The Miconia Saga: 20 Years of Study and Control in French Polynesia (1988-2008)

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Abstract

This paper reviews the main results obtained during 20 years of study and control (1988-2008) of the invasive alien tree *Miconia calvescens* DC (Melastomataceae) in French Polynesia and includes some updated information obtained since the last overview, published in 1998. The goals are to assess the data acquired on the bio-ecology, the current distribution of the species, and the results of the control efforts, as well as to discuss the future perspectives in managing this dominant plant invader in French Polynesia.

The "Miconia Research and Control Program" in French Polynesia was initiated in 1988, nearly 50 years after the introduction of *M. calvescens* to Tahiti as a garden ornamental and 20 years after the first dense stands were observed in the wild. The species now occurs on the main high volcanic islands of the Society Archipelago (Tahiti, Moorea, Raiatea, Tahaa) and in the Marquesas (Nuku Hiva, Fatu Hiva) and is recognized as the most invasive plant in French Polynesia. With the long-term financial support of the French Polynesian government, an estimated US$770,000 has been invested in *M. calvescens* research over the past 20 years. This research resulted in the acquisition of critical data on the origin and introduction history of *M. calvescens*, its current island distribution, and its bio-ecology including genetics, growth, reproduction, dispersal, and seed bank dynamics. In addition, the establishment, dispersal, and impacts of a fungal pathogen, *Colletotrichum gloeosporioides* f. sp. *miconiae*, introduced as a biological control agent to French Polynesia (Tahiti in 2000, Raiatea in 2004 and Nuku Hiva in 2007) was assessed. Among the main scientific outcomes are:

1) *M. calvescens* is one of the few plant invaders that are able to penetrate into undisturbed native island forest and to suppress the recruitment, growth and/or reproduction of endemic plants species;
2) biological control can reverse this process and can contribute to habitat restoration;
3) new legislation was enacted regarding invasive species;
4) a biosecurity system was put into place; and,
5) local, national, regional, and international long-term partnerships were established.

One of the most crucial outcomes has been the importance of public information and education of local communities and authorities. *M. calvescens* has become a "charismatic" invasive species and a "bête noire" for the scientific and conservation communities and is now used as a model for the prevention of new introductions of potential plant (and animal) invaders in French Polynesia and other Indo-Pacific tropical islands.

Introduction: An Ecologically and Scientifically Successful Species

"*Je n'hésite pas à qualifier ce Miconia d'ennemi n°1 de la végétation tahitienne*" (Raynal 1973).

The successful invasion of the native island rainforests of French Polynesia and Hawai'i by the small tree *Miconia calvescens* DC (Melastomataceae) has become a classical example in invasion ecology, often cited in recently published academic textbooks in the fields of terrestrial biodiversity, ecology, conservation or island biogeography (e.g. Hamilton and Hamilton 2006, Mittermeier *et al.* 1999, Lévêque and Monoulou 2001, Ramade 2002, Whittaker and Fernandez-Palacios 2007), as well as in popular books dealing with invasive species and their impacts on biodiversity (Devine 1998: 268-274, Baskin 2002: 54-55, Van Driesche and Van Driesche 2000: 277-291, Wilson 2007: 61). It is noteworthy that Mabberley's "Plant Book," which constitutes a good proxy for botanical knowledge worldwide, did not cite *M. calvescens* in its first edition of 1987 (Mabberley 1987). The second edition, published ten years later in 1997, includes a short mention on the species and its invasiveness ("*M. calvescens Blume (M. magnifica, trop. Amer., natur. Tahiti (penetrating native forest) and Sri Lanka),*" Mabberley 1997: 454), and the third and last edition of 2008 provides a more detailed and precise description: "*M. calvescens DC. (M. magnifica, trop. Amer., invasive Tahiti (introd. cult. orn. 1937, penetrating native forest, by 1996 covering over two-thirds of is.), Hawai'i and Sri Lanka),"* (Mabberley 2008: 543).

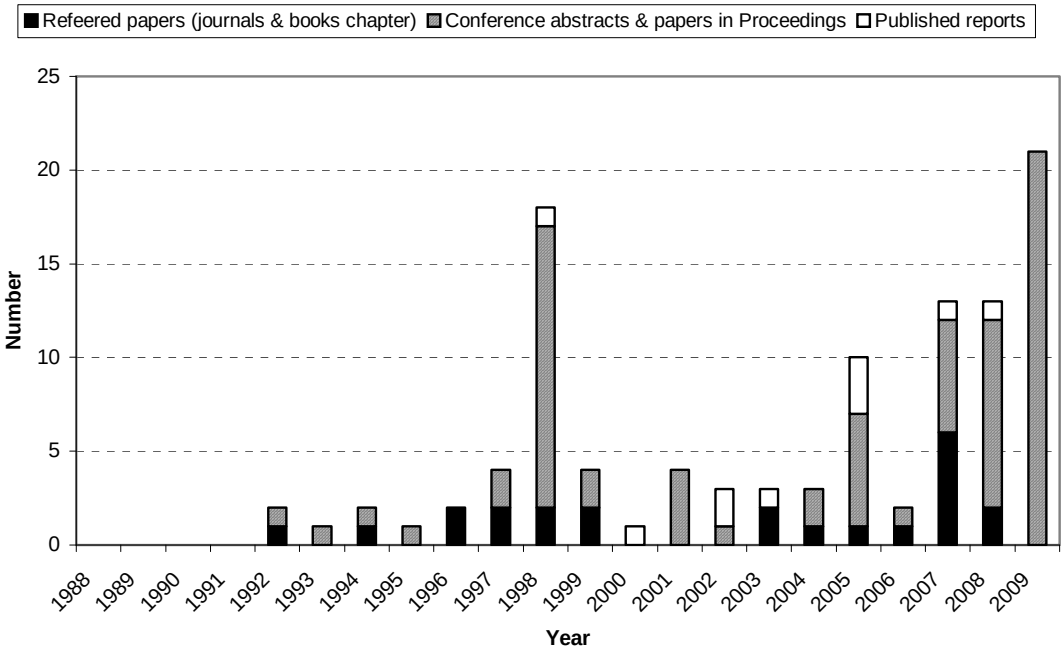
We calculated that there are at least 105 refereed papers, conference abstracts, and published reports specifically dedicated to *M. calvescens* (Figure 1) with a dramatic increase of the number of publications between the 1988-1999 period (N=35) and the 2000-2009 period (N=72), including two peaks (in 1998 and in 2009) which correspond to the "Proceedings of the First Regional Conference on Miconia Control" held in Tahiti (French Polynesia) in 1997 and the "2009 International Miconia Conference" in Maui, Hawai'i (USA). These publications demonstrate the growing importance of the interest in *M. calvescens* by the scientific community, in relation to the recent spread of the species in Australia, studies on potential biological control agents conducted in its native range of Tropical America, and economic cost-benefits analyses in Hawai'i. There are numerous professional and personal websites dedicated to *M. calvescens* compared to other weeds or invasive plants of worldwide importance. The more relevant include the "Global Invasive Species Database" <www.issg.org/database/species/ecology.asp?si=2&fr=1&sts=sss&lang=EN>, the "Pacific Island Ecosystems at Risk" <www.hear.org/Pier/species/miconia_calvescens.htm>, the "Hawai'i Invasive Species Council" <www.hawaiiinvasivespecies.org/pests/miconia.html>, the "New South Wales Agriculture Weed Alert" <www.dpi.nsw.gov.au/__data/assets/pdf_file/0006/156624/miconia-alert.pdf>, the "Biosecurity Queensland (Queensland Primary Industry and Fisheries) Pest Alert and Fact Sheet" <www.dpi.qld.gov.au/documents/Biosecurity_EnvironmentalPests/IPA-Miconia-PP142.pdf>, the "Initiative sur les Espèces Exotiques Envahissantes Outre-Mer" of the French IUCN Committee <www.especes-envahissantes-outremer.fr/>, "Wikipedia" <http://en.wikipedia.org/wiki/Miconia_calvescens>, and the New Caledonian "TPE-Miconia-NC" <www.miconia.fr/>. A Google search on Internet using the two words "*Miconia calvescens*" gives a total of at least 37,900 results!

