Forestry plantations as a pathway for invasive alien plants in the National Park at Réunion island

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reçu le 12/06/2019 ; accepté le 16/10/2019

RÉSUMÉ : Une des priorités pour contrôler les futures invasions floristiques est d'identifier les voies d'introduction aux abords des aires naturelles. Dans cette étude, nous avons testé si les forêts cultivées peuvent favoriser l'envahissement par les plantes exotiques à l'intérieur du Parc national de la Réunion. Les résultats montrent une diminution significative du pourcentage de la biomasse végétale des plantes exotiques des forêts cultivées vers le milieu naturel. Les différences sont également significatives au niveau d'un des deux sites étudiés concernant les moyennes du nombre de plantes exotiques et de la somme de l'abondance des plantes. Dans les deux cas, de nombreuses espèces sont présentes seulement en sous-bois de forêts cultivées ou également à l'entrée du Parc national. Cette étude préconise de renforcer les actions de détection précoce et de réponse rapide. Les auteurs proposent également la mise en place de méthodes de gestion alternatives de ces habitats incluant une approche participative de la population dans des programmes de restauration.

ABSTRACT**:** Identifying pathways of introduction remains a major priority to prevent future plant invasions into natural areas. In this study, we assessed whether forestry plantations favor alien plant dissemination into the National Park of Reunion. Results showed significant decrease in the percentage of alien plant biomass from the forestry plantations to the undisturbed areas. At one site, a significant difference was also found for the mean alien species number and the mean alien plant abundance. In both sites, numerous alien species were present in the understorey of *Cryptomeria* plantations only, with some already escaping and occurring at the entrance of the National Park. This study recommends strengthening early detection and rapid response of alien plants and suggests alternative management approaches in forestry plantations, including the use of community-based restoration programmes.

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INTRODUCTION

Invasive alien species are unfortunately known as the main threat on biodiversity conservation within protected areas (e.g. FOXCOFT *et al.,* 2013). One of the priorities to control future invasion in protected areas is to identify pathways of introduction (e.g. FOXCROFT *et al.,* 2010). Target 9 of the Strategic Plan for Biodiversity and the Aichi Biodiversity Targets by the Convention on Biological Diversity's Conference of Parties (UNEP, 2011) refers to 'By 2020, invasive alien species and pathways are identified and prioritized, priority species are controlled or eradicated, and measures are in place to manage pathways to prevent their introduction and establishment'.

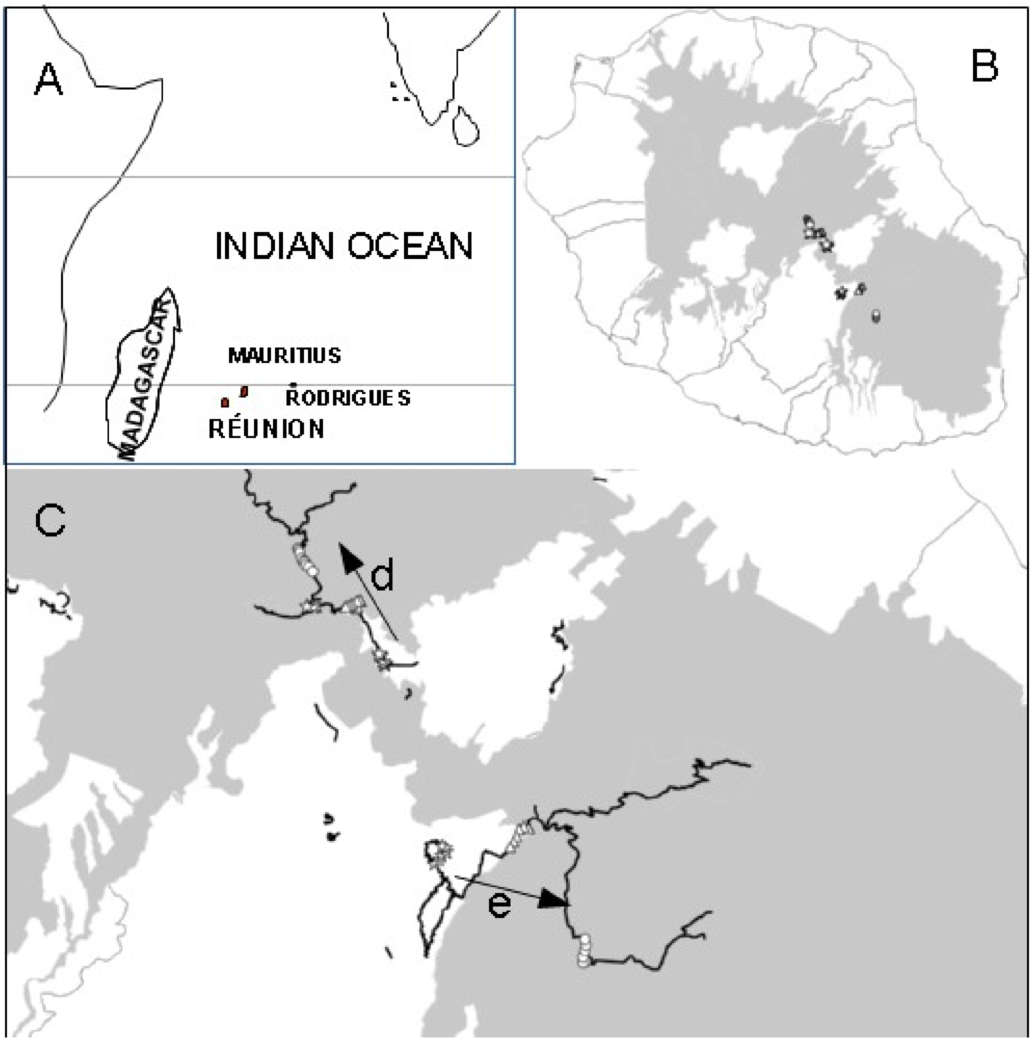

Figure 1. – Localisation of Reunion island (A), of the National Park (in grey, B) and of the transects (C, black line are the forestry roads, stars are transect in forestry plantations, triangle at the edge of natural habitat of the National Park and circle natural habitat inside National Park). d corresponds to Bébour and e to the volcano. Grid show the forestry plantations. Arrows show the direction of the pathways into the National Park.

Disturbance favours alien plant invasions, from natural disturbances (e.g. RESTREPO & VITOUSEK, 2001) to anthropogenic ones (e.g. DICKIE *et al.,* 2014). Natural habitats on Reunion island are surrounded by a whole range of land uses (including forestry plantations of alien trees) and it would be good to assess their role as invasion pathways.

Reunion island is a good model to test this hypothesis. The island is unfortunately known for its numerous alien plant species (BARET *et al.,* 2006) due in part to natural (STRASBERG, 1995; BARET *et al.,* 2008; POTGIETER *et al.,* 2014) and anthropogenic disturbances (BARET & STRASBERG, 2005; BARET *et al.,* 2007). Furthermore, a national park covers forty percent of the island (BARET *et al.,* 2013) (*Fig. 1*). Plantations of alien trees (mainly *Cryptomeria japonica*) for timber production are next to natural habitats, often at the entrance of the National Park. In this study we assessed whether forestry plantations, juxtaposed to native areas, represent a pathway or a buffer for invasive alien plant species? If forestry plantation operate as a buffer, we expect alien plant biomass or alien plant richness, to be higher in forestry plantation than in the national park. If forestry plantation operate as a pathway, we expect alien plant biomass or alien plant richness, to be similar in forestry plantation than in the national park.

METHODS

STUDY AREA AND TRANSECT LOCALISATION

The study was carried out at Reunion island (21°06'S, 55°30'E), an island localised in the western Indian ocean within the Mascarene archipelago (including Mauritius and Rodrigues (*Fig. 1*). With 2512 km^2 in area, a submit of 3070 m asl, and steep slope, this island still possess 30% of native habitat considered as intact (STRASBERG *et al.,* 2005), but unfortunately threatened by invasive alien plant species (BARET *et al.,* 2006) mainly due to human disturbances (BARET & STRASBERG, 2005; BARET *et al.,* 2007).

The surveys have been conducted in two different sites, both at the entrance of the National Park, along Bébour/Petite Plaine (called after Bébour) and along the volcano roads (*Fig. 1*).

SAMPLING METHOD

We surveyed alien vascular plants presence and abundance in three different types of habitats: (1) in forestry plantations (“disturbed forests”) located just before the entrance of the National Park, (2) at the entrance of the national park (called after “natural habitat edge”), and (3) inside the national park with intact natural areas (called after “natural habitat core”).

The sampling design followed MACDONALD & NOTT, (1987) but was adapted at the island scale (MACDONALD *et al.,* 1991). Sampling was carried out by car, using 100m sampling units (car odometer). Within each 100 m segment (10 m wide), the presence or absence of alien plants and the abundance of each species present was scored using standardised ratings (*Tab. I*), (MACDONALD *et al*., 1991). We also estimated the contribution of alien plants through an expert estimation of the total above-ground plant biomass: it represents the percentage of the alien plant biomass present through all the vegetation observed.

