18th century
Pongamia pinnata	3	C, Ma	M	1874
Rhamnus nepalensis	1		M	1830s or before
Santalum album	3	C	M	1837 or before
Tamarindus indica	3	L	M	17th century (?)
Terminalia arjuna	3	R	M	1850 or before
Tibouchina viminea	3	U	M	1887
Ziziphus mauritiana	3	L	M	18th century

[a] 1: Page and D'Argent (1997); 2: Strahm (1999); 3: Interview this study.
[b] C: Coastal zone; L: Dry lowland, Ma: Mangroves; R: Riverine forest; U: Upland forest.
[c] M: island of Mauritius; R: Rodrigues.
[d] Data for the island of Mauritius from Rouillard and Gueho (1999), data for Rodrigues from Strahm (1989).

2.2.4. Main invasive non-woody plant species

Although the scope of this study did not include herbaceous species, it is important to mention them briefly as some of them are of equal concern in the Republic of Mauritius, especially on small islets, in the coastal zone, in wetlands and as agricultural weeds.

- Grasses: *Arthraxon quartinianus, Bothriochloa pertusa, Cenchrus echinatus, Cynodon dactylon, Cyperus rotundus, Cyperus stoloniferus, Heteropogon contortus, Panicum maximum, Paspalum conjugatum, Paspalum paniculatum, Pennisetum purpureum, Phalaris arundinacea, Sporobolus virginicus, Stenotaphrum dimidiatum* and *Themeda quadrivalvis.*

- Creepers: *Argyreia nervosa, Cissus* spp., *Cynanchum callialata, Lonicera confusa, Mikania micrantha, Neuracanthus richardianus, Paederia foetida* and *Thunbergia grandiflora.*

- Aquatic plants: *Eichhornia crassipes.*

- Other herbaceous plants: *Ageratina riparia, Argemone mexicana, Chromolaena odorata, Clerodendrum serratum, Cordia curassavica, Desmanthus virgatus, Erigeron karwinskianus, Furcraea foetida, Hedychium* spp., *Hippobroma longiflora, Impatiens flaccida, Justicia gendarussa, Kalanchoe pinnata, Opuntia vulgaris, Ossaea marginata, Rubus rosaefolius, Stachytarpheta jamaicensis, Strobilanthes hamiltonianus, Turnera angustifolia* and *Wikstroemia indica.*

2.3. Degree of invasion

2.3.1. Small islets

A survey of small offshore islets identified *Leucaena leucocephala*, *Lantana camara* and, to a lesser degree, *Flacourtia indica* as the main invasive woody plant species (Bell *et al.* 1994). *Ricinus communis* is frequent on Cocos and Sables. Dulloo (1999) cites *Litsea glutinosa* as invasive on Ile aux Aigrettes, while Newfield *et al.* (2003) also described *Tabebuia pallida* as problematic on this island. *Opuntia vulgaris*, *Furcraea foetida*, *Desmanthus virgatus* and some grasses are important invasive non-woody plant species. *Opuntia vulgaris* is not under biological control on the small islets in contrast with the situation on the island of Mauritius.

2.3.2. Coastal zone

On the islands of Rodrigues and Mauritius, the natural habitats of the coastal zone have been destroyed almost completely. *Casuarina equisetifolia* has been widely planted. Two invasive woody plant species have been identified in the coastal zone: *Mimusops coriacea* and *Pongamia pinnata* (J. Mauremootoo, personal observation; Rouillard and Guého 1999). Sedges, grasses and some herbaceous species are especially problematic in this zone.

2.3.3. Mangroves

Not many invasive species affect mangroves. The only abundant invasive woody plant species is *Pongamia pinnata* (J. Mauremootoo and J.-C. Sevathian, personal observations; Rouillard and Guého 1999).

2.3.4. Riverine forests

The forests along rivers are protected by law, but these are all secondary forests and are dominated by exotic species. Although these forests protect watercourses and aid erosion control, native species that are better adapted to cyclones would probably do a better job. Nonetheless, because of the high degradation and the high edge:area ratio, restoration would be very difficult. Frequent exotic woody plant species are *Acacia concinna, Flacourtia indica, Flacourtia jangomas, Hiptage benghalensis, Litsea monopetala, Livistona chinensis, Pongamia pinnata, Raphia farinifera, Ravenala madagascariensis, Rubus alceifolius, Schinus terebinthifolius, Syzygium jambos* and *Terminalia arjuna* (J. Mauremootoo & J.-C. Sevathian, personal observations; Rouillard and Guého 1999; Blanchard 2000).

2.3.5. Lowland dry and semi-dry forests

Lowland forests experience annual rainfall of 1 000–1 800 mm and can be found below 200–400 m asl (Page and D'Argent 1997). The natural lowland dry and semi-dry forest has almost completely disappeared. Invasive woody plant species in this habitat are *Acacia cocinna, Acacia farnesiana, Acacia nilotica, Albizia lebbeck, Cordia dichotoma* (syn. *C. myxa*), *Eugenia uniflora, Flacourtia indica, Haematoxylum campechianum, Hiptage benghalensis, Lantana camara, Leucaena leucocephala, Litsea glutinosa, Pithecellobium dulce, Schinus terebinthifolius, Tamarindus indica* and *Ziziphus mauritiana* (J. Mauremootoo and J.-C. Sevathian, personal observations; Rouillard and Guého 1999).

2.3.6. Upland humid and mountain forests

Upland forests occur above 200–400 m asl where annual rainfall exceeds 2 000 mm (Page and D'Argent 1997). Invasive woody plant species in this habitat are *Ardisia crenata, Clidemia hirta, Ligustrum robustum* subsp. *walkeri, Litsea* spp., *Psidium cattleianum, Ravenala madagascariensis, Rubus alceifolius* and *Syzygium jambos*.

Lorence and Sussman (1986) quantified invasions in two lower mountain forests (Brise Fer 550 m asl, Bon Courage 200–260 m asl). Exotic woody plant species made up five percent (Brise Fer) and 14.5 percent (Bon Courage) of the total species numbers in the two forests with exotic species accounting for 34.5 percent and 20.5 percent, respectively, of all mature individuals. The relative abundance of invasive species was markedly higher among seedlings and saplings at 97.5 percent and 74 percent in Brise Fer and Bon Courage, respectively; if only the saplings were considered, the relative abundances were 20.5 percent and 22.2 percent. The most abundant exotic plant species in the mature stage were *Psidium cattleianum, Ligustrum robustum* subsp. *walkeri* and *Syzygium jambos* (along rivers), while *L. robustum* subsp. *walkeri, Litsea glutinosa, Ardisia crenata* and *P. cattleianum* were the most abundant immature plant species.

