Une analyse socio-économique de la gestion et du contrôle des plantes envahissantes dans l'archipel des Mascareignes

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THESE

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Une analyse socio-économique de la gestion et du contrôle des plantes envahissantes dans l'archipel des Mascareignes

Par

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Summary

Biological invasions contribute to the degradation of biodiversity globally. Invasive alien plants have impacted on natural resources management and have generated substantial costs of control and economic loss. Various management options have been put in place to control the level of invasions of targeted species. The public's perception of invasive species varies among stakeholders. Controversies and conflicts emerged as a consequence of diverging opinions on the management of invasions. I conducted an inter-disciplinary study on the socio-ecological and economic dimensions related to the management of the invasive *Rubus alceifolius,* following a biological control programme in Réunion Island (France). Firstly, I carried out an economic analysis of the management options for *R. alceifolius* with future scenario on the cost of invasion. Secondly I assessed the impact of the recovery of native species post biological control. Thirdly a preliminary socio-anthropological investigation to understand the rationale behind controversies amongst identified stakeholders, was investigated. Lastly, an exploratory gap-analysis of the policy framework corresponding to a biological control programme was conducted. I found that the biological control programme of *R. alceifolius* was successful within the elevation limit of 800 m, from both an economic and ecological perspective. Given the shortfall in the decision-making process and implementation, this study demonstrated the crucial need to identify and involve stakeholders in all stages of a biological control programme. I conclude with key recommendations for successful biological programmes.

Résumé

Les invasions biologiques font partie des changements globaux qui contribuent à la perte de biodiversité. Les plantes invasives ont un impact sur les écosystèmes naturels largement documenté dans les îles océaniques. Parmi les nombreuses espèces non indigènes dans les iles plusieurs espèces de plantes invasives peuvent aussi provoquer des pertes économiques ; elles engendrent notamment d'importants coûts pour leur contrôle. Dans l'archipel des Mascareignes plusieurs programmes de gestion ont été mis en place pour contrôler l'extension des principales espèces invasives. La perception du public sur les espèces invasives varie fortement entre les parties prenantes. En raison d'opinions divergentes sur la gestion des invasions, les travaux de recherche et de mise en œuvre de programme de lutte ont très récemment généré des conflits d'usage. Ce travail de thèse a permis de conduire une étude pluridisciplinaire sur les dimensions socio-écologiques et économiques de la gestion de l'invasion de *Rubus alceifolius*, objet d'un programme de contrôle biologique à l'île de La Réunion. Nous avons mené une analyse économique des différentes options de gestion de *Rubus alceifolius* et des coûts futurs de son invasion. Nous avons aussi évalué l'impact de la lutte biologique sur le rétablissement des espèces indigènes dans une aire protégée. Le succès du programme de contrôle biologique de *Rubus alceifolius* a démontré dans les habitats d'altitude < 800 m, aux plans économique et écologique. Afin de comprendre la raison des conflits entre les parties prenantes nous avons parallèlement développer un travail de recherche préliminaire en socio-anthropologie. Nous avons pu mettre en évidence des faiblesses dans le processus de prise de décision et de mise en œuvre collective de ce programme de lutte. Ces travaux de thèse mettent en exergue le besoin crucial d'identifier et d'impliquer les parties prenantes à toutes les étapes du programme de contrôle biologique.

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Introduction générale

Les invasions biologiques font partie des changements globaux avec un enjeu environnemental à l'échelle mondiale, ayant des impacts sur les habitats naturels, ainsi que sur l'économie, et la santé (Simberloff, 2003a; Simberloff et al., 2013). Au niveau continental, l'impact des invasions biologiques se fait à l'échelle des écosystèmes et certaines publications nous parlent aussi des statuts juridiques, de la gestion et du contrôle des invasions et des politiques environnementales (Hulme, 2009; Keller et al., 2011).

