Mémoire de stage

présenté par

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Sujet:

Predicting the risk of plant invasion on islands: the case of *Miconia calvescens* in the Marquesas, French Polynesia (South Pacific)

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Abstract

Predicting the distribution of alien plant species in newly introduced areas where they are found in small numbers is crucial for biodiversity management. *Miconia calvescens* (Melastomataceae), a small tree native to Central and South America, has become one of the world's worst plant invader in tropical rainforest including in the Society Islands (French Polynesia), the Hawaiian Islands and the Australian state of Queensland. In this study, we aim to predict the potential distribution of *Miconia* in the Marquesas Islands (French Polynesia) where it has been recently introduced (in Nuku Hiva and Fatu Hiva) and where the species is still not in equilibrium with its environment. We used MaxEnt models to combine occurrence records from its native and introduced ranges with 1) large-scale climatic variables; and 2) fine-scale topographic variables. Results produced with climatic variables confirm that *Miconia* has the potential to spread over most Marquesas Islands where it is still absent. According to the most accurate results obtained with topographic variables, ca. 45% of Nuku Hiva and 35% of Fatu Hiva present suitable environmental conditions for *Miconia*. Despite theoretical limitations associated with projecting distribution of alien species in areas with different recipient communities, our approach provides valuable information for stakeholders.

Résumé

Prédire la distribution de plantes envahissantes dans des zones où elles sont peu abondantes, est crucial pour la gestion de la biodiversité. *Miconia calvescens* (Mélastomatacées), un petit arbre originaire d'Amérique centrale et du sud, est devenu l'une des plantes envahissantes les plus néfastes dans les forêts tropicales dont celles des îles de la Société (Polynésie française), des îles de Hawaii et dans l'Etat du Queensland en Australie. Le but de cette étude est de prédire la répartition potentielle de *Miconia* aux îles Marquises (Polynésie française) où il a été récemment introduit (Nuku Hiva et Fatu Hiva) et où l'espèce n'est pas encore en équilibre avec son environnement. Nous avons utilisé MaxEnt pour associer les données d'occurrence de son aire d'origine et d'introduction avec (1) des variables climatiques à grande échelle ; et 2) des variables topographiques à échelle fine. Les résultats produits avec les variables climatiques confirment que *Miconia* pourrait se répandre sur les îles Marquises où il est encore absent. D'après le modèle le plus précis obtenu avec les variables topographiques, environ 45% de Nuku Hiva et 35% de Fatu Hiva présentent des conditions environnementales favorables pour le *Miconia*. Malgré des limitations théoriques associées à la projection de distribution d'espèces envahissantes dans de nouvelles communautés, notre approche apporte de précieuses informations pour les gestionnaires.

Summary

1. Introduction

According to the Millennium Ecosystem Assessment (2005), invasive alien species are one of the main drivers of biodiversity loss, especially on oceanic islands because of their isolation and small size (Kueffer et al., 2010). Those newly introduced species often have competitive advantages under environmental conditions where their natural predators are not present while many endemic species have lower competitive capacities and lower growth plasticity (Loope et Mueller-Dombois, 1989). Moreover, the low species richness and the low number of species in certain taxonomic lineages in comparison with continent provides opportunity for invasive species to take advantage of vacant niches or unused resources (Denslow, 2003).

First Polynesian settlers in the last two millennia then the European colonizers in the past centuries, who brought many alien plants and animals, led to the destruction of native habitats in many islands. Some of these species have become naturalized and turned into "pests". As a typical example, *Miconia calvescens* DC (hereafter "*Miconia*"), a small tree native to Central and South America, has become invasive in the tropical rainforests of French Polynesia, Hawaii and Queensland (Australia), where it has been introduced between the 1930's and the 1960's as an ornamental plant because of its large leaves with purple undersides (Meyer, 2009). As a result, the species has been classified among the "100 of the world's worst invasive alien species" (Lowe et al., 2000).

French Polynesia, a French overseas territory, is situated in the South Pacific Ocean between the Tropic of Capricorn and the Equator and belongs to one of the 34 biodiversity hotspots called "Polynesia-Micronesia" (Mittermeier et al., 2004). It is formed by about 120 oceanic islands and islets divided in five archipelagoes: Austral, Gambier, Marquesas, Society (including Tahiti and Moorea) and Tuamotu archipelagoes. Our study focus on the Marquesas Islands (Figure 1), one of the most isolated archipelagoes in the world located 1,400 km north-east of Tahiti and 4,000 km south-east of the Hawaiian Islands (North Pacific). Due to this remoteness, the vascular flora of the Marquesas is unique (with an endemism rate of 48%), but also highly vulnerable (Lorence et al., 2016). Indeed, according to the IUCN Red List, the highest number of threatened plant species in French Polynesia is found in the Marquesas (131 species) (IUCN France et al., 2015). Invasive alien plant and animal species are among the main threats to the flora (Meyer, 2016).

At the present time, *Miconia* is found in small numbers in the Marquesas where it is present on only two islands, Nuku Hiva and Fatu Hiva. In the early 90's, several control programs (manual uprooting, chemical and biological control) have been established on those two islands. Despite more than 25 years of control effort, *Miconia* is still present as rough terrain, steep slopes and a dense vegetation limit control surveys (Meyer et al., 2011). The two recent outbreaks in native rainforest of Nuku Hiva are alarming for the integrity of its native flora.

The use of 'Species Distribution Models' (SDM) to predict environmental suitability for species has become popular in the last few decades (Guisan et Thuiller, 2005). They are empirical models associating species occurrence data (latitude and longitude coordinates which refers to the presence or absence of the species) to environmental factors. SDM find application in many fields including conservation, ecology, evolution, epidemiology and invasive species management (Phillips et al., 2006). They are especially useful in poorly sampled tropical regions (e.g. remote tropical islands) where it provides a valuable tool for studying species ranges (Anderson et al., 2002; Phillips et al., 2006).

Numerous statistical approaches have been proposed for SDM. 'Bioclim' was one of the first used for predicting species distribution based on climatic comparison. 'Domain' is a simple statistical approach which was used to assist conservation ecologists (Kriticos et Randall, 2001). 'Generalised Linear Models' (GLMs) are based on an extensive occurrences database which can produce a fine-scale potential distribution of a species but need a large amount of information of this species (Kriticos et Randall, 2001). 'Genetic Algorithm for Rule-set Production' (GARP) and 'Maximum Entropy' (MaxEnt) approach are commonly used SDM (Anderson et al., 2002; Miller, 2010) which use machine learning techniques in order to describe the environmental conditions (e.g climate, geology) in which a species is found (Kriticos et Randall, 2001; Miller, 2010). Recently, Thuiller et al. (2009) created a computer platform for ensemble forecasting (BIOMOD) which combines several SDM together to better predict the distribution of species.

Building an SDM on the basis of the current distribution of *Miconia* in the Marquesas, where the species is at an early stage of invasion, would violate the postulate behind SDM assuming that the species is in equilibrium with its environment (i.e at an advanced stage of invasion) (Guisan et Thuiller, 2005). Thus, only regions where the equilibrium is (or nearly) respected can provide a reliable perspective of the environmental envelope occupied by the species. These regions include highly invaded islands and islands at a relative early stage of invasion where *Miconia* is present and reproducing for a long time: e.g. Tahiti (ca. 80 years), the Hawaiian Is. (ca. 60 years), the Australian state of Queensland (ca. 50 years), and Moorea (ca. 50 years) (Meyer, 2009). The Marquesas, the Hawaiian Is. and the Society Is. are closely related regions with many common features: a volcanic origin of approximately the same age (Armstrong, 1983; Dupon et al., 1993), a high endemism rate and many endemic and native genera in common (Wagner et al., 1990; Florence, 1993), comparable climates due to their similar distance to the Equator and a shared human colonization history (Armstrong, 1983; Dupon et al., 1993). In this study, we also used the native range of *Miconia* to build SDM, keeping in mind that projecting the niche occupied by the species on the basis of its natural continental distribution would ignore inherent characteristics of island ecosystem such as low species richness, low functional redundancy or specialized habitat.

Several studies have attempted to map the potential distribution of invasive alien species in new introduced areas based on SDM calibrated with occurrences in the native and invaded range of the species. Some of them are only based on occurrences of the native range and mostly use the GARP statistical approach as Peterson and Vieglais (2001) who predicted species invasion of the cattle egret (*Bubulcus ibis* Linnaeus), the house finches (*Carpodacus mexicanus* Stalius Muller), the Asian longhorn beetle (*Anoplophora glabripennis* Motschulsky) and the Japanese white spotted citrus longhorn beetle (*Anoplophora malasiaca* Thomson) in United states. This method has also been used to evaluate other species invasions including four alien plant species (e.g garlic mustard (*Alliaria petiolate* M.Bieb.), L*espedeza sericea* Thunb, Russian olive (*Elaeagnus angustifolia* L.) and *Hydrilla verticillata* (L.f.) Royle) in North America (Peterson et al., 2003) and American basses (*Micropterus salmoides* Lacepède and *Micropterus dolomieu* Lacepède) in Japan (Iguchi et al., 2004). More recently, Giovanelli et al. (2007) used MaxEnt for predicting the potential distribution of the American bullfrog (*Lithobates catesbeianus* Shaw) in Brazil.

Some other studies are only based on occurrences of the studied invaded range and use different statistical approaches. GARP was used to predict the geographical distribution of spiny pocket mice (*Heteromys* spp.) in South America (Anderson et al., 2002), the sugarcane woolly aphid (*Ceratovacuna lanigera* Zehnter) in Asia (Ganeshaiah et al., 2003) and non-native plants in Yosemite National park (Underwood et al., 2004). Pouteau et al. (2011a) also used GARP model and compared it with a support vector machine (SVM) model for *Miconia* predictive mapping in the Papenoo valley of Tahiti. In their study, Muñoz and Real (2006) assessed the potential range expansion of the monk parakeet (*Myiopsitta monachus* Boddaert) in Spain with GLM model. Ward (2007) modeled the potential geographic distribution of invasive ant species in New Zealand using three different methods (Bioclim, Domain and MaxEnt). The current alternative is to take in consideration all distributional information that are available from both the native range and other invaded regions (Jiménez-Valverde et al., 2011).

Kriticos and Randall (2001) compared the potential distribution of the cactus *Cereus jamacaru* DC in Australia using its native range (Brazil), its invaded range (South Africa) and both of its native and invaded ranges together. They highlighted the need to consider both native and invaded ranges to get an accurate prediction of the potential distribution of an invasive alien species in a new area. Then, several studies have treated the subject, forecasting the distribution of invasive plants such as *Miconia* in the world (González-Muñoz et al. (2015), based on BIOMOD approach. Potential distribution of invasive animals was widely studied with GARP, such as the freshwater New Zealand mudsnail (*Potamopyrgus antipodarum* J.E.Gray) in Australia and North America (Loo et al., 2007) and eastern North American owls (*Strix varia* Barton) in western North America (Peterson and Robins, 2003). MaxEnt was also used for this purpose, predicting the potential invasion of the American bullfrog (*Lithobates catesbeianus* Shaw) in Europe (Ficetola et al., 2007), in Ecuador (Iñiguez et Morejón, 2012) and in Mexico (Lopez et al., 2017) and the invasive fungus guava rust (*Puccinia psidii* s.l. Winter) in Australia (Kriticos et al., 2013; Elith et al., 2012). Renteria et al. (2017) used Bioclim and Domain to predict the potential distribution of 25 plants in South Africa and results were used to prioritize the management of invasive plant.

The aim of this study is twofold: 1) to examine whether *Miconia* has the potential to invade inhabited islands of the Marquesas where it is still thought to be absent; and 2) to determine the fine-scale potential distribution of *Miconia* in the Marquesas where it is now present in order to refine prospecting areas and to guide management strategies. To address the first question, we built an SDM based on climatic variables and the distribution of *Miconia* in Central America (native range), Queensland, the Hawaiian Is. and the Society Is. (invaded range). For the second question, we used an SDM based on topographic variables and the distribution of the species on the closely related islands of the Hawaiian and the Society archipelagoes.

2. Material and method

2.1. Study species

Miconia calvescens DC (Myrtales: Melastomataceae, hereafter "*Miconia*") has a native range starting from 20°N in Southern Mexico to 20°S in Argentina. The bicolorous form of *Miconia calvescens* with very large leaves (up to 1 m in length) and purple undersides (Appendix 1), valued in horticulture, occurs only in Central America (from southern Mexico to Costa Rica) (Meyer 1994). In its native range, *Miconia* is found from lowland to mountain tropical forests. It can grow under dense shade of primary forests, in open vegetation and disturbed areas (Meyer, 1996). The success of *Miconia* as an invasive plant species would be due to its self-reproductive capacity, large (50,000 seeds/m²) and persistent (at least 16 years) soil seed bank, active seed dispersal by birds and rodents and accidental transportation by human (Meyer, 2009). *Miconia* forms monospecific stands in mesic and wet habitats (over 2000 mm/years) and causes decreasing incoming light, which slow the growth of native species (Meyer, 1995). As an example, at least 40 to 50 of the 107 plant species native to Tahiti are threatened by *Miconia* (Meyer and Florence, 1996). Because of this impact, it has been declared as a "threat to the biodiversity" in 1997 in French Polynesia (Meyer et al., 2011).

2.2. Study sites

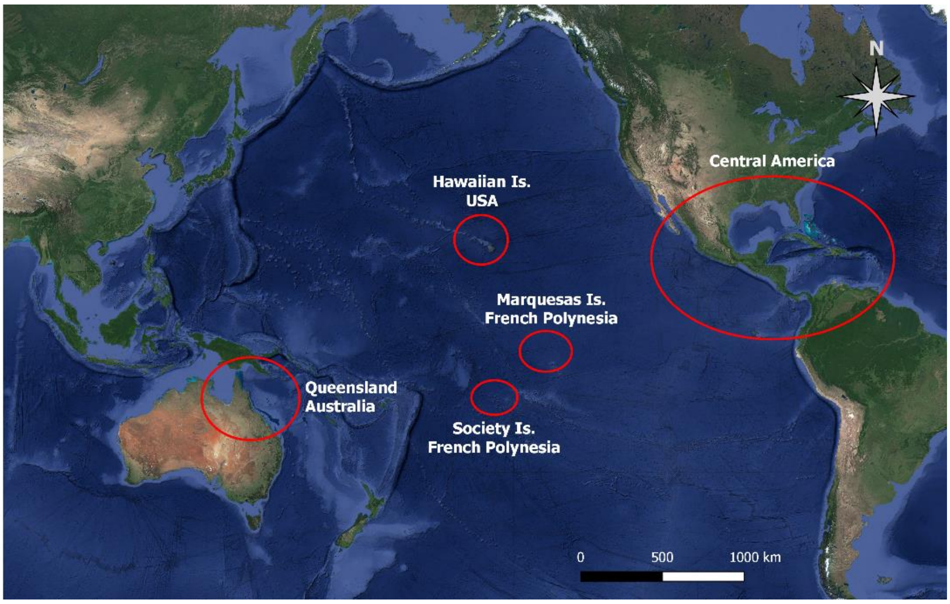

Figure 1: Location of the Marquesas and of the different regions used to calibrate species distribution models that will be projected on the Marquesas

2.2.1. The Marquesas Islands, French Polynesia

Situated between 8 and 11°S and between 138 and 141°W, the Marquesas have a low moist tropical climate with mean annual temperatures averaging 25°C and annual precipitation varying between 900 and 2,200 mm/year. Six of the dozen main oceanic islands composing the archipelago are inhabited (Figure 2) : Nuku Hiva, Ua Huka, Ua Pou, Hiva Oa, Tahuata, Fatu Hiva (Galzin et al., 2016b). Two of these islands are invaded by *Miconia*: Nuku Hiva and Fatu Hiva. Despite control efforts on those islands, new populations with mature plants have been recently observed (early 2015).

On the island of Nuku Hiva, *Miconia* has probably been introduced in 1996 by construction vehicles carrying soil infected by seeds. Seedlings had been discovered in 1997 during a botanical expedition (Meyer, 1997). Two infestation sites were located in rainforest at 400 and 750 m elevation (Butaud, 2015).

In Fatu Hiva (or Fatu Iva), isolated plants or small populations of *Miconia* have been observed in seven sites, probably disseminated on the island by birds or contaminated soil transported by pigs or hunters. On this island, *Miconia* is found in rainforest at 600 m (Taputuarai, 2017).

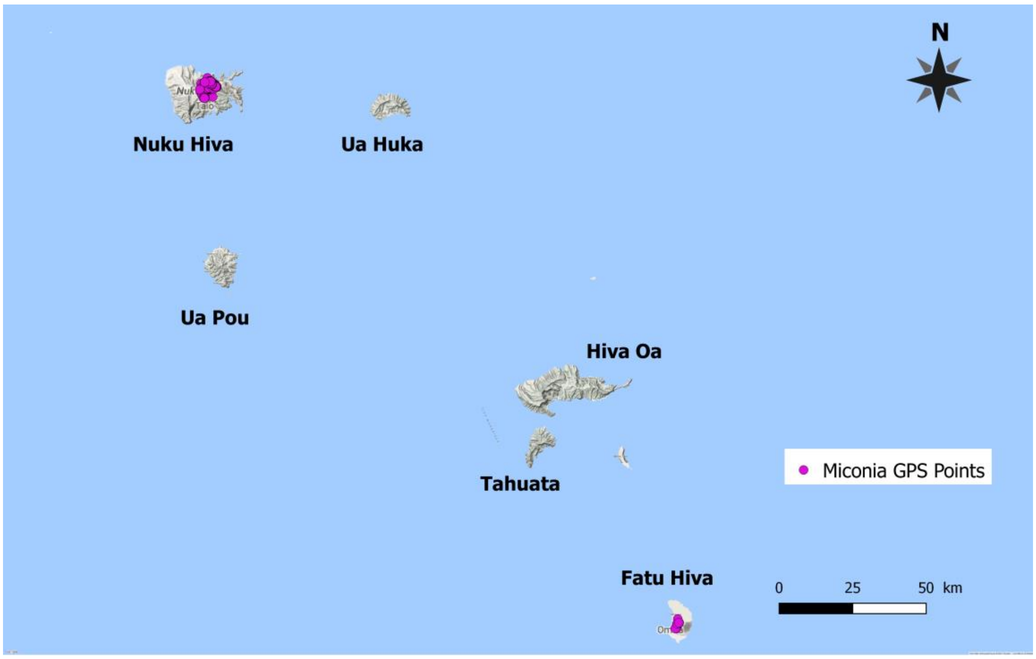

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Figure 2: Map of the Marquesas with reported occurrences of Miconia

2.2.2. The Society Islands, French Polynesia

With 14 islands situated between 16 and 18°S and between 148 and 154°W, the Society is the main group of high volcanic islands in French Polynesia. *Miconia* is already established in four islands of this archipelago: Tahaa, Raiatea, Moorea and Tahiti. We focused on the highly invaded islands of Tahiti and Moorea (hereafter referred as to the Society Islands; Figure 3) because Raiatea and Tahaa are on an early stage of invasion (Meyer and Malet, 1997). The climate of the Society Is. is tropical oceanic with two seasons: a humid and warm season (from October to March) and a drier and cooler season (from April to September). Mean annual temperature is 26°C and annual rainfall averages 1700 mm/year (Laurent et al., 2004).

Tahiti is the highest (2,241 m) and largest island of the Society archipelago (1,045 km²) (Dupon et al., 1993). *Miconia* was introduced for its ornamental value in the Papeari Botanical Garden in 1937 from the Peradeniya Botanical Garden of Sri Lanka by H.W. Smith, an American botanist (Meyer, 1996). Since that time, *Miconia* has spread to occupy 65% of the Tahitian rainforests (Meyer, 2009). In 1982, hurricanes hit Tahiti and probably opened the canopy, favoring growth and reproduction of *Miconia* located in the understory vegetation (Meyer, 1996).

Moorea (130 km²), the nearest island from Tahiti (20 km North from Tahiti), has been invaded by *Miconia* from the 1970's probably dispersed by wind, birds or accidentally introduced by people (e.g. hikers, ornamental plants) coming from Tahiti (Meyer, 1996). It has reached to spread 20-25% of the island.

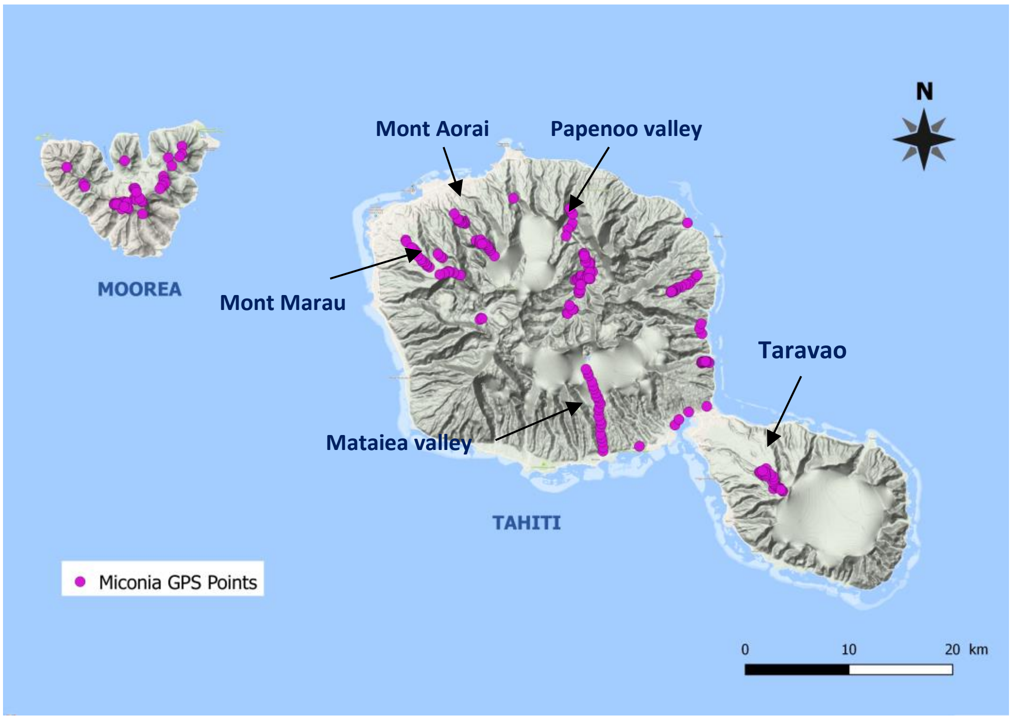

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Figure 3: Map of the Society Is. with reported occurrences of Miconia

2.2.3. The Hawaiian Islands, USA

The Hawaiian archipelago is composed of 132 islands expanding over 2,580 km on the North Pacific Ocean between 154 and 178°W, and between 18 and 28°N. Most of the terrestrial area is concentrated on eight main islands (Figure 4) (Wagner et al., 1990). *Miconia* is present on four of them: Oahu, Hawaii, Maui and Kauai. On these islands, *Miconia* occurs where rainfall reaches at least 1500 mm/year (Medeiros et al., 1997).

Oahu is the first island where *Miconia* has been detected, introduced in the Wahiawa Botanical Garden in 1961.

Miconia then reached Hawaii, the largest island of the archipelago also known as Big Island, in 1964 at the Herbert Shipman estate.

On the island of Maui, an isolated plant was first discovered during a reconnaissance mission by helicopter in 1996 (Chimera et al., 1996) but it is supposed to have reached the island in the late 1960's. The first control effort against *Miconia* was established on this island in 1991.

Kauai is the last island that had been invaded, in the early 1980's (Medeiros et al., 1997).

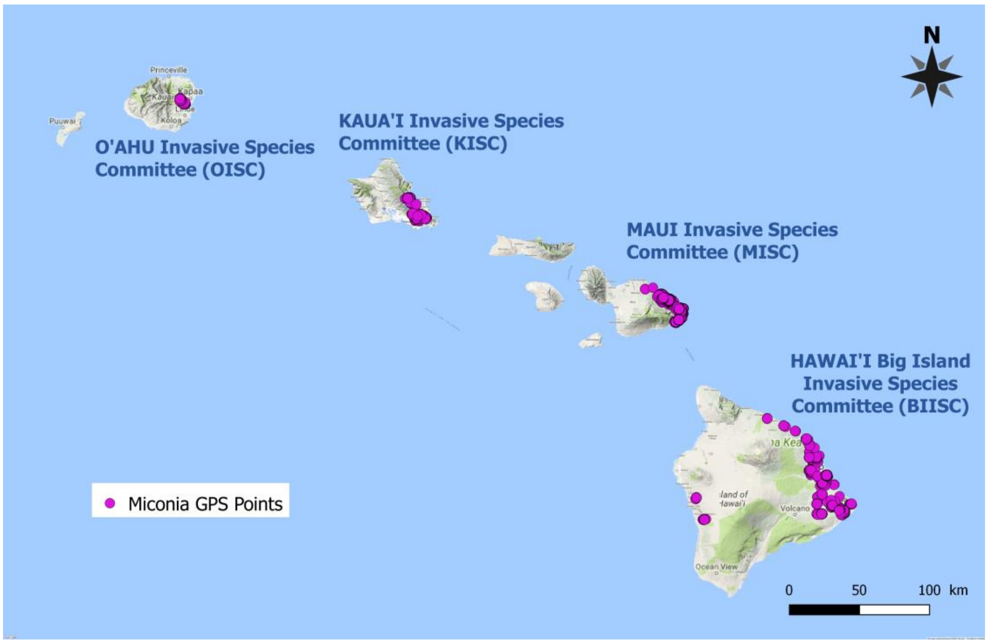

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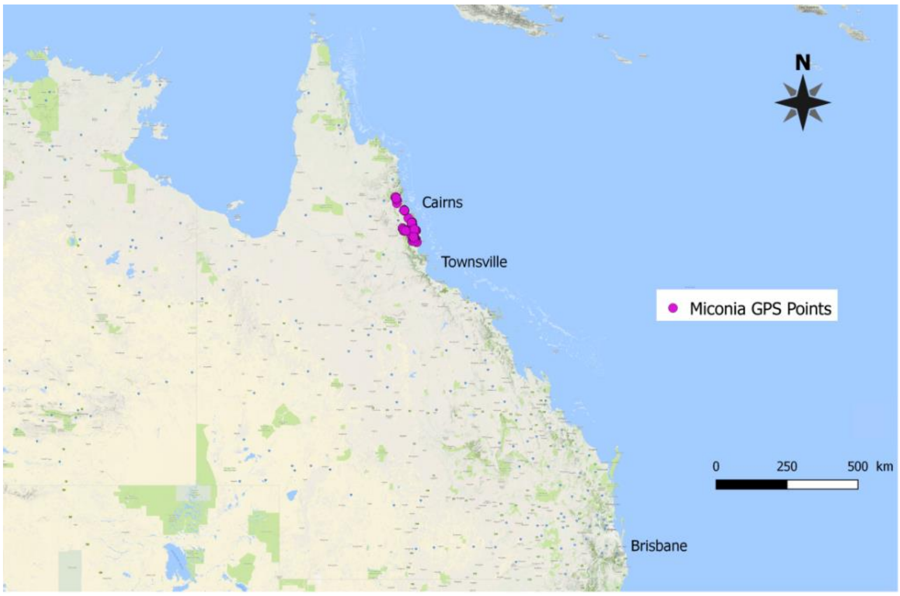
Figure 4: Map of the Hawaiian Is. with reported occurrences of Miconia

2.2.4. Queensland, Australia

Miconia has first been recorded in the Townsville Botanical Garden (Northern Queensland) in 1963. The species has been declared as a noxious plant in Australia in 1997 and an eradication program was launched subsequently (Csurhes, 2008). In Queensland, *Miconia* is found close to nursery stocks and private gardens but some plants have naturalized in neighboring forests and have produced a large quantity of seeds and seedlings. In the wet tropical rainforests of North Queensland, rainfall averages 2,630 mm/year and temperature averages 20°C during the wet season (Congdon and Herbohn, 1993). In this study we will consider the region of Queensland (Figure 5) with an extent ranging from 140 to 153°W and from 12 to 26°S.



©2017 Google / (Data source: National Four Tropical Weed Eradication Program)

Figure 5: Map of the Queensland state with reported occurrences of Miconia

2.2.5. Central America

The region of Central America (8 to 17°N and 77 to 100°W) from southern Mexico to Guatemala where the bicolorous form of *Miconia* is naturally present was considered in this study (Figure 5). There, *Miconia* is found in tropical rainforests, mountain rainforests, dense mixed forests and secondary forests where mean annual precipitation exceeds 2000 mm/year and mean annual temperature averages 22°C (Budowski, 1965; Meyer, 1997). It can be observed up to 1,350 m above sea level in Guatemala according to herbarium specimen (www.tropicos.org). Little information is known about the distribution and the habitat of *Miconia* in its native range where it did not draw most botanists' attention. Most of the available information comes from herbarium specimens.

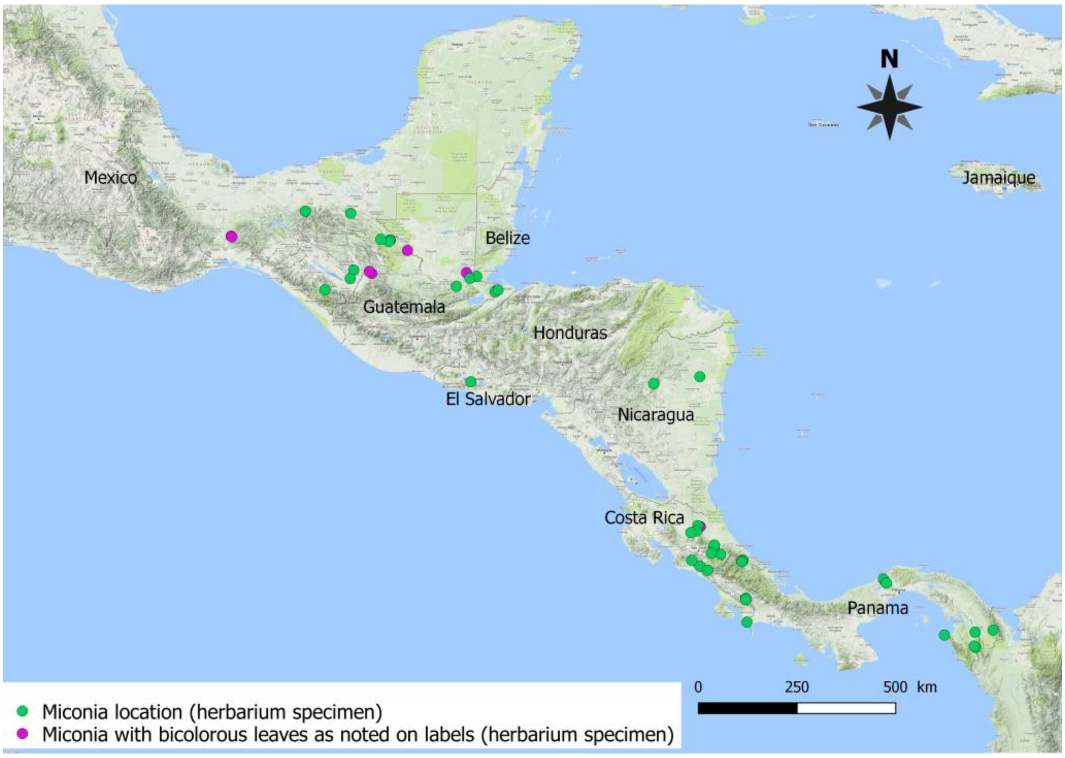


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Figure 6: Map of Central America with reported occurrences of Miconia

Table 1: Summary of the characteristics of the regions and islands used to train species distribution models that will be projected on the Marquesas

Archipelago/ Region	Island	Latitude	Longitude	Area (km²)	Age of Islands (Ma)	Max elevation (m)	*Miconia* Invaded area (%)	*Miconia* Invaded area (ha)
Central America		8-17°N	77-100°W	-	-	4,220	-	-
Queensland, Australia		12-26°S	140-153°W	$1.8x10^6$	-	930	<0.05	50,000**
Hawaiian Is.	Hawaii	19°34'N	155°30'W	10,458	0.4	4,203	5.8	61,000**
	Maui	20°48'N	156°20'W	1,887	1.3-1.15	1,764	6.4	12,000**
	Oahu	21°28'N	157°59'W	1,573	3.6-2.4	1,225	1.8	2,800**
	Kauai	22°05'N	159°30'W	1,433	5.1-3.8	1,598	0.7	1,000**
Society Is.	Tahiti	17°38'S	149°30'W	1,045	1.67-0.25	2,241	75	80,000*
	Moorea	17°32'S	149°50'W	130	2.15-1.36	1,207	25	3,500*
Marquesas	Nuku Hiva	8°51'S	140°08'W	339	4.53-3.62	1,224	<0.01	5*
	Hiva Oa	9°45'S	139°00'W	320	2.55-1.44	1,276	NA	NA
	Ua Pou	9°23'S	140°04'W	105	4-2.35	1,203	NA	NA
	Fatu Hiva	10°29'S	138°40'W	84	1.81-1.11	1,125	<0.01	1*
	Ua Huka	8°53'S	139°32'W	83	3.24-0.76	884	NA	NA
	Tahuata	9°56'S	139°05'W	69	2.11-1.74	1,050	NA	NA

**Estimated range* (Meyer, 2009) ***Calculated according to our occurrence dataset with QGIS*
(Source: Armstrong, 1983; Laurent et al., 2004; Galzin et al., 2016*a)*

2.3. Data acquisition

2.3.1 Occurrence records

A database containing a set of latitude and longitude coordinates of *Miconia* localities has been created for different regions of the world where the species is established (Table 2): Nuku Hiva and Fatu Hiva (n=401), Central America (n=53), Tahiti and Moorea (n=220), the Hawaiian Is. (n=2,040) and in Queensland (n= 282).

In French Polynesia (Tahiti and Moorea in the Society Is., Nuku Hiva and Fatu Hiva in the Marquesas), occurrences were gathered by the "Délégation à la Recherche" (Research Department of French Polynesia or REC), the "Direction de l'Environnement" (Environmental Department of French Polynesia or DIREN) and the "Moorea Biocode Project", a research program coordinated by the University of Berkeley. These inventories were supplemented by field surveys during this study (Appendix 2).

In the Hawaiian Is., the Invasive Species Committee (ISC) also provides us with their sets of occurrence records from the four invaded islands: Oahu (OISC, n=142), Maui (MISC, n=650), Kauai (KISC, n=161) and Big Island (BIISC, n=1,087). There, occurrences were collected in the field or from helicopter flights (Maui) which began in the early 1990's.

The Australian National Four Tropical Weed Eradication Program (4TWP) provided us with their database of *Miconia* records. The program began in 2001, conducting field surveys on foot and sometimes by helicopters (Erbacher et al., 2008).

Herbarium specimens from the Global Biodiversity Information Facility (GBIF; https://www.gbif.org/) and the Tropicos websites (www.tropicos.org) were consulted. In its native range of South and Central America, all specimens identified as *Miconia calvescens* (n=1,485) have been checked in order to make sure that leafs had purple undersides. Among these records, only 18 annotations of purple leaf undersides (bicolor form) were referenced and found in Central America only. The bicolor form seems to be predominant in Central America (Meyer, 1994 and herbarium specimen) and is the only form present in the invaded areas. Thus, in our study we decided to consider occurrences of Central America only (n=53 after cleaning) where most of bicolor population is found.

Table 2: Summary of the occurrence database

Archipelago/ Region	Island	Number of occurrences (raw data)	Number of occurrences(after 'cleaning')	Data source*
Central America		146	53	GBIF, Tropicos
Queensland, Australia		2,665	282	4TWP
Hawaiian Is.	Hawaii	3,924	1,087	BIISC
	Maui	24,534	650	MISC
	Oahu	2,265	142	OISC
	Kauai	1,842	161	KISC
Society Is.	Tahiti	2,213	172	REC (n=18), this study (n=200), UPF (n=1,995)
	Moorea	102	48	REC (n=10), UPF (n=45), Moorea Biocode (n=39), this study (n=8)
Marquesas	Nuku Hiva	370	370	DIREN
	Fatu Hiva	31	31	DIREN
Total		**38,092**	**2,996**	

**Abbreviations meaning see page 32*

Databases were then verified and cleaned by correcting errors such as the use of different units like foot versus meters. We checked and removed duplicate points and data with no latitude and/or longitude value. All points on which *Miconia* might be cultivated i.e. located at less 50 m from habitations and in botanical gardens were removed from the final database. We selected only mature specimens from all regions except from Central America where the maturity status was unknown.

In the Society Is., a lot of occurrences (around 2,000) were recorded in the Papenoo valley (data from Pouteau et al, 2011a), which may introduced a bias in SDM due to an over-representation of a specific environment. Thus, we used the R package 'spThin' to spatially thin (using a distance of 100 m) the database of Tahiti and Moorea (Aiello-Lammens et al., 2014).

2.3.2. Environmental data

2.3.2.1. Climatic data for predicting the risk of invasion in the Marquesas

Climate is one of the most important factors that determine the suitability of a site for a plant to grow (Miller, 2010). Variables were downloaded from the WorldClim version 2 database (http://www.worldclim.org/Fick et Hijmans, 2017), a free climate data model based on records from 1971 to 2000 with a spatial resolution of ca. 1 km. We selected five climatic variables (Table 3) among those proposed by WorldClim according to our knowledge of the physiological needs of *Miconia* and to variable collinearity (Appendix 3).

Table 3: Climatic variables used to predict the risk of invasion of Miconia *in the Marquesas*

Variables	Unit
Average Annual Temperature	°C
Annual Rainfall	mm/year
Precipitation of the driest month	mm
Precipitation seasonality	%
Annual Wind Speed	m/s

As described by Merow et al. (2013) and Dormann et al. (2013), environmental variables are frequently correlated thus collinearity analyses may help in selecting the appropriate variables. We removed highly correlated variables using a correlation analysis implemented by the R package 'corrplot' (Wei et Simko, 2016) based on sites where *Miconia* is known to occur (ca. 3,000 occurrences). When several variables had a correlation coefficient higher than 0.8 (Figure 7), only one of them was kept (e.g we set aside minimum temperature and maximum temperature and kept annual temperature).

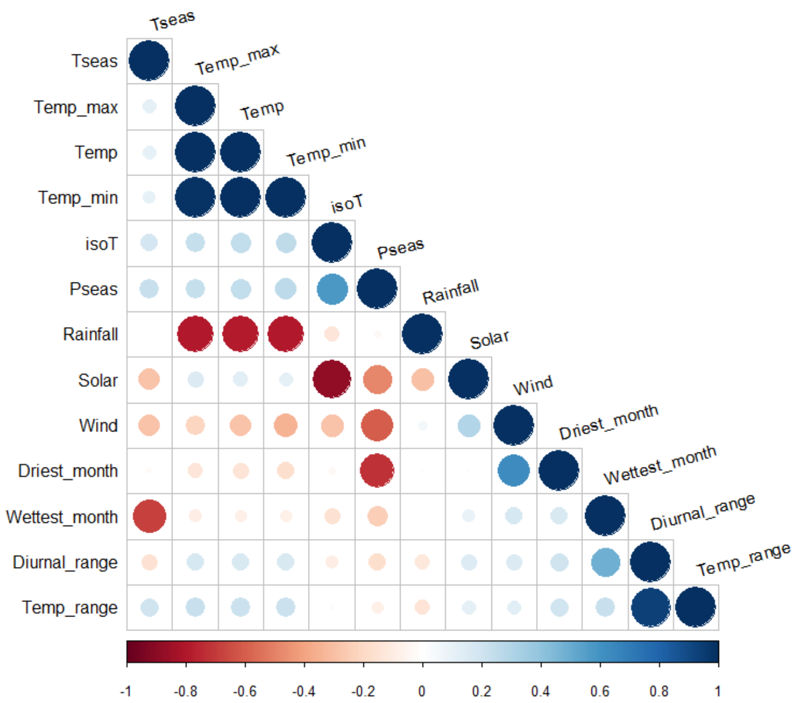


Figure 7: Correlation matrix between Worldclim variables for sites where Miconia *is known to occur (ca. 3,000 occurrence records in all regions)*

We also suppressed variables whose values did not overlap between regions. As an example, isothermality (referring to how large the day-to-night temperatures oscillate relative to the annual variation) in sites of the Society Is. where *Miconia* occurs (ranging from 1718% to 2484%), did not match with isothermality in the Marquesas (ranging from 174% to 539%) (Figure 8).

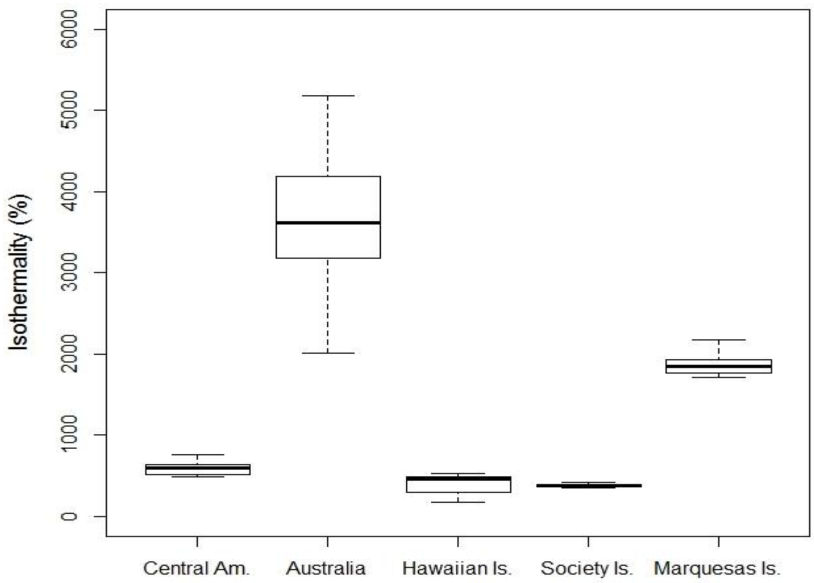


Figure 8: Boxplots of isothermality in the Marquesas and in sites where Miconia *has been reported to occur in the other four regions*

The climatic variables were also used to determine the environmental envelope (i.e the conjunction of ecological conditions within which a species is able to persist and maintain stable population; Grinnell, 1917) where *Miconia* is present. Temperature and precipitation are known to be the best explaining factor for plant growth. Then, identifying the climatic limit (e.g temperature and precipitation) of *Miconia* could help in better understanding the process of invasion (Jiménez-Valverde et al., 2011). Here, for each studied region, we listed the maximum, average and minimum temperature and precipitation of *Miconia* occurrences.

2.3.2.2. Topographic data for refining prospections and guiding management strategies on Nuku Hiva and Fatu Hiva

LaRosa et al. (2007) used four environmental variables to map the distribution of *Miconia* in Hawaii: elevation, precipitation, slope and windwardness. In their study of the invasion in the largest valley of Tahiti (Papenoo), Pouteau et al. (2011a) used rainfall and vegetation data as well as five physiographic descriptors derived from a Digital Elevation Model (DEM): elevation, slope steepness, annual potential insolation, a topographic wetness index and slope exposure. In our study, the same physiographic descriptors were used except slope exposure as it may be collinear with annual potential insolation. As we focused on an entire island as LaRosa et al. (2007) in Hawaii, we added the variable windwardness to our SDM. The 5 m-resolution DEM of the Society Is. and the Marquesas were provided by the "Direction de l'Urbanisme" of the Government of French Polynesia. The 10 m-resolution DEM of the Hawaiian Is. was downloaded on the website of the University of Hawaii (http://www.soest.hawaii.edu/).

Elevation (id. the DEM, expressed in meters) is linearly correlated with air temperature (according to a lapse rate of -0.6°C/100 m) (Baruch and Goldstein, 1999) which is one of the major factors that control vegetation zonation and key processes such as evapotranspiration, carbon fixation, plant productivity and mortality in mountain ecosystems (Chen et al., 1999).

Slope (radian) drives water flux and can influence seed dispersion (Wilson and Gallant, 2000).

The potential solar radiation (kwh/m²) quantifies the energy received by the soil, which appears to have an influence on photosynthesis and evapotranspiration necessary for plants to grow (Fu and Rich, 1999).

The topographic wetness index (TWI) was used to describe the hydrological flow (Equation 1). A low TWI corresponds to a convex area (mountain crest) and a high value a concave area (hillslope bases).

Equation 1

$$TWI = \ln(\frac{As}{\tan(\beta)})$$

Where *As* refers to the specific catchment area (m²) (id. The flow accumulation) and β to the slope steepness (radian) (Gessler et al., 2000). We measured TWI by calculating *As* then using the 'raster calculator' in QGIS to apply Equation 1.

Windwardness refers to a windward/leeward unidimensional index (Böhner et Antonić, 2009) that takes a value above 1 for areas exposed to wind and below 1 for wind shadowed areas. Calculation requires specifying the dominant wind direction. Thus, for each island, wind direction has been defined according to meteorological stations (Laurent et al., 2004; Armstrong, 1983).

Topographic variables were derived from the DEM with the software SAGA (System for Automated Geoscientific Analyses), a free open source extension of QGIS (Conrad et al., 2015).

2.3.3. Species distribution modelling

Among the existing statistical methods used to model species distributions, we chose the maximum entropy modeling (MaxEnt) approach, an SDM renowned to be easy to use and to perform well (Merow et al., 2013). This SDM method is based on presences and pseudo-absences (randomly selected points where the absence of the target species is assumed), which is interesting in our study in which absence data were lacking (Phillips et al., 2006). An SDM operates by modelling statistical relationships between occurrence location of a species and environmental variables (or constraints). MaxEnt is based on the maximum entropy approach (i.e it minimizes the relative entropy between the probability density estimated for the presence records and that for the landscape) which estimates a distribution probability for each pixel in the study area satisfying the given constraints (Phillips et al., 2006).

MaxEnt takes occurrence data and a set of environmental or climatic layers as input with a user-defined extent divided into grid cells. From this extent, absence data necessary for running the model will be randomly extracted (Merow et al., 2013). MaxEnt provides a species potential distribution map of the input layer area, a table with the variables contribution to the models and a receiver operating characteristics (ROC) curve as output. MaxEnt can also be used to project a species potential distribution from an invaded area over a new area by putting in the projection directory the environmental variables of this new area. In this study, MaxEnt was used with default parameters.

In order to evaluate the SDM, we used the area under the receiver operating characteristics curves (AUC), a common metric to evaluate the performance of a model (Phillips et al., 2006). The ROC curve is a plot of *sensitivity* (i.e. presence correctly predicted as presences) on the y-axis and *1-specificity* (i.e. absences correctly predicted as absences) on the x-axis. Sensitivity is the conditional probability that an occurrence is correctly classified as invaded or a random absence point is classified as non-invaded. Specificity is the inverse: it is the conditional probability that an occurrence is not correctly classified as invaded or a random absence point is not classified as non-invaded. The value of AUC was used to compare SDM performances (Phillips et al., 2006). A random model is expected to have an AUC of 0.5 and a model with an AUC of 1 will be considered as perfect. The AUC is a useful indicator to estimate the accuracy of an SDM but it should to be used with caution, as (1) it is calculated from occurrences used to calibrate the SDM and not from occurrences in the newly invaded area (the Marquesas in our case), and (2) a higher geographical extent will give a higher AUC. As a result, we can hardly compare AUC between SDM calibrated from different study areas (Lobo et al., 2007).

We therefore computed a new evaluation metric to be able to compare SDM outputs. This metric aims at quantifying whether an SDM distinguishes between invaded sites in the new area and the background habitat suitability. It was calculated as the mean probability over invaded sites in the Marquesas σ(invaded.sites) divided by the mean probability over the whole island σ(island).

The SDM built to predict the risk of invasion in the Marquesas archipelago (based on climatic data) were calibrated with each region (Central America, Queensland, Hawaiian Is. and Society Is.) taken individually then with all regions together. We thus obtained five potential distribution maps in the Marquesas.

The SDM built to refine prospections and guide management strategies on Nuku Hiva and Fatu Hiva (based on topographic data) were calibrated with Big Island (10,458 km²) taken individually due to limited computational resources, the rest of Hawaiian Is. (Oahu, Maui and Kauai) and the Society Is. As a result, we obtained three local-scale maps of the potential distribution of *Miconia* on Nuku Hiva and Fatu Hiva.

3. Results

3.1. Predicting invasion risk of Miconia *in the Marquesas*

The SDM fitting the climatic envelope occupied by *Miconia* in Australia yielded the highest AUC (0.994) and the SDM based on the Central American distribution of the species predicted invaded sites on Nuku Hiva 5.6 times better than random (Table 4). In contrast, the SDM calibrated on the Society Is. produced the lowest AUC (0.890) and did not predict invaded sites on Nuku Hiva better than random.

Table 4: Precision of the SDM based on climatic variables calibrated from occurrences of the studied regions

	Central America	Australia	Hawaiian Is.	Society Is.	All regions
AUC	0.96	0.99	0.95	0.89	0.98
σ(invaded.sites)/σ(island)	5.6	3.9	1.9	1.0	2.5

Each SDM presented a different pattern of variables contribution (Figure 9). Rainfall made the greatest contribution in the SDM based on Central America (67.9%) and all regions taken together (42.3%), precipitation of the driest month was the most contributing variable in the SDM based on Australia (81.5%), average temperature in the SDM based on the Hawaiian Is. (32.1%) and precipitation seasonality in the SDM based on the Society Is. (32.3%).

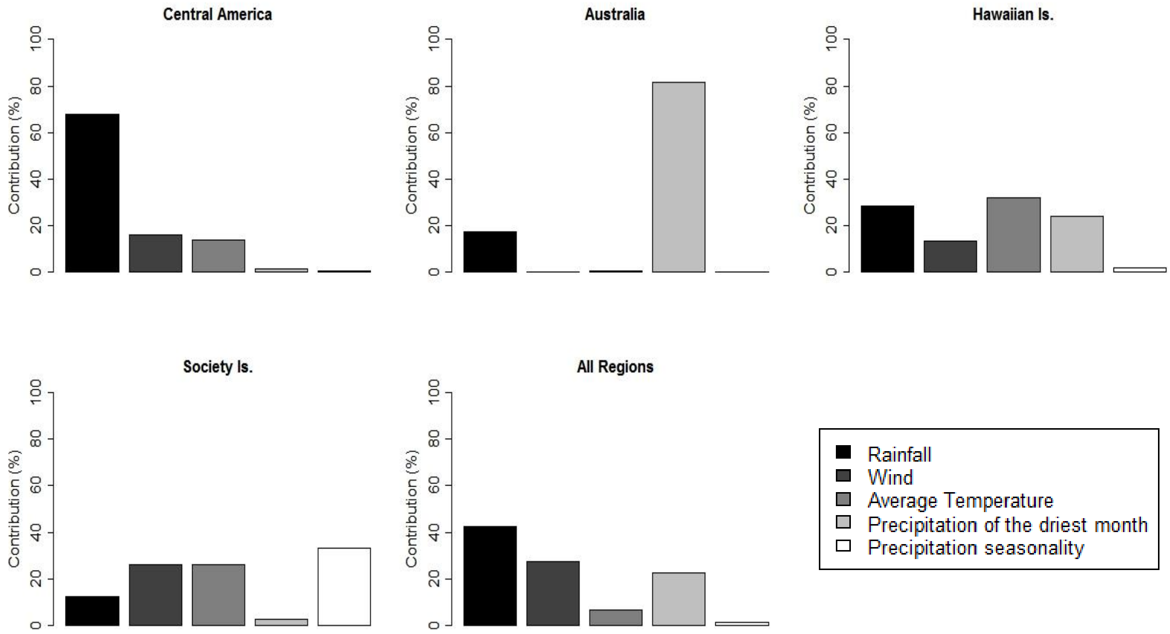
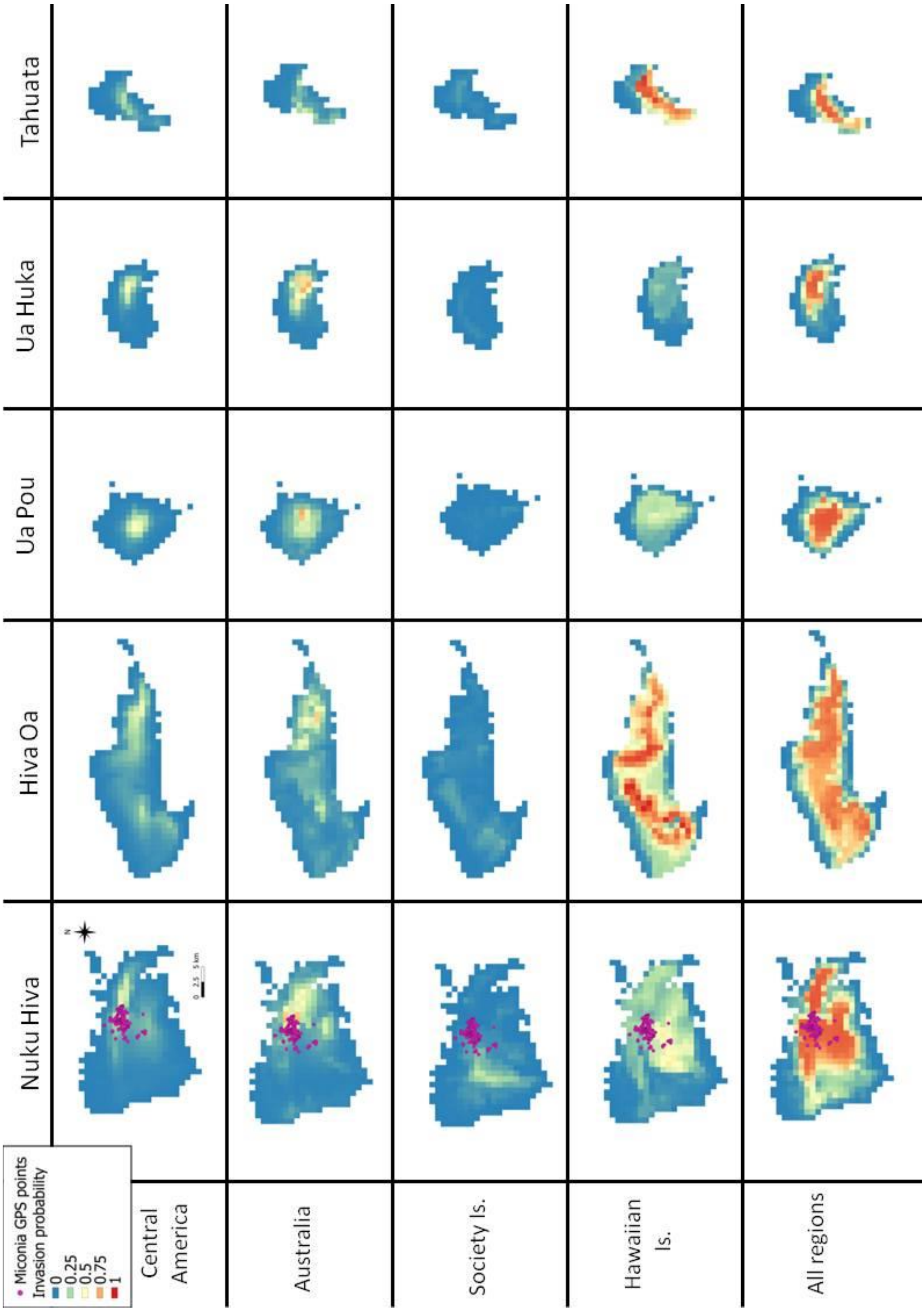


Figure 9: Contribution of the climatic variables for the SDM calibrated from occurrences of the studied regions

According to the SDM used to fit the distribution of *Miconia* in the Hawaiian Is. and all regions taken together, the islands of Hiva Oa, Ua Huka, Ua Pou and Tahuata, where *Miconia* is still absent, appeared to be potentially suitable for *Miconia* (Figure 10). Our result also showed that *Miconia* has the potential to spread over a large area of mid-elevation and mountain forests on the island of Nuku Hiva if *Miconi*a reaches its equilibrium. The SDM built from the distribution of *Miconia* in Central America and Australia described lower invasion probabilities and more localized areas situated in the east coast of Nuku Hiva, Hiva Oa and Ua Huka. Overall, the SDM based on the Society Is. predicted low invasion risk in all Marquesas.

Figure 10: Potential distribution of Miconia *in the Marquesas based on climatic variables.*



Fatu Hiva Island is not represented here, since it is not present in the Worldclim database

According to Worldclim database, the climatic variables indicated a lower temperature limit of 17°C and lower precipitation limit of 1,400 mm/year for *Miconia* (Table 5). The highest temperature was found in Central America (28.4°C) and the highest precipitation was found in the Queensland (6,050 mm/year). *Miconia* is situated in environment with precipitation averaging ca. 2,500 mm/year and temperature averaging ca. 23°C.

Table 5: Climatic envelope of Miconia *in its native range (Central America) and different regions where it has become invasive*

Archipelago /Region	Island	Area (km²)	Min Rainfall *Miconia* (mm/year)	Average* Rainfall *Miconia* (mm/year)	Max Rainfall *Miconia* (mm/year)	Min T°C *Miconia* (°C)	Average* T°C *Miconia* (°C)	Max T°C *Miconia* (°C)
Central America			1,400	2,800 ±90	4,400	19.2	23.8 ±0.2	28.4
Queensland, Australia		1.8×10^6	1,550	3,650 ±50	6,050	18.6	23.2 ±0.1	27.6
Hawaiian Is.	Hawaii	10,458	1,500	2,550 ±10	3,200	17.8	22.0 ±0.1	25.4
	Maui	1,887	2,100	2,800 ±40	5,100	17.2	21.8 ±0.1	24.8
	Oahu	1,573	1,560	2,650 ±60	4,920	17.6	22.5 ±0.1	25.4
	Kauai	1,433	1,640	2,850 ±90	2,980	18.2	22.8 ±0.1	26.3
Society Is.	Tahiti	1,045	1,790	1,950 ±10	2,100	20.1	23.9 ±0.1	27.9
	Moorea	130	1,720	1,830 ±10	1,980	19.9	23.3 ±0.1	26.6
Marquesas	Nuku Hiva	339	1,660	2,130 ±10	2,400	20.3	23.4 ±0.1	26.6
	Fatu Hiva	84	NA	NA	NA	NA	NA	NA
Mean			**1,660**	**2,580** ±190	**3,680**	**18.8**	**23.0** ±0.2	**26.5**

Source: Rainfall and temperature data come from Worldclim bioclimatic variables (Fick and Hijmans, 2017). *Area from* Armstrong (1983) and Laurent et al. (2004). **average ± standard error*

3.2. Refining prospection areas and guiding management strategies on Nuku Hiva and Fatu Hiva

The SDM based on topographic variables and the distribution of *Miconia* in the Society Is. had an AUC of 0.77 and predicted invaded area 1.2 times better than random (Table 6). Even if the other models had higher AUC, they did not predict invaded sites on Nuku Hiva and Fatu Hiva better than random with 0.8 and 0.4 for Big Island and Oahu, Kauai, Maui respectively.

Table 6: Precision of the SDM based on topographic variables calibrated from occurrences of the studied regions

	Society Is.	Big Island	Oahu, Kauai, Maui
AUC	0.77	0.92	0.87
σ(invaded.sites)/σ(island)	1.2	0.8	0.4

For the SDM based on the Society Is., slope seemed to best explain the distribution of *Miconia* with 37.6% of contribution. The SDM based on the Hawaiian Is. (Big Island and Oahu, Kauai, Maui) presented the same pattern of variable contribution with elevation making the greatest contribution (75.5% for Big Island and 48.6% for Oahu, Kauai and Maui) followed by windwardness (19.6% for Big Island and 41.8% for Oahu, Kauai and Maui) (Figure 11).

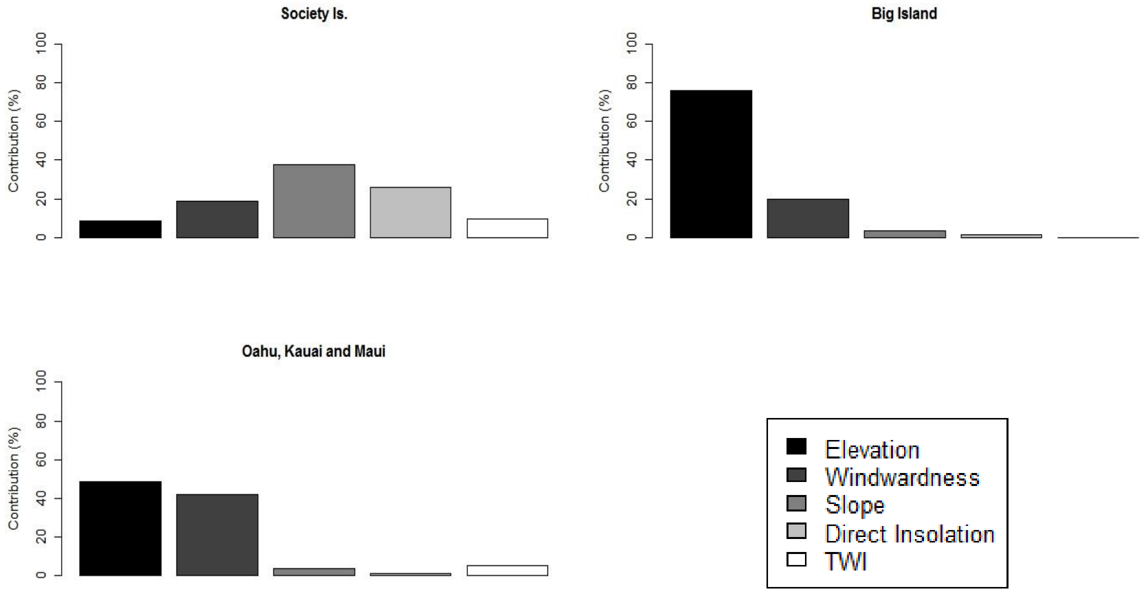
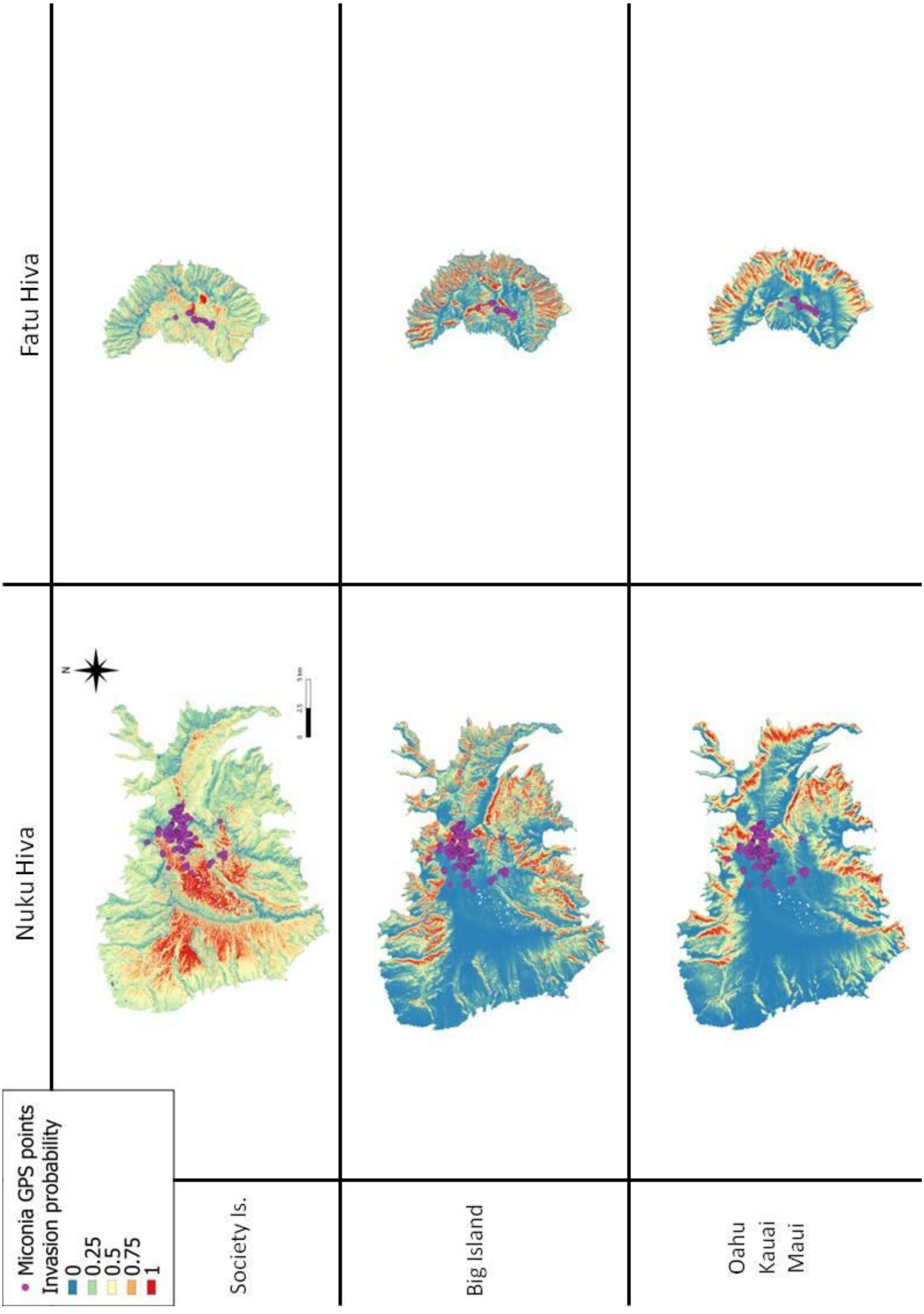


Figure 11: Contribution of the topographic variables for the SDM calibrated from occurrences of the studied regions

The most accurate results obtained with topographic variables from the Society Is. showed that 46% of the island of Nuku Hiva and 33% of Fatu Hiva present suitable environmental condition for *Miconia* (invasion probability>0.5) (Figure 12). However, the SDM based on the Hawaiian Is. predicted less potential invaded areas only located on the island coast whereas current *Miconia* plants are situated in the land.

Since we obtained a fairly good precision (Table 6) and best distribution with the SDM calibrated with the Society Is., we have also predicted the potential distribution of *Miconia* in the Marquesas islands where it is still absent (Hiva Oa, Ua Pou, Ua Huka, Tahuata; Appendix 4).

Figure 12: Potential distribution of Miconia *in the Island of Nuku Hiva and Fatu Hiva based on topographic variables*



3. Discussion

The distribution of *Miconia* has been extensively explored in already highly invaded areas based on SDM (e.g. on Tahiti (Pouteau et al., 2011a) and Moorea (Pouteau et al., 2011b)) and in areas at a relative early stage of invasion (e.g Big Island (LaRosa et al., 2007)). However, the potential distribution of the species had never been assessed in newly introduced areas. More generally, scientists using SDM are often reluctant to project the distribution of an invasive species from an area to another because of theoretical limitations associated with the fact that different areas may host different recipient communities (Gallien et al., 2010). Here, we used several SDM based on the native and the invaded range of *Miconia* and we observed both convergences and divergences between SDM. This multi-region approach provides valuable information for local stakeholders on what could be expected in the future and the associated level of confidence.

3.1. Invasion risk of **Miconia** *in the Marquesas*

SDM based on climatic variables indicated that *Miconia* has the potential to spread over most islands in the Marquesas where it is still absent (Figure 10). The SDM built from occurrences of *Miconia* in the Hawaiian Is. and all regions taken together converged and predicted a wider potential distribution than the SDM based on occurrences in Central America and Australia. The SDM that predict the widest distribution of *Miconia* should focus the attention of stakeholders because they reflect the nature of invasive species and predict the worst situation to be considered (Jiménez-Valverde et al., 2011).

The SDM based on the Society Is. appears to be the least consistent because it fails to predict high risk areas in the Marquesas where some islands are already experiencing alarming invasion. There are several possible interpretations of this result such as the accuracy of input environmental data sets. Indeed, Worldclim presents high uncertainties on the Pacific Islands due to a low number of weather stations in some remote islands and specific microclimates inherent to islands (Hijmans et al., 2005; Fick et Hijmans, 2017). A high level of uncertainties could also exists in the Marquesas archipelago where only 11 weather stations have been set up (five in Nuku Hiva, three in Hiva Oa, and one in Ua Huka, Ua Pou and Fatu Hiva) (Laurent et al., 2004). This could explain why we do not have a high probability of invasion with the SDM based on the Society Is. and why we do not have the same variable contributions depending on the studied regions.

The native region of Central America has a relatively low number of occurrences which could have under-predicted the potential distribution of *Miconia* in the Marquesas. The relative early stage of invasion in Australia and the Hawaiian Is. could also have affected the resulting maps. For the above mentioned reasons, the SDM calibrated with all regions taken together may have produced the most reliable potential distribution of *Miconia* in the Marquesas.

3.2. Invasion risk of Miconia *on Nuku Hiva and Fatu Hiva*

The SDM obtained from topographic variables and based on the Hawaiian Is. diverged from the SDM based on the Society Is. and the latter appear to better predict the current invaded sites on Nuku Hiva and Fatu Hiva than the former (Table 6). According to results obtained from Society Is., *Miconia* could spread over a large area of mesic to wet vegetation and mountain cloud rainforests, where endemic and endangered species are found on the islands of Nuku Hiva and Fatu Hiva (Figure 12).

The SDM based on the Hawaiian Is. are the least consistent because they predicted potential invaded areas mainly located on lowland dry coasts of Nuku Hiva and Fatu Hiva where we suspect that *Miconia* will not spread because of unfavorable ecological conditions. This result could be due to different stages of invasion between the Society and the Hawaiian Is. On Tahiti, *Miconia* has been established for almost 80 years so that we hypothesize that the species has reached its equilibrium distribution. In the Hawaiian Is., *Miconia* may have not reached all potential areas because it has been introduced later (50 to 60 years ago) and intensive controls made by the Invasive Species Committees may have limited its expansion. As a result, we noticed that *Miconia* is not found above 870 m on the Hawaiian Is. whereas it is present up to 1,315 m on Tahiti. As elevation best explains the potential distribution of *Miconia* in the Hawaiian Is., the SDM based on those islands can hardly predict the potential distribution of *Miconia* in the Marquesas.

3.3. Management recommendations

Based on our most accurate predicted *Miconia* invasion in the Marquesas, we would recommend strengthening biosecurity control on islands where *Miconia* is still thought to be absent but has the potential to become invasive (Hiva Oa, Ua Pou, Ua Huka, Tahuata). The most cost-effective method of control with invasive species is to prevent their introduction in new area where they have a high risk of invasion (Genovesi, 2005).

On Nuku Hiva where *Miconia* has expanded rapidly over the past few years, eradication seems unrealistic and pragmatic conservation strategies should be urgently adopted in order to control *Miconia* in the most sensitive sites (e.g. populations of protected/endangered species, key habitats). On Fatu Hiva, eradication efforts should be reinforced to prevent the island from what Nuku Hiva is experiencing.

4. Conclusion and future work

The accuracy of SDM projected in the Marquesas can be improved by acquiring more reliable climatic variables and collecting more occurrence data, especially in Tahiti, Moorea and Central America. The availability of precipitation and temperature maps in the Marquesas is a major issue for scientific research in the field of ecology.

Our most accurate results obtained with climatic and topographic variables could be used to predict the potential invasion of *Miconia* in other tropical islands or countries where the species has been introduced (e.g. New Caledonia, Sri Lanka, Papua New Guinea, (Meyer et al., 2011)) or where it is still absent. It could also be applied to other plant species invasive in French Polynesia and other Pacific Islands (e.g the trees *Spathodea campanulata*, *Psidium cattleianum*, *Albizia moluccana*).

In a future work, it would be valuable to include vegetation maps of the Islands in SDM in order to refine potential distribution maps by excluding vegetation types unsuitable for *Miconia* even if climate and topography are suitable (e.g grasslands, fernlands). This could improve the prediction of areas to be surveyed by managers and control teams. We could also investigate how future climate change could alter the distribution of *Miconia* in the Marquesas and calculate uncertainties linked with the SDM used.

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List of abbreviation

4TWP	National Four Tropical Weed Eradication Program
As	Specific catchment area
AUC	Area under the curve
BIISC	Big Island Invasive Species Committee
CABI	Centre for Agricultural Biosciences International
DEM	Digital Elevation Model
DIREN	Environmental Department of French Polynesia
GBIF	Global Biodiversity Information
Is.	Islands
ISC	Invasive species committee
IUCN	International Union for Conservation of Nature
KISC	Kauai Invasive Species Committee
MaxEnt	Maximum entropy
MISC	Maui Invasive Species Committee
OISC	Oahu Invasive Species Committee
REC	Research Department of French Polynesia
ROC	Receiver Operating Characteristics
SAGA	System for Automated Geoscientific Analyses
SDM	Species Distribution Model
T°C	Temperature
TWI	Topographic Wetness Index
UPF	University of French Polynesia

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Appendix

Appendix 1: A) Two isolated plants of Miconia *in the Mont Marau, North coast of Tahiti (1,316 m elevation), B) Highly invaded area in the Mataiea valley, east coast of Tahiti (100-200 m elevation)*

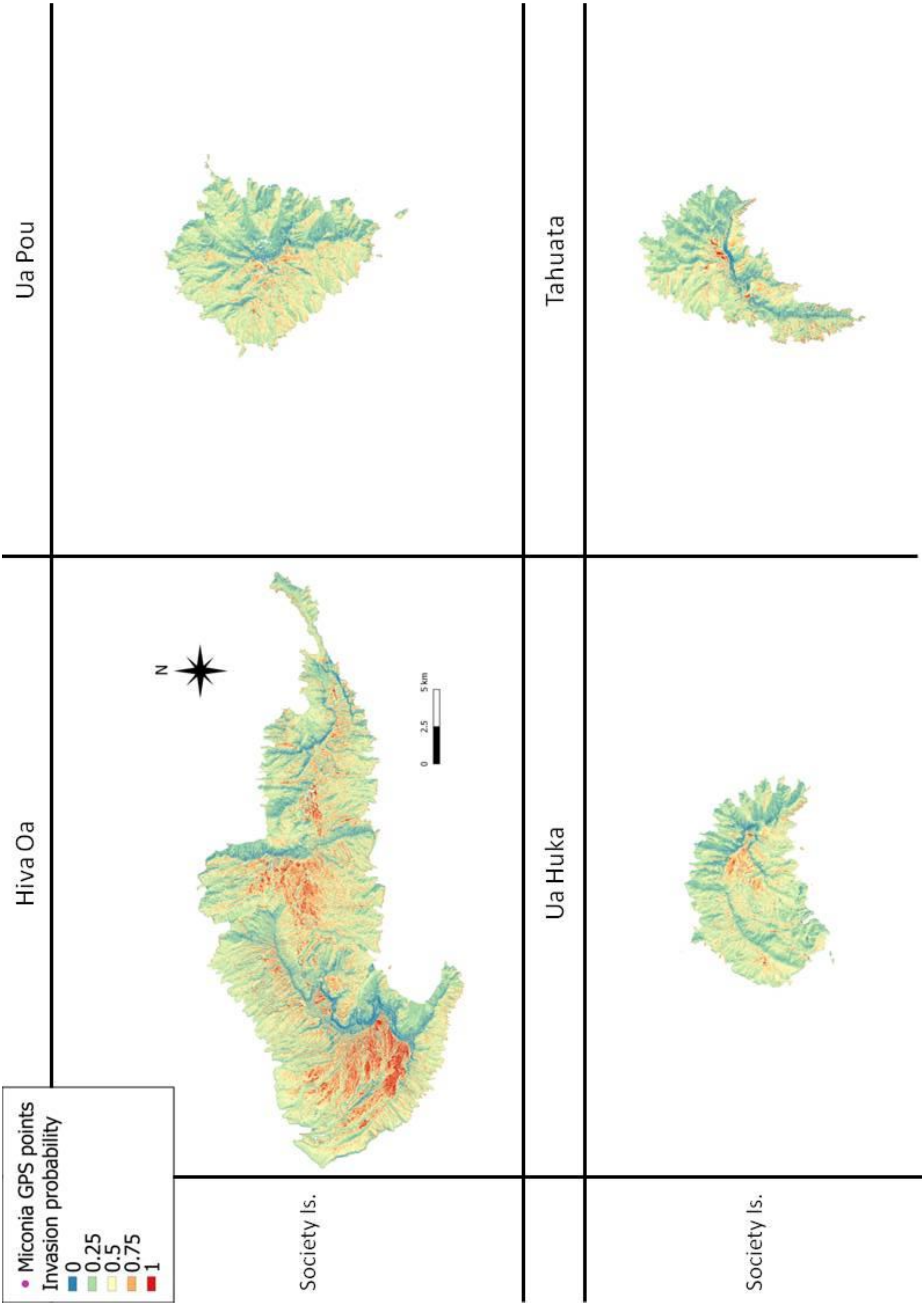
Appendix 2: Summary of Miconia *occurrences collected in the field on Tahiti and Moorea*

Site	Date	Botanist	Number of points	Maturity
Mont Aorai	11/05/2017	Ravahere TAPUTUARAI	10	Mature
Maraetia	28/05/2017	Jean-Yves MEYER	5	Mature
Mont Marau	21/06/2017	Jean-Yves MEYER	26	Mature
Belvedere Pirae	26/06/2017	Ravahere TAPUTUARAI	17	Mature
Moorea	20/07/2017	Ravahere TAPUTUARAI	8	Mature
Mont Aorai	21/07/2017	Ravahere TAPUTUARAI	15	Mature
Taravao	26/07/2017	Ravahere TAPUTUARAI	18	Mature
Plateau de Taravao	03/08/2017	Ravahere TAPUTUARAI	5	Mature
Belvedère Taravao	17/08/2017	Ravahere TAPUTUARAI	17	Mature
Vallon de Taravao	17/08/2017	Ravahere TAPUTUARAI	17	Mature
Mont Marau	22/08/2017	Jean-Yves MEYER	13	Mature
Jardin botanique Papeari	01/09/2017	Jean-Yves MEYER	1	Mature
Côte ouest	01/09/2017	Jean-Yves MEYER	8	Mature
Plateau de Tupa	07/09/2017	Jean-Yves MEYER	2	Mature
Faaone	08/09/2017	Ravahere TAPUTUARAI	11	Mature
Hitiaa	12/09/2017	Ravahere TAPUTUARAI	14	Mature
Vallée de Mataiea	26/09/2017	Jean-Yves MEYER	21	Mature
	Total Tahiti		**200**	
	Total Moorea		**8**	

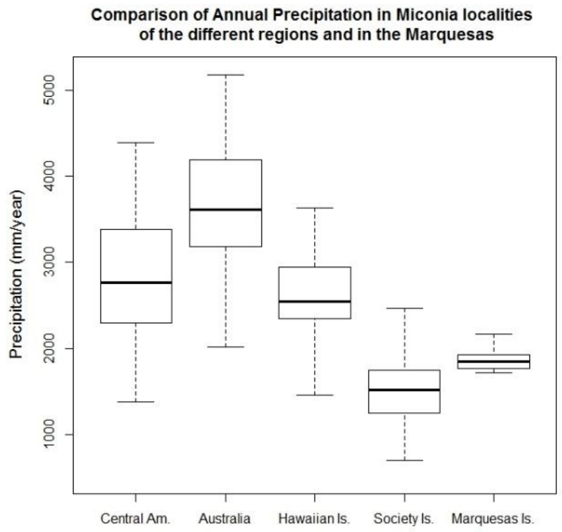
Appendix 3: Table summarizing the climatic variables studied and the reasons why we kept or rejected them

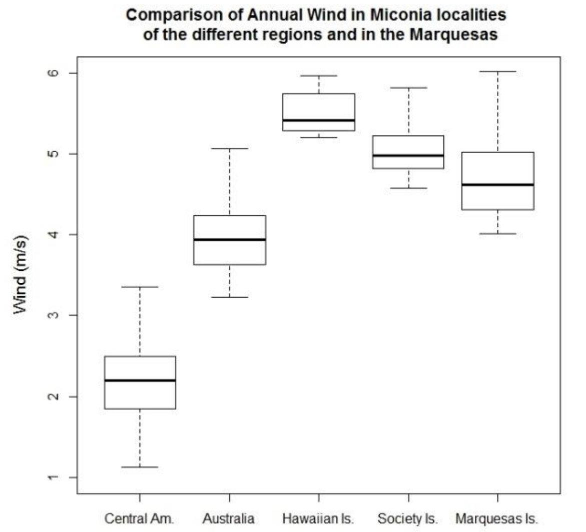
Worldclim variables	Unit	Abbreviation	Reasons
Average Annual Temperature	°C	Temp	selected
Annual Rainfall	mm/year	Rainfall	selected
Annual Wind speed	m/s	Wind	selected
Isothermality	%	IsoT	values didn't overlap between regions
Maximum Temperature	°C	Temp_max	correlation > 0.8 with average annual temperature
Minimum Temperature	°C	Temp_min	correlation > 0.8 with average annual temperature
Precipitation of Driest month	mm	Driest_month	selected
Precipitation of Wettest month	mm	Wettest_month	values didn't overlap between regions
Precipitation Seasonality	%	Pseas	selected
Annual Mean Diurnal Range	°C	Diurnal_range	values didn't overlap between regions
Annual Temperature Range	°C	Temp_range	values didn't overlap between regions
Solar Radiation	kJ/m²/j	Solar	correlation > 0.8 with average annual temperature
Temperature seasonality	%	Tseas	values didn't overlap between regions

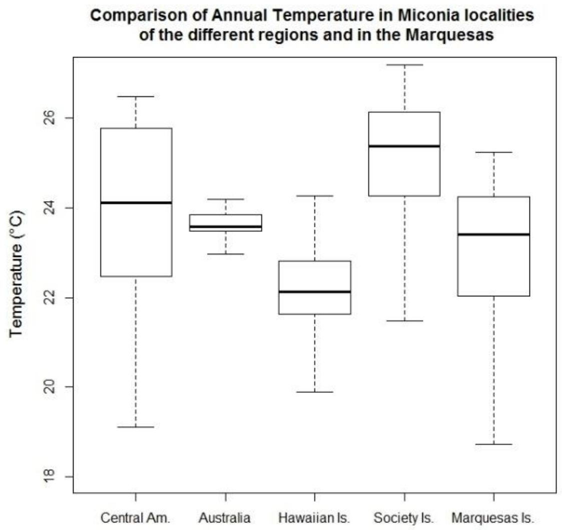
Appendix 4: Potential distribution of Miconia *in the Islands of Hiva Oa, Ua Huka, Ua Pou and Tahuata based on topographic variables*

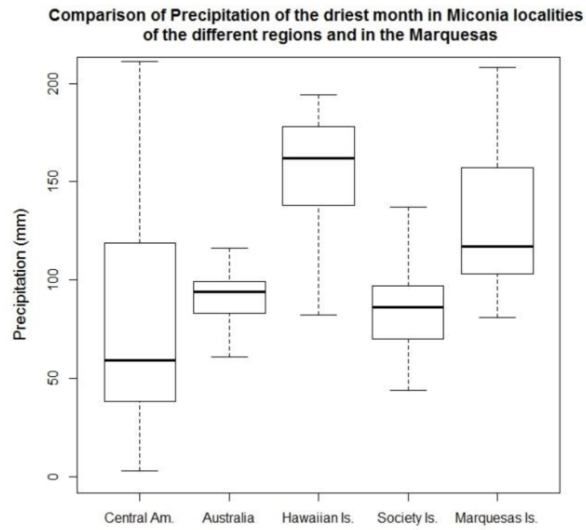


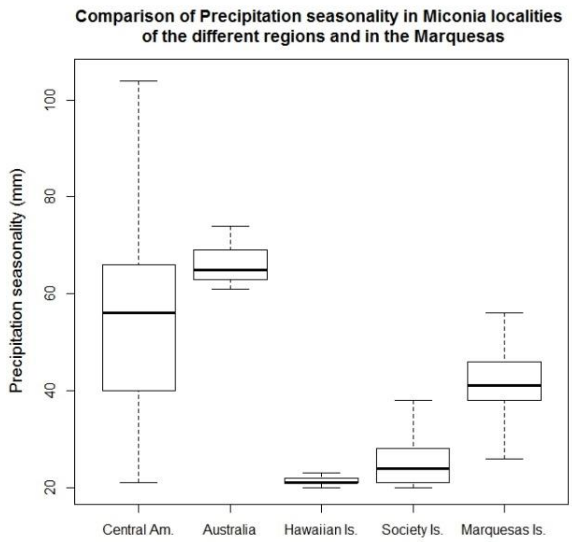
Appendix 5: Boxplots of the five climatic variables in the Marquesas and in sites where Miconia *has been reported to occur in the other four regions*











Appendix 6: Raw data used for building the graphs of contribution variables

Contribution of the climatic variables (%)					
	Central America	Australia	Hawaiian Is.	Society Is.	All regions
Rainfall	67.9	17.6	28.7	12.2	42.3
Wind	16	0.1	13.3	25.9	27.4
Average Temp.	13.9	0.8	32.1	26.1	6.4
Precipitation of the driest month	1.7	81.5	24	2.6	22.6
Precipitation seasonality	0.4	0	1.9	33.2	1.3

Contribution of the topographic variables (%)			
	Society Is.	Big Island	Oahu, Kauai, Maui
DEM	8.5	75.7	48.6
Windwardness	18.8	19.6	41.8
Slope	37.6	3.3	3.6
Direct Insolation	25.7	1.3	0.9
TWI	9.5	0.1	5.1

Appendix 7: Poster presented to the Island Invasives conference in Dundee (Scotland in July 2017)

Predicting the risk of plant invasion on islands: *Miconia calvescens* in the Marquesas, French Polynesia (South Pacific)

Mélanie Libeau[1,2], Robin Pouteau[3], Ravahere Taputuarai[4] & Jean-Yves Meyer[1]

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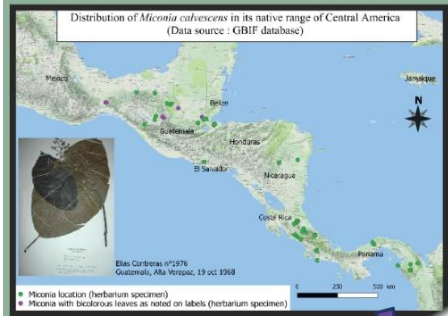
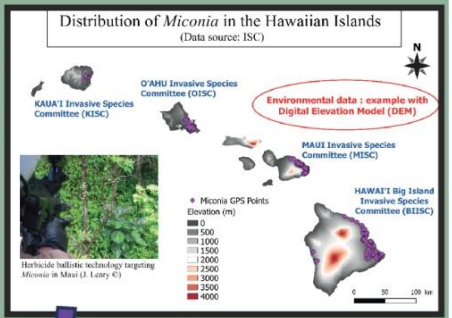
Introduction: Predicting the potential distribution of alien plant species in newly introduced areas where they are found in small numbers is crucial for management (Lockwood *et al.* 2007). Indeed, predictive models can be useful tools to assess the risk of invasion and refine the areas for further surveys and control. *Miconia calvescens* (Melastomataceae) is classified among the 100 world's worst invasive alien species (Lowe *et al.* 2000). This small tree (4-12 m) native from Central and South American tropical rainforests has become a dominant plant invader in the Society Islands (French Polynesia), the Hawaiian Islands (USA) and the Queensland region of Australia where it was introduced between the 1930's and the 1960's as an ornamental plant because of its large leaves with purple undersides (Meyer *et al.* 2011).

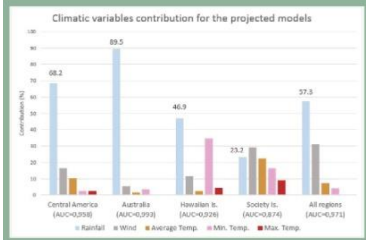


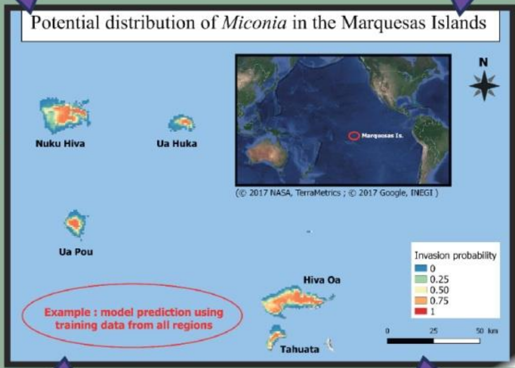
Objectives: Our goal was to project the environmental envelope occupied by *Miconia* in its native and introduced range (Tahiti and Moorea in the Society Is., the Hawaiian Is., Australia) onto the Marquesas which is considered as a « biodiversity hotspot » in French Polynesia (Galzin *et al.* 2016) and where *Miconia* has been recently introduced (in the 1990's).

Material and methods: We used maximum entropy modelling (MAXENT) to project *Miconia*'s potential distribution onto the Marquesas by combining occurrences collected in the field (in its introduced range) or extracted from herbarium specimens (in its native range) with five WorldClim climatic variables: rainfall, wind, minimum, maximum, and average temperature.

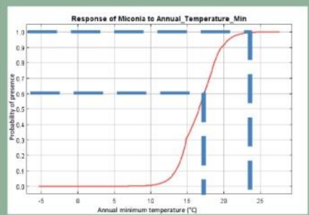


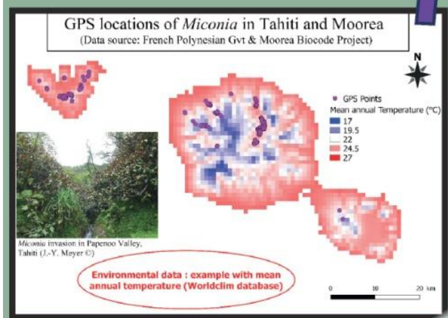
Results 1: *Miconia* potential distribution maps in the Marquesas were produced by projecting climatic variables from Central America, Australia, the Hawaiian and the Society Is., first separately then all together. Rainfall is making the greatest contribution to models for all regions except the Society Is. (see graph below).



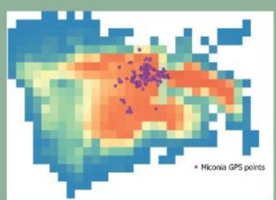


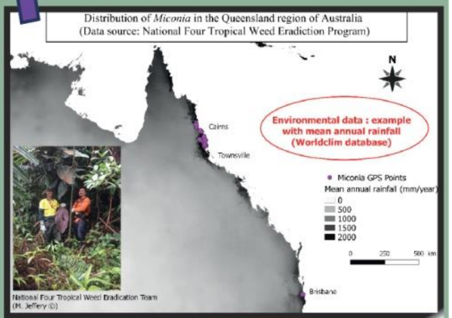
Results 2: The *Miconia* environmental envelope (« ecological niche » *sensu* Warren 2012) has been identified using all available databases. It indicates a lower temperature limit of 17°C and a lower mean annual rainfall limit of 1500 mm/year. The model performed with all regions gives a probability of *Miconia* presence of 60% at 17°C, reaching 100% at 24°C (see graph below).





Conclusion 1: The best predictive model for the Marquesas is the one built from all regions together that gives an AUC of 0.97 and where 97% of current *Miconia* occurrences in Nuku Hiva have a habitat suitability > 0.75 (see figure below).





Conclusion 2: The predicted maps consistently confirm that *Miconia* has the potential to spread over a large area of native lowland rainforest and montane cloud forest in Nuku Hiva unless appropriate control strategies are rapidly adopted. Because most islands where *Miconia* is still absent in the Marquesas (Ua Huka, Ua Pou, Hiva Oa, and Tahuata) appear potentially suitable for the species, biosecurity measures should also be strengthened.

Future prospects: Our next step is to perform MAXENT modelling with topographic variables extracted from fine scale (< 100 m²) digital elevation models which might be more reliable than climatic variables at relatively coarse resolution (1 km²) with uncertainties on remote oceanic islands (Hijmans *et al.* 2005). The final model could be applied to better predict the potential distribution of *Miconia* in other tropical islands and countries where it has been introduced (e.g. New Caledonia, Sri Lanka, Papua New Guinea) or where it is still absent, and a similar approach could be developed for other invasive alien species.

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