2.3.7. Production land

Production land includes land under either agriculture or forestry.

Problems with woody plant species invading agricultural land are minor. *Lantana camara* is invading rangeland on Rodrigues. The Mauritius Sugar Industry Research Institute (MSIRI) produced a booklet on the main weeds of sugar cane on Mauritius, which included 64 herbaceous species (McIntyre 1991).

The 1998 Annual Report of the Forestry Service recorded the following woody weeds: *Clidemia hirta, Psidium cattleianum* and *Rubus alceifolius* in upland plantations; *Homalanthus populifolius* in plantations on the plateau; and *Hiptage benghalensis* in lowland plantations.

Problems with invasive species in agriculture and forestry are less severe in drier areas.

3. ENVIRONMENTAL AND ECONOMIC IMPACTS

The negative environmental and economic impacts of invasive species on Mauritius and Rodrigues are grouped into four categories: ecosystem impacts, impacts on biotic interactions, genetic effects and impacts on anthropogenic systems.

3.1. Ecosystem impacts

Ecosystem impacts discussed here include all negative changes to ecosystem processes and conditions. Species that have a pronounced effect on ecosystem level are sometimes called 'transformer species'. Invasive species can interfere with the natural disturbance regime (fire, flooding, water dynamics of coast and rivers, erosion, forest gap dynamic), or alter the conditions in the ecosystem (availability of light, water, nutrients).

Change of disturbance regime:

- Exotic trees are said to be generally more vulnerable to cyclones than the native trees of Mauritius and Rodrigues. This leads to more frequent and larger forest gaps, increased soil erosion and, in some areas, floods. A species that is easily damaged by cyclones, for instance, is *Ravenala madagascariensis*.

Change of habitat conditions:

- Nitrogen fixing trees such as *Acacia nilotica* and *Leucaena leucocephala* increase soil nitrogen availability.

- *Acacia nilotica* is invading watersheds on Rodrigues. This could well be negatively affecting water supplies on the island. *Eucalyptus* is another example of a genus that is very water demanding and thus changes the water budget of an ecosystem. *Eucalyptus* species have been extensively planted on Rodrigues in areas including watersheds, but they have so far not proved to be invasive.

- Fallen leaves of *Casuarina equisetifolia* are said to change the surface and topsoil microstructure, which has a detrimental effect on sea turtle nesting. Their dense root systems make it very difficult for sea turtles to dig holes in the sand in which to lay their eggs.

- The observation that the particularly extensive and shallow root system and the leaf litter of *Psidium cattleianum* are likely to dry out the topsoil, hindering native seedling establishment (V. Florens, personal communication) merits further study.

3.2. Impacts on biotic interactions

Impacts on biotic interactions include competition between native and exotic plant species (interactions within one trophic level) as well as interactions between different trophic levels (frugivores, herbivores, insectivores).

Competition between native and exotic plant species:

- Native species being outcompeted by invasive species during the regeneration (seedling, sapling) phase is the most obvious and well-documented negative impact on Mauritius and Rodrigues (see Section 4.2. Restoration activities). It has been observed that invasive species have driven some native species into microhabitats with harsher conditions, i.e. rockier, steeper or drier, than their traditional niches (V. Florens, personal communication).

- Many invasive species form thickets or monospecific stands that provide very poor habitats for native flora and fauna, and allow little understorey vegetation or regeneration. Monospecific stands or thickets of the following species are found: *Acacia nilotica, Hiptage benghalensis, Psidium cattleianum, Lantana camara* (on Rodrigues), *Leucaena leucocephala, Ligustrum robustum* subsp. *walkeri, Ravenala madagascariensis, Syzygium jambos* and *Tabebuia pallida*.

- It has been hypothesized that allelopathic properties help *Lantana camara* (see Ambika *et al.* 2003) and *Ligustrum robustum* subsp. *walkeri* outcompete native species.

Interactions between different trophic levels:

- Fruit production of *Psidium cattleianum* in the austral winter when native fruit availability is generally low maintains high densities of pigs and monkeys. These exotic animals are thus at high densities at the end of *P. cattleianum*'s fruiting season when the main breeding season for native birds and the fruiting season for native trees begins. Monkeys cause significant damage to both native birds and trees. Pigs, in turn, disturb forest trees and ferns and may cause considerable damage to ground-dwelling invertebrates. High pig densities increase the number of pig wallows, which are used as breeding sites by mosquitoes. This leads to an increase in populations of mosquitoes that may cause disease problems for native birds.

- Knowledge about the effects of exotic vegetation on native invertebrates, mammals and birds is scarce and equivocal (see Section 4.2. Restoration activities and Section 5.2. Conflicts of interest).

Vectors of diseases and pathogens:

- A preliminary study quantifying fruit fly infestations of native fruit trees and *Psidium cattleianum* in an upland forest suggests that *P. cattleianum* may represent a major reservoir for fruit flies (Eydatoulah 1999).

3.3. Genetic effects

No genetic impacts (hybridization) have been recorded for Mauritius or Rodrigues.

3.4. Impact on anthropogenic systems (weeds)

In this section negative impacts by invasive species that directly affect anthropogenic systems are included, i.e. mainly agricultural weeds, and health related impacts.

- *Leucaena leucocephala* is used as a fodder plant, but can be poisonous to animals (Rouillard and Guého 1999).
- Thorny bushes like *Acacia nilotica* render land inaccessible to cattle on Rodrigues.

4. CONTROL MEASURES AND HABITAT RESTORATION

4.1. Control measures

4.1.1. Biological control

This section is based on Fowler *et al.* (2000), except where another source is explicitly cited.

Several biological control agents were introduced to control five weed species on the island of Mauritius from 1914 to 1982. To date, the biocontrol programmes against *Opuntia vulgaris*, *Opuntia tuna* and *Cordia curassavica* have been completely successful. *Lantana camara* is under partial biological control. The only unsuccessful biological control programme was the release of the curculionid beetle *Athesapeuta cyperi* against the grass *Cyperus rotundus* in 1981.

The first biological control agent to be introduced was the scale insect *Dactylopius ceylonicus* against *O. vulgaris* and *O. tuna* cacti in 1914. It suppressed *O. vulgaris* but failed to control *O. tuna*. Successful control of both species was achieved with the introduction of a second scale, *Dactylopius opuntiae*, in 1928. The abundance of *Opuntia* spp. recovered in the late 1940s, probably because of the deliberate introduction of the predatory coccinellid beetle *Cryptolaemus montrouzieri* for the biological control of the pineapple mealybug (*Dysmicoccus brevipes*). The predator seems to have attacked the *Dactylopius* spp. Therefore, in 1950 another control agent, the moth *Cactoblastis cactorum*, was released and restored successful biological control. In a survey in 1998 only a few scattered individuals of *Opuntia* spp. were found on the island of Mauritius, and these showed signs of damage by the larvae of *C. cactorum*. No *Dactylopius* spp. were seen during the survey.