Les invasions biologiques participent largement au changement global en cours et agissent en synergie avec les autres facteurs notamment le changement climatique et l'utilisation du sol (Vitousek et al., 1997; Ricciardi, 2007; Ricciardi et al., 2017). Dans la plupart des écosystèmes, les espèces envahissantes contribuent directement ou non à la perte de biodiversité : elles peuvent modifier la structure et le fonctionnement des habitats, réduire la diversité biologique ou diminuer les services écosystémiques (Chapin et al., 2000; Simberloff et al., 2014). Le nombre d'Espèces Exotiques Envahissantes (EEE) recensées dans les milieux naturels augmente avec l'extension des activités humaines. Les superficies concernées par ces nombreux cas d'invasion rendent la gestion des EEE de plus en plus difficile à l'échelle locale, régionale et mondiale (Pyšek & Richardson, 2010). Plusieurs options de gestion sont traditionnellement utilisées pour contrôler les espèces envahissantes : contrôle mécanique, contrôle physique, contrôle chimique, contrôle biologique classique, contrôle biologique augmentatif, perturbation de la reproduction, gestion intégrée des ravageurs et gestion générale des écosystèmes (Simberloff, 2013). Le contrôle des EEE peut conduire à une éradication efficace, dans de rares cas, en particulier dans les petites îles aux superficies réduites par rapport aux régions continentales (Glen et al., 2013). Simberloff (2003) nous explique que certaines caractéristiques sont propices à une éradication réussie, en termes de ressources nécessaires, avec l'engagement d'un projet à long terme, la bonne gestion et gouvernance, des études complètes de la biologie de l'espèce cible, et la gestion de la restauration.

L'impact des plantes exotiques envahissantes dans les écosystèmes insulaires

D'un point de vue biologique, les EEE constituent une menace majeure pour la biodiversité dans le monde (McNeely, 2001a), en particulier dans les îles. Dans le cadre des îles océaniques, il existe beaucoup de cas d'invasions biologiques ayant un impact sur la biodiversité menacée des zones insulaires (Caujapé-Castells et al., 2010; Kueffer et al., 2010). Les îles ont des taux élevés d'endémisme et abritent de nombreux organismes qui ont co-évolués, de sorte qu'une seule extinction entraîne souvent une cascade d'extinctions (Cheke & Hume, 2008). Les impacts des EEE sur les îles sont aigus et parfois irréversibles (Reaser et al., 2007), avec des conséquences majeures sur la biodiversité et sur les services écosystémiques (Perrings, Mooney & Williamson, 2010; Pimentel, 2011) nous fournissant de la nourriture, de l'eau, des combustibles, ou régulant le climat et l'eau ou encore d'ordre culturel. En outre, les invasions peuvent avoir des conséquences négatives directes ou indirectes sur la production économique, ce qui peut entraîner des coûts considérables pour la société (Pimentel, 2011). Par exemple, à Hawaii, les EEE sont considérés à la fois comme une menace économique et écologique pour les écosystèmes naturels et l'agriculture (DiTomaso et al., 2017). Il est crucial de poursuivre la recherche pour mieux comprendre l'impact des EEE, leurs conséquences sur les écosystèmes insulaires (Dulloo, Kell & Jones, 2002) et comment les gérer.

La dispersion des EEE par l'homme est devenue un phénomène mondial et a été initiée par la création de routes y compris maritimes, puis par des avions ou des cargos (Nentwig, 2007). La volonté de développer fortement une région ou un pays en utilisant ses ressources donne lieu à une modification des habitats, permettant la recolonisation par d'autres espèces. L'introduction de nouvelles espèces amène souvent des compétitions, généralement sous la forme d'un changement dans la disponibilité des ressources (Davis, 2003). Avec une mondialisation croissante, l'invasion par des espèces non indigènes est maintenant considérée comme un enjeu mondial, mais la perception des invasions biologiques nécessite d'être étudiée (McNeely, 2001b).

Depuis Elton (1958), face au problème croissant des invasions biologiques qui menacent la biodiversité, il y a de nombreux cas de lutte, mais aussi d'études sur les mécanismes d'invasibilité et de travaux de recherche plus fondamentaux pour comprendre, prédire et donc prévenir les nouvelles invasions (tels que les traits qui favorisent le caractère invasif, ou les écosystèmes qui sont plus exposés). Une synthèse du processus d'invasion a été définie par Richardson et al. (2000), conceptualisant l'introduction d'une espèce qui a pu surmonter plusieurs obstacles jusqu'à s'établir et se propager dans un habitat naturel. De plus, il existe de nombreux facteurs qui favorisent l'invasion, en donnant une définition de ses caractéristiques biologiques et des vecteurs potentiels de propagation (Blackburn et al., 2011). Cependant la science des invasions biologiques reste une discipline récente et novatrice qui a connu certains débats sur la définition d'une espèce invasive ainsi que les raisons des invasions (Richardson & Ricciardi, 2013).