However, a few popular books and websites still promote the cultivation of the species, under its horticultural name *Miconia magnifica* Triana. A certain H. Alton Lee (posted Friday, November 16, 2007, on the website <http://greatmoviestropicalgardening.blogspot.com/2007/11/miconia-magnifica.html> wrote that "*a very rare plant […] is the stunningly*

beautiful Miconia magnifica, which can grow to tree size. It has the reputation of being an invasive pest in truly tropical areas, but where it can be contained […], it is a remarkable and truly awesome tropical, the leaves are among the most spectacular of any plant one can name and can get very large. I have grown this plant in a pot –very large- and it has bloomed […]. It also set seed, but I was told they would likely be unviable in Florida, this proved incorrect as I have managed to get two seedlings, one of which has survived. The plant is very cold tender and it also requires a lot of water, pretty much impossible to find, but worth the search. As Robert Lee Riffle has stated in his superb book on Tropical Plants, (among the very best books available on Tropicals): "It is almost unbelievable that more of these beauties have not been exploited for gardeners in frost-free regions." A critical review of Robert Lee Riffle's (1940-2006) book published in 1998 (Riffle 1998), winner of the 1999 Garden Book of the Year Award from the American Horticultural Society, was published on the Amazon book review website by Charles Chimera (University of Hawai'i at Mānoa, Honolulu). He answered that "*it is almost unbelievable to me that, despite all of the attention and effort that has gone into protecting the world's rare tropical ecosystems, that nothing is mentioned in the book about the potential for certain plants such as Miconia to become aggressive invaders when grown outside of their native range*" (Chimera 1999).

M. calvescens also provides an excellent case study for a long-term management program to control an invasive alien species using different control strategies (eradication versus containment) and methods (manual, chemical, biological control) and with many lessons learned both at the scientific level and the social dimension.

Figure 1. Number of publications on *M. calvescens* since 1988.
Unpublished reports or short notes published in popular/non scientific papers are not included.



This paper reviews the main results obtained during 20 years of study and control (1988-2008) of *M. calvescens* in French Polynesia and provides some updated data since the last overview presented in 1997 at the "First Regional Conference on Miconia Control" (Meyer and Smith 1998).

Current Invasive Status

"*La progression de cette « peste » est dangereusement rapide […] S'il n'est pas porté, de façon urgente, remède à cette invasion, il est à craindre que d'ici peu d'années la presqu'île entière soit couverte de ces bois de Miconia*" (Raynal 1973).

When the "Miconia Research and Control Program" was initiated in 1988 in French Polynesia by the Government of French Polynesia (formerly called the Territory of French Polynesia) and IRD (formerly called ORSTOM), the plant was already well established in Tahiti. *M. calvescens* was planted as an ornamental in a private botanical garden in 1937 (nowadays called the "Jardin Botanique Harrison Smith"), became naturalized in the late 1960s, and by the early 1970s dense stands were observed in the wild on the Taravao plateau (Raynal 1973, Meyer 1996, 2008). In July 28, 1981, the botanist Francis Raymond Fosberg, who was highly knowledgeable about the Pacific Islands flora, wrote in his field book (pages 36-37), after his visit to the Taravao plateau: "*This forest is completely invaded by Miconia calvescens, forming a close stand with a dense canopy, through which protrude some of the old forest trees. The Miconia is said to favour Cyathea forests, to invade them and in a short time to crowd the tree ferns out. At the present rate it will not be long before it invades the wet middle elevation and probably low elevation forests.*"

M. calvescens now occurs on four of the main high volcanic islands of the Society Archipelago (Tahiti, Moorea, Raiatea, Tahaa), and two islands in the Marquesas (Nuku Hiva, Fatu Hiva), with different degrees of invasion in relation to the initial introduction and the number and area of invaded sites (Table 1).

Table 1. Current degree of *M. calvescens* invasion in the different islands of French Polynesia.
** year of first discovery*

Island	Area (km²)	Year of introduction	Number of invaded sites or valleys	Elevation range (m)	Invaded area in ha (% total)	Degree of invasion
Tahiti	1,045	1937	> 100	10-1,400	> 80 000 (> 75%)	High
Moorea	140	1960's	> 20	10-1,100	> 3 500 (> 25%)	High
Raiatea	170	1955	> 10	10-1,000	> 470 (> 2.5%)	Medium
Tahaa	90	1990's	1	20-200	< 10 (> 0.1%)	Low
Nuku Hiva	340	1995*	3	400-1,000	< 5 (< 0.01%)	Low
Fatu Hiva	85	1997*	3	500-600	< 1 (< 0.01%)	Low

On the main island of Tahiti, the invaded area has not increased since the last published records (Meyer 1998b). We assume that *M. calvescens* has attained its maximal distribution ranging from almost sea-level to 1,400 m elevation wherever the mean annual rainfall is above 2,000 mm. The area invaded by *M. calvescens* is significantly higher on Moorea than previously cited (> 3,500 ha versus > 1,200 ha estimated in 1998), but this increase may be due to the more intensive field surveys carried out on this island during the past 10 years, especially on the highest summits and previously unexplored ridges and peaks (Bock 1998, Meyer and Taputuarai, unpub.data.). On Raiatea, however, where more than 470 ha are

considered to be invaded compared to the 240 ha in 1998, the increase is both the result of newly discovered dense stands and the spread of *M. calvescens* into new areas, especially on the highest summit ridges and slopes (up to 1,000 m elevation), and the surrounding Temehani plateau cliffs and valley bottoms (Meyer and Tavaearii, unpub. data).

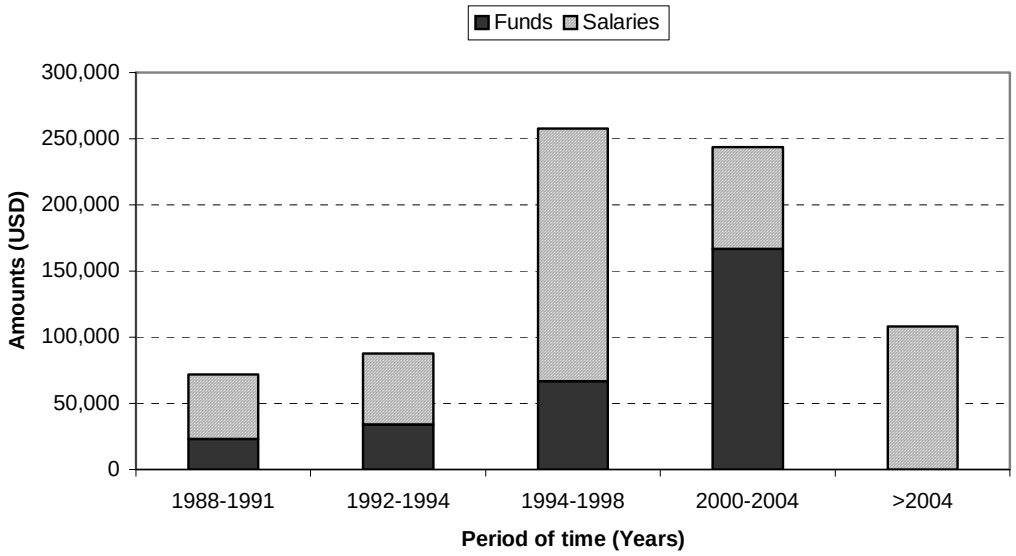
Small populations have also been newly reported in the Marquesas, on the island of Nuku Hiva, on the Toovii high-elevation plateau (seven flowering trees destroyed in 2008, Benne 2009), and on Fatu Hiva along the Omoa-Hanavave road (ca. 50 plants including a few plants 4-6 m tall found in 2009, Taputuarai 2009). No other high island in the Austral, Society or Marquesas Archipelago has been invaded in French Polynesia since 1997 (Meyer 1998b), which demonstrates the relative success of the information and education campaigns on *M. calvescens* and the biosecurity measures set up by the French Polynesian authorities to contain the spread of the plant invader.

M. calvescens is indeed recognized by the local authorities as the worst invasive plant in French Polynesia: it was legally declared "noxious" in 1990 (Decree n°290 CM, March 14, 1990), then classified as one of the 13 invasive alien plants recognized to be a "threat to biodiversity" in 1998 (Decree n°244 CM, February 12, 1998), and now belongs to the list of the 35 plants threatening the biodiversity in French Polynesia (Decree n°65 CM, January 23, 2006). These regulations state that new introduction, propagation and cultivation, as well as transportation between islands of these 13 plant invaders are totally banned. The Service du Développement Rural" or SDR (i.e. the Department of Agriculture of the French Polynesian government), based in the archipelagos of the Marquesas and the Austral Islands, has forced private entrepreneurs to clean their vehicles (e.g. 4WD cars, bulldozers) transported by boats before landing on islands (Pierre Atai, SDR-Rurutu, pers. comm. 1998; Teiki Richmond, SDR-Hiva Oa, pers. comm. 2007). In official letters dated in 1999, both the Government of French Polynesia (addressed to its "Direction de l'Equipement", the Department of Equipment) and the French High Commissioner (to its "Direction de l'Assistance Technique"), and relayed by the "Chambre syndicale des métiers du génie civil et des travaux publics" (Union Chamber of the Civil Engineering and Public Works professions), have agreed to add a special condition for public works (e.g. roads, airstrips, wharfs, etc.) by private companies stating that: "*the titular has to clean in a very careful manner all the public works engines and equipments before its departure to islands other than Tahiti, in order to fight against miconia.*"

Research and Control Efforts

Over the past 20 years, with the long-term financial support of the French Polynesian government, an estimated US$770,000 (about 69 million CFP or French Pacific Francs) has been invested to study the bio-ecology and island distribution of *M. calvescens*, and to search for efficient control methods (Figure 2). The two main investment funds were provided by the "Contrat de Développement Etat-Pays" (Development Contract between the French state and the French Polynesian government) between 1994-1998 and 2000-2004, demonstrating the support of politicians (the Assembly of French Polynesia and the Ministries of the Environment, Agriculture, Education and Research). Since 2004, only salaries for one research scientist and a technician for the post-release monitoring of the biological control agent in Tahiti and other islands were paid by the "Délégation à la Recherche" (the Research Department of the French Polynesian government).

Figure 2. Money spent on the "Miconia Research and Control Program" for the period 1988-2008. *M. calvescens* control operations on Raiatea are not included.



If the additional US$20,000 (ca. 2 million CFP) per year for the miconia control campaigns which were organized once a year on the island of Raiatea over the 1992-2008 period (i.e. a total of US$320,000) is added, the total cost of the *M. calvescens* study and control program for the last 20 years can be estimated to be about US$1M. By comparison, a total of US$1.4M (127 million CFP) was spent by the Service du Développement Rural to control fruit flies (*Bactrocera* spp.) in French Polynesia between 1997 and 2001, and US$1.2M (110 millions CFP) by the Direction de l'Environnement (the Department of Environment) to map and control ca. 500 ha invaded by the little fire ant (*Wasmannia auropunctata*) in Tahiti by aerial treatment (using helicopter) between 2006 and 2008 (Ministère de l'Environnement, pers. comm. 2009). On the island of Maui (Hawai'i), public control efforts exceed US$1M/yr (Burnett *et al.* 2007). A cost-benefit analysis reveals that the estimates of potential expected losses on the island of O'ahu caused by *M. calvescens* to groundwater recharge may be as high as US$137M/yr (Kaiser 2006).

Main Results and Outcomes

"*Cette plante très prolifique germe et croît facilement dans l'ombre des sous-bois, où la compétition des espèces indigènes ne la gêne d'aucune manière. Arrivé à une taille adulte (une dizaine de mètres) l'arbre étend ses frondaisons au soleil, produit des milliers de fleurs et de fruits qui le multiplient alentour en un temps record. Son ombre beaucoup plus dense que l'ombre forestière naturelle étouffe et élimine les végétaux indigènes*" (Raynal 1973).

Impacts, invasiveness and invasibility

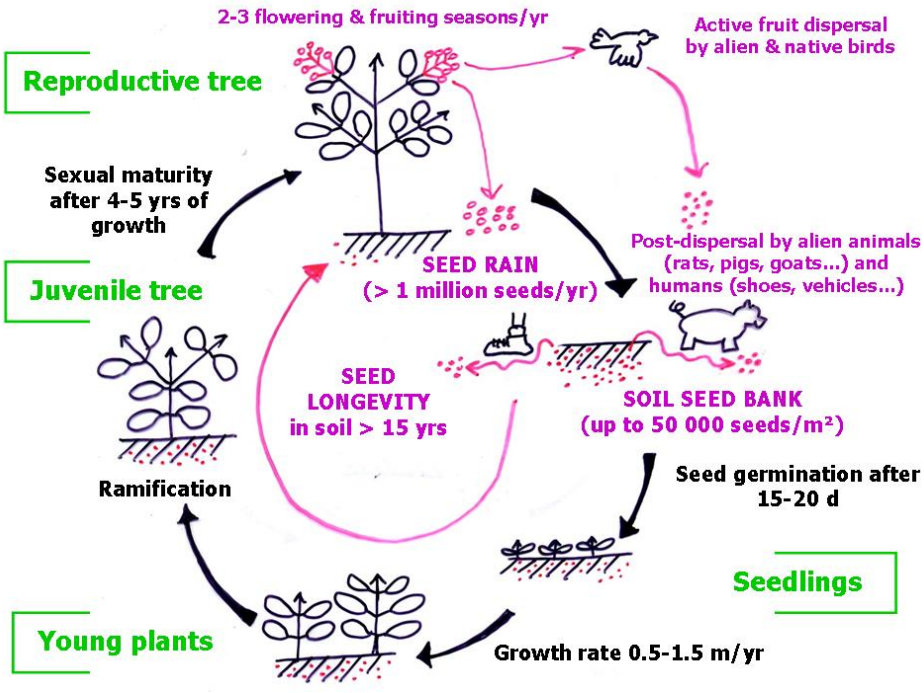
M. calvescens represents one of the most dramatic and devastating cases of a documented plant invasion on an island, having successfully invaded all native mesic and wet forests of Tahiti from sea level to high-elevation mountains up to 1,400 m in less than 50 years, and driving between 40-50 species of the 107 plants endemic to Tahiti to near-extinction (Meyer and Florence 1996). The species forms dense, almost monotypic stands (up to 3 to 6 individuals/m²) with a closed canopy of large leaves, causing a dramatic decrease in the light

availability in the forest understory (0.4-0.6% in a dense miconia forest compared to 1-3% in native montane cloud forest, Meyer 1994, Meyer *et al*. 2007). Most of these threatened plants are understory herbs (including terrestrial orchids), shrubs or small trees that cannot survive or reproduce in the shade of a dense *M. calvescens* canopy. Studies conducted on Tahiti have demonstrated that the reproductive capacity (i.e. fertility) of the endangered endemic shrubs *Psychotria* spp. and subshrubs *Ophiorrhiza* spp. (Rubiaceae), and the seedling recruitment of the small endangered endemic tree *Myrsine longifolia* (Myrsinaceae) decrease with a higher level (i.e. density) of invasion (Meyer *et al.* 2003, Meyer *et al.* 2007, Fourdrigniez and Meyer 2009). The replacement of native forests by dense monotypic stands of *M. calvescens*, coupled with the potentially severe impacts on the watersheds (e.g. increase of runoff and reduction in groundwater recharge) and soil erosion (Kaiser 2006, T. Giambelluca, pers. comm. 2008) make the species an "ecosystem transformer" *sensu* Richardson *et al*. (2000).

The successful invasion by *M. calvescens* is a combination of both its biological and ecological characteristics (or life history traits) and invasion potential or "invasiveness," and the site susceptibility (or resistance) to invasion or "invasibility." A small tree commonly 4-16 m tall, the species is native to Central and South America, where it is rarely found as an understory species in dense rainforest and a colonizer of small forest gaps (Meyer 1994, 1996). In Costa Rica, the species is very scarce, occurring in just a few locations on the Caribbean slope, below 1,000 m, in sites receiving substantial sunlight, and often on steep slopes (Burckhardt *et al.* 2005). The species can be considered a late successional pioneer species, adapted to low light levels for seed germination and growth, i.e. relatively shade-tolerant, but with a relative rapid vegetative growth (up to 1.5 m/yr in French Polynesia, Meyer and Malet 1997), an early sexual maturity (after 4-5 years in French Polynesia, Meyer 1998a) and a prolific fruit production. As with most of the species belonging to this particular functional group, *M. calvescens* benefits from additional light for flowering and fruiting, such as in semi-open vegetation (e.g. forest edges, riverbanks) or after disturbances (e.g. treefall gaps, cyclones). In the tropical rainforest of Queensland, Australia, steep slopes with less litter and debris accumulation, better light penetration and higher levels of disturbance from land slips and treefalls may improve habitat suitability for *M. calvescens* seed germination, seedling establishment and persistence (Murphy *et al*. 2008).

In Costa Rica, there is only one flowering season (Araya *et al.* 2004), whereas in Tahiti, three major flowering peaks occur per year (Meyer 1998a). As an example, a large mature tree, 10 m in height and 10 cm of diameter at breast height, can bear up to 200 panicles, each of them containing between 100 and 500 fruits with an average number of 190 seeds per fruits, thus producing more than 50 million seeds annually (Meyer, unpub. data). The small fleshy berries (0.6-0.7 cm diameter) are eaten in Tahiti and Moorea by frugivorous birds, such as the introduced silvereye *Zosterops lateralis* and red-vented bulbul *Pycnonotus cafer*, and the endemic gray-green fruit dove *Ptilinopus purpuratus* (Meyer 1994, Spotswood and Meyer in press), and actively dispersed over long distances. Spread over short distances occurs by seeds or fruits post-dispersal by alien animals, such as rats (*Rattus* spp., Meyer 1994), feral pigs (*Sus scrofa*), goats (*Capra hircus*), and by humans on infected hiking boots, vehicles, bulldozers and other equipment (Figure 3).

Figure 3. *M. calvescens* life cycle in Tahiti (*in* Meyer 2008).



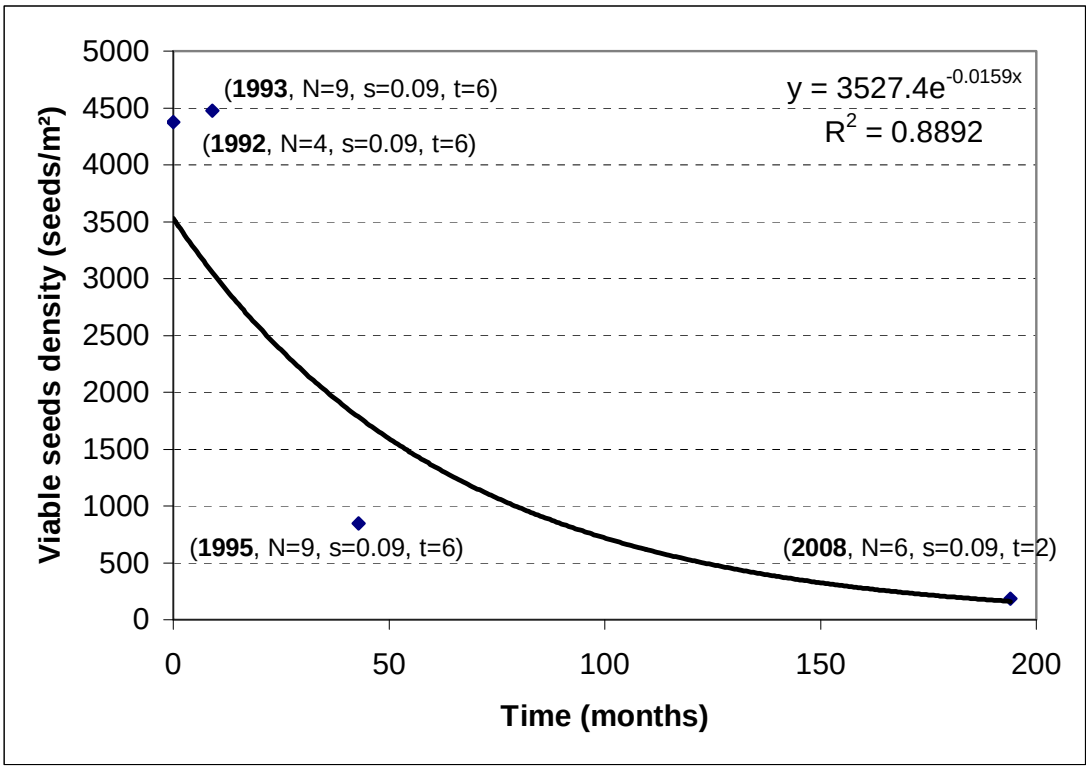
Seed germination rate is high (90% in 15-20 days in laboratory conditions) under very low light conditions, but seeds remain dormant if stored in complete darkness (Meyer 1994). The soil seed bank is very large (up to 50,000 seeds/m² in dense monotypic forests of Tahiti, Meyer 1994) and persists for many years. According to the most recent data, the longevity of the seeds in soil samples originally collected from the island of Raiatea is at least 16 years (Figure 4). The mean number of seeds dropped from more than 4,300 seeds/m² in 1992 (Meyer and Malet 1997) to 190 seeds/m² in 2008.

The vegetation structure of the native (or primary) forests in French Polynesia is likely to have an important role in contributing to the success of *M. calvescens*. The lowland and upland rainforests are relatively small in stature, characterized by a low canopy (generally between 12 and 15 m in height), simplified vertical structure, low number of canopy species, and trees with small crowns and small leaves. This particular forest physiognomy allows *M. calvescens* to easily attain and overtop the canopy where it can flower and fruit profusely (Meyer and Lavergne 2001).

The lack of specific natural enemies in French Polynesia, a phenomenon called "ecological release," is also one of the main reasons explaining *M. calvescens'* ability to spread and build large populations.

Paradoxically, in regard to species adaptation to new environments, *M. calvescens* shows a considerable low genetic differentiation throughout the Pacific Islands where it was introduced (French Polynesia, Hawai'i and New Caledonia). Populations have undergone severe bottlenecks and high levels of inbreeding (Le Roux *et al.* 2008). This is not surprising, as the plant is believed to have been introduced to these islands through a very small number of propagules, all originating from Tahiti.

Figure 4. *M. calvescens* seed longevity in soil seed bank.
Germination of seeds in soil samples from Raiatea. N= number of soil replicates, s = soil surface in m², t = monitoring time in months). Laboratory conditions: 25-28°C, 50-70% relative humidity.



Manual and chemical control

"*En premier lieu, il conviendrait de promulguer l'interdiction formelle de planter cette espèce où que ce soit en Polynésie. L'arrachage de la totalité des pieds jeunes dans les vallées non encore sérieusement infestées devrait être envisagé*" (Raynal 1973).

Different control strategies are conducted in French Polynesia depending on the different degrees of invasion (Table 2). Manual and chemical control are utilized in small localized areas of high ecological value in the highly invaded islands (Tahiti and Moorea), e.g. in areas with remnant populations of endangered endemic plants such as the trees *Planchonella tahitensis* (Sapotacaeae) or *Lepinia taitensis* (Apocynaceae), to improve seedling recruitment and growth (Meyer and Taputuarai, unpub. data). Containment is used on islands with many small populations over a large area (Raiatea). Eradication is the preferred method on islands where the number of populations is small and distributed in a small area, and with few reproductive trees (Tahaa, Nuku Hiva, Fatu Hiva).

On the island of Raiatea, where more than 470 hectares are estimated to be invaded (R. Tavaearii, SDR-Raiatea, pers. comm. 2009), i.e. less than 3% of the island surface, the control strategy is to eliminate all the reproductive trees (cut with a machete or a chainsaw and sprayed with an herbicide) and to remove by hand most of the juveniles and seedlings in order to deplete the soil seed bank.

A partnership between the three departments of Agriculture (Service du Développement Rural), Environment (Direction de l'Environnement) and Research (Délégation à la Recherche) was set up in 1992 and formalized in 1998 with the creation of the "Inter-Ministerial Technical Committee to control Miconia and other invasive plants" (Decree n°1151 CM, August 31, 1998). Its aims are to define control/management strategies, to procure adequate funding, and to set up priorities concerning public information, education, research and legislation (Meyer 1998c).

"Miconia removal campaigns" have been organized once a year, since 1992, by the Service du Développement Rural (Department of Agriculture) of Raiatea. A total of ca. 3,500 people have been involved since 1992, including the French Army (between 40-80 soldiers), local volunteers (nature protection groups, churches, sports teams, schoolchildren), employees of the three "Communes" (Counties) (Uturoa, Tumaraa, Taputapuatea), with the financial support of the Direction de l'Environnement and the scientific support of the Délégation à la Recherche in Tahiti. The local community (shopkeepers, wholesalers, farmers) generously contributes to the campaigns by providing goods (e.g. drinks and food) for the military troops and civilian volunteers. The three counties assist with providing logistical support (small buses called "trucks," and 4WD vehicles). Four campaigns are necessary to treat all the invaded areas that cannot be treated during one campaign per year (R. Tavaearii, SDR-Raiatea, pers. comm. 2009).

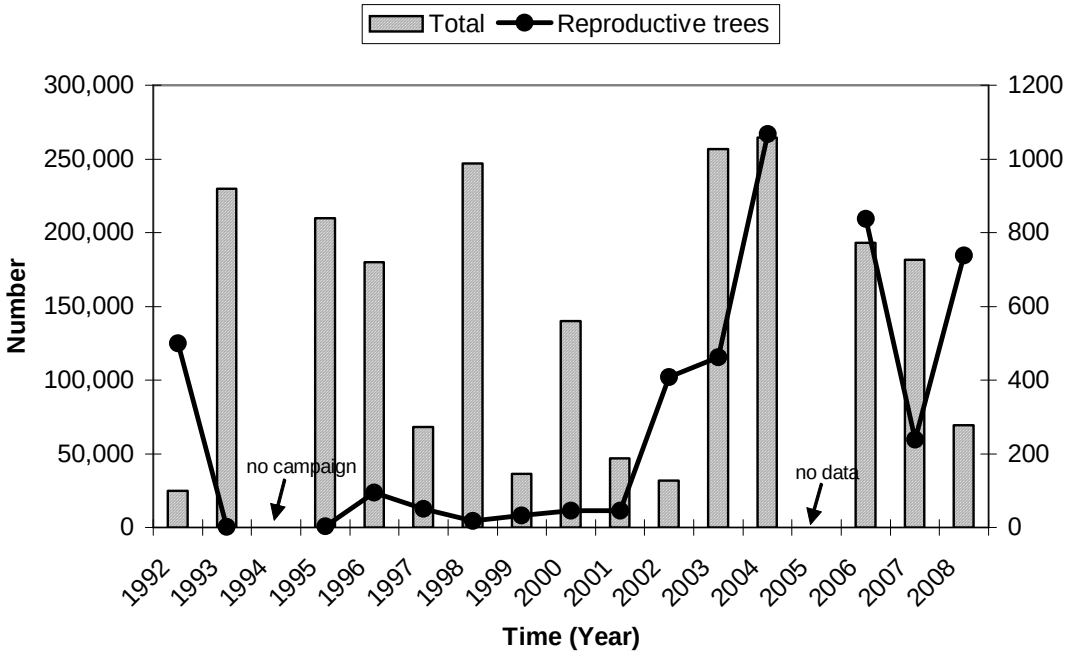
Table 2. Control strategy and methods in the different islands of French Polynesia.

Island	Invaded area in ha (% total area)	Degree of invasion	Control strategy	Control methods	Number of plants destroyed (mature trees)
Tahiti	> 80,000 (> 75%)	High	Control in small areas of high ecological value	Manual and chemical + Biocontrol (2000)	Not evaluated
Moorea	> 3 500 (> 25%)	High	Control in small areas of high ecological value	Manual and chemical + Biocontrol (2000)	Not evaluated
Raiatea	> 470 (> 2.5%)	Medium	Containment	Manual and chemical (1992) + Biocontrol (2004)	> 2,200,000 (> 4540)
Tahaa	> 10 (> 0.1%)	Low	Eradication	Manual and chemical (1995) + Biocontrol (2004)	> 10,000 (> 8)
Nuku Hiva	< 5 (< 0.01%)	Low	Eradication	Manual and chemical (1997) + Biocontrol (2007)	> 8,000 (14)
Fatu Hiva	< 1 (< 0.01%)	Low	Eradication	Manual and chemical (1997) + Biocontrol (2007)	> 3,000 (5)

A total of more than 2,200,000 plants were destroyed between 1992 and 2008, including 4,540 reproductive trees (Table 2). There is no trend toward a significant decrease of the number of plants removed with time for different reasons:
1) the duration of the control campaign varies between 5 and 14 days in any one year;
2) the number of participants or volunteers varies between 20 and 120; and above all,
3) the surface of the treated or surveyed areas varies from one year to another and has increased with the discovery of new populations since 2007 (Figure 5).

The number of reproductive plants remains high, thus eradication, which was the management goal in the 1990s, is no longer an option.

Figure 5. Number of *M. calvescens* plants destroyed during the control campaigns with the French Army in Raiatea (1988-2008).
Data according to the Service du Développement Rural, Raiatea.

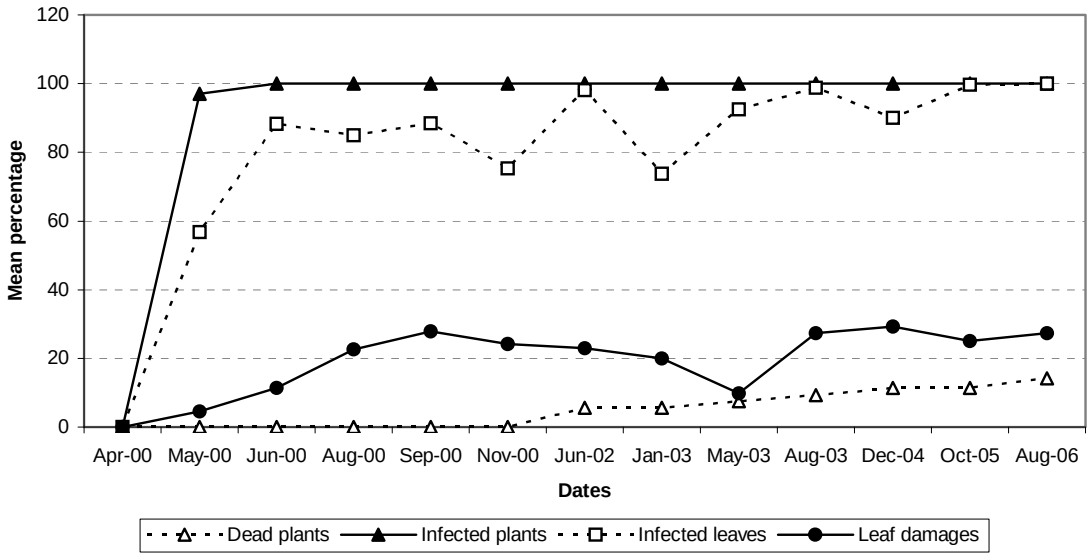


Biological control
"*A coup sûr, le moyen le plus efficace et le moins coûteux, à long terme, serait d'exterminer l'espèce dans toutes ses stations, mais ceci de façon sélective, si possible par un moyen de lutte biologique (maladie cryptogamique, insecte prédateur ?) qui reste toutefois à déterminer. Des recherches devront être effectuées dans l'aire indigène de ce Miconia, en Amérique*" (Raynal 1973).

Because conventional manual and chemical control methods have shown their limits in heavily invaded islands such as Tahiti and Moorea, especially where *M. calvescens* has formed dense monospecific stands on steep, mountainous slopes, biological control is viewed as the only effective alternative. In addition, the low genetic diversity of the species indicates that it is unlikely to rapidly evolve resistance against effective control mechanisms, including biological control (Le Roux *et al.* 2008).

A fungal pathogen *Colletotrichum gloeosporioides f. sp. miconiae* Killgore and L. Sugiy. (Melanconiales, Coelomycetes, Deuteromycetinae), found in Brazil in 1997 (hereafter *Cgm*), and proven to be highly-specific to *M. calvescens* in laboratory conditions at the Hawai'i Department of Agriculture's containment facility, was successfully introduced to the tropical oceanic island of Tahiti in 2000 (Killgore and Meyer 2005). This fungus causes leaf spots, defoliation, and eventually death of young seedlings in laboratory conditions (74% mortality, one month after inoculation, Meyer *et al.* 2008). About 110 seedlings and saplings (between 10 cm and 2.8 m in height) in two permanent plots in Tahiti (Taravao Plateau at 620 m with a mean annual rainfall of 3,300 mm and Lake Vaihiria at 600 m and 7,000 mm) were monitored for a period of six years after the inoculation to assess the pathogen's dispersal and impacts on *M. calvescens* in the wild. Leaf spots were observed ca. 30 days after inoculation. Percentage of infected plants reached 100% after three months, and between 90-99% of leaves were infected (Figure 6). Mortality rate for the monitored plants was 15% and reached 30% for seedlings less than 50 cm tall (Meyer *et al.* 2008).

Figure 6. Impacts of the *Cgm* on *M. calvescens* monitored plants (N=110) in the permanent plot of Taravao.



Within three years, the fungus had disseminated throughout the island of Tahiti and had infected nearly all the *M. calvescens* plants up to 1,400 m in montane rainforests. It was also found on the neighbouring island of Moorea without any intentional release there. Leaf damage on *M. calvescens* canopy trees increased from 5% to 45% with elevation in permanent plots set up between 600 and 1,020 m. Within three years, the *Cgm* had established, reproduced, and spread throughout the island of Tahiti and even to the neighbouring island of Moorea, located ca. 20 km away. The *Cgm* has succeeded in infecting nearly all the *M. calvescens* plants on both islands, particularly in high-elevation montane rainforests or cloudforests, by natural means without causing any apparent harm to non-target plant species (Meyer *et al.* 2008). Leaf damage caused by *Cgm* is more severe in high-elevation areas of Tahiti (and of Moorea and Raiatea, Meyer, Taputuarai and Fourdrigniez, unpub. obs.) where cooler and wetter conditions prevail, suggesting that temperature and moisture (as humidity or free water) are important factors for disease development. The

reproduction and dissemination of the pathogen was delayed at the Taravao site due to a drought period that occurred when the pathogen was released in 2000. The same pattern was observed in Hawai'i after the release of the *Cgm* in 1997 (Eloise Killgore, Hawai'i Department of Agriculture, pers. comm.).

Although this biocontrol agent may slow the growth of established *M. calvescens* plants (between 17- 35 % of the surviving *M. calvescens* plants showed multiple damages, especially rotten stems and curved leaves) and cause the dieback of young seedlings, it alone will not control the massive invasion of *M. calvescens*. Partial defoliation of *M. calvescens* canopy trees (up to 45%) favoured the recruitment of native plants, including rare threatened endemic plants such as the tree *Myrsine longifolia* (Myrsinaceae) or the subshrub *Ophiorrhiza subumbellata* (Rubiaceae) by enhancing the light availability in the understory (Meyer *et al.* 2007, Fourdrigniez and Meyer 2009, Meyer and Fourdrigniez, submitted). The number and cover of understory plants increases with time, an effect which is more pronounced for light-demanding species. The majority of colonizing understory species (80%) are native trees, shrubs and ferns, with little or no reinvasion by other alien plants (Meyer, Taputuarai and Fourdrigniez, in prep.).

The *Cgm* was released on the island of Raiatea (Society Islands) in 2004, and in Nuku Hiva (Marquesas Islands) in 2007. On these islands, manual and chemical control will be necessary to achieve complete eradication, but the fungal pathogen is expected to reduce the number of *M. calvescens* plants, especially those at the seedling stage.

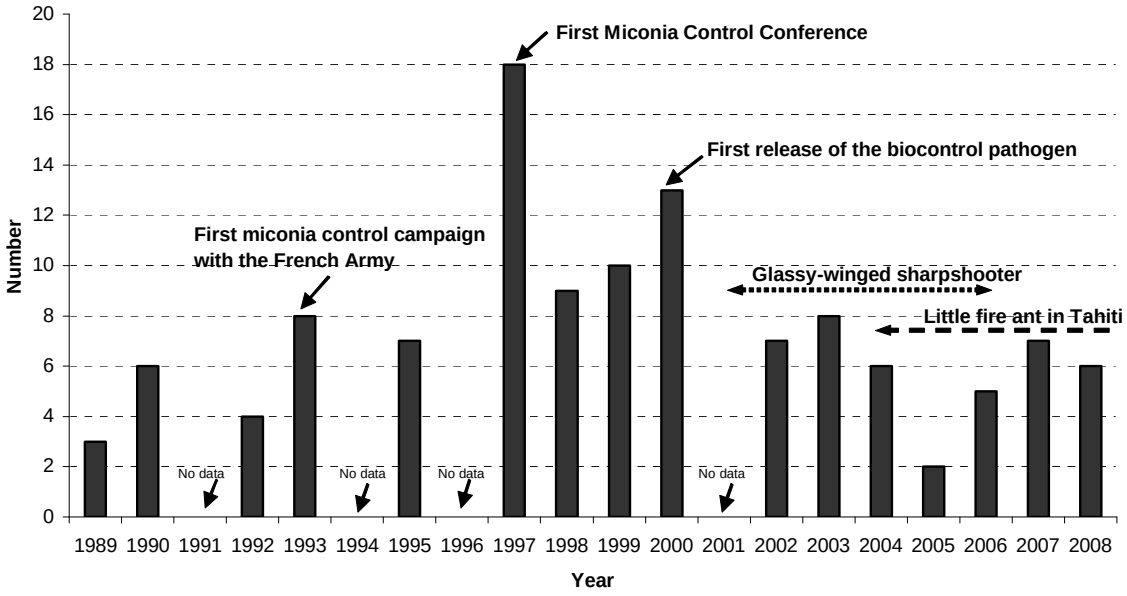
Education and information

"*Une politique de sauvegarde du milieu naturel polynésien par la création de zones réserves sera inopérante si elle ne s'accompagne pas, en même temps, d'une surveillance étroite des introductions d'espèces biologiques*" (Raynal 1973).

One of the most crucial lessons learned has been the importance of public information and education of local communities and authorities, an important step in raising awareness and local involvement in control efforts, including biocontrol. The great success of the "Miconia Research and Control Program" was certainly the awareness campaign with a high number of articles published in the local newspapers, with a peak during the "First Regional Conference on Miconia Control" in 1997 and the release in 2000 of the biological control agent.

Many television spots and footage on *M. calvescens*' biological control program were made both at the local (e.g. in the DVD "Eléments Terre" sponsored by the Ministère de l'Environnement, Government of French Polynesia in 2004, or on the television news on "Tahiti Nui Television" in August 2008) and the French levels (e.g. "Sentinelles de la Nature", Ushuaïa TV, in 2005, "Biotiful Planète, Polynésie", WWF/Gédéon, in 2007, "Héros de la Biodiversité", France 2/France 3, in 2009). However, the media interest in French Polynesia has recently shifted to the newly introduced glassy-winged sharpshooter (*Homalodiscus coagulata*) since 2001, followed by the little fire ant (*Wasmannia auropunctata*) since 2004 (Fig. 8).

Figure 8. Number of articles dealing specifically with *M. calvescens* published in the two local newspapers "La Dépêche de Tahiti." *(18,500 copies/day, 88,400 readers/day, 46% of the inhabitants of more than 15 years old) and "Les Nouvelles de Tahiti" (6,500 copies/day, 27,000 readers/day, 14% inhabitants).*



Conclusions: Lessons Learned

Because of its invasiveness in tropical island rainforests of Oceania (French Polynesia, Hawa'ii and New Caledonia) and its impacts on the endemic flora in Tahiti, *Miconia calvescens* has become a "charismatic" invasive alien plant species and a "bête noire" for the scientific and conservation communities. The species is now used as a model for the prevention of new introductions of potential plant (and animal) invaders in French Polynesia, in other Indo-Pacific tropical islands (e.g. in the French Overseas territories and countries, Soubeyran 2008), and some tropical countries (e.g. the Queensland region in Australia).

The French Polynesian experience has shown that *M. calvescens* eradication is extremely difficult without an adequate logistical capacity (e.g. ground teams, and helicopters for aerial surveys to detect remote *M. calvescens* populations), long-term funding support, and a very strong commitment by everyone (Meyer 2008). Biological control appears to be the only efficient and cost-effective option over a long-time period, and can contribute to partial habitat restoration, as demonstrated in Tahiti where the fungal pathogen *Colletotrichum gloeosporioides f. sp. miconiae* has caused partial deforestation of *M. calvescens* canopies followed by the recovery of the native vegetation. Additional host-specific biocontrol agents are still much needed to fully control the massive invasion by *M. calvescens* in the Society Islands, especially at low or mid-elevation.

In French Polynesia, the recent decrease of interest by the media, the end of the funding support for *M. calvescens* research programs (but not for the post-release monitoring of the biocontrol fungal pathogen), as well as the cancellation of the "2009 Miconia Removal Campaign" on the island of Raiatea are of big concern for the future of *M. calvescens* management. A new "push" is urgently needed for international cooperation in order to share experiences, research data, control methods, management strategies, and funding.

The current distribution of *M. calvescens* in the economically poor and politically unstable country of Sri Lanka is unknown since 1998 (Meyer 1998b) and should be re-assessed. The species is now being considered as an invasive plant by both the scientists (Prof. B. Marambe, Department of Crop Science Faculty of Agriculture, University of Peradeniya, and Dr. Siril Wijesundara, Director General of the Department of Botanic Gardens in Sri Lanka, pers. comm. 2010), the national authorities (Anonymous 2001) and the local public (see e.g. the "Sri Lanka Guardian", March 12, 2010, <www.srilankaguardian.org/2010/03/will-miconia-destroy-our-upcountry.html>.

Despite the huge amount of information about its invasiveness and impacts, the species is unfortunately still cultivated in some greenhouses in tropical regions (more particularly in the Caribbean region, e.g. in Martinique, French Antilles, Elisabeth Etifier-Chalono, pers. comm. 2006, in the Dominican Republic, Hispaniola Island, Saara DeWalt, pers. comm. 2008, in Dominica island, Bradley Guye, pers. comm. 2009, and in South-east Asia, e.g. in the Hong Kong Park Conservatory <www.the-eleven.com/~tjlegg/photos/hongkongpark-may2006/pages/page_27.php>. It is still possible to buy and import seeds or plants, e.g. in La Réunion Island, where a plant imported from France was found in pot and destroyed ten years ago (Joël Dupont, pers. comm. 2000). The "Miconia Saga" has not ended…

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Literature Cited

Araya, A.L., P. Hanson, and O.J. Rocha. 2004. Reproductive and vegetative phenology for two populations of *Miconia calvescens* DC (Melastomataceae) in Costa Rica: an invasive plant in the Hawaiian and French Polynesia Islands. Abstract, *Annual Meeting of the Association for Tropical Biology and Conservation*, *12-16 July, Miami.*

Baskin, Y. 2002. *A Plague of Rats and Rubbervines: The Growing Threat of Species Invasions.* Island Press, Washington.

Benne, F. 2009. Rapport final sur l'arrachage et la prospection du miconia sur l'île de Nuku Hiva. Unpublished report, Marquises Rando.

Bock, P.A. 1998. Distribution and dispersal of *Miconia calvescens* DC, an invasive alien tree, in Moorea, French Polynesia. In: *The Biology and Geomorphology of Tropical Islands* Student Research Papers Fall 1998. Richard B. Gump South Pacific Biological Research Station, Moorea, University of California, Berkeley, pp. 13-21.

Burckhardt, D., P. Hanson, and L. Madrigal. 2005. *Diclidophlebia lucens*, n.sp. (Hemiptera: Psyllidae) from Costa Rica, a potential control agent of *Miconia calvescens* (Melastomataceae) in Hawai'i. *Proc. Entomol. Soc. Wash.* 107(4):741-749.

Burnett, K., B. Kaiser, and J. Roumasset. 2007. Economic lessons from control efforts for an invasive species: *Miconia calvescens* in Hawai'i. *Journal of Forest Economics* 13:151-167.

Chimera, C. 1999. A Hawaiian conservation biologist's nightmare. *Review of* Riffle, R. L. *The Tropical Look: An Encyclopedia of Landscape Plants for Worldwide Use.* Thames and Hudson, 1998, posted on <Amazon.com>, September 10, 1999.

Devine, R. 1998. *Alien Invasion: America's Battle With Non-native Animals and Plants.* National Geographic Society. Washington, DC.

Fosberg, F.R. 1981. Unpublished field notes. Botany Department, Smithsonian Institution, Washington, DC.

Fourdrigniez, M., and J.-Y. Meyer. 2009. The positive effects of a biocontrol pathogen agent introduced against the invasive alien tree miconia (*Miconia calvescens*, Melastomataceae) on the growth and fertility of two threatened endemic plants *Ophiorrhiza* spp. (Rubiaceae) in Tahiti (French Polynesia). Abstract, *11th Pacific Science Inter-Congress, 2-6 March, Papeete.*

Hamilton, A., and P. Hamilton. 2006. *Plant Conservation: An Ecosystem Approach.* People and Plants Conservation Series, WWF, Royal Botanic Gardens, Kew, Earthscan, London.

Kaiser, B.A. 2006. Economic impacts of non-indigenous species: *Miconia* and the Hawaiian economy. *Euphytica*148:135-150.

Killgore, E., and J.-Y. Meyer. 2005. Biological control of miconia in Hawai‘i and French Polynesia with a fungal pathogen. Abstract, *Proceedings of the 2005 Meeting of the Weed Science Society of America, Honolulu,* p. 90.

Le Roux, J.L., Wieczorek, A.M., and Meyer, J.-Y. 2008. Genetic structure of the invasive tree *Miconia calvescens* in Pacific islands. *Diversity and Distributions* 14(6):935-948.

Lévêque, C., and J.-C. Monoulou. 2001. *Biodiversité: Dynamique Biologique et Conservation.* Dunod, Paris.

Mabberley, D.J. 1987. *The Plant-Book: A Portable Dictionary of the Vascular Plants.* Cambridge University Press, Cambridge.

Mabberley, D.J. 1997. *The Plant-Book: A Portable Dictionary of the Vascular Plants,* 2nd ed. Cambridge University Press, Cambridge.

Mabberley, D.J. 2008. *Mabberley's Plant-Book: A Portable Dictionary of Plants, Their Classification and Uses,* 3rd ed. Cambridge University Press, Cambridge.

Meyer, J.-Y. 1994. Mécanismes d'invasion de *Miconia calvescens* DC en Polynésie française. Thèse de doctorat, Université Montpellier II Sciences et technique du Languedoc, Montpellier. <http://www.hear.org/articles/meyer1994/pdfs/meyer1994miconiadissertation.pdf>.

Meyer, J.-Y. 1996. Status of *Miconia calvescens* (Melastomataceae), a dominant invasive tree in the Society Islands (French Polynesia). *Pacific Science* 50(1):66-76.

Meyer, J.-Y. 1998a. Observations on the reproductive biology of *Miconia calvescens* DC (Melastomataceae), an alien invasive tree in the island of Tahiti (South Pacific Ocean). *Biotropica* 30(4):609-624.

Meyer, J.-Y. 1998b. Epidemiology of the invasion by *Miconia calvescens* and reasons for a spectacular success. In: Meyer, J.-Y., and C.W. Smith (eds.). *Proceedings of the First Regional Conference on Miconia Control, August 26-29, 1997, Papeete, Tahiti.* Gouvernement de Polynésie française, University of Hawaii at Manoa, Centre ORSTOM de Tahiti, pp. 4-26.

Meyer, J.-Y. 1998c. The establishment of an Inter-Ministerial Committee to control *Miconia calvescens* and other invasive species in French Polynesia. In: Wittenberg, R., and J.W. Cock (eds.). *Invasive Alien Species: A Toolkit of Best Prevention and Management Practices.* CAB International, Wallingford, p. 35.

Meyer, J.-Y. 2008. Is eradication of the invasive tree miconia feasible? Lessons from 15 years of active management in French Polynesia (Pacific Islands). In: van Klinken, R. D., V.A. Osten, F.D. Panetta, and J.C. Scanlan (eds.). *Proceedings of the Sixteenth Australian Weeds Conference.* Queensland Weeds Society, Brisbane, p. 433.

Meyer, J.-Y., and J. Florence 1996. Tahiti's native flora endangered by the invasion of *Miconia calvescens* DC (Melastomataceae). *Journal of Biogeography* 23:775-781.

Meyer, J.-Y., and J.-P. Malet. 1997. Study and management of the alien invasive tree *Miconia calvescens* DC (Melastomataceae) in the islands of Raiatea and Tahaa (Society Islands, French Polynesia): 1992-1996. *University of Hawaii Coop. Nat. Park Res. Studies Unit*, Technical Report 111, Honolulu.

Meyer, J.-Y., and C.W. Smith (eds.). 1998. *Proceedings of the First Regional Conference on Miconia Control, August, 26-29, 1997, Papeete, Tahiti.* Gouvernement de Polynésie française, University of Hawaii at Manoa, Centre ORSTOM de Tahiti.

Meyer, J.-Y. and C. Lavergne. 2001. The role of forest structure in plant invasions on tropical oceanic islands. In: Ganeshaiah, Uma, R. Shaanker, and K.S. Bawa (eds.). *Tropical Ecosystems: Structure, Diversity and Human Welfare: Proceedings of the International Conference on Tropical Ecosystems.* Oxford-IBH, New Delhi, pp. 456-458.

Meyer, J.-Y., and Fourdrigniez. Submitted 2010. Conservation benefits of biological control: the recovery of a threatened endemic plant subsequent to the introduction of a fungal pathogen to contain an invasive tree on the island of Tahiti (South Pacific). *Biological Conservation*.

Meyer, J.-Y., J. Florence, and V. Tchung. 2003. Les *Psychotria spp.* (Rubiacées) endémiques de Tahiti (Polynésie française) menacés par l'invasion de *Miconia calvescens* (Melastomatacées): statut, répartition, écologie, phénologie et protection. *Revue d'Ecologie (Terre Vie)* 58 :161-185.

Meyer, J.-Y., A. Duplouy, and R. Taputuarai. 2007. Dynamique des populations de l'arbre endémique *Myrsine longifolia* (Myrsinacées) dans les forêts de Tahiti (Polynésie française) envahies par *Miconia calvescens* (Mélastomatacées) après introduction d'un champignon pathogène de lutte biologique : Premières investigations. *Revue d'Ecologie (Terre et Vie)* 62:17-33.

Meyer, J.-Y., R. Taputuarai, and E.M. Killgore. 2008**.** Dissemination and impact of the fungal pathogen *Colletotrichum gloeosporioides* f. sp. *miconiae* on the invasive alien tree *Miconia calvescens* (Melastomataceae) in the rainforests of Tahiti (French Polynesia, South Pacific). In: Julien, M.H., R. Sforza, M.C. Bon, H.C. Evans, P.E. Hatcher, H.L. Hinz and B.G. Rector (eds.). *Proceedings of the XII International Symposium on Biological Control of Weeds. La Grande Motte, France.* CAB International, Wallingford, pp. 594-599.

Mittermeier, R.A., N. Myers, and C.G. Mittermeier. 1999. *Hotspots: Earth's Biologically Richest and Most Endangered Terrestrial Ecoregions.* Cemex, Conservation International.

Murphy, H.T., B.D. Hardesty, C.S. Fletcher, D.J. Metcalfe, D.A.Westcott, and S.J. Brooks. 2008. Predicting dispersal and recruitment of *Miconia calvescens* (Melastomataceae) in Australian tropical rainforests. *Biological Invasions* 10:925-936.

Ramade, F. 2002. *Dictionnaire Encyclopédique de l'Ecologie et des Sciences de l'Environnement,* 2ème ed. Dunod, Paris.

Raynal, J. 1973. Mission botanique en Polynésie française. Unpublished report, Laboratoire de Phanérogamie, Muséum national d'Histoire naturelle, Paris, Juin-juillet.

Richardson, D.M., P. Pyšek, M. Rejmanek, M.G. Barbour, D. Panetta, and C.J. West. 2003. Naturalization and invasion of alien plants: concepts and definitions. *Diversity and Distributions* 6:93-107.

Riffle, R.L. 1998. *The Tropical Look: An Encyclopedia of Landscape Plants for Worldwide Use.* Thames and Hudson.

Soubeyran, Y. 2008. *Espèces Exotiques Envahissantes Dans les Collectivités Françaises d'Outre-mer: Etat des Lieux et Recommandations.* Collection Planète Nature, Comité français de l'UICN, Paris.

Spotswood, E., and J.-Y. Meyer. In press. Interactions between plants and their bird dispersers in the Society archipelago (French Polynesia). *Proceedings of the 11th Pacific Science Inter-Congress, March 2-6, Tahiti.*

Sri Lanka: State of the environment. 2001. *United Nations Environment Programme, Regional Resource Center for Asia and the Pacific, Thailand*. <http://www.rrcap.unep.org/pub/soe/srilanka_biodiversity.pdf>.

Taputuarai, R. 2009. Rapport de mission à Fatu Hiva (Marquises sud) du 22 au 30 mars 2009. Unpublished report, MaNature, Papeete.

Van Driesche, J., and R. Van Driesche. 2000. *Nature Out Of Place: Biological Invasions in the Global Age.* Island Press, Covelo.

Whittaker, R.J., and J.M. Fernandez-Palacios. 2007. *Island Biogeography,* 2nd ed. Oxford University Press, Oxford.

Wilson, E.O. 2007. *Sauvons la Biodiversité!* Dunod, Paris.