The other fully successful weed biocontrol programme in Mauritius targeted the woody shrub *Cordia curassavica*. In 1947, the first agent, a chrysomelid beetle *Physonota alutacea*, was introduced from the native range of the target weed in the Caribbean region. Despite the release of over 30 000 individuals (adults, larvae or eggs), the insect failed to establish, possibly because of ants. A progressive feature of this programme, compared with the *Opuntia* programme, was the extensive host range testing of both *P. alutacea* and the subsequently released chrysomelid, *Metrogaleruca obscura*. For instance, *M. obscura* was tested on 122 non-target plant species in the beetle's native range, and on 86 non-target plant species after the beetle had been imported into quarantine in Mauritius. Ecological studies were also carried out on *M. obscura*. These included a study of the life history and natural enemies in its native range in the Caribbean, experiments using simulated herbivory to examine the effect of *M. obscura* on seed production by *C. curassavica*, and trials using field cages to show that *M. obscura* was capable of severely defoliating the host plant in the absence of natural enemies. In contrast, hardly any safety tests were carried out with another released agent, the eurytomid wasp *Eurytoma attiva*, which attacked the fruits. *Cordia curassavica* has been under successful and continuous biological control since the early 1950s.

Lantana camara was one of the main invasive plant species besides *Rubus alceifolius* in the nineteenth century. In the early 1950s, a biological control research project identified a fungus in the genus *Capnodium* as a potential agent. A polyphagous ortheziid bug (*Orthezia insignis*) that was accidentially introduced was also noted to attack *L. camara*. In the 1960s, it was observed that *L. camara* was partially controlled by an accidentally introduced tingid bug (*Teleonemia scrupulosa*). In the 1950s and 1960s a noctuid moth (*Diastema tigris*) and a pyralid moth (*Salbia haemorrhoidalis* [syn. *Syngamia haemorrhoidalis*]) were deliberately introduced as biocontrol agents (Rouillard and Gueho 1999). *Salbia haemorrhoidalis* probably contributes to the suppression of the target weed. A chrysomelid beetle released in the 1960s (*Uroplata girardi*) is widespread but has probably only a minimal impact. Another noctuid moth (*Hypena laceratalis*), either an accidental introduction or possibly native, may also attack *L. camara* (adapted from Rouillard and Gueho 1999). *Lantana camara* is still frequently naturalized on Mauritius but has never become a major invasive species. In contrast, it has become a major pest on Rodrigues, where not all biological control agents are present. On Mauritius, new biotypes imported by horticulturalists may escape biological control and become invasive.

No deliberately introduced insects have been reported attacking non-target plants. However, *Orthezia insignis*, one of the species that feeds on *L. camara*, is a polyphagous scale insect and a common tropical pest (e.g. of *Solanum melongena* in Mauritius), and may also attack native plants.

Conclusions

- Biological control programmes are expensive and need long-term research. The example of the failed control of *Cyperus rotundus* shows that under-resourced programmes are not successful. One way to greatly reduce costs is to build on successful biological control research projects conducted in other countries. For Mauritius, promising current projects include one targeting *Psidium cattleianum* in Hawaii using a leaf gall forming eriococcid, *Tectococcus ovatus*, and another against *Ageratina riparia* in New Zealand using a white smut fungus (*Entyloma ageratinae*) and a gall fly (*Procecidochares alani*).

- The release of the known, host specific biological control agents against *Lantana camara* on Rodrigues and on small islets would be a relatively easy measure.

- Biological control allows the control of targeted species on a large scale, but it does not restore the infested forests. The suppressed invasive species may simply be replaced by another invasive species. Biocontrol must always be part of an integrated restoration programme.

4.1.2. Chemical control

On Mauritius and Rodrigues, chemical control is mostly complementary to mechanical methods. Herbicides are used to stop regrowth of cut stems.

Chemical control was attempted in the Brise Fer Conservation Management Area (CMA) by volunteers from Raleigh International over a six-week period in 1993. *Psidium cattleianum* and *Ligustrum robustum* subsp. *walkeri* were cut at about waist height and a ten percent solution of Garlon (triclopyr) was applied to the stumps with a small brush. The conditions were humid and therefore not ideal for the application of Garlon, and the results were not good. Even a concentration of 20 percent Garlon failed to provide control in another trial; the herbicide only retarded the formation of new shoots (Mungroo 1997; Mungroo and Tezoo 2000). However, trials with Garlon where the plants were cut 20 cm above the ground were promising (Mungroo and Tezoo 2000).

The Mauritius Sugar Industry Research Institute (MSIRI) successfully applied two herbicides, Tordon 101 (picloram) and Roundup (glyphosate), in ten percent solutions brushed on cut stems against *Psidium cattleianum* and *Ligustrum robustum* subsp. *walkeri* in the Mondrain Nature Reserve (McIntyre 1997). The same method was used against *Flacourtia indica* and *Leucaena leucocephala* on Ile aux Aigrettes. Other herbicides used on Ile aux Aigrettes in this period were Garlon, Velpar (hexazinone) and Diester (2,4-D and 2,4,5-T) (Newfield *et al.* 2003). Picloram was found to be more effective than glyphosate against both species, although *L. leucocephala* proved to be more resistant than *F. indica* to both herbicides (McIntyre 1997). The ten percent Tordon solution worked best, but replication was very small (6–7 trees). In 1993, less successful, herbicide trials were conducted with Escort (metsulfuron) at one percent, Garlon at five percent and Velpar at five percent (Newfield *et al.* 2003). In 2002 the use of herbicides was increased for chemical maintenance weeding. All regenerating weeds are sprayed using five percent Roundup. A sprayguard over the sprayer nozzle is used to avoid spraying the foliage of newly planted native species. The chemical maintenance weeding procedure takes about eight percent of the time needed for manual weeding of the same area (A. Khadun, personal communication).

4.1.3. Mechanical control

Mechanical control is by far the most widely used approach for controlling invasive species.

Costs of mechanical control depend on initial forest quality, substrate characteristics, exotic species composition and logistic considerations such as the remoteness of the site (Mauremootoo and Towner-Mauremootoo in press) and thus vary greatly.

In a lowland forest (Ile aux Aigrettes) the labour needed for initial weeding was about 2 000 person-hours per hectare (Mauremootoo and Towner-Mauremootoo in press). Work was carried out by sugar cane workers in the off-season, contract labour and some volunteers (c. 6–35 persons during a 21-week period from January to June). Labour costs of approximately US$3 000 per hectare have been estimated. Long-term maintenance weeding costs about US$140 per hectare per year (Mauremootoo and Towner-Mauremootoo in press).

Weeding was mainly done mechanically by uprooting (pulling by hand or removing mechanically for larger plants) and, where this was not possible, by simply cutting the tree stems (and brushing a herbicide on the cut stem). The main target species were *Leucaena leucocephala, Flacourtia indica* and *Tabebuia pallida.* The woody material was burned in designated sites. A great deal of replanting of native species has been undertaken in areas cleared of dense weed infestations (Newfield *et al.* 2003).

For initial weeding of upland CMA plots, a labour requirement of 315 to 890 person-hours per hectare has been estimated (Mauremootoo and Towner-Mauremootoo in press). The lower labour figure, compared with Ile aux Aigrettes, reflects the higher initial quality of the vegetation and the deeper soil of this upland plot.

There are some species-specific difficulties for mechanical control:

- *Ravenala madagascariensis* is very difficult to control because of its high biomass and high water content. It is difficult to burn or to remove.
- Some species, such as *Leucaena leucocephala* and *Acacia nilotica,* form large seed banks that are thought to remain in the soil for up to ten years.
- Thorny species such as *Acacia nilotica, Flacourtia indica* and *Rubus alceifolius* increase removal costs considerably.
- *Flacourtia indica* is difficult to hand weed because of its tenacious roots from which it readily sprouts.
- *Hedychium* spp. have highly efficient vegetative reproduction. The complete removal of the rhizomatous roots is very labour intensive.

4.2. Restoration activities

On the island of Mauritius, restoration activities are focused on a series of CMAs chosen as representative of the different vegetation types found on the island. CMAs in the Black River Gorges National Park are fenced using 2-m high chain link fencing of 7.5 mm mesh size to keep deer and pigs out. In most cases the base of the fence on the outer side is covered with small rocks to prevent pigs from burrowing into the fenced area. The total fence costs some US$70 per running metre (Mauremootoo and Towner-Mauremootoo in press).

CMAs within this national park are managed by the National Park and Conservation Service (NPCS). Management of these CMAs dates largely from the creation of the national park in 1994; about one hectare was weeded prior to the creation of the park, and less than five hectares were fenced. After initial weeding, the CMAs managed by the NPCS were weeded manually four times a year (Mungroo 1997; Mungroo and Tezoo 2000), but since 1999 the frequency of maintenance weeding has been reduce to three times a year. The annual budget for maintenance weeding for the 39 ha of CMAs in the national park in 2003 was US$74 000 (Mauremootoo and Towner-Mauremootoo in press). Three full-time workers are employed by the Forest Service for invasive species control within the Perrier Nature Reserve (a CMA outside the national park) (H. Paupiah, personal communication).

On Rodrigues, restoration efforts have been focused on two nature reserves, Grande Montagne and Anse Quitor. First work (beginning in 1986) was done on a small scale with the help of volunteers, then in 1996 a five-year project was funded by GEF (Global Environment Facility of the United Nations Environment Fund, UNEP). The nursery constructed in 1996 produces on average 75 000 plants per year for the restoration of the two sites (R. Payendee, personal communication). In Anse Quitor, some 6 ha have been restored, with approximately 19 000 individuals of 25 different native species planted up to 2002. In Grande Montagne, some 10 ha have been restored by replanting approximately 80 000 individuals of 50 native species up to 2002 (Mauremootoo and Payendee 2002). In 2002 a pilot project was started to replant native forest in coastal areas on Rodrigues (R Payendee, personal communication).

Intensive restoration is also being conducted in one privately managed reserve and on several small islets (see Table 3). In addition to the intensive restoration sites included in Table 3 there are some other small managed plots, and an expansion of the CMA areas is planned.

A first phase of intensive habitat management started in the mid 1980s. The work undertaken in the Mondrain Nature Reserve (Strahm 1988) exemplifies the efforts made at this time. Based on results from a pilot study conducted in a 50 × 20 m plot in June 1985, the initial weeding was undertaken in two time periods (November 1985 – June 1986; November 1986 – June 1987) by a team of five sugar cane workers. In May 1986 the reserve was completely fenced. Follow-up weeding has been carried out since by a smaller team: Mr G. D'Argent undertakes weeding 3–4 times each week and two workers carry out more intensive weeding during two months per year. (G. D'Argent, personal communication). Today the forest reserve is composed of mainly native species.

TABLE 3: MAIN RESERVES IN WHICH INTENSIVE INVASIVE SPECIES CONTROL AND HABITAT MANAGEMENT ARE IMPLEMENTED ON MAURITIUS AND RODRIGUES

Island	Reserve	Habitat	Altitude (m asl)	Area (ha)	Managed since	Reserve type[a]
Mauritius	Machabée	Upland	c. 550	0.4	1986 (1930s)	CMA (BRG)
	Mont Cocotte	Upland	c. 770	0.4	1987	CMA (BRG)
	Mare Longue	Upland	c. 550	3.5	1993	CMA (BRG)
	Florin	Upland	c. 500	2.5	1995	CMA (BRG)
	Bellouguet	Intermediate altitude	c. 300	2.5	1994	CMA (BRG)
	Fixon	Intermediate altitude	c. 300	4.3	1994	CMA (BRG)
	Le Pétrin	Upland	660	6.2	1994	CMA (BRG)
	Brise Fer	Upland	570–600	19.3	1986–1996	CMA (BRG)
	Ile aux Aigrettes	Island, lowland	0–10	26	1986	MWF
	Round Island	Island, lowland	0–280	151	2002 (1980s)	MWF/NPCS
	Mondrain	Semi-dry	500–530	5	1985	MRSAS
	Perrier	Upland	c. 550	1.5	1969	CMA (MFS)
Rodrigues	Grande Montaigne	Intermediate altitude	350	10	1986	MWF/RFS
	Anse Quitor	Lowland dry	20	6	1986	MWF/RFS

[a] BRG: Black River Gorges National Park; CMA: Conservation Management Area; MFS: Mauritius Forestry Service; MRSAS: managed by the Mauritius Royal Society of Arts and Sciences; MWF: managed by the Mauritian Wildlife Foundation; NPCS: managed by the National Park and Conservation Service; RFS: Rodrigues Forestry Service.

The habitat restoration programme on Ile aux Aigrettes is particularly well documented. A weed management strategy plan has just been released, based on the first 15 years of management (Newfield *et al.* 2003). The management plan provides a case study of past experiences and future needs for restoration work on Mauritius and Rodrigues. Some important aspects are listed below.

- In general, a good habitat restoration strategy should define the minimum restoration efforts that are absolutely essential as well as the maximum efforts that would be efficient in terms of cost–benefit. Prioritization of target species and habitats, and adaptation of weeding intensity to specific species and the state of the habitats, based on past experiences, are essential. Good documentation and monitoring are critical for any restoration project.

- A restoration programme includes different phases: initial weeding and replanting, maintenance weeding and long-term management:

    - In the initial phase the main exotic vegetation cover is removed (initial weeding). In degraded habitats it is necessary to replant immediately with native species to slow down secondary invasions and regrowth of exotic species from the seed bank. On Ile aux Aigrettes, seedlings are replanted at a density of up to four plants per square metre. The main species planted include *Dodonaea viscosa, Gastonia mauritiana, Pandanus vandermeeschii, Tarenna borbonica* and *Dracaena concinna.* Seedlings are produced in a nursery on the island and are planted out during the rainy season in square plugs 4–5 cm deep; the seedlings are usually about 20 cm high when planted.
    - After initial weeding and replanting, regrowth and reinvasion of exotic species has to be controlled regularly. Continuity is absolutely crucial to deplete the soil seed bank and to assure successful regrowth of native vegetation cover. On Ile aux Aigrettes, the first maintenance weeding of the newly planted areas is carried out between one and six months after the initial weeding and replanting, with a second several months later, depending on the state of weed regrowth. All species except grasses are removed by hand. Weeding is then carried out once a year.
    - After the restoration of the native canopy, regrowth of exotic species will probably decline strongly. Nonetheless, low-intensity weeding will almost certainly have to be continued infinitely. On Ile aux Aigrettes the major initial weeding and replanting are expected to be finished by 2004. Intensive maintenance weeding will continue until about 2008.

- Weeding intensity and frequency should be prioritized according to the state of the habitat. For instance, dry habitats where regeneration is slow do not need annual weeding, whereas this is essential in humid forests. Equally, removal of exotic species in the seedling and sapling stage is only necessary where juvenile exotic species interfere with the regeneration of native species. On Ile aux Aigrettes, weeding intensity falls into four categories: high maintenance, medium maintenance, low maintenance and follow-up weeding.

- Different exotic species need different weeding intensities. On Ile aux Aigrettes, the exotic plant species have been divided into four groups based on the following control targets: ‘eradication’ (success criterion = not found on the island for at least five years), ‘zero density’ (no adult trees, but external reinvasions and regrowth from the seed bank), ‘sustained control’ (achieving zero density is improbable, but the amount of control required reduces with the recovery of an intact canopy), and ‘no long-term control’ (for species with minor impact).

In a pilot study on Ile aux Aigrettes, large herbivores (Aldabra giant tortoises, *Geochelone gigantea*) have been released to control the regrowth of exotic species (Zavaleta *et al.* 2001). It is hypothesized that the loss of the former keystone grazers (Mauritian giant tortoises *Geochelone inepta* and *Geochelone triserrata* according to Arnold 1979) increased the competitiveness of exotic weeds. The release of *G. gigantea* on a large scale will only be carried out after it has been proved that native species do not suffer from grazing by giant tortoises. In addition, before the giant tortoises could be released island-wide, herbivore-dispersed weeds such as *Leucaena leucocephala* would have to be eradicated.

The numerous spatially enclosed restoration projects allow the effects of restoration measures on the native fauna and flora to be assessed:

- In 1986, Strahm (1994) surveyed a 50 × 20 m plot weeded in the late 1930s by R. E. Vaughan and P. O. Wiehe. Since then, the plot has been sporadically reweeded but not fenced. In spite of inconsistent management the plot was considerably more diverse in 1986 than an adjacent non-managed plot.

- The regeneration of the rare endemic species *Diospyros egrettarium* was quantified on Ile aux Aigrettes (Mauremootoo 1997; Moodhoo 1997). Based on tree height distributions in five 15 × 15 m quadrats, it was concluded that seedling production and survival strongly increased after weeding and rat eradication. It was suggested that both interventions played an important role. Rats killing *Diospyros* spp. seeds is a ubiquitous phenomenon in the forests of Mauritius (Mauremootoo 1997).

- A study compared the regeneration of a CMA and an unmanaged area in an upland humid forest (Mauremootoo 1997). A comparison of numbers of seedlings and saplings per metre-squared plot showed dramatically higher numbers of native seedlings and saplings in the managed plot. However, native mature tree abundance was also higher in these plots. It is therefore not clear if the differences stem from a lower juvenile mortality of native species in the managed plots or simply from an increased native propagule pressure (seed rain).

- A similar comparative study focused on the effects on the snail fauna (Florens 1996; Mauremootoo 1997; Florens *et al.* 1998). There were markedly higher numbers of individuals of exotic ground-dwelling macrofauna in the managed plots. The same trend could not be demonstrated for the native ground-dwelling macrofauna, and there were many more native arboreal snails in the unmanaged plots. The authors suggested that native foliage- and trunk-dwelling snails may have been kept at unnaturally high densities by the presence of a dense exotic understorey. The high density of the exotic ground-dwelling macrofauna, compared with the native macrofauna, may be a cause for concern.

- Padayatchy (1998) compared the abundance of two endemic day geckos (*Phelsuma guimbeau* subsp. *rosagularis* and *Phelsuna cepediana*) in a weeded and an unweeded upland forest plot. The relative abundance of insect prey was also assessed using sticky barrier traps. The results showed that there was no difference in the number of insects or geckos between the plots.

- Motala (1999) resurveyed an upland forest, Machabée, where a survey had been carried out 60 years earlier by R. E. Vaughan and P. O. Wiehe. Overall, the native tree and sapling/seedling abundances have suffered a drastic reduction over the 60 years, although the decline in middle-storey and canopy trees has been less severe. The abundance of native trees and shrubs is only 29 percent of the level 60 years ago. The most dramatic reductions have occurred in species found in the lower and medium strata of the forest, while canopy trees have survived relatively better, although they show no signs of regeneration.

- Seegoolam (1999) studied the effect of weeding and fencing on the regeneration of ferns in three plots within the Brise Fer upland CMA: plot 1 was first fenced and weeded in 1986; plot 2 was weeded in 1993 and fenced in 1996, plot 3 was weeded and fenced in 1996. An unmanaged control plot was also monitored. There were more ferns within the managed plots. Plot 1 had the highest creeping ground fern regeneration, and plot 3 the highest diversity of epiphytic ferns, although there were very few ground ferns in that plot.

- Native butterflies were on average 19 times more abundant in surveyed CMAs than in non-managed areas (Mauremootoo and Towner-Mauremootoo in press).

- Forest areas seriously invaded by *Psidium cattleianum* are poor habitats for all native bird species. However, the non-threatened endemic grey white-eye, *Zosterops borbonicus,* was found in higher numbers in non-managed areas compared to CMAs with comparable levels of native canopy cover (Mauremootoo and Towner-Mauremootoo in press). Nevertheless, such elevated densities will only be ephemeral as the unmanaged forest degrades to monospecific thickets.

- No quantitative data are available, but observations strongly suggest that echo parakeets (*Psittacula echo*) and pink pigeon (*Columba mayeri*) increase the use of sites immediately after initial weeding (C. Jones, personal communication).

- Monitoring programmes for vegetation and reptiles have been established on Round Island since 1975 (Bullock *et al.* 2002). Following eradication from the island of goats in 1979 and rabbits in 1986, vegetation cover has increased greatly. In many cases the increase is in native species, but overall weed cover has also increased considerably and some native species appear to have decreased in density. Reptile monitoring results are more difficult to interpret because of the high variation and the inherent difficulties of reptile sampling.

- Systematic vegetation monitoring for Ile aux Aigrettes only began in 1999, with permanent quadrats established in 2001 (Rammen 2001). Data are currently being analysed but it is clear that native cover has increased considerably over the first three years, at the expense of introduced plant species.

- Christopher Kaiser (University of Zurich, Switzerland) has recently started a Ph.D. project to compare pollinator communities in a restored CMA with an adjacent invaded and unmanaged forest plot in an upland habitat. The aim of this project is to establish to what degree locally restored plant communities attract original endemic pollinator and seed-disperser species. Studies of pollination networks revealed that entire communities are often characterized by generalists rather than highly specialized plant–animal interactions (Waser *et al.* 1996). Endemic lizards and birds are probably frequent pollinators of endemic plant species on oceanic islands (Nyhagen *et al.* 2001; Hansen *et al.* 2002; Olesen *et al.* 2002; Olesen and Valido 2003).

- A number of new projects have just been initiated by the University of Mauritius (see Box 1: Research projects of the University of Mauritius).

BOX 1: RESEARCH PROJECTS OF THE UNIVERSITY OF MAURITIUS
By Vincent Florens, University of Mauritius

1. Fruit productivity of the Mauritian endemic tree* Canarium paniculatum *under weeded and unweeded conditions

Canarium paniculatum (Burseraceae) is an endemic canopy tree of the Mauritian upland montane forests. Its natural regeneration is very poor, threatening its survival. Attempts to explain this situation have incriminated invasive exotic species, but none of these supposed exotic species effects has been quantified, let alone verified. This project aims to determine the role that competition with exotic invasive weeds may have on the fruit productivity of the species.

The working hypothesis is that the presence of weeds in the immediate vicinity of the trees results in reduced fruit productivity compared with trees growing in weed-free conditions. This may be the result of, for example, competition for resources between the tree and the weeds or some form of allelopathy. The reduced fruit productivity would then translate into reduced regeneration.

Objectives:

1. Randomly select a set of trees in both weeded and unweeded areas in two different locations (Brise Fer and Mare Longue forests).
2. Determine the relative fruit productivity of each tree by visually estimating the fruit numbers on the tree and by sampling seeds found at the base of the bole using 16 quadrats of 1 m^2 each.
3. Measure the diameter at breast height (DBH) of trees in the immediate vicinity of each *C. paniculatum* tree studied.
4. Compare the relative fruit productivity of *C. paniculatum* in the two types of environment and investigate whether varying basal area (cross-sectional area of trees at breast height) of other species around *C. paniculatum* trees impact on its fruit productivity.

2. Investigations of reinfestation rates of alien weeds inside Conservation Management Areas (CMAs) on the island of Mauritius

In-situ conservation management on the island of Mauritius includes removal of exotic (alien) weeds followed by maintenance weeding of reinvading seedlings. The aim of this project is to investigate (i) the distance of exotic seed sources and (ii) the canopy cover as factors in weed reinfestation in CMAs.

The working hypotheses are that (i) the number of reinvading seedlings decays with distance from the edge of a CMA, and (ii) there is an inverse relationship between canopy cover and weed reinvasion.

Objectives:

1. Determine weed seedling densities in quadrats along randomly chosen transects running from the edges towards the centres of two CMAs (Brise Fer, Mare Longue), and collect data from control quadrats in unweeded adjacent areas.
2. Collect data on canopy cover above each of the quadrats.
3. Correlate weed density with both distance from the edge of the CMA and canopy cover and compare species diversity and density between the weeded and unweeded areas.

3. Impact of alien invasive woody weeds on native tree diversity in the upland montane forests of Mauritius

This project aims to quantify how native tree species diversity varies with the extent of forest degradation by exotic weeds.

The working hypotheses are that (i) the greater the weed infestation, the lower the native tree species diversity, and (ii) a threshold intensity of weed invasion exists beyond which native species loss increases sharply.

BOX 1 (CONT.): RESEARCH PROJECTS OF THE UNIVERSITY OF MAURITIUS

Objectives:
1. Select random and replicated plots with varying degrees of weed invasion in native forest in three locations (Brise Fer, Mare Longue, Macchabé).
2. Determine native species richness and total basal area, and diversity and density of exotic weeds in each plot.
3. Investigate whether there is any correlation between degree of weed invasion, as determined by these three parameters, and diversity of native plants.

4. Investigating the susceptibility of native trees to alien weed invasion in upland Mauritian montane forests in relation to the trees' ecological traits

Many native tree species have become extinct on Mauritius and many more are declining or on the brink of extinction. Nevertheless, a number of native species seem relatively unaffected and show little or no such decline. This project aims to determine which species of native trees suffer most from weed-driven forest degradation in the upland forests of Mauritius and what ecological features they share, if any.

The working hypothesis is that native trees most prone to disappear from degrading forest share some common ecological characteristics.

Objectives:
1. Randomly select replicated transects in each of two study sites.
2. Determine the size frequency distribution of each native tree species and the basal area of the exotic weeds at each site.
3. Classify native tree species' regeneration in broad categories (good, medium or bad).
4. Determine whether species falling into each category share certain ecological features.

5. Impact of gazon chinois (*Panicum umbellatum*) on native plant regeneration in upland Conservation Management Areas (CMAs) of Mauritius

Areas weeded of invasive exotic plants often provide a modified habitat conducive to the spread of species that hitherto could not have invaded the forest. The grass *Panicum umbellatum* is such a species in the upland montane forests of Mauritius. The impacts of this secondary invasion have not been studied. This project aims to determine the effect that the grass may have on the regeneration of Mauritian native trees found in the managed remnants of the upland montane forests of Mauritius.

The working hypothesis is that *P. umbellatum* hinders regeneration of native trees in weeded forest plots.

Objectives:
1. Select a set of stratified random samples within three CMAs (Brise Fer, Mare Longue, Florin).
2. Determine percentage grass cover and the number of native seedlings present in each sample.
3. Correlate percentage grass cover with number of native tree seedlings present.

6. A comparison of the ground-dwelling insect diversity in weeded and unweeded areas in the upland montane forests of Mauritius

In-situ conservation of Mauritian native forests involves drastic removal of all exotic weeds from the conserved areas. The impact of the resulting major change in microclimatic conditions on groups such as insects is likely to be massive and yet is virtually unknown on the island of Mauritius. This project aims to determine the effect that weeding as a conservation management intervention may have on the diversity and abundance of ground-dwelling insects in the remnants of the upland montane forests of Mauritius.

The working hypothesis is that the removal of exotic weeds will improve the quality of the habitat for ground-dwelling insects, which would consequently increase in diversity and abundance following weeding.

BOX 1 (CONT.): RESEARCH PROJECTS OF THE UNIVERSITY OF MAURITIUS

Objectives:
1. Randomly select replicated sites in both weeded and unweeded areas in two locations (Brise Fer and Mare Longue forests).
2. Set up pitfall traps within these sites and regularly visit the traps to collect the catches.
3. Determine the relative species diversity (using recognizable taxonomic units) and density of ground-dwelling insects in the study areas.

Discussion

The conservation sector on Mauritius and Rodrigues can build on almost 20 years of intensive restoration work. Nevertheless, restoration work is being undertaken in only two percent of the potential area on the island of Mauritius and in 18 percent of the potential land on small islets (Mauremootoo and Towner-Mauremootoo in press). A scaling up of restoration efforts is needed.

Potential islets for new restoration initiatives include Flat Island (250 ha), and Gunner's Coin (76 ha).

Even though several research projects have been started, little is known about the effect of restoration practices on the native fauna and flora, especially invertebrates, epiphytes and fungi. In many of these species groups, basic taxonomic work is lacking (see for instance Dulymamode *et al.* 2001).

On the island of Mauritius, restored sites form tiny islands within exotic vegetation. Habitat fragmentation leads to a high influx of exotic species' propagules. It is not known to what extent populations of native plants and invertebrates are self-sustaining in these small restored fragments, and if meta-population dynamics are interrupted. For instance, the positive effects of small islands of restored vegetation on birds are probably minor. Restoration on a larger scale would be more favourable.

Fencing is not effective against monkeys that break branches of native trees, eat their fruits and disperse invasive species, or against rats that prey on seeds and eat eggs and young birds, reptiles and invertebrates. The type of predator exclusion fencing used in Australia and New Zealand could be effective against rats and monkeys. However, such fences could have a negative fragmenting effect on populations of native invertebrates. This would apply particularly to so-called 'superfences', not yet in operation on Mauritius, that exclude even small vertebrates (V. Florens, personal communication). Population control of exotic animals through hunting and trapping may be less expensive than fencing.

Blanket initial weeding of large contiguous areas in a short period of time could well have negative effects because it could lead to sudden changes in the microclimate and possible destruction of refugia for native species. Gradual or mosaic weeding may be more beneficial.

For the initial weeding of heavily degraded areas, the use of fire may be a less expensive alternative to mechanical control.

Future restoration attempts should be fine-tuned based on past experiences (see the example of Ile aux Aigrettes in Section 4.2. above). Additional simple techniques to increase the efficiency of restoration work may include: direct sowing of native species seeds, preventing exotic regrowth with biodegradable mulches, use of grazers (see the example of giant tortoises on Ile aux Aigrettes, Section 4.2.), initial weeding being conducted prior to the fruiting season of exotic species, or rat control during the main fruiting season of native species (the austral summer).

Traditional conservation funding will not be sufficient for the necessary large-scale restoration efforts. Cofinanced multipurpose projects have to be identified (mainstreaming). For instance, large-scale restoration of Rodriguan watershed areas may be achieved using an approach similar to that pioneered by the South African Working for Water programme (Van Wilgen *et al.* 1996). In this programme restoration work is sold as a water and job provision programme. In the case of Rodrigues the benefits for the lagoon could also be promoted as such projects could take surplus fisher people away from the overfished lagoon and into the under-protected forest (Mauremootoo and Towner-Mauremootoo in press).

Sugar cane workers have been used in the past for restoration work during the low season. The mechanization of sugar production may render former sugar cane workers redundant, and these people may be provided with jobs in the restoration sector.

5. AWARENESS AND CONFLICTS OF INTEREST

5.1. Awareness

Awareness of the invasive species problem is high within responsible authorities, and among conservation experts. However, public awareness and awareness among decision makers on this issue is apparently low. There has so far been no systematic public awareness-raising attempt regarding invasive species on either Mauritius or Rodrigues.

Awareness of environmental problems is generally low. Knowledge about the native flora appears to be declining among the population as a whole.

Many biology students at the University of Mauritius had never visited a native forest before beginning their studies. Some are even not aware of the existence of native forests. Pine (*Pinus* spp.) forests are thought to be typical forests by many Mauritians (V. Florens, personal communication).

A BSc study carried out at the University of Mauritius (Prosper 1998) assessed local knowledge of the native flora, the threat to it and its utilization (medicinal plants, thatching, fruits) on Rodrigues. Eighty-five plant species were used by local people, mostly for medicinal purposes. However, these practices appeared to be declining, together with the botanical knowledge. Perception of environmental problems affecting Rodrigues was limited. Awareness of the threat of disappearing local knowledge needs to be raised.

The Mauritian Wildlife Foundation (MWF) on Rodrigues employs a full-time environmental educator who targets primary school children and local communities within the Rodrigues Environmental Education Programme (REEP) (started in 1998) (R. Payendee, personal communication).

Through the Sustainable Use of Rodriguan Endemic Plants project (UNEP/GEF Small Grants Programme, 2000–2002), propagation techniques for endemic plant species used in local medicine and handicraft were developed and the establishment of community-based nurseries for these species was initiated. The project was conducted in collaboration with the National Handicraft Promotion Agency, several artisans' associations, and local village councils (R Payendee, personal communication).

5.2. Conflicts of interest

Exotic species also have obvious positive effects. It can therefore be anticipated that eradication and control attempts will trigger conflicts of interest. Some examples are listed below.

- The most obvious example of a potential conflict of interest is *Psidium cattleianum*. Biological control agents may be available for large-scale control of *P. cattleianum* in the near future. However, the fruit is highly valued in Mauritius and a biological control programme may be opposed.

- Many invasive species are ornamentals, widely planted in gardens and parks, e.g. *Ravenala madagascariensis*.

- Invasive and potentially invasive forestry trees are still planted. For instance: *Albizia lebbeck*, *Eucalyptus* spp., *Pinus* spp. (mainly *Pinus elliottii*) and *Tabebuia pallida*. However, production forestry is expected to be reduced in the coming years in Mauritius and Rodrigues.

- Invasive species, for instance *Acacia nilotica*, have been planted for erosion control on Rodrigues.

- Species such as *Lantana camara* are thought to be melliferous. The honey industry, especially on Rodrigues, is very high profile. Proposals have been put forward for the introduction of melliferous plant species not currently found on Rodrigues from Mauritius. One suggested species is *Schinus terebinthifolius*, which is likely to be highly invasive on Rodrigues.

- *Litsea* sp. is regarded as a medicinal plant (see Part 2: The Comoros archipelago, Box 1: *Litsea glutinosa* in the Comoros archipelago: dynamics, ecology and control). Information on medicinal plants in Mauritius is given in Rouillard and Guého (1999).

- The leaves of *Ravenala madagascariensis* are used as plates in Indian ceremonies.

- Some exotic plant species are used as substitutes for native species by native birds. Of the six forest-living native passerines of the island of Mauritius, five are largely restricted to native vegetation. Only the grey white-eye *Zosterops borbonicus* is abundant, occurring in all wooded vegetation. Nevertheless, the nesting success of the endemic fody (*Foudia madagascariensis*) is markedly increased in plantations of the exotic *Cryptomeria japonica*. However, these plantations are only used if adjacent to native vegetation (for foraging) (Safford 1997b). *Averrhoa carambola* was planted as a food source for the echo parakeet. *Syzygium jambos* provides a habitat for the Rodrigues fody (*Foudia flavicans*) and brush warbler (*Acrocephalus rodericanus*) (Strahm 1989; Showler *et al.* 2002). The endemic fruit bat on Rodrigues eats both fruits and flowers of *S. jambos* (Strahm 1989). *Ravenala madagascariensis* is a habitat for endemic lizards that in turn are the main food resource for the Mauritius kestrel (*Falco punctatus*).

6. LEGISLATIVE FRAMEWORK TO CONTROL INVASIVE WOODY PLANT SPECIES

Phytosanitary control is efficient and well established in Mauritius. Quarantine measures are particularly effective against pests and diseases of sugar cane. In the airport there are announcement boards, and a card for declaring all plant material has to be filled in by all arriving passengers. However, this information appears not to be acted upon. There are quarantine facilities at the airport and the marine port. In total, 15 technical officers plus two scientists work for the Quarantine Service.

Containment between Rodrigues and Mauritius is difficult to implement. Quarantine and disposal facilities are not currently available.

All soil imports are forbidden by international law. Seed importation appears to be easy to carry out, although an import permit is needed.

So far there is no legislation applicable to invasive species. The Plant Act, which regulates phytosanitary measures, is currently under revision. The production of a black list of invasive species that would not be allowed into Mauritius is currently under discussion.

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APPENDICES

Appendix 1: list of abbreviations and acronyms

asl	above sea level
BRG	Black River Gorges National Park
CMA	Conservation Management Area
FAO	Food and Agriculture Organization of the United Nations
GEF	Global Environment Facility
MFS	Mauritius Forestry Service
MRSAS	the Mauritius Royal Society of Arts and Sciences
MSIRI	Mauritius Sugar Industry Research Institute
MWF	Mauritian Wildlife Foundation
NPCS	National Parks and Conservation Service
REEP	Rodrigues Environmental Education Programme
RFS	Rodrigues Forestry Service
UNEP	the United Nations Environment Fund

Appendix 2: some common names of cited plants

Species name	Common name(s)
Acacia spp.	Acacias, Wattles
Ageratina riparia	Mist flower
Albizia lebbeck	Bois noir, Siris tree
Averrhoa carambola	Carambola
Camellia sinensis	Tea
Casuarina equisetifolia	Casuarina, Filao
Cinnamomum verum	Cinnamon
Citrus limon	Lemon
Citrus medica	Citron
Cocos nucifera	Coconut
Coffea spp.	Coffee
Cordia curassavica	Black sage
Cryptomeria japonica	Japanese (red) cedar
Cyathea cooperi (syn. *Sphaeropteris cooperi*)	Fanjan australien
Diospyros spp.	Ebony
Eichhornia crassipes	Water hyacinth
Eucalyptus spp.	Eucalypts
Gossypium spp.	Cotton
Grevillea banksii	Grévillaire rouge
Indigofera spp.	Indigo
Lantana camara	Lantana
Leucaena leucocephala	Leucaena
Ligustrum robustum subsp. *walkeri*	Sri Lankan privet, Troène de Ceylan
Mangifera indica	Mango
Melaleuca quinquenervia	Niaouli
Mikania micrantha	Mikania, Mile-a-minute
Pandanus spp.	Pandans, screwpines
Panicum maximum	Guinea grass, Fatak grass
Panicum umbellatum	Gazon chinois
Pennisetum purpureum	Elephant grass
Pinus spp.	Pines
Pongamia pinnata	Coqueluche
Psidium cattleianum	Cherry/Chinese/Strawberry guava, Goyavier
Raphia farinifera	Raffia palm
Ravenala madagascariensis	Traveller's tree
Rubus alceifolius	Giant bramble, Raisin marron
Saccharum officinarum	Sugar cane
Schefflera actinophylla	Umbrella tree, Arbre ombrelle
Schinus terebinthifolius	False pepper
Solanum melongena	Aubergine, Eggplant
Spathodea campanulata	Tulip tree, Tulipier du Gabon
Syzygium aromaticum	Clove

Species name	Common name(s)
Syzygium jambos	Rose apple, Jambrosa
Tabebuia pallida	Calice du pape, Pink tecoma
Tamarindus indica	Tamarind
Terminalia catappa	Badamier, Tropical almond
Ulex europaeus	Gorse
Zea mays	Maize