We selected two sites (Volcano and Bébour localisation, see *Fig. 1*). For each site, we conducted three transects: one in *Cryptomeria japonica* forestry plantations (respectively at 1 and 4 km from the entrance to the National Park, for Bébour and Volcano sites, one at the entrance of the National Park, and the last one in natural habitat within the National Park (respectively at 3 and 5,7 km from the entrance). Each transect measured 1000 m and we surveyed vegetation on both sides, excepted in the forestry plantation of the volcano site, where only one side has been prospected. Thus 20 segments of 100 m length by 10 m wide have been surveyed for each transect, except for the Volcano forestry plantation (10 segments on one side only). We estimated plant biomass for each segment except for the forestry plantation of Bébour where we have this information only for eight segments due to logistic constraints. Plant biomass was homogeneous within this transect, so this did not affect the global analysis.

TABLE I: Abundance ratings (A) used in the surveys. Plant abondance refers to the number of plants observed within a 100 m segment, or if more than 20 plants, their contribution to the total vegetation along the segment.

Rating	Plant abondance
3	1 plant
4	2 – 4 plants
5	5 – 9 plants
6	10 – 19 plants
7	≥ 20 but not forming a dominant component
8	Species codominant along the entire segment
9	Species almost forming a continuous monospecific stand

DATA ANALYSIS

The data were analysed as follows: the Frequency of occurrence (F) was calculated for each species as the number of sections in which the species was recorded, divided by the total number of sections in a transect or group of transects. The Abundance of a species (A) was calculated as the sum of the abundance ratings recorded on a transect divided by the number of sections in which the species was recorded. The Importance Value (IV) for a species was the product of its frequency and abundance (FxA). The priority ranking is done by the IV, the highest IVs correspond to the most invasive plants.

For each 100 m segment surveyed (10 m wide), we recorded the total number of alien plant species, the % of alien plant biomass and the sum of species abundance. For each variable, normality was tested using the Shapiro-Wilk Normality Test, but some data were not distributed normally after logarithmic and square root transformations. Therefore, comparisons between the different disturbances were carried out with a rank sum test, the Mann-Whitney U test, a non-parametric procedure that tests for difference in the central values of two independent samples. Data were analysed using R software.

RESULTS

The mean of alien plant biomass (%) and the total number of alien plant species decreased for each transect, from forestry plantations to natural forests (*Fig. 2*). The same trend was observed for the sum of abundance on the Bébour site but not on the Volcano one. A Mann-Whitney U test highlighted significant difference between forestry plantations and natural habitat core areas for all the variable tested at the Volcano site, but only for the mean of alien plant biomass for Bébour site (*Tab. II*).

Some alien plants were only present within the forestry plantations and did not occur in the other transects (*Tab. III* & *IV*). It was the case for the following woody species: *Acacia mearnsii*, *Ligustrum ovalifolium*, *Rubus fraxinifolius,* and herbaceous species*: Persicaria capitata*, *Ranunculus bulbosum*, *Verbascum thapsus* on the volcano site, and for the following woody species: *Boehmeria macrophylla, Cryptomeria japonica, Rhododendron sp.,* and the herbaceous ones*: Hedychium flavescens*, *Coronopus didymus*, *Youngia japonica*, *Conyza sumatrensis* on the Bébour site. For the volcano site, it was mainly shrub and tree species. For the Bébour site, it was mainly herbs and shrub species.

Others alien species did not occur in natural habitat (core transect) but were present at the edge of natural habitats. It is the case at Bébour site of *Lonicera japonica*, *Tibouchina urvilleana*, *Geranium robertianum*, *Persicaria chinensis*, *Acacia mearnsii*, *Fuchsia boliviana*, *Strobilanthes hamiltonianus*, *Sphaeropteris cooperi* for the species already known in natural habitat as invasive or transformer. *Cestrum elegans* was also present in this section but not considered nowadays as invasive. At the volcano site, the species already known as invasive are *Fragaria vesca*, *Rumex obtusifolius*, *Prunella vulgaris*, *Eriobotrya japonica*, *Oxalis corniculata*, *Trifolium dubium*, *Rumex acetosella*. For the Volcano site, it was mainly herbs. For the Bébour site, it was mainly shrubs.

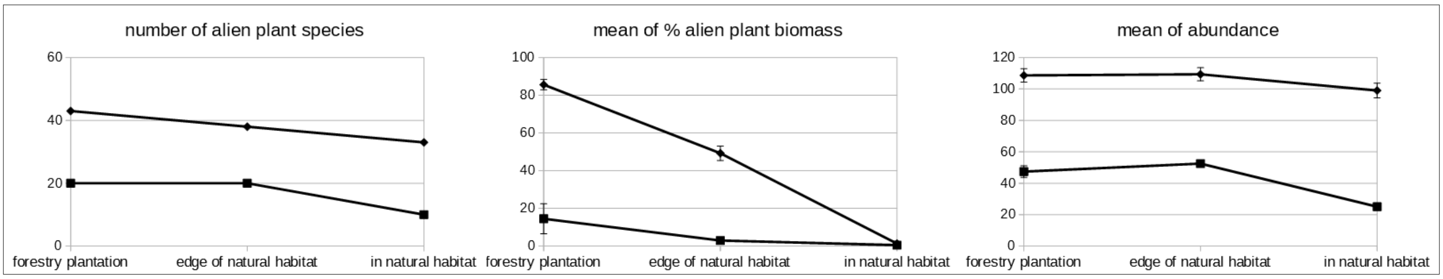

Figure 2. – Total number of alien plant species and mean (±standard error) for a 100 m segment of alien plant biomass %, total number of alien plant species and sum of abundance for each 100 m transect segment in forestry plantation, natural habitat edge and natural habitat core at the volcano (square) and Bébour sites (diamond).

DISCUSSION

Numerous alien plant species are already present in the core areas of the National Park but not invade all natural areas. The aim of our work was to identify pathways which can favour alien plant dissemination into the National Park and threaten native habitats. Forestry plantations at the border of the National Park, appear to be one of the pathways favouring plant dissemination within the national park.

*WHICH SPE*CIES THREATEN NATURAL HABITATS?

Our results showed a significant decrease in alien plant biomass in both sites from the forestry plantation to the core areas of natural habitats. The mean number of alien species and the sum of abundance only decreased significantly on the volcano site (characterised by subalpine shrublands) but not to the Bébour site (characterised by mountain rainforests) (*Tab. II*).

In both cases, we can observe that some alien plant species are present only in the understorey of *Cryptomeria japonica* forestry plantation, and/or at the entrance of National Park (natural forest edge) (*Tab. III* and *IV*). Even if our surveys are not exhaustive, it seems very important to set up early detection and rapid response actions for these species. Early detection and rapid response is also one of the priorities identified in the local invasive species strategy (Baret *et al*., 2010). On the subalpine shrubland site (volcano site), the most problematic species appear to be *Acacia mearnsii*, *Eryobotria japonica*, but also several herbaceous species such as *Persicaria capitata* or *Verbascum thapus* (*Tab. III*). On the mountain rainforest site (Bébour), the most problematic species are *Hedychium flavescens* (present only in the understorey of *C. japonica* forestry plantation) and *Sphaeropteris cooperi* and *Cestrum elegans*, mainly present in the understorey of forestry plantations but also present at the edge of natural habitats. *Hedychium flavescens* is known to occur mainly in open areas, but the two other species are a real threat of the native habitats. *Lonicera japonica*, *Tibouchina urvillei*, *Persicaria chinensis*, *Acacia mearnsii* and *Strobilanthes halmitonianus* are the other species that we need to control urgently. Most of these species are already known as invasive at the island scale (BARET *et al.,* 2006; TASSIN *et al.,* 2006) but did not occur in the sites surveyed in this study.

Our results underline that forestry plantations act as a reservoir for alien plants and thus possible a source of alien plant dissemination in natural habitats. We strongly suggest modifying forestry plantation management in order to reduce alien plant dissemination into natural areas.

TABLE II: Mean (±standard error) of the species number (Nb sp), of alien plant biomass (%), of alien plant species abundance sum, for forestry plantation, at the edge of natural habitat and in natural habitat inside the National Park, in 2 localisations. Within each variable, a change in the letters means that values were significantly different at the 5% level according to a Mann–Whitney test.

Volcano:

	Nb SP	%Plant biomass	Sum of abundance
forestry plantation	7,90±0,67[a]	14,5±7,92[a]	47,40±3,71[a]
edge of natural habitat	8,10±0,32[a]	2,95±0,30[a]	52,50±1,72[a]
natural habitat	4,30±0,32[b]	0,50±0,00[b]	25,05±1,70[b]

Bébour:

	Nb SP	%Plant biomass	Sum of abundance
forestry plantation	18,15±0,53[a]	85,63±2,74[a]	108,65±4,28[a]
edge of natural habitat	16,70±0,71[a]	49,25±3,84[a]	109,35±4,17[a]
Inatural habitat	16,35±0,84[a]	1,32±0,19[b]	99,00±4,63[a]

WHAT CAN WE DO?

Forestry plantations appear to operate as a buffer because invasive alien plant biomass significantly decreased in natural habitats. However, forestry plantations remain a pathway for alien species introduction as alien plant richness (and the sum of abundance) is very similar in natural habitats and forestry plantations in Bebour. In other words, alien species occurring in forestry plantations can spread into natural habitats but with a reduced biomass. It partly confirm numerous results that disturbances favoured alien plant dissemination (e.g. Dickie et al., 2014). Unfortunately, these forestry plantations are near the entrance of the National Park or even inside the National Park This is the case, not only for the alien *Cryptomeria japonica* trees, but also for an endemic *Acacia heterophylla* tree. Even if it is an endemic tree, disturbances created by its plantation limit indigenous biodiversity in favour of alien plant species (Baret et al., 2007).

Numerous studies have already confirmed Elton's hypothesis (RICHARDSON D,, & PYŠEK P., 2007) that a diversified ecosystem is more resistant to alien plant invasiveness (TILMAN *et al.,* 1997; LAVOREL *et al.,* 1999; SYMSTAD, 2000; DUKES, 2001). Since funding to manage natural forests but also forestry plantations is limited, it is urgent to develop new methods to favour indigenous species richness and limit alien plants spread.

Local population also used indigenous species as medicinal plants, bee-keeping, cooking wood, harvesting (LAVERGNE R., 1989; LUCAS R., 2006; BARET *et al.,* 2012; MINATCHY *et al*., 2017; CORBIN *et al.*, 2018).

TABLE III: Alien plants occurring at the volcano site in forestry plantation, edge of natural habitats, and core of natural habitats in the National Park. The importance value (IV), the associated ranking, the growth form and the degree of invasiveness (DI, according to Richardson et al 2000, with 1: casual, 2: naturalized, 3: invasive, 4: transformer) are indicated for each species. Species highlighted in bold represent the main threat for native habitats.

			Forestry		Edge		Core	
G form	Taxon	DI	IV	R	IV	R	IV	R
Herb	*Anthoxanthum odoratum* L.	4	7,60	1	7,85	1	7,00	1
Herb	*Erigeron karwinskianus* DC.	3	6,70	3	7,00	2	7,00	1
Herb	*Hypochaeris radicata* L.	3	7,00	2	7,00	2	3,55	2
Herb	*Plantago lanceolata* L.	2	3,50	6	6,90	5	2,70	3
Herb	*Taraxacum sect. Ruderalia* Kirschner, H. Øllg. et Stepanek	3	1,40	10	6,40	6	1,50	4
Herb	*Cenchrus clandestinus* (Hochst. ex Chiov.) Morrone	3	4,20	5	3,55	7	1,15	6
Herb	*Paspalum urvillei* Steud.	3	0,40	15	0,65	11	0,45	7
Herb	*Holcus lanatus* L.	4	3,50	6	6,95	4	1,20	8
Shrub	*Ulex europaeus* L.	4	2,10	8	0,45	13	0,35	8
Tree	*Prunus* L. *sp.*	2			0,15	19	0,15	9
Herb	***Fragaria vesca*** L.	3			1,30	8		
Herb	*Rumex obtusifolius* L.	3			1,10	9		
Herb	*Oenothera rosea* Aiton	2			0,90	10		
Herb	*Prunella vulgaris* L.	3	0,30	17	0,65	11		
Herb	*Verbena brasiliensis* Vell.	2	0,30	17	0,45	13		
Tree	***Eriobotrya japonica*** (Thunb.) Lindl.	3			0,35	15		
Herb	*Tragopogon pratensis* L.	2	0,30	17	0,30	16		
Herb	*Oxalis corniculata* L.	3	0,80	12	0,20	17		
Herb	*Trifolium dubium* Sibth.	3			0,20	17		
Herb	*Rumex acetosella* L.	3			0,15	19		
Tree	***Cryptomeria japonica*** (L. f.) D. Don	1	6,10	4				
Tree	***Acacia mearnsii*** De Wild.	4	1,60	9				
Herb	***Persicaria capitata*** (Buch.-Ham. ex D. Don) H. Gross	3	1,30	11				
Shrub	***Rubus fraxinifolius*** Poir.	2	0,70	13				
Shrub	***Ligustrum ovalifolium*** Hassk.	2	0,50	14				
Herb	*Ranunculus bulbosus* L.	2	0,40	15				
Herb	***Verbascum thapsus*** L.	3	0,30	17				

In order to preserve natural habitats and traditional uses of indigenous species, the National Park has set-up project with local communities called PEI Run sustainable. Such projects enable alien plant control and indigenous species plantation that communities could use sustainably. These kind of projects could be developed in the understorey of forestry plantations through partnership with implementing agencies and NGOs. As a result, indigenous species richness would increase, alien plant biomass would decrease limiting alien plant dissemination.

TABLE IV: Alien plants occurring at the Bebour site in forestry plantations, the edge of natural habitats and at the core of natural habitats in the National Park. The importance value (IV), the associated ranking, the growth form and the degree of invasiveness (DI, according to Richardson et al. 2000, with 1: casual, 2: naturalized, 3: invasive, 4: transformer) are indicated for each species. Species highlighted in bold represent the main threat for native habitats.

			Forestry		Edge		Core	
G form	Taxon	DI	IV	R	IV	R	IV	R
Herb	*Anthoxanthum odoratum* L.	4	3,25	14	7,00	4	7,45	1
Herb	*Ageratina riparia* (Regel) R.M. King et H. Rob.	4	7,05	1	6,20	7	7,15	2
Herb	*Hypochaeris radicata* L.	3	2,70	18	4,05	14	7,10	3
Herb	*Erigeron karvinskianus* DC.	3	5,10	6	7,15	3	7,05	4
Shrub	*Boehmeria penduliflora* Wedd. ex D.G. Long	4	4,00	12	4,05	13	7,00	5
Tree	*Psidium cattleianum* Sabine	4	6,75	3	7,65	1	6,80	6
Herb	*Potentilla indica (*Andrews) Th. Wolf	3	4,45	11	6,30	6	5,15	7
Herb	*Paspalum urvillei* Steud.	3	0,60	34	4,20	12	5,10	8
Herb	*Rumex cf obtusifolius* L.	3	4,80	9	5,55	9	4,85	9
Herb	*Persicaria capitata (Buch.-Ham. ex D. Don) H. Gross*	3	6,90	2	4,65	11	4,30	10
Herb	*Cenchrus clandestinus (Hochst. ex Chiov.) Morrone*	3	1,05	29	7,50	2	3,85	11
Herb	*Verbena brasiliensis* Vell.	2	1,80	21	0,25	34	3,75	12
Herb	*Prunella vulgaris* L.	3	1,25	26			3,45	13
Herb	*Holcus lanatus* L.	4	0,35	39	3,00	17	3,25	14
Herb	*Zantedeschia aethiopica* (L) Spreng.	3	5,10	6	1,50	20	3,00	15
Herb	*Begonia cucullata* Willd.	3	2,80	17	1,10	24	2,65	16
Herb	*Croocosmia x crocosmiiflora* (Lemoine ex Anonymous) N.E. Br.	3	6,40	4	1,95	19	2,60	17
Herb	*Myosotis discolor* Pers.	2	1,40	22	3,45	16	2,50	18
Tree	*Solanum mauritianum* Scop.	3	5,50	5	2,40	18	2,50	19
Herb	*Oenothera rosea* Aiton	2	0,95	31	0,40	30	2,05	20
Climber	*Rubus alceifolius* Poir.	4	1,35	24	3,85	15	1,75	21
Shrub	*Fuchsia magellanica* Lam.	4	0,55	35	0,20	35	1,30	22
Herb	*Plantago* L. *sp.*	2	0,20	42	1,45	21	1,20	23
Shrub	*Hydrangea macrophylla* (Thunb.) Ser.	4	3,85	13	5,65	8	0,70	24
Herb	*Fragaria vesca* L.	3					0,50	25
Tree	*Eryobotrya japonica* (Thunb.) Lindl.	3	0,45	37			0,45	26
Herb	*Trifolium* L. *sp.*	3					0,35	27
Climber	*Ipomoea sp. cf indica* (Burm.) Merr.	3			0,35	32	0,20	30
Shrub	*Fuchsia x exoniensis* Paxton	3					0,20	30
Climber	*Rubus roseifolius* Sm.	3	3,15	16	1,35	22	0,15	31
Herb	*Oxalis corniculata* L.	3	0,70	33	0,20	35	0,15	31
Shrub	*Begonia rex* Putz.	2	0,15	44			0,15	31
Tree	*Prunus* L. *sp.*	2					0,15	31
Climber	***Lonicera japonica***	4	0,80	32	5,05	10		
Shrub	***Begonia diadema*** Linden ex Rodigas	2	0,35	39	1,25	23		
Shrub	***Tibouchina urvilleana*** (DC.) Cogn.	3	0,20	42	1,10	25		
Herb	*Geranium robertianum* L.	3	1,35	24	1,00	26		
Herb	*Colocasia esculenta* (L.) Schott	2	3,20	15	0,65	27		
Shrub	*Persicaria chinensis* (L.) H. Gross	3			0,65	28		
Tree	***Acacia mearnsii*** De Wild.	4			0,50	29		
Shrub	*Fuchsia boliviana* Carrière	3	1,40	22	0,40	30		
Shrub	***Strobilanthes hamiltonianus*** (Steud.) Bosser et Heine	4			0,35	33		
Shrub	***Cestrum elegans*** (Brongn. ex Neumann) Schltdl.	2	4,85	8	0,15	37		
Tree	***Sphaeropteris cooperi*** (Hook. ex F. Muell.) R.M. Tryon	3	2,15	20	0,15	37		
Tree	*Musa* L. *(possibly planted)*	1			0,15	37		
Shrub	***Hedychium flavescens*** Carey ex Roscoe	3	4,55	10				
Shrub	*Boehmeria macrophylla* Hornem.	2	2,45	19				
Herb	*Lepidium didymum* L.	2	1,25	26				
Shrub	*Rhododendron* L. *sp.*	2	1,05	29				
Herb	*Youngia japonica* (L.) DC.	2	0,55	35				
Tree	*Cryptomeria japonica* (L. f.) D. Don	1	0,40	38				
Herb	*Conyza sumatrensis* (Retz.) E. Walker	2	0,30	41				

If well-managed, forestry plantations could be a good opportunity to limit alien plant dissemination in playing a role of a buffer zone between anthropogenic areas and naturals ones. This supports the study by FOXCROFT *et al.* (2010) who identified protected-area boundaries as a filter of plant invasions. As BARET *et al.* (2013) underline, it is important to set up a proactive management, including population.

CONCLUSION-PERSPECTIVES

Our study highlights forestry plantations as a possible pathway of alien plant species within natural areas. Surveys conducted in this study should be repeated regularly in order to identify control priorities through time. It is also important to conduct additional surveys in different locations at the border of the national park in order to have a good indicator of the current and future alien plant threats.

AKNOWLEDGEMENT

The authors thank National Park and the University of Reunion to support indirectly this study and Jean-Marie Pausé and Anne Belo for field assistance.

REFERENCES

BARET S., BAIDER C., KUEFFER C., FOXCROFT L.C. & LAGABRIELLE E., 2013. – Threats to Paradise? Plant invasions in Protected Areas of the Western Indian Ocean Islands. *In*: Foxcroft LC, Pyšek P, Richardson DM, Genovesi P (eds) *Plant Invasions in Protected Areas: Patterns, Problems and Challenges*. Springer, Dordrecht, **7**: 423-447.

BARET S., COURNAC L., THÉBAUD C., EDWARDS P. & STRASBERG D., 2008. – Effects of canopy gap size on recruitment and invasion of the non-indigenous *Rubus alceifolius* in lowland tropical rain forest on Réunion. *Journal of Tropical Ecology,* **24**: 337-345.

BARET S., JULLIOT C., & RADJASSEGARANE S., 2010. – Stratégie de lutte contre les espèces invasives à la Réunion. *Rapport DIREN, Conseil Général de la Réunion, Région Réunion, Office National des Forêts, Parc national de la Réunion.*

BARET S., LAVERGNE C., FONTAINE C., SALIMAN M., HERMANN S., TRIOLO J., BAZIL S., SERTIER J-C., LEQUETTE B., GIGORD L., LUCAS R., PICOT F. & MULLER S., 2012. – Une méthodologie concertée pour la sauvegarde des plantes menacées de l'île de La Réunion. *Revue d'Ecologie (Terre et Vie)* Suppl**11**:85-100.

BARET S., LE BOURGEOIS T., RIVIÈRE J.-N., PAILLER T., SARRAILH J.-M. & STRASBERG D., 2007. – Can species richness be maintained in logged endemic *Acacia heterophylla* forests (Réunion island, Indian ocean)? *Revue d'Ecologie (Terre et Vie),* **62**: 273-284.

BARET S. & STRASBERG D., 2005. – The effects of opening trails on exotic plant invasion in protected areas on La Réunion island (Mascarene archipelago, Indian Ocean). *Revue d'Écologie (Terre et Vie),* **60**: 325-332.

BARET S., ROUGET M., RICHARDSON D.M., LAVERGNE C., EGOH B., DUPONT J. & STRASBERG D., 2006. – Current distribution and potential extent of the most invasive alien plant species on La Réunion (Indian Ocean, Mascarene Islands). *Austral Ecology,* **31**: 747-758.

CORBIN M., HAVART E. & LEDOYEN F., 2018. – Soigner par les plantes, Kakouk dévoile.... Orphie éditions, La Réunion, 236p.

DICKIE I.A., BENNETT B.M., BURROWS L.E., NUÑEZ M.A., PELTZER D.A., PORTÉ A., RICHARDSON D.M., REJMÁNEK M., RUNDEL P.W. & VAN WILGEN B.W., 2014. – Conflicting values: ecosystem services and invasive tree management. *Biological Invasions,* **16**: 705-719.

DUKES J.S., 2001. – Biodiversity and invisibility in grassland microcosms. *Oecologia*, **126**: 563-568.

FOXCROFT L.C., JAROŠÍK V., PYŠEK P., RICHARDSON D.M. & ROUGET M., 2010. – Protected-Area Boundaries as Filters of Plant Invasions. *Conservation Biology*, **25** (2): 400–405.

FOXCROFT L.C., PYŠEK P., RICHARDSON D.M. & GENOVESI P., 2013. – *Plant Invasions in Protected Areas: Patterns, Problems and Challenges.* Springer, Dordrecht, **7**: 656 p.

LAVERGNE R., 1989. – Plants médicinales, tisaneries et tisaneurs de La Réunion. Thèse de doctorat, 28 janvier 1989. Université de Montpellier, France, 610p.

LAVOREL S., PRIEUR-RICHARD A.H. & GRIGULIS K., 1999. – Invasibility and diversity of plant communities: from patterns to processes. *Diversity Distributions*, **5**: 41-49.

LUCAS R., 2006. – Cent plantes endémiques et indigènes de La Réunion. Azalées éditions, La Réunion, 206p.

LUKE J., POTGIETER L.J., WILSON J.R.U., STRASBERG D. & RICHARDSON D.M., 2014. – Casuarina Invasion Alters Primary Succession on Lava Flows on La Reunion Island. *Biotropica,* **46**(3): 268–275.

MACDONALD I.A.W. & NOTT T.B., 1987. – Invasive alien organisms in central South West Africa/Namibia: results of a reconnaissance survey conducted in November 1984. *Madoqua,* **15**: 21-34.

MACDONALD I.A.W., THÉBAUD C., STRAHM W. A. & STRASBERG D., 1991. – Effects of alien plant invasions on native vegetation remnants on La Réunion (Mascarene Islands, Indian Ocean). *Environmental Conservation,* **18**, 51–61.

MINATCHY J., THOMAS H. & BARET S., 2017. – Liens entre la mise en place d'une filière d'utilisation d'une plante exotique envahissante et la conservation des milieux naturels: cas du goyavier *Psidium cattleianum* Afzel. ex Sabine à La Réunion (Myrtales: Myrtaceae). *Cahiers scientifiques de l'océan Indien occidental,* **8**: 29-40.

RESTREPO C. & VITOUSEK P. M., 2001. – Landslides, Alien Species, and the Diversity of a Hawaiian Montane Mesic Ecosystem. *Biotropica,* **33**: 409–420.

RICHARDSON D.M., & PYŠEK P., 2007. – Elton, C.S. 1958: The ecology of invasions by animals and plants. London: Methuen. Progress in Physical Geography, **31**(6): 659–666.

RICHARDSON D.M., PYŠEK P., REJMÁNEK M., BARBOUR M.G., PANETTA F.D. & WEST C.J., 2000. – Naturalization and invasion of alien plants: concepts and definitions. *Diversity and Distributions,* **6**: 93–107.

STRASBERG D., 1995. – Processus d'invasion par les plantes introduites à la Réunion et dynamique de la végétation sur les coulées volcaniques. *Ecologie,* **26**(3): 169-180.

STRASBERG D., ROUGET M., RICHARDSON D.M., BARET S., DUPONT J. & COWLING R.M., 2005. – An assessment of habitat diversity, transformation and threats to biodiversity on Reunion Island (Mascarene Islands, Indian Ocean) as a basis for conservation planning. *Biodiversity & Conservation,* **14**: 3015-3032.

SYMSTAD A.J., 2000. – A test of the effects of functional group richness and composition on grassland invasibility. *Ecology*, 81: 99-109.

TASSIN J., RIVIERE J.-N., CAZANOVE M. & BRUZZESE E., 2006. – Ranking of invasive woody plant species for management on Reunion Island. *Weed Research*, **46**(5): 388-403.

TILMAN D., KNOPS J., WEDIN D., REICH P., RITCHIE M. & SIEMANN E., 1997. – The influence of functional diversity and composition on ecosystem processes. *Science*, **277**: 1300-1302.

UNEP., 2011. – *The Strategic Plan for Biodiversity 2011–2020 and the Aichi Biodiversity Targets*, COP CBD Tenth Meeting UNEP/CBD/COP/DEC/X/2 (https:/*/www.cbd.int/decisions/cop/?m=cop-10 / https://www.cbd.int/sp/targets/rationale/target-9/*), 29 October 2010, Nagoya, Japan.