Les principaux travaux de recherche en écologie des invasions dans les îles de l'Océan Indien

Les travaux récents de recherche dans la gestion et le contrôle des EEE dans la région Océan Indien nous exposent l'importance de l'aide à la planification et de la gestion en milieu insulaire de la région du sud-ouest de l'Océan Indien (IUCN, 2018). D'ordre général, il y a un manque d'informations complètes sur l'impact des EEE sur la perte de la biodiversité, en particulier sur les îles situées dans l'hémisphère sud, dans des zones sensibles de la biodiversité (Bellard et al., 2017). Il est nécessaire de réduire les impacts négatifs des invasions biologiques, afin de préserver le patrimoine naturel et culturel. L'IUCN (2018) nous montre qu'il y a une forte nécessité de contrôler les invasions biologiques, afin de préserver la biodiversité insulaire menacée et les services écosystémiques. Cependant il y a un besoin, pour la région Océan Indien, de planifier et de prioriser les fonds afin de maintenir la recherche et la gestion des EEE et la création de plans stratégiques et de plans d'action à l'échelle nationale. Les Seychelles connaissent une avancée dans la gestion des EEE, y compris la création d'un guide pratique sur l'identification et l'élimination de EEE prioritaires qui a été récemment publié par Rocamora & Henriette (2015) afin d'optimiser cette gestion. En termes de recherche récente sur les plantes envahissantes, les recherches se focalisent sur le statut d'invasion de certaines espèces ou encore les liens avec les activités anthropiques. Kull et al. (2018) nous démontre l'invasion de Madagascar sur une grande étendue d'hectares par *Grevillea banksii, Melaleuca quinquenercia, Acadia mangium* et *Eucalyptus* spp. Ces plantes envahissantes sont des ressources socio-économiques pour la communauté locale, pour la production de charbon. La perception de certaines espèces invasives diffère, notamment le cas de *Grevillea banksii* utilisée à Madagascar par la communauté locale comme bois de chauffe et aussi perçue comme élément du paysage par les autorités locales (Kull et al., 2018). Cependant cette espèce invasive suscite des questionnements sur l'impact sanitaire des fumées pendant la production de charbon ou les difficultés à contrôler cette espèce dans le cadre des reconversions de l'utilisation des sols pour le pâturage à Madagascar (Kull et al., 2018). D'autres cas d'étude sur la gestion des EEE par Udo, Darrot & Atlan (2018) nous expliquent qu'une plante introduite, *Ulex Europaeus,* à l'île de La Réunion, pour son utilisation en pâturage, a connu une évolution au niveau de son statut dépendant de la sphère sociale des acteurs et utilisateurs de cette plante au fil d'un siècle. Le statut social d'*Ulex Europaeus* s'est transformé d'une plante utile et nationale à une espèce nocive puis envahissante. La gestion des EEE dépend principalement des activités anthropiques ainsi que de leurs perceptions et connaissances par la communauté locale.

La perception des invasions biologiques

Des études ont été entreprises pour comprendre les caractères d'invasion de certaines espèces en analysant les effets de l'implication humaine et des activités anthropiques sur la propagation des espèces exotiques et envahissantes. Les plantes ont été nommées en tant qu'espèces exotiques et envahissantes selon les gestionnaires et les décisionnaires, mais peuvent être considérées différemment d'un point de vue de la population générale. Kueffer & Kull (2017) nous expliquent que la perception et le jugement de la nature sont généralement liés aux aspects sociaux, émotionnels, culturels et cognitifs chez l'homme. La description de la « nature » pourrait être identifiée comme une plante ou un animal, une arrière-cour ou étendue à une forêt en fonction des points de vue (Kueffer & Kull, 2017). En termes de définitions attribuées aux EEE, la perception des gestionnaires et décisionnaires diffère de celle autres acteurs d'une communauté donnée. Dans la gestion des ressources naturelles, les terminologies utilisées pour désigner les êtres humains sont un groupe d'individus ou les « parties prenantes ». La définition des parties prenantes a été donnée par (Freeman, 2010) comme tout groupe d'individus pouvant affecter ou être affecté par la réalisation des objectifs de l'entreprise. Les parties prenantes sont liées à des changements impliquant généralement plusieurs organisations et entraînant une perception divergente.

> **Encadré 1 : Lutte biologique contre *R. alceifolius* à l'île de La Réunion**
>
> *Après un an de post-biocontrôle, l'agent de lutte C. janthina a réussi à pulluler et sa couleur gris-bleu métallique l'a rendu remarquable sous la forme d'un nuage bleu sur les arbres pollinifères et nectarifères de l'île de La Réunion. La diminution inattendue de la récolte de miel en 2009 dans plusieurs régions de l'île de La Réunion, ainsi que les interactions supposées des abeilles avec C. janthina sur les arbres ont amené les apiculteurs à exprimer leur mécontentement. Ils ont protesté contre le centre*

La plupart des études ont été menées sur l'écologie de l'invasion et les modèles d'invasion (Richardson, 2011) et récemment sur l'impact de l'invasion (Vilà et al., 2010; Kumschick et al., 2012). Ce qui fait qu'une espèce non indigène devienne envahissante est qu'elle a longtemps été observée, étudiée avec la science empirique et pourtant elle est considérée comme incomplète quand il s'agit des dimensions sociales de la perception du terme «envahissant» par les communautés locales ou des individus (Robbins, 2010). La perception de la définition de «invasion», «invasive» ou «exotique» d'un point de vue sociétal pourrait être influencée par la politique et la culture (Robbins, 2010). D'un point de vue des activités anthropiques, le problème est lié à l'invasion biologique par les humains qui sont responsables du déplacement du biote donné d'une zone à une autre (McNeely, 2001b). Selon McNeely (2001a), l'invasion biologique s'explique principalement par des facteurs économiques, de gestion, culturels, sanitaires, éthiques, historiques, et psychologiques. Les différentes méthodes de gestion des EEE comportent des coûts de contrôles, mais d'autres espèces sont considérées comme des espèces à revenus économiques. De Lange & van Wilgen (2010) nous démontrent la perte économique en Afrique du Sud dépendant des méthodes de contrôles de certaines EEE à revenus en sélectionnant quatre groupes fonctionnels de plantes invasives et leurs effets sur les écosystèmes, le pâturage et la conservation de la biodiversité. En Afrique du Sud, van Wilgen (2012) a étudié l'impact du contrôle des espèces envahissantes de pins (*Pinus sp.*) et des eucalyptus (*Eucalyptus sp.*)

d'un point de vue économique, mais aussi culturel, historique et psychologique, car la population locale les perçoit en tant qu'espèces écologiquement bénéfiques. Selon la population locale, le contrôle des pins ou des eucalyptus provoquait un effet de déforestation, et selon eux les arbres sont le patrimoine de leur région. La gestion des pins et des eucalyptus par les autorités sud-africaines a pour but de minimiser les impacts de leurs invasions sur les services écosystémiques tels que l'eau des nappes phréatiques. Cette dichotomie était une source majeure de conflits entre le gouvernement et la population locale.

Les invasions biologiques à l'île de La Réunion

Depuis le début de la colonisation de l'île de La Réunion au 17^{e} siècle (Defos du Rau, 1960) ainsi que l'introduction d'espèces exotiques sur le territoire, il a fallu deux siècles avant que les premiers relevés sur l'invasion des plantes soient entrepris au 19^{e} siècle par De Cordemoy (1895). Certaines espèces de plantes étaient enregistrées par De Cordemoy (1895), puis par Rivals (1952) et Cadet (1977) en tant qu'espèces hautement envahissantes avec la nécessité d'une gestion et d'un contrôle pour limiter les effets sur les habitats naturels. *Rubus alceifolius*, est une des espèces envahissantes mentionnées par De Cordemoy (1895), qui nécessitait un plan de gestion prioritaire.

La gestion et le contrôle de la plante exotique envahissante, *Rubus alceifolius*, ont évolué au cours des 40 dernières années à l'île de La Réunion (France). Le contrôle mécanique puis l'association contrôle mécanique avec contrôle chimique ont été sélectionnés parmi les options de contrôle. Le premier programme de lutte biologique visant à protéger la forêt indigène en France a été initié dans la gestion de l'espèce cible *Rubus alceifolius* par l'agent de contrôle, *Cibdela janthina* (Hyménoptère : Argidae), survenue en 2008 à l'île de La Réunion. Bien que le biocontrôle soit utilisé en agriculture depuis de nombreuses décennies, notamment dans les départements d'outre-mer, peu d'études ou de recherches ont porté sur le niveau d'impact biologique et économique du contrôle biologique dans la gestion des espèces introduites en milieu naturel.

Le processus décisionnel impliquant la sélection de la libération d'un agent de lutte biologique est problématique, malgré l'utilisation classique du contrôle mécanique ou chimique dans la gestion des invasions biologiques. En France, le contrôle biologique est corrélé aux textes juridictionnels, partagés entre agriculture et environnement en droit français. Le choix de l'utilisation du programme de lutte biologique avant la loi sur la biodiversité (votée en 2016) a été plus complexe pour l'homologation d'un agent de lutte biologique visant à protéger la biodiversité menacée, car il n'y avait pas de référence spécifique à l'utilisation d'un agent de lutte. Les autorités gouvernementales au niveau local et national ont décidé de libérer un insecte pour contrôler la ronce exotique *Rubus alceifolius* qui a envahi l'île de La Réunion à grande échelle. Le lâcher a été réalisé par le Centre de coopération Internationale en Recherche Agronomique pour le Développement (CIRAD) suite à un programme de recherche financé par le Conseil Régional (la Région Réunion) et la Direction de l'Environnement, de l'Aménagement et du Logement (DEAL) (voir encadré 1). Les recherches antérieures sur le contrôle de *R. alceifolius* se concentraient sur quelques aspects clés, mais aucune n'avait une approche pluridisciplinaire du problème. Amsellem et al. (2000) a fait une comparaison de la diversité génétique des populations de *R. alceifolius* entre les régions d'origine et les îles envahies dans la région du sud-ouest de l'Océan Indien (SOOI). Baret (2002) a étudié les caractères biologiques de *R. alceifolius*, ses mécanismes d'invasion en relation avec les facteurs écologiques et anthropogéniques tandis que Mathieu (2015) a étudié la biologie, la modélisation et les interactions de l'agent de lutte biologique sélectionné *C. janthina*. Puisque les questions sociétales ont été également suscitées dans l'après-biocontrôle, il était impératif d'entreprendre une étude de recherche multidisciplinaire, impliquant les aspects écologiques avec une analyse socio-économique après la libération de l'agent (analyse ex post).

Dans le processus de gestion des ressources naturelles (y compris celui d'un programme de lutte biologique), qui a été mené auprès des autorités, seuls quelques acteurs ont été impliqués dans la prise de décision. Les acteurs clés étaient le CIRAD, les autorités gouvernementales locales et centrales (la chambre d'agriculture, la DEAL, le conseil régional). Néanmoins, plusieurs mois après le programme de lutte biologique, des controverses et des conflits ont eu lieu pendant une longue période entre les différentes parties prenantes. Le conflit a fait l'objet de réflexions ou d'opinions de la part de quelques parties prenantes, notamment les apiculteurs, qui se sentaient exclues du processus décisionnel de ce programme de lutte biologique. Les médias locaux ont rédigé de grands titres qui ont suscité un intérêt public. Les controverses ont amené la DEAL à demander une analyse économique des différentes options de gestion mises en œuvre pour *R. alceifolius*. Il était nécessaire de comprendre d'un point de vue social la raison sous-jacente des problèmes formulés qui conduit les parties prenantes à blâmer et à réclamer une assistance pour leur perte en production de miel. Le CIRAD a été sollicité pour mettre en place un tel programme et a proposé de cofinancer une bourse de recherche doctorale pour une analyse socio-économique post-contrôle parmi les parties prenantes. Entre-temps, la Commission de l'Océan Indien et l'Union internationale pour la conservation de la nature (UICN) développaient des travaux de coopération sur le contrôle des espèces envahissantes.

Les problématiques de recherche

L'apparition des invasions biologiques avec l'arrivée de l'homme dans l'archipel des Mascareignes a perturbé les habitats naturels menaçant ainsi ces écosystèmes riches en endémicité. *R. alceifolius* a connu une longue histoire d'invasion depuis le premier trace écrite par De Cordemoy (1895) qui démontrait déjà un fort niveau d'invasion à l'île de la Réunion, suivie par plusieurs recherches, thèses et publications. *R. alceifolius* a été contrôlée par plusieurs méthodes et le choix de la lutte biologique nécessite une étude sur le succès d'un tel programme. Afin de pouvoir étudier la gestion de l'invasion de *R. alceifolius*, j'ai adopté une problématique transversale qui me permettra de mieux démontrer le potentiel succès de sa gestion.

Premièrement d'un point de vue économique, quels sont les bénéfices et coûts liés aux différentes méthodes de lutte ?

En milieu naturel, quel est le succès de la lutte biologique sur la recolonisation des espèces endémiques et exotiques ?

D'un point de vue sociétal, quels sont les éléments qui ont mené à une controverse de point de vue des apiculteurs ?

Les objectifs de ce travail de recherche

J'ai travaillé activement avec l'UICN sur un projet relatif aux espèces envahissantes de la région du sud-ouest de l'Océan Indien, