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

4. Réunion

By

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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.

Kueffer, C. and Mauremootoo, J. 2004. *Case Studies on the Status of invasive Woody Plant Species in the Western Indian Ocean. 3. Mauritius (Islands of Mauritius and Rodrigues)*. Forest Health & Biosecurity Working Papers FBS/4-3E. Forestry Department, Food and Agriculture Organization of the United Nations, Rome, Italy.

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TABLE OF CONTENTS

List of tables and boxes

Tables

Boxes

1. GENERAL BACKGROUND

The information in this section is based on Blanchard (2000) and Le Corré and Safford (2001).

Réunion is an overseas department (*département*) of France with a population of some 750 000 inhabitants. It has been permanently inhabited since 1646.

Réunion (21°07' S, 55°32' E) lies 600 km from the nearest continental land mass, Madagascar, in the Western Indian Ocean. Together with Mauritius (164 km to the east-northeast) and Rodrigues it forms the volcanic archipelago of the Mascarenes. Réunion comprises a total land area of 2 512 km^2. Sixty percent of the land mass is over 1 000 m asl (above sea level), rising to a maximum altitude of 3 069 m asl (Piton des Neiges). The topography is characterized by two volcanoes, the lower still active (Piton de la Fournaise), forming a mountainous ridge running across the island. The age of the island is estimated at 2.1 million years. There are very few reefs and small islets around the main island.

The climate is strongly influenced by southeasterly trade winds leading to a drier and hotter leeward (western) side of the mountain ridge with some 1 000 mm rainfall per year and annual mean temperatures of 23–25°C in the lowland areas, and a wetter and cooler eastern side with up to 4 000 mm rainfall per year at this altitude. The mountains receive 2 000–5 000 mm (locally up to 9 000 mm) annual rainfall, and mean annual temperatures are below 16°C over a wide area, with frosts frequent in winter above 2 000 m. The wettest, hottest months are from December to April, while September to November are driest, and June to August are coolest. During the wet season the island is frequently hit by tropical cyclones.

Of the some 550 native flowering plant species, about 30 percent are endemic to Réunion, with a further 25 percent endemic to the Mascarenes. The native fauna includes or included at least 52 native, breeding vertebrate species (birds, bats and reptiles). Of these, 27 (52 percent) are or were endemic to Réunion, and a further seven (13 percent) are or were endemic to the Mascarenes.

Thanks largely to its topography, Réunion represents the highest diversity of habitats in the Mascarenes. Four main altitudinal vegetation zones can be distinguished: lowland dry or semi-dry vegetation (palm savanna, semi-dry ebony forest), intermediate-altitude humid forest, mountain cloud forest, and high-altitude ericaceous heathland communities. In some instances, coastal vegetation, marshland vegetation, riverine vegetation, secondary forests and forest plantations, agricultural land, and early successional stages on volcanic lava flows are also considered in this Part. Natural dry and semi-dry lowland and coastal vegetation have been almost completely destroyed. However, 20–30 percent of the vegetation, especially in the uplands, is conserved in its primary or natural state. Thus, Réunion retains a much larger area of natural ecosystems than the other Mascarenes (around seven times that remaining on Mauritius).

At least six plant species and 21 vertebrate species which were endemic have become globally extinct, while 18 percent of the native flora and 35 percent of the surviving vertebrate species have been reduced to threatened or near-threatened status. Today, exotic plants and animals (especially grazing by goats and predation by rats) are the main threats to the native flora and fauna.

2. INVASIVENESS AND DEGREE OF INVASION

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

2.1. A brief history of invasions

This section is based on Cheke (1987), Strasberg (1994) and Blanchard (2000).

The history of invasions has to be considered in parallel to the deforestation and fragmentation of native forest vegetation.

- Before the first permanent settlements in 1646, the negative impact of invasive species on natural vegetation was mainly from exotic animals (rats, cats, pigs, cattle, goats).

- By 1715 about half of the lowland palm savanna had been destroyed.

- The introduction of coffee (*Coffea* spp.) in 1715 triggered fast human population growth and development in the lowlands. By the end of the 1780s the population was 45 800, and the lowland palm savanna, semi-dry forest and humid forest had all been destroyed.

- Around 1800 the coffee industry was producing 3 500 tonnes per year. Production subsequently declined to 1 500 tonnes per year by 1810 and the industry had virtually disappeared by the end of the nineteenth century.

- The high-altitude plateaux formed by former volcanoes (cirques) in the centre of the island were settled during the first half of the nineteenth century. The emancipation of slaves in 1848 accelerated forest destruction. By 1848 the island's population was 110 000.

- The sugar cane (*Saccharum officinarum*) industry developed from 1850 onwards.

- By the middle of the nineteenth century feral livestock had been hunted out of existence, leaving (exotic) rats as the only widespread invasive animals. However, deer have since been reintroduced in some areas.

- By 1880 little forest was left below 1 000 m asl.

- In 1870 *Pelargonium* × *asperum* (geraniums) were introduced. From 1900 to 1925 the development of the geranium industry led to further forest destruction in the western parts of the island.

- After the Second World War the Forest Service (Office national des forêts de la Réunion), ONF–Réunion, started a large-scale programme to replace natural forest with plantations. With the exception of *Acacia koa (*syn. *A. heterophylla),* replanting was undertaken with exotic species such as *Acacia* spp., *Casuarina* spp., *Cryptomeria japonica*, *Eucalyptus* spp. and *Melia azedarach*.

2.2. Invasiveness

The first catalogue of invasive plant species in Réunion was prepared by Lavergne (1978) who listed 16 species. In 1989 a strategy for the management of invasive plant species in Réunion was proposed (Macdonald 1989). As part of this, a list of 33 main invasive species, selected from 62 species found naturalized in undisturbed forests, was published (Macdonald *et al.* 1991). Ranking for severity of invasiveness and negative impact was based on five parameters: absolute abundance, feasibility of control, potential future extent of invasion, rate of spread and ecological impact. This list has since become the main reference document on main invasive plant species in Réunion. ONF–Réunion published a list that was in essence a subset of the species of Macdonald *et al.* (1991) (Sigala 1999). The invasive species control projects carried out by ONF–Réunion have mainly targeted species listed in Macdonald *et al.* (1991) (Hivert 2003). The list of problematic invasive species published by MacDonald *et al.* (1991) has recently been re-evaluated using a different prioritization method (Cazanove 1999). Forty exotic species have been classified using a method developed for the United States (Hiebert 1996) which includes two axes: impact and feasibility of control. All authors as well as the participants of this study largely agreed on a set of 18 main invasive woody plant species while another 15 species were also cited (see below).

Thébaud (1989), working from records published in the *Flore des Mascareignes* up until 1978 (Bosser *et al.* 1978–ongoing), stated that 1 100 plant species have been introduced to Réunion, (of which 460 are naturalized). Strahm (1999), using the same source, gave a figure of 694 naturalized exotic plant species (of which 32 are invasive). Based on historical and field data, Lavergne (2001) estimated that 2 100 plant species have been introduced since the beginning of the nineteenth century. A comprehensive database of invasive and potentially invasive species based on extensive field surveys is in preparation (Lavergne *et al.* in prep.). The database includes 700 naturalized plant species; of these, about 100 are invasive and about 100 are potentially invasive (see below). In the study by Lavergne *et al.*, the invasive species are divided into four groups: (i) main invasive plant species that should be carefully managed in nature reserves; (ii) species that are invasive both in anthropogenic and natural habitats and should be monitored everywhere and controlled in nature reserves; (iii) species that are invasive only in anthropogenic habitats and should be monitored; and (iv) potentially invasive species that should be monitored and eradicated if necessary.

2.2.1. Main invasive woody plant species

Eighteen woody plant species are classified as main invasive species (Table 1), 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.

Psidium cattleianum, Rubus alceifolius, Lantana camara, Ligustrum robustum subsp. *walkeri* and *Solanum mauritianum* were, in this order, the five most problematic woody plant species according to Macdonald *et al.* (1991). In addition, *Ulex europaeus* was noted but its invasive status was not analysed. *Hiptage benghalensis*, *Ligustrum robustum* subsp. *walkeri*, *Psidium cattleianum, Rubus alceifolius* and *Ulex europaeus* were the most problematic invasive woody plant species according to Cazanove (1999). Furthermore, *Casuarina equisetifolia, Clidemia hirta* and *Syzygium jambos* achieved high scores for invasiveness in both studies, and were identified as invasive in all the references included in Table 1. These ten species are marked in bold in Table 1 to signify that they are the most problematic invasive woody plant species in Réunion. *Fuchsia magellanica*, *Leucaena leucocephala* and *Tibouchina viminea* were also considered as invasive in almost all the references but were generally judged to be less problematic.

TABLE 1: MAIN INVASIVE WOODY PLANT SPECIES IN RÉUNION
The most problematic species are in bold type

Species	References[a]	Habitats[b]	Introduction date (Ref.[a])
Ardisia crenata	2, 3, 5, 6, 8	LH, U	
Casuarina equisetifolia	1, 2, 4, 5, 6, 8	C, VF	1768 (1)
Clidemia hirta	2, 3, 4, 5, 6, 7, 8	P, LH, U	
Fuchsia × exoniensis	3, 4, 7, 8	U	
Fuchsia magellanica	2, 3, 4, (5), 6, 7, 8	U	
Hiptage benghalensis	1, 2, 3, 4, 5, 6, 7, 8	P, LD	
Lantana camara	1, 2, 4, (5), 6, 7, 8	P, LD	mid 19th century (1)
Leucaena leucocephala	1, 2, 4, 5, 6, (8)	P, LD, VF	1825 or before (1)
Ligustrum robustum* subsp. *walkeri	2, 3, 4, 5, 6, 7, 8	LD, U	1960s
Litsea glutinosa	1, 2, 6, 8	C, P, LD, LH, VF	19th century (1)
Prosopis juliflora	1, 3, 4, 8	C, LD, LH	1913 (1)
Psidium cattleianum	1, 2, 3, 4, 5, 6, 7, 8	P, LH, U, VF	1818 (1)
Rubus alceifolius	1, 2, 3, 4, 5, 6, 7, 8	P, R, LH, U, VF	mid 19th century (1)
Schinus terebinthifolius	1, 2, 5, 6, 8	C, P, LD, LH	mid 19th century (1)
Solanum mauritianum	1, 2, 3, 4, 5, 6, 7, 8	P, U	1825 or before (1)
Syzygium jambos	1, 2, 3, 4, 5, 6, 7, 8	P, R, LH	end 18th century (1)
Tibouchina viminea	1, 2, 3, 4, 6, 7, 8	U (disturbed)	
Ulex europaeus	1, 2, 3, 4, 5, 6, 7, 8	P, HH	1825 or before (1)

[a] 1: Lavergne (1978); 2: Macdonald *et al.* (1991); 3: Sigala (1999); 4: Lavergne (2000); 5: Cazanove (1999); 6: Strahm (1999); 7: Hivert (2003); 8: Interview during this study.
[b] C: Coastal habitat; HH: High-altitude heathland; LD: Lowland dry forest; LH: Lowland humid forest; P: Production land; R: Riverine forest; U: Upland forest; VF: Volcanic lava flows.

TABLE 2: NON-CONSENSUS INVASIVE WOODY PLANT SPECIES IN RÉUNION

Species	Reference[a]	Habitat[b]
Acacia mearnsii	3, 5, 6, 7	P, R, U
Boehmeria macrophylla	1, 2, 4	R, VF, U
Boehmeria penduliflora	1, 2, 4, 7	VF, U
Caesalpinia decapetala	5, 7	R
Casuarina glauca	1	U
Dichrostachys cinerea	3, 7	P, LD
Eucalyptus robusta	5	U
Eriobotrya japonica	1	U
Flacourtia indica	4	C, R, LD, LH
Fuchsia boliviana	1, 3, 4	U
Litsea monopetala	4	U
Pinus pinaster	1	U
Tecoma stans	7	R, LD
Trema orientalis	1, 7	LH, U
Ravenala madagascariensis	4, 7	R, U

[a] 1: Macdonald *et al.* (1991); 2: Lavergne (2000); 3: Cazanove (1999); 4: Strahm (1999); 5: Hivert (2003); 6: Tassin (2002); 7: Interview during this study.
[b] C: Coastal habitat; LD: Lowland dry forest; LH: Lowland humid forest; P: Production land; R: Riverine forest; U: Upland forest; VF: Volcanic lava flows.

2.2.2. Non-consensus woody species

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

2.2.3. Potentially invasive woody species

Potentially invasive species are known to be invasive elsewhere in the world and/or are showing strong tendencies to invade secondary or primary vegetation in Réunion (Meyer *et al.* submitted). This section presents a subset of the most important potentially invasive plant species in Réunion represented in a database currently in development (Lavergne *et al.* in prep. and Appendix 2). In total, more than 100 species are listed in the database at present. The database is based on transect surveys (470 transects with a total length of 47 km) conducted since 1998.

The species listed below are those judged by the database authors to pose greatest potential risk at the present time (more information on them is given in Appendix 2): *Acacia auriculiformis, Acacia dealbata, Acacia melanoxylon, Aleurites moluccana, Azadirachta indica, Chrysobalanus icaco, Cinnamomum camphora, Cyathea cooperi* (syn. *Sphaeropteris cooperi*), *Fraxinus floribunda, Gmelina arborea, Grevillea banksii, Ligustrum ovalifolium, Melaleuca quinquenervia, Melia azedarach, Parkinsonia aculeata, Pinus caribaea* subsp. *hondurensis, Psidium friedrichsthalianum, Samanea saman, Schefflera actinophylla, Spathodea campanulata, Swietenia mahogani* and *Tabebuia pallida.*

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 Réunion, especially in high-altitude shrub and heathland, in wetlands and as agricultural weeds.

- Grasses: *Anthoxanthum odoratum, Carex balfourii, Cortaderia selloana, Ehrharta stipoides, Holcus lanatus, Melinis minutiflora, Panicum maximum, Scirpus fluitans* and *Stenotaphrum dimidiatum.*

- Creepers: *Lonicera japonica, Merremia tuberosa, Antigonon leptopus* and *Cocculus orbiculatus.*

- Prostrate herbaceous species: *Duchesnea indica, Erigeron karwinskianus, Hypochaeris radicata* and *Polygonum capitatum.*

- Erect herbaceous species: *Ageratina riparia, Colocasia esculenta, Cuphea ignea, Furcraea foetida, Hedychium coccineum, Hedychium flavescens, Hedychium gardnerianum, Polygonum senegalense, Strobilanthes hamiltonianus, Verbascum thapsus* and *Zantedeschia aethiopica.*

- Ferns: *Nephrolepis biserrata* and *Pteridium aquilinum.*

- Aquatic plants: *Eichhornia crassipes, Pistia stratiotes* and *Ludwigia octovalvis.*

2.3. Degree of invasion

2.3.1. Coastal vegetation

The main invasive woody plant species in the coastal zone are *Casuarina equisetifolia, Prosopis juliflora* and *Schinus terebinthifolius* (especially along the east coast) and, to a lesser extent, *Litsea glutinosa.* In the coastal zone a climber (*Cocculus orbiculatus*), a grass (*Stenotaphrum dimidiatum*) and an aquatic plant (*Eichhornia crassipes*) are especially problematic.

2.3.2. Production land

Production land includes land under either agriculture or forestry.

The main woody weeds invading agricultural land and secondary plantation forests are *Acacia mearnsii, Clidemia hirta, Dichrostachys cinerea, Hiptage benghalensis, Lantana camara, Leucaena leucocephala, Litsea glutinosa, Psidium cattleianum, Rubus alceifolius, Schinus terebinthifolius* and *Syzygium jambos*. According to Cazanove (1999), *Rubus alceifolius* and *Acacia mearnsii* are the most problematic woody weeds in lowland pasture. In higher altitude pastures *Ulex europaeus* is an agricultural weed.

Problematic non-woody plant species include grasses, sedges, forbs and climbers. In Réunion, weeds constitute a major constraint to crop production (T. Le Bourgeois, personal communication).

CIRAD (Centre de coopération internationale en recherche agronomique pour le développement) and the Ministry of Agriculture produced an interactive CD-ROM to highlight the main agricultural weeds of Réunion (Le Bourgeois *et al.* 1999). A research programme conducted by CIRAD is ongoing to define weed communities according to the different cropping systems and ecological areas of Réunion (T. Le Bourgeois, personal communication).

2.3.3. Lowland semi-dry forest

The lowland semi-dry forests generally extend up to750 m asl but they occur at up to 1 200 m asl in the cirques. In the past, their vegetation included palm savanna and ebony forests (general information taken from Strasberg 1995 and Blanchard 2000). The remaining natural vegetation is estimated to occupy about one percent of the original area, mainly in a few remote dry ravines. Annual rainfall is below 1 500 mm, temperatures are high (18–24°C) and the vegetation experiences several months of drought each year.

The main invasive threat comes from the woody climber *Hiptage benghalensis.* Other woody plant species growing in lowland semi-dry forest include *Lantana camara, Leucaena leucocephala, Ligustrum robustum* subsp. *walkeri* and *Tecoma stans.* An important non-woody plant species is *Furcraea foetida.*

2.3.4. Lowland humid forest

The lowland humid forest, extending up to 1 100 m asl, was previously the habitat with the tallest trees (with heights of up to 10–20 m). Temperature and rainfall are high. The mean temperature is 17–24°C and the total annual rainfall is between 1 500 and 10 000 mm annually (general information taken from Strasberg 1995 and Blanchard 2000). The surviving natural vegetation is estimated to occupy some seven percent of the original area. The degree of invasion in lowland forests often exceeds 90 percent (D. Strasberg, personal comunication).

The main invasive woody plant species in this habitat are *Ardisia crenata, Clidemia hirta, Psidium cattleianum, Rubus alceifolius* and *Syzygium jambos.*

2.3.5. Upland humid and mountain forest

Upland humid and mountain forests lie between 1 000 and 2 000 m asl (general information taken from Strasberg 1995 and Blanchard 2000). They experience lower temperatures (14–17°C) and higher annual rainfall (2 000–8 000 mm). The tallest trees are between 6 and 10 m in height. Tree ferns, mosses and epiphytes are abundant (general information taken from Strasberg 1995 and Blanchard 2000). Surviving natural vegetation is estimated to occupy some 60 percent of the original area. According to Macdonald *et al.* (1991) the upland humid forests still consist of mainly native species. The degree of invasion in mountain forests is even lower.

The main invasive woody plant species are *Fuchsia magellanica, Fuchsia* × *exoniensis, Ligustrum robustum* subsp. *walkeri, Psidium cattleianum, Rubus alceifolius* and *Solanum mauritianum.* All species except *Rubus alceifolius* and *Solanum mauritianum* invade undisturbed forest. According to Cazanove (1999), *Ligustrum robustum* subsp. *walkeri, Rubus alceifolius,* and *Psidium cattleianum* are the most problematic species in upland humid

forests. *Psidium cattleianum* is the most problematic species in mountain forests (Macdonald *et al.* 1991).

The main invasive non-woody plant species are *Hedychium gardnerianum* and *Strobilanthes hamiltonianus.*

2.3.6. High-altitude shrub vegetation and heather formations

Above 2 000 m asl, the vegetation consists of low-stature (up to 4 m high) heather formations and shrub prairies. The mean temperature is below 10°C and the diversity of woody plant species is very low (general information taken from Strasberg 1995 and Blanchard 2000). Natural vegetation is estimated to occupy some 80 percent of the original area. The degree of invasion is low, but the principal invasive woody plant species is *Ulex europaeus.*

The main invasive non-woody plant species are *Anthoxanthum odoratum, Hypochaeris radicata, Holcus lanatus, Prunella vulgaris, Rumex acetosella* subsp. *angiocarpus* and *Verbascum thapsus.*

2.3.7. Pioneer vegetation on volcanic lava flows

Boehmeria penduliflora and *Casuarina equisetifolia* are the most prominent invasive species in the early successional stages on volcanic lava flows (Macdonald *et al.* 1991). On older flows *Psidium cattleianum, Rubus alceifolius* and, to a lesser degree, *Leucaena leucocephala* and *Litsea glutinosa* are also abundant. The relative abundance of exotic species is low in the early successional stages (importance value [abundance × frequency] of all exotic species on a young [1976] flow: 12.9) and increases with the age of the volcanic flow (importance value on an old [1890] flow: 74.3) (Macdonald *et al.* 1991). This trend may be the result of harsher conditions in early successional stages (Macdonald *et al.* 1991) or because early successional species are mainly wind-dispersed while late successional species are bird-dispersed (Strasberg 1995).

3. ENVIRONMENTAL AND ECONOMIC IMPACTS

The negative environmental and economic impacts of invasive species in Réunion 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 at the ecosystem level are sometimes called 'transformer species' (see Richardson *et al.* 2000). Invasive species can interfere with the natural disturbance regime (fires, floods, water dynamics of coast and rivers, erosion, forest gap dynamics), or alter the conditions in the ecosystem (availability of light, water, nutrients).

Changes to the natural disturbance regime:

- Some Poaceae, such as *Aristida setacea, Heteropogon contortus, Melinis minutiflora* and *Themeda quadrivalvis,* and the fern *Pteridium aquilinum* increase the abundance of dry plant material especially in anthropogenic dry savanna habitats and therefore increase the risk of fires.

- The creeper *Rubus alceifolius* increases the frequency of gap formation (Macdonald *et al.* 1991). Trees overgrown with *R. alceifolius* are more easily hit by cyclones. Open forest gaps provide ideal conditions for secondary invasions of many exotic species (see for instance Strasberg 1995).

- Exotic plant species are often less adapted to the wind and heavy rain associated with cyclones than Réunion's native flora. Thus, frequency of forest gaps and erosion along steep slopes increases with relative abundance of exotic species (Macdonald *et al.* 1991).

Change of conditions:

- *Boehmeria penduliflora* and especially *Casuarina equisetifolia* grow on volcanic lava flows and interrupt natural succession (Macdonald *et al.* 1991).

- *Casuarina equisetifolia* increases nitrogen levels in the soil of volcanic lava flows.

- *Acacia mearnsii* is thought to reduce water flow in rivers at higher altitudes in Réunion.

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:

- The most pronounced impact of invasive woody plant species in Réunion is the prevention of the regeneration of native species (see for instance Macdonald *et al*. 1991; Gigord *et al*. 1999; Lavergne *et al*. 1999). Competition from exotic species is especially problematic with species capable of invading rare relict habitats such as semi-dry ravines or mountain forests (see Section 2.3. Degree of invasion) (Macdonald *et al.* 1991).

- Many invasive species form thickets or monospecific stands; for instance, *Casuarina equisetifolia, Clidemia hirta, Dichrostachys cinerea, Fuchsia magellanica, Fuchsia* × *exoniensis, Ligustrum robustum* subsp. *walkeri, Psidium cattleianum, Rubus alceifolius, Syzygium jambos* and *Tibouchina viminea.*

- *Syzygium jambos* has been reported to exhibit allelopathic effects. It has also been suggested that *Ligustrum robustum* subsp. *walkeri* has allelopathic properties (Lavergne *et al.* 1999).

- Some exotic species are thought to compete specifically with native species that occupy a similar niche. For instance, *Boehmeria macrophylla* may compete with the endemic *Boehmeria stipularis* in montane valleys.

Interactions between different trophic levels:

- An increase in the population density of some exotic frugivorous birds (*Acridotheres tristis, Pycnonotus jocosus*) can be anticipated because of the profusion of exotic fruit (from *Ligustrum robustum* subsp. *walkeri, Clidemia hirta, Psidium cattleianum, Rubus alceifolius, Solanum mauritianum, Lantana camara, Ardisia crenata, Schinus terebinthifolius*). As a consequence, there may be increased competition between *Pycnonotus jocosus* and the endemic bulbul *Hypsipetes borbonicus*.

3.3. Genetic effects

No genetic impacts (hybridization) from invasive plant species have been recorded for Réunion. Nonetheless, *Rubus alceifolius* has probably hybridized with the native species *Rubus roridus* in Madagascar (see Section 7.1. Case Study: *Rubus alceifolius*). Congeneric pairs of exotic and native species do exist in Réunion, for instance in the genera *Syzygium* and *Boehmeria*, thus the risk of genetic impact exists. Forestry workers of ONF–Réunion observed a probable hybrid between *Acacia heterophylla* and *Acacia melanoxylon* in Palmiste (Petite France) (J. Hivert, personal communication).

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.

- Many invasive woody plant species are also agricultural weeds (see Section 2.3. Degree of invasion).

- The leaves and fruits of *Ligustrum robustum* subsp. *walkeri* are poisonous to animals and humans.

4. CONTROL MEASURES AND HABITAT RESTORATION

4.1. Control measures

4.1.1. Biological control

Two biological control research projects started in 1997, one conducted by CIRAD (against *Rubus alceifolius*) and the other by CABI Bioscience (against *Ligustrum robustum* subsp. *walkeri*) (see Section 7.1. Case Study: *Rubus alceifolius* and Section 7.2. Case Study: *Ligustrum robustum* subsp. *walkeri*). They were each planned as five-year initiatives and both cost in total some €380 000.

4.1.2 Mechanical and chemical control

Mechanical and chemical control of invasive plant species in Réunion has so far mainly been conducted by ONF–Réunion. Recently, a study was conducted to collate and assess past efforts (see Box 1: Invasive plant species control methods – experiences of the Office national des forêts of Réunion).

A research project is underway to study the impact of mechanical control measures on native biodiversity (see Box 2: The INVABIO research project in Réunion).

BOX 1: INVASIVE PLANT SPECIES CONTROL METHODS – EXPERIENCES OF THE OFFICE NATIONAL DES FORÊTS, RÉUNION
Including Table 3
By Jean Hivert, ONF–Réunion

The Office national des forêts (Forest Service), Réunion (ONF–Réunion), the principal agency for the management of natural habitats in the territory, started their first attempts to control invasive species in the 1980s. From September 2002 to May 2003, a study was conducted with the financial support of the regional council (Conseil régional de la Réunion) and the European Union to collate information on, categorize and assess the different control methods used so far (Hivert 2003). This approach proved to be necessary because of the multitude of actors involved in past control projects and missing documentation from the projects. This box summarizes the results of the survey.
A survey was undertaken by conducting interviews with 32 people in charge of the regional sections of ONF–Réunion, and by visiting 100 field sites. The control projects were documented and assessed according to the following scheme.
Characterization of the site:

- Habitat type (i) natural habitats with minor anthropogenic interference (primary habitats), (ii) production forests (plantations) and (iii) degraded habitats (secondary habitats)
- Altitude
- Description (slope, accessibility, canopy openness, vegetation density)

Description of the applied method:

- Surface of treated area
- Treatment season
- Treatment frequency
- Type of labour
- Total person-days
- Mechanical:
  - Tools used (e.g. machete, chain saw, bush cutter; hoe, bulldozer)
  - Disposal of removed plant material (e.g. burning, compost, pile)
- Chemical:
  - Herbicide product
  - Dosage
  - Method of application
- Post-treatment measures (e.g. monitoring, replanting scheme)

Assessment of the effectiveness of the control method
Effectiveness of control was estimated by making a site visit, generally less than a year after the treatment was implemented. Thus any regrowth of the treated invasive species could be recorded. It was not possible to assess the long-term effects of the different methods. The assessment did not evaluate the costs and the negative impact on the ecosystem. However, in line with the precautionary principle, it was assumed that all chemical control methods carry a risk of polluting and disturbing the habitat. Methods that used phytocides were therefore rated separately. The assessment of the method's success involved assigning it to one of the following six categories:

A. Effective, to be implemented
B. Reasonably effective, to be improved
C. Ineffective, to be abandoned
a. Effective, involving chemical control, to be implemented
b. Reasonably effective, involving chemical control, to be improved
c. Ineffective, involving chemical control, to be abandoned

BOX 1 (CONT.): INVASIVE PLANT SPECIES CONTROL METHODS – EXPERIENCES OF THE OFFICE NATIONAL DES FORÊTS, RÉUNION

Table 3 summarizes the results of the assessment. The control measures of ONF–Réunion concerned 23 invasive species; 11 (47 percent) mentioned by Lavergne (1978) and 15 (65 percent) mentioned by Macdonald *et al*. (1991). The sites were in either primary habitats (41 percent) or secondary habitats, including forest plantations (59 percent). Control measures were common for some species (*Rubus alceifolius, Hedychium* spp., *Solanum mauritianum, Lantana camara, Fuchsia* spp.) while occasional for others (i.e. only one site; *Caesalpinia decapetala, Eucalyptus robusta, Tibouchina viminea*).
In total, 61 different methods have been applied, including solely mechanical (27, 44 percent), solely chemical (7, 12 percent) and combined mechanical and chemical interventions (27, 44 percent). Even for a single species the methods used differed widely. It was rare for the same method to have been used at more than one site. This suggests that internal communication between the different units of ONF–Réunion as well as links with experts living in Réunion and other Indian Ocean small island countries and territories were inadequate. Nine herbicides were used. The most frequently used products were: Garlon (triclopyr), Roundup (glyphosate), Krénite (fosamine-ammonium) and Missile (glyphosate). Between 4 and 250 person-days were used per hectare depending on the control method. In general chemical methods were the least labour intensive. The best season for the conduct of a control attempt was shortly before fruiting began.
The assessment of the methods shows that an effective method (category A or a) exists for 16 of the 23 invasive species included in the survey. These species seem in principle to be manageable with methods already used by ONF–Réunion. However, in some cases the costs are very high.
Among the assessed methods, 46 percent (28) were found to be effective (category A or a); nine of these were solely mechanical methods (category A), and 19 involved chemical control. Twenty-three percent (14) were rated as reasonably effective (category B or b), with six of these involving chemical control. Finally, 31 percent (19) were rated as ineffective, nine of which involved chemical control; these 19 methods should be abandoned.
In the case of some species, such as *Clidemia hirta, Hiptage benghalensis* and *Syzygium jambos,* control measures proved to be difficult (no existing method was rated as A or a). For *Caesalpinia decapetala*, *Eucalyptus robusta* and *Psidium cattleianum,* only ineffective methods were found (Category C or c). New experiments testing alternative methods are urgently needed for these species.

Conclusions

- The survey showed that for some species there are effective control methods, and that awareness of the invasive species problem is high within ONF–Réunion.
- ONF–Réunion needs a global invasive species management strategy:
  - Large-scale efforts should be concentrated on the species for which an effective method is available
  - For the other species new experimental trials of alternative methods should be set up
  - A global strategy should also include spatial planning to define priority zones for the control of invasive species
- As control of invasive species proved to be very expensive, ONF–Réunion established an early detection system for new invasive species. Based on a simple field protocol, the employees of ONF–Réunion report all exotic species that they have not observed in the field previously.
- Finally, given the wealth of new information that this survey produced for Réunion, repeating this approach in other small islands of the Indian Ocean has potential.

TABLE 3: INVASIVE SPECIES CONTROL METHODS APPLIED BY ONF-RÉUNION
List of treated species, number of sites per habitat type and assessment of control methods. Shading indicates species for which ONF–Réunion has an effective control method.

Plant habit	Species name[a]	No. of sites per habitat type				No. of control methods per category			
		Primary habitat	Plantation	Secondary habitat	Total	A/a	B/b	C/c	Total
Herbaceous	*Digitaria radicosa* *Panicum maximum* *Paspalum paniculatum*	0	4	1	5	1/3	0/0	1/0	5
	Hedychium gardnerianum (1, 2) *Hedychium flavescens* (1, 2)	5	5	2	12	1/0	2/0	1/2	6
	Strobilanthes hamiltonianus	1	2	0	3	0/0	0/0	1/2	3
Agave	*Agave vera-cruz* *Furcraea foetida* (1, 2)	1	2	1	4	1/0	1/0	0/0	2
Woody climber	*Hiptage benghalensis* (1, 2)	3	0	0	3	0/0	1/0	0/1	2
Shrub	*Caesalpinia decapetala* (2)	0	0	1	1	0/0	0/0	1/0	1
	Clidemia hirta (2)	0	2	0	2	0/0	0/1	1/0	2
	Fuchsia magellanica (2) *Fuchsia × exoniensis*	6	1	0	7	1/2	0/0	1/1	5
	Lantana camara (1, 2)	3	3	3	9	1/1	0/0	1/0	3
	Ligustrum robustum subsp. *walkeri* (2)	1	3	0	4	0/2	1/1	0/0	4
	Rubus alceifolius (1, 2)	11	10	6	27	2/5	2/2	1/1	13
	Solanum mauritianum (1, 2)	3	2	4	9	0/4	1/0	1/0	6
	Tibouchina viminea (1, 2)	1	0	0	1	0/1	0/0	0/0	1
	Ulex europaeus (1)	2	0	1	3	1/1	0/0	0/0	2
Small tree	*Psidium cattleianum* (1, 2)	2	2	0	4	0/0	0/0	1/1	2
Tree	*Acacia mearnsii* (2)	0	3	0	3	1/0	0/1	0/0	2
	Eucalyptus robusta	0	1	0	1	0/0	0/0	0/1	1
	Syzygium jambos (1, 2)	2	0	0	2	0/0	0/1	0/0	1
Total		**41**	**40**	**19**	**100**	**9/19**	**8/6**	**10/9**	**61**

[a] 1: Species cited by Lavergne (1978); 2: Species cited by MacDonald *et al.* (1991).

BOX 2: THE INVABIO RESEARCH PROJECT IN RÉUNION

The national biological invasions research programme 'INVABIO' was launched in 2000 by the French Ministry of Environment and Sustainable Development (Ministère de l'écologie et du développement durable). Within this framework, in 2002 the University of Réunion and the National Herbarium (Conservatoire botanique national de Mascarin) started a three-year research project entitled 'Invasions by exotic plants in an oceanic island: ecological impact and heritage value of the invaded native ecosystems of La Réunion island'. The project's main objective is to determine the impact of mechanical control methods on native biodiversity and community dynamics.

Survey of a past eradication project

In 2000–2001, the exotic species *Hedychium gardnerianum* (Zingiberaceae) (wild ginger) was eradicated in an intermediate-altitude humid forest (Les Makes Biological Reserve) by ONF–Réunion. In 2002, woody and herbaceous plant and soil invertebrate abundances were measured in 100 1-m^2 quadrats (50 where *H. gardnerianum* had been eradicated [eradication treatment], 50 where it had not [control treatment]). Photosynthetically active radiation was measured simultaneously below and above the layer of *H. gardnerianum* leaves, and compared with the forest canopy layer. The soil seed bank was monitored.

Preliminary results:

- The absolute abundance (number of individuals) of native graminids (Poaceae and Cyperaceae) and exotic species was higher where *H. gardnerianum* had been eradicated.
- Species richness (number of species) was greater in the eradication treatment. Native pioneer species were markedly more abundant (i.e. *Aphloia theiformis*, *Claoxylon* spp., *Dombeya* spp., *Phyllanthus phillyreaefolius*) than in the non-treated areas.
- Human intervention induced an increase in both indigenous and exotic species numbers, but led, in particular, to an increase in the abundance of exotic species (i.e. *Ardisia crenata*, *Litsea glutinosa*, *Psidium cattleianum*, *Solanum mauritianum*, *Boehmeria macrophylla*, *Duchesnea indica*, *Geranium robertianum*) relative to the native species.
- In the soil seed bank, seeds of exotic species were more numerous in the eradication treatment than in the control.
- Crustacea (arthropods) and molluscs (gastropods) represented more than 80 percent of the total soil invertebrate macrofauna in both treatments.
- The foliage of *Hedychium gardnerianum* absorbed 85–95 percent of the light that reached the understorey, thus reducing light available for seedling regrowth to less than one-sixth of the level in the absence of *H. gardnerianum*.

Experimental study

An experiment was begun in early 2003. It was hypothesized that mechanical eradication of *H. gardnerianum* has two main impacts: (i) an increase in light availability on the forest floor (through cutting the stems) and (ii) soil disturbance (through pulling up rhizomes). In order to separate the impact of these two disturbances, four different treatments are being applied (with three replicates per treatment; 200 m^2 plots; 12 plots):

1. Total eradication → light increased and soil disturbed.
2. Stem cutting only → light increased and soil undisturbed.
3. Total eradication + induced shade → shaded and soil disturbed.
4. Control → shaded and soil undisturbed.

BOX 2 (CONT.): THE INVABIO RESEARCH PROJECT IN RÉUNION

The following measurements are being taken in all four treatments:

- Abundance of woody plant seedlings, herbaceous plants and molluscs
- Mortality of native woody plant seedlings
- Growth rates of two dominant native understorey species (*Chassalia corallioides, Gaertnera vaginata*)
- Photosynthetically active radiation at ground level and above the *H. gardnerianum* foliage
- Humidity and temperature of the air above and below the *H. gardnerianum* foliage, and of the topsoil
- Litter decomposition rate

In addition, germination experiments are being conducted with two exotic species (*Ardisia crenata*, *Hedychium gardnerianum*), and three native species (*Aphloia theiformis*, *Gaertnera vaginata*, *Geniostoma borbonicum*).
The results of this research project will be available in 2004.

4.2. Restoration activities

All habitat restoration so far has been undertaken by ONF–Réunion. Forty-one percent of the invasive species control efforts of ONF–Réunion have been targeted at primary habitats (see Box 1: Invasive plant species control methods – experiences of the Office national des forêts of Réunion. Sigala (1999) stated that restoration is easiest where soils are fertile because of faster regrowth of replanted native tree species. In infertile soils reinvasion exceeds growth of replanted native species. Mean total costs per hectare for restoration in lowland humid forest were estimated at €46 000, compared with €24 000 in lowland dry forest (Sigala 1999).

So far no prioritization of areas for habitat restoration has been implemented. The University of Réunion is currently planning a research project on spatial modelling of invasion processes and management planning (D. Strasberg, personal communication).

The proposed national park, Parc national des hauts de la Réunion, would, based on the biosphere concept of UNESCO (United Nations Educational, Scientific and Cultural Organization), include almost all areas relevant to nature conservation in Réunion. A future national park administration could act as a coordinating agency for habitat restoration.

5. AWARENESS AND CONFLICTS OF INTEREST

5.1. Awareness

The term ‘invasion’ (‘envahissement’) was already being used for *Rubus alceifolius* by the end of the nineteenth century (de Cordemoy 1892). Since then, *R. alceifolius* has been the plant for which public awareness of its negative impact has been highest.

Scientific interest emerged in the 1970s (Cadet 1974, Lavergne 1978). Until the beginning of the 1980s, however, ONF–Réunion was not aware of the invasive species problem (Macdonald *et al.* 1991). In 1989 a strategy for the management of invasive plant species in Réunion was proposed (Macdonald 1989), which triggered the ONF–Réunion invasive species control programme (Hivert 2003), and several Ph.D. research projects (Strasberg 1994; Radjassegarane 1999; Amsellem 2000; Lavergne 2000; Baret 2002; Tassin 2002).

Public awareness of the invasive species issue in Réunion is considered to be low. There has been no major public awareness building campaign, although in 1995 ONF–Réunion and the Ministry of Environment (Direction régionale de l'environnement – DIREN) produced a poster and a flyer (*Belles, mais …envahissantes*) on problematic invasive species. There were also several newspaper articles, TV transmissions and public talks concerning the topic.

A recent campaign by a local NGO (SREPEN, Société réunionnaise pour l'étude et la protection de l'environnement) focused on the exotic tree fern *Cythea cooperi* (syn. *Sphaeropteris cooperi*).

There has been an initiative to involve horticulturalists within the framework of the annual national floricultural contest, 'Concours départemental des villes et villages fleuris de France'.

Among experts, awareness of the invasive species problem is high. Since 2000 there have been several roundtable discussions with local and international experts where the management of invasive species has been discussed. DIREN intends to assemble a local committee on invasive species (Biological Invasions Committee of Réunion) with the aim of defining a national invasive species management strategy. This committee is being created:

- To exchange technical and scientific research experiences
- To define and diffuse best practices in integrated control
- To monitor invasions in natural environments in order to prevent proliferation
- To develop legislative tools to control and prevent invasions

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 prominent conflict of interest concerns *Psidium cattleianum*. Its fruit are at the centre of an annual local feast, the 'Fête du Goyavier', and are also a local agricultural product. Research was conducted by CIRAD to model the growth of *P. cattleianum* to optimize fruit production (Normand 2002).

- Many invasive or potentially invasive woody plant species, especially new introductions, are ornamentals; for instance: *Ardisia crenata, Fuchsia* spp., *Lantana camara, Ligustrum robustum* subsp. *walkeri, Ravenala madagascariensis, Tecoma stans* and *Tibouchina viminea*. The flowering of *Ulex europaeus* in the high-altitude prairies is an attractive landscape feature for tourists.

- Many invasive or potentially invasive species were and still are planted as forestry trees (compare Tassin and Riviere 2001 and Section 2.2. Invasiveness).

- *Casuarina equisetifolia* and *Casuarina glauca* are used to counter erosion and to stabilize coastlines. Many steep slopes are vegetated solely by exotic species (e.g. *Lantana camara, Leucaena leucocephala*), which at the moment provide the only erosion control in these sites.

- The fruits of *Schinus terebinthifolius* are exported. *Schinus terebinthifolius* is also thought to be an important melliferous plant.

- The native avifauna seems to have adapted rather well to exotic and secondary forest vegetation (Cheke 1987).

6. LEGISLATIVE FRAMEWORK TO CONTROL INVASIVE WOODY PLANT SPECIES

As an overseas territory of France, French and ultimately European Union legislation applies in Réunion. However, because invasive plant species are less problematic in Europe, developing laws specifically for the management of invasive plant species is difficult. Border control and restrictions on importing plant material are especially problematic to apply because of the high priority that free trade is given in European and international legislation, and because of the open border policy within the European Union.

In Réunion, there is no legislation specifically designed for the management of invasive plant species. Existing relevant legislation deals with phytosanitary measures. Import of plant material is regulated in two different acts. A prefectorial act from 1991 regulates imports by private individuals (this act will be revised in 2003 or 2004.) Currently, private individuals are prohibited from importing plant material. Importation of seeds is not restricted for private individuals from the European Union and is allowed from other countries so long as the individual has a phytosanitary passport. A national act from 1992 regulates commercial imports of plant material. For all such imports, authorization needs to be obtained from the Plant Protection Unit of the Ministry of Agriculture (Service de protection des végétaux [SPV] de la Direction de l'agriculture et de la forêt [DAF]). The act includes a list of pests and weeds for which importation is prohibited; these are mainly agricultural pests. According to a revised version of this law, from 2000 an import permit can be denied if, based on a phytosanitary risk assessment, a negative economic impact on production in agriculture or forestry can be predicted. A European Union act (Directive 2000/29/Ce) also regulates commercial imports, and this is mirrored in national legislation (Arrêté du 02/09/93 modifié).

Any import of soil is forbidden by international law.

Another national law states that control measures are obligatory for a list of agricultural pests and weeds. The control programmes can be delegated to a union of agriculturalists (Fédération des groupements de défense contre les organismes nuisibles, FDGDON).

SPV employs two controllers at the airport and another two at the marine port. Thus, means to apply border regulations are limited.

7. CASE STUDIES

7.1. Case Study: *Rubus alceifolius*

By Stéphane Baret, University of Réunion and Thomas Le Bourgeois, CIRAD Réunion

7.1.1. Natural distribution

Rubus alceifolius (Rosaceae) (raisin marron or giant bramble) is of South East Asian origin. It is native to Burma, Thailand, Laos, Vietnam, Cambodia, southeastern China, Taiwan, Indonesia and Malaysia. It grows under subtropical and tropical conditions. According to Van Thuan (1968) there are several distinct ecotypes: a form with large leaves (native to Java), a form with small leaves (northern Vietnam), and a form with hairy leaves (Thailand, Laos).

In its native range, it grows mainly in forest openings, along paths and rivers and in disturbed areas from low to high altitudes (essentially between 300 and 1 400 m asl). In dense primary forest, it generally grows after fire.

7.1.2. Biology of Rubus alceifolius

Within the genus *Rubus* there are at least eight species capable of invading natural habitats (Daehler 1998): *R. alceifolius, R. argutus, R. cuneifolius, R. discolor, R. ellipticus, R. fruticosus, R. moluccanus* and *R. inermis* (syn. *R. ulmifolius*). Characteristics that lead to the effective invasiveness of the genus are the rates of asexual vegetative and apomictic reproduction (Nybom 1988, 1995; Thompson 1997), high resistance to cutting, uprooting and herbicide application (Amor 1973; 1974, 1975), and efficient dispersal rates of the fruit by frugivores (Jordano 1982; Thompson 1997; Kollmann *et al.* 2000).

Rubus alceifolius has a plant habit midway between a bush and a woody climber (Baret *et al.* 2003), with various propagation strategies (seeds, tip rooting or terrestrial layering, cuttings), a short juvenile period, regular and abundant fruit and seed production (in the lowlands only), strong vegetative growth and wide phenotypic plasticity; these properties allow it to colonize disturbed native habitats rapidly. A key aspect of the development of this species is its growth strategy, which changes with elevation. Below 1 100 m asl, *R. alceifolius* can spread by sexual reproduction (generating a large seed bank) and vegetative multiplication, while above 1 100 m it spreads by vegetative means only (Baret 2002).

Rubus alceifolius has been shown to be tetraploid in its area of origin as well as in Réunion. A single triploid individual has been analysed from Vietnam (Amsellem *et al.* 2001a). There is evidence of a switch from sexual reproduction to apomixis between the native and the introduced range. It has been suggested that the Madagascan populations are the result of hybridization of introduced *R. alceifolius* and native populations of *R. roridus,* a closely related species, and that apomixis was a consequence of this hybridization (Amsellem *et al.* 2001b).

Rubus alceifolius fruits for up to three months per year. It is pollinated by only a small number of pollinators, among them the honey bee (*Apis mellifera*), a wasp (*Polistes hebraeus*) and an endemic bird (the white-eye *Zosterops olivaceus*). The fruit are dispersed by three bird species (*Z. olivaceus*, the exotic Indian mynah *Acridotheres tristis* and the exotic red-whiskered bulbul *Pycnonotus jocosus*) (Thébaud 1989; Mandon-Dalger 2002). The seeds are preferentially dispersed to open habitats, which are particularly suitable for *R. alceifolius.* (Thébaud 1989). *Rubus alceifolius* forms large seed banks (a seed longevity of ten years has been estimated for the genus *Rubus*; see Marks 1983).

Baret (2002) identified phenotypic plasticity, growth rate, seed bank, and vegetative growth as the most important contributory factors in the invasiveness of *R. alceifolius*.

7.1.3. Introduction to Réunion

Rubus alceifolius was introduced to Réunion around 1845 (de Cordemoy 1892). It seems that it had already become invasive by the end of the nineteenth century. In the Indian Ocean region, *R. alceifolius* was probably first introduced to Madagascar, although there were several independent introductions. It may have been introduced to Madagascar from Java or Thailand (Amsellem *et al.* 2000). Estimates of dates for the introduction of *R. alceifolius* to Madagascar vary between some centuries (Owadally 1960; Rivals 1960) and some thousand years (Wigboldus 1994) ago. From Madagascar *R. alceifolius* was introduced to Réunion, Mauritius and Mayotte (Kalkmann 1993). The population in each of these countries is clonal, i.e. consists of a single genotype (Amsellem *et al.* 2000). From one of the Indian Ocean small islands, the species spread to Queensland (Australia).

7.1.4. Economic importance

Rubus alceifolius is of no economic importance in Réunion. The red fruit can be eaten and used for making jam. In Sumatra the young leaves are eaten. The plant is rich in tannins. It is used as a medicinal plant against fever and inflammation (Lavergne 1978). In Malaysia a tea of the roots is used to treat dysentery (Kalkmann 1993).

7.1.5. Distribution and extent of the invasion by Rubus alceifolius *in Réunion*

Rubus alceifolius is one of the most abundant invasive species in Réunion. It invades all open habitats that are sufficiently humid. It is especially abundant in forest openings (trails, gaps, deforested areas), along rivers and along the edges of humid forests. It is also a pioneer species of boulder fields and volcanic lava flows. In the drier western part of the island it appears above 500 m asl in ravines and climbs up to 1 700 m asl. In the eastern part it occurs from sea level to 1 600 m asl.

7.1.6. Mechanical and chemical control

Rubus alceifolius has the longest history of management (15 years) and is the most widely managed (c. 240 ha) of any invasive species tackled by ONF–Réunion. It has been targeted on 27 sites at altitudes ranging from 50 to 1 600 m asl (Hivert 2003).

An efficient control method without negative impacts, according to Hivert (2003), is to cut the stems with a machete and then remove the root stumps of all the plants. The plant material is piled up and sometimes disposed of by burning (Hivert 2003). Mechanical removal and burning takes between 120 and 150 person-days per hectare, while mechanical removal alone takes between 60 and 80 person-days per hectare. Recently, trials were begun to evaluate chaffing the uprooted and cut plant material with a machine. Cutting the stems without removing the plant material proved to be ineffective. Methods where the cut stems were treated with a herbicide were rated as quite effective but carried the risk of polluting the environment (Hivert 2003).

For one area (Bélouve/Bébour) control was completely successful; 30 years ago the area was dominated by *R. alceifolius* yet it is now almost completely free of it.

7.1.7. Biological control

A biological control research programme was launched in 1996 by the regional council (Conseil régional de la Réunion), with the support of ONF–Réunion, the French Ministry of Environment and Sustainable Development (Ministère de l'écologie et du développement durable) and the European Union. The costs of the five-year project are €500 000. The work started in 1997 with the assistance of the CIRAD and the University of Réunion. During several missions in Southeast Asia (Thailand, Vietnam, Laos, Indonesia, China), a large number of insects and pathogens of 22 *Rubus* species was collected (Le Bourgeois 1998, 2000, 2001). Among the three plant pathogen species collected, only one species, the rust fungus *Hamaspora acutissima*, seemed promising. Studies conducted on this rust showed that it was too specific to Asian *Rubus* species, however, and not effective against the *Rubus alceifolius* from Réunion. A total of 38 insect species were collected and the four more promising ones progressed through biological studies and host specificity tests (CABI Bioscience 1999). From these, the argid sawfly *Cibdela janthiana* has been selected as a potential biological control agent. Before releasing *C. janthiana* in Réunion, studies are focused on complementary tests in quarantine in Réunion.

7.1.8. Conclusions

- The results of this study show that open canopy (gaps**,** wide forest trails, reforested areas) favours the germination and/or vegetative growth of *R. alceifolius*. Therefore, it seems most promising to manage the habitats in such a way that the frequency of open canopies is reduced.

- Conventional weed control strategies are not applicable on an island-wide scale to eradicate *R. alceifolius* because of the enormous area and broad range of habitats already colonized by this species.

- The study shows that the invasive strategy of *R. alceifolius* varies according to the environment (seed reserves in the soil *vs.* vegetative growth). It is unlikely that a pathogen or insect will be found in the near future that can both reduce seed reserves in the soil and hamper the growth of the weed. Moreover, such a control agent will have to be able to survive and reproduce in ecologically varying habitats. Therefore a combination of several biological control agents will probably be needed.

- In contrast, mechanical and chemical methods have been found, in Réunion, to be efficient for controlling this weed on small surface areas (Hivert 2003).

- In summary, successful control of *R. alceifolius* in Réunion should be based on a combination of mechanical, chemical and biological methods and habitat management.

7.2. Case Study: *Ligustrum robustum* subsp. *walkeri*

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7.2.1. Natural distribution

Ligustrum robustum (Oleaceae) is a privet native to India, Bengal, Bangladesh, China, Burma, Cambodia, Laos, Myanmar, Thailand and Vietnam (Green 1995). The native range of the subspecies *Ligustrum robustum* subsp. *walkeri* (Sri Lankan privet, troène de Ceylan) is restricted to the south of India and to Sri Lanka. In India, the species occurs in wet, montane regions up to 1 500 m asl. In Sri Lanka it can be found in submontane forests, often near streams, at altitudes between 450 and 2 000 m asl (Green 1985, 1987).

Recent studies based on morphology and DNA analyses show that populations of *L. robustum* subsp. *walkeri* from South India and Sri Lanka are taxonomically distinct (CABI Bioscience 1998; Shaw and Milne 1999; Lavergne 2000). Based on further studies these two regional varieties may be considered as two different species (P. S. Green, personal communication, 1998).

Ligustrum robustum subsp. *walkeri* is a post-pioneer species, i.e. it prefers marginal habitats. In secondary vegetation, it grows along roads and paths, and next to crop plantations and habitation. In submontane native forest, it is found mainly along forest edges, along streams, in gullies and on steep slopes.

7.2.2. Biology

A combination of biological and ecological characteristics has led to the rapid range expansion of *L. robustum* subsp. *walkeri* in Réunion (Lavergne 2000).

- Both sexual and vegetative regeneration is vigorous. One hundred percent of individuals coppice naturally from cut stumps. A germination rate of 100 percent is obtained under laboratory conditions. In a closed-canopy forest germination reaches 40 percent.

- The rapid spread of the population is closely linked to heavy and continuous fruit production. Each shoot can produce up to 9 000 fruit over nine months of the year. Reproductive maturity is reached after a minimum of two years in open areas and in 4-5 years in closed-canopy forest.

- The fruit (a berry-like drupe) is dispersed by gravity in the vicinity of the parent plant and by frugivorous birds over a distance of more than 1 km. The red-whiskered bulbul *Pycnonotus jocosus* and the endemic bulbul *Hypsipetes borbonicus* disperse the fruit in human-disturbed habitats and in native forest, respectively.

- The self-compatibility of the breeding system allows for the establishment of new populations from only one founder individual. However, the species can also be pollinated by insects (honeybees) which are attracted by the strongly perfumed flowers.

- *Ligustrum robustum* subsp. *walkeri* growth is not seasonal. The annual height growth rate of the seedlings of 17.2 percent is considerable more than that of typical woody native species (8.9–13.8 percent) (Lavergne *et al.* 1999).

- The seedlings often form a dense carpet-like seedling bank.

- It is a very shade-tolerant invader, i.e. it can form dense stands made up of different growth stages under a closed canopy. It is hemi-sciaphilous, i.e. it prefers shady sites in small gaps or forest margins in its primary life stage but grows up into the canopy layer as a mature plant.

- Its dense foliage leads to very low light levels in the understorey, reducing the growth and regeneration of the light-demanding native species.

- There may be a direct impact on the regeneration of native species from the allelopathic effects of its leaves and fruit.

7.2.3. Introduction to Réunion

The first introduction of *L. robustum* subsp. *walkeri* to Réunion was from Mauritius to Cilaos village as a hedge plant in the 1960s. It was naturalized in the Forêt du Grand Matarum in 1975 (a voucher specimen collected from there by Cadet is deposited as No. 4955 in the National Herbarium, Conservatoire Botanique National de Mascarin). The plant was also introduced during the same period to the Salazie region (Hell-Bourg and Ilet à Vidot). *Ligustrum robustum* subsp. *walkeri* has escaped from gardens and has severely infested wastelands and firmly established itself along drainage banks and path and road verges, on landslides, in secondary forests and *Cryptomeria japonica* plantations and, recently, also in undisturbed native forest.

7.2.4. Distribution and extent of the invasion

The invasion in Réunion is still in an early stage. MacDonald *et al*. (1991) observed in 1989 that *L. robustum* subsp. *walkeri* had been invading *C. japonica* plantations near Cilaos village for at least the previous 20 years. It had also been invading a disturbed patch of native forest on the Piton des Neiges slopes for approximately ten years.

The latest field surveys indicate that the plant is still spreading (Lavergne 1995). Very high-density infestations have been observed above Cilaos village at 1 300–1 400 m asl in a human-disturbed native forest. Some mature plants are established up to 1 km from the village and seedlings are commonly found in intact forest up to 1 700 m asl on the Piton des Neiges slopes. Thus, the boundaries of invasion have shifted by 300 m in altitude in six years (1989–1995).

In 1995, the infestation covered more than 3 000 ha between 550 and 1 700 m asl, including approximately 450 ha of undisturbed native vegetation. Small populations have been discovered at Col de Bellevue (on Route Nationale 3, 1 600 m asl) and on Les Makes road (at Pente Tunnel, 600 m asl).

Easily propagated from cuttings, it continues to be used as a hedge plant in Cilaos and Salazie gardens and along paths.

7.2.5. Economic importance

The plant is used for medicinal purposes in China. A tea from the leaves is said to cure headaches, among other ills (CABI Bioscience 2000). The Tea Research Institute at Mei Tang (Guizhou Province) is actively researching the propagation of this plant as a crop. Local people from Réunion could produce dried leaves for export.

In Réunion itself, *L. robustum* subsp. *walkeri* has no real economic importance except as an ornamental hedge plant.

7.2.6. Mechanical/chemical control

ONF–Réunion has been carrying out mechanical/chemical control against *L. robustum* subsp. *walkeri* since 1989. Several hundred hectares are treated each year on the Piton des Neiges slopes and in the secondary forests of the Cirque de Salazie. Various herbicides and application techniques were assessed in a trial in 1996 (Médoc 1997). The most effective technique lasts for three years and is applied in natural, fairly undisturbed forests. In the first year, seedlings are removed by hand and mature plants are cut at the base and then treated with a solution of glyphosate (Missile at 360 g/l). Further control measures are necessary during the first two years after treatment to eliminate all regrowing plants.

7.2.7. Biological control

A biological control research programme was launched in 1996 by the regional council (Conseil régional de la Réunion), with the support of ONF–Réunion, the French ministry of the environment and sustainable development (Ministère de l'écologie et du développement durable) and the European Union. The costs of the five-year project are €460 000 (c. US$511 000). Work started in 1997 with the assistance of CABI Bioscience (UK Centre). During several missions to India, Sri Lanka, China, Vietnam and Europe, a large number of insects and pathogens were collected from *Ligustrum* species (CABI Bioscience 2000). Among the 30 plant pathogen species collected, only one species, the mitosporic fungus *Thedgonia ligustrina*, is promising. Twenty-one insect species were assessed and host specificity testing begun (CABI Bioscience 1999). The epiplemid moth *Epiplema albida* seems to be a promising biocontrol agent (CABI Bioscience 2002). Before releasing *E. albida* in Réunion, research is currently concentrating on collecting fresh *E. albida* material from Sri Lanka, eliminating its associated parasitoids, and then conducting complementary tests in quarantine in Réunion.

7.2.8. Conclusions

The PhD research of Lavergne (2000) identified two weaknesses of *L. robustum* subsp. *walkeri* that can be exploited to control the species:

- The longevity of the seeds in the soil is rather short (maximum two years). The systematic elimination of all seedlings and adults over a period of two years guarantees the total eradication of the species in a site. Additionally, knowing that the minimum juvenile period is two years in open areas and 4–5 years under forest canopy, the control efforts need to be applied only every 2–4 years, according to the light conditions.

- Under shaded conditions, the plant does not bear fruit. The juvenile period is shortest in open areas and longest under forest canopy. It is possible to delay sexual maturity by preserving a dense forest cover. This suggests that priority should be given to the control of populations in open areas and along forest edges.

8. CONCLUSIONS AND RECOMMENDATIONS

8.1. Relevance of the problem

Réunion has a flora and habitats that are globally unique. Large areas of essentially primary habitats still exist. The main threats to these are exotic plants and animals. Effective management of the invasive species problem is of paramount importance for the conservation of native biodiversity.

8.2. A global strategy

All invasive species management actions should be coordinated by a global strategy at both the island (Réunion) and the regional (Indian Ocean) scale.

8.3. Priority for prevention and precautionary measures

Potentially new invasive plant species are still introduced every year to Réunion, mainly ornamentals. About half of the invasive species in Réunion are ornamentals. The invasive species problem demands an approach in accordance with the precautionary principle. Prevention is cheaper than repair. It is therefore necessary to control further deliberate introductions of potentially invasive plant species. Legislative mechanisms should be defined for efficient border control.

8.4. Awareness building

There is a general lack of awareness of the invasive species problem. An awareness-building campaign should be started that targets decision makers and stakeholders (ONF–Réunion, relevant ministries, botanical gardens, NGOs, horticulturalists, agriculturalists) as well as the general public.

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APPENDICES

Appendix 1: list of abbreviations and acronyms

3P	Pôle de protection des plantes
asl	above sea level
CIRAD	Centre de coopération internationale en recherche agronomique pour le développement
DAF	Direction de l'agriculture et de la forêt
DIREN	Direction régionale de l'environnement
FAO	Food and Agriculture Organization of the United Nations
FDGDON	Fédération des groupements de défense contre les organismes nuisibles
INVABIO	national biological invasions research programme
NGO	Non-Governemental Organization
ONF	Office national des forêts
SPV	Service de protection des végétaux
SREPEN	Société réunionnaise pour l'étude et la protection de l'environnement
UNESCO	United Nations Educational, Scientific and Cultural Organization

Appendix 2: potentially invasive species in Réunion

From: Lavergne *et al*. in prep

Species name (Vernacular name[s])	Family	Comments
Acacia auriculiformis (Acacia)	Mimosaceae	Planted for reforestation in Réunion. A recent introduction. Probably currently in a lag phase. Invasive in Micronesia (Pohnpei) and the United States. Considered a noxious environmental weed by Randall (2002) and highly invasive by Binggeli *et al.* (1998) in the tropics and subtropics. It is a threat to ecosystems in the Pacific region (Space 2003). It is invasive in Mayotte.
Acacia dealbata (Acacia bernier)	Mimosaceae	Naturalized in the uplands of Réunion with typical pioneer behaviour. Invasive in South Africa and Madagascar. Considered a noxious environmental weed by Randall (2002) and highly invasive by Binggeli *et al.* (1998) in the tropics and subtropics.
Acacia melanoxylon (Acacia bois noir, Acacia rouge)	Mimosaceae	Naturalized in Réunion in the locality of Les Palmistes (on the west coast). May invade the humid forests of the western part of Réunion. It is a threat to ecosystems in the Pacific region (Space 2003).
Aleurites moluccana (Bancoulier)	Euphorbiaceae	Naturalized in some lowland ravines and in the south of Réunion. Invasive on Christmas Island (Indian Ocean). Considered a noxious environmental weed by Randall (2002) and moderately invasive by Binggeli *et al.* (1998) in the tropics and subtropics. It is a threat to ecosystems in the Pacific region (Space 2003).
Azadirachta indica (Neem)	Meliaceae	Planted for reforestation in Réunion. Regenerates naturally in the forest in Etang Salé. Considered a noxious environmental weed by Randall (2002) and moderately invasive by Binggeli *et al.* (1998) in the tropics and subtropics. It is a threat to ecosystems in the Pacific region (Space 2003).
Chrysobalanus icaco (Icaquier)	Chrysobalanaceae	Recent deliberate introduction to Réunion as a fruit tree (see Quilici and Jeuffrault 2001). Very invasive in Seychelles and Tahiti (Raiatea). Considered a noxious environmental weed by Randall (2002) and moderately invasive by Binggeli *et al.* (1998) in the tropics and subtropics. It is a threat to ecosystems in the Pacific region (Space 2003).
Cinnamomum camphora (Camphrier)	Lauraceae	Naturalized in Réunion in Cirque de Salazie, Dioré, Basse Vallée and La Crête Jacques Payet. May invade the humid forests of these areas. It is a threat to ecosystems in the Pacific region (Space 2003).
Fraxinus floribunda (Frêne de l'Himalaya)	Oleaceae	Naturalized in Réunion in Bois de Nèfle St-Denis, Brûlé de Saint-Denis, Plaine d'Affouche, and Dos D'Ane. May invade the mountain forests and La Roche Ecrite nature reserve. Many *Fraxinus* species are invasive elsewhere in the world.
Gmelina arborea (Cumbulu)	Verbenaceae	An ancient introduction to Réunion. Recommended for reforestation there. Invasive in Australia and South Africa. Considered a noxious environmental weed by Randall (2002) and moderately invasive by Binggeli *et al.* (1998) in the tropics and subtropics. It is a threat to ecosystems in the Pacific region (Space 2003).
Grevillea banksii (Grévillaire rouge)	Proteaceae	Cultivated as an ornamental shrub in Réunion. Naturalized in one locality (Entre-Deux). Considered a noxious environmental weed by Randall (2002). Considered moderately invasive by Binggeli *et al.* (1998) in the tropics and subtropics. It is a noxious weed in Hawai'ian rain forests (Stone and Scott 1985).
Ligustrum ovalifolium (Troène)–	Oleaceae	Naturalized in Réunion in Les Palmistes (on the west coast) and Brûlé de Saint-Denis. May invade humid forests in the west of Réunion and La Roche Ecrite nature reserve. It is a threat to ecosystems in the Pacific region (Space 2003).

Species name (Vernacular name[s])	Family	Comments
Melaleuca quinquenervia (Niaouli)	Myrtaceae	Widely planted along roads in Réunion. Invasive in South Africa, Hawaii, United States (Florida) and Madagascar. It is listed in the Global Invasive Species Database (IUCN 2003). Considered a noxious environmental weed by Randall (2002) and highly invasive by Binggeli *et al.* (1998) in the tropics and subtropics. It is a threat to ecosystems in the Pacific region (Space 2003).
Melia azedarach (Margosier, Lilas de Perse)	Meliaceae	Widely naturalized and planted for reforestation in Réunion. Invasive in South Africa, United States (Arizona), Hawaii, Tanzania. Considered a noxious environmental weed by Randall (2002) and moderately invasive by Binggeli *et al.* (1998) in the tropics and subtropics. It is a threat to ecosystems in the Pacific region (Space 2003).
Parkinsonia aculeata (Epine de Jérusalem)	Caesalpiniaceae	Ornamental planted in the western parts of Réunion. Naturalizes in secondary dry vegetation. Very invasive in Australia. Considered a noxious environmental weed by Randall (2002) and highly invasive by Binggeli *et al.* (1998) in the tropics and subtropics. It is a threat to ecosystems in the Pacific region (Space 2003).
Pinus caribaea subsp. *hondurensis* (Pin des Caraïbes)	Pinaceae	Recommended for reforestation in Réunion. Invasive in Hawaii and Australia. Considered a noxious environmental weed by Randall (2002). It is a threat to ecosystems in the Pacific region (Space 2003).
Psidium friedrichsthalianum (Coronille)	Myrtaceae	Recent deliberate introduction to Réunion as a fruit tree (see Quilici and Jeuffrault 2001). Regenerates quickly under planted trees (Pagezy and Hladik 2003). Given the invasiveness of the genus *Psidium*, this species should not be planted in Réunion.
Samanea saman (Arbre à confiture)	Caesalpiniaceae	Planted for reforestation in Réunion. Invasive in Hawaii. Considered a noxious environmental weed by Randall (2002) and moderately invasive by Binggeli *et al.* (1998) in the tropics and subtropics. It is a threat to ecosystems in the Pacific region (Space 2003).
Schefflera actinophylla (Arbre ombelle)	Araliaceae	A new ornamental tree present in the gardens of Réunion. Very invasive in the Pacific islands: Pohnpei, Guam, Rarotonga, Fiji, Tahiti, Raiatea, Hawaii, Niue and Samoa. Considered a noxious environmental weed by Randall (2002) and highly invasive by Binggeli *et al.* (1998) in the tropics and subtropics.
Spathodea campanulata (Tulipier du Gabon)	Bignoniaceae	Widely planted in Réunion along roads as an ornamental tree, and also along forestry roads within forests. It is able to regenerate vegetatively through cuttings. Seeds are wind dispersed. Already naturalized in some areas. Possibly in a lag phase. It is listed in the Global Invasive Species Database (IUCN 2003). Problematic in Mayotte (Pascal 1997).Very invasive in the Pacific region, East Africa, Papua New Guinea, Singapore (Space 2003). Considered a noxious environmental weed in Randall (2002).
Cyathea cooperi (syn. *Sphaeropteris cooperi* (Fanjan australien)	Cyatheaceae	Prolific numbers are grown in gardens in Réunion. Weedy in Mauritius, New Zealand, Hawaii, South Africa, the Azores, and southwestern Australia (Low 1999). Considered moderately invasive by Binggeli *et al.* (1998) in the tropics and subtropics.
Swietenia mahogani (Mahogani)	Meliaceae	Planted for reforestation in Réunion. Considered a noxious environmental weed by Randall (2002) and moderately invasive by Binggeli *et al.* (1998) in the tropics and subtropics.
Tabebuia pallida (Calice du pape)	Bignoniaceae	Cultivated in Réunion up to 700 m asl. Planted for reforestation in the eastern parts of Réunion, especially in Etang Salé. Invasive in Mauritius, Rodrigues and Seychelles. Considered moderately invasive by Binggeli *et al.* (1998) in the tropics and subtropics. It is a threat to ecosystems in the Pacific region (Space 2003).

Appendix 3: some common names of cited plants

Species name	Common name(s)
Acacia dealbata	Silver wattle, Bernier
Acacia mearnsii	Black wattle
Acacia melanoxylon	Australian blackwood, Acacia bois noir, Acacia rouge
Ageratina riparia	Mist flower
Aleurites moluccana	Candlenut, Bancoulier
Azadirachta indica	Neem
Casuarina equisetifolia	Casuarina, Filao
Chrysobalanus icaco	Cocoplum, Icaquier
Cinnamomum camphora	Camphor, Camphrier
Coffea spp.	Coffee
Cortaderia selloana	Pampas grass
Cryptomeria japonica	Japanese (red) cedar
Cyathea cooperi (syn. *Sphaeropteris cooperi*)	Fanjan australien
Eichhornia crassipes	Water hyacinth
Eucalyptus spp.	Eucalypts
Fraxinus floribunda	Frêne de l'Himalaya
Gmelina arborea	Cumbulu
Hedychium gardnerianum	Wild ginger
Lantana camara	Lantana
Leucaena leucocephala	Leucaena
Ligustrum ovalifolium	Troène
Ligustrum robustum subsp. *walkeri*	Sri Lankan privet, Troène de Ceylan
Melaleuca quinquenervia	Niaouli
Melia azedarach	Persian lilac, Margosier, Lilas de Perse
Melinis minutiflora	Molasses grass
Panicum maximum	Guinea grass, Fatak grass
Parkinsonia aculeata	Jerusalem thorn, Epine de Jérusalem
Pelargonium spp.	Geraniums
Pinus caribaea subsp. *hondurensis*	Pin des Caraïbes, Honduran pine
Pinus pinaster	Maritime pine
Pistia stratiotes	Water lettuce
Psidium cattleianum	Cherry/Chinese/Strawberry guava, Goyavier,
Psidium friedrichsthalianum	Coronille
Ravenala madagascariensis	Traveller's tree
Rubus alceifolius	Giant bramble, Raisin marron
Saccharum officinarum	Sugar cane
Samanea saman	Arbre à confiture

Species name	Common name(s)
Schefflera actinophylla	Umbrella tree, Arbre ombrelle
Schinus terebinthifolius	False pepper
Spathodea campanulata	Tulip tree, Tulipier du Gabon
Swietenia mahogani	Mahogany, Mahogani
Syzygium jambos	Rose apple, Jambrosa
Tabebuia pallida	Calice du pape, Pink tecoma
Ulex europaeus	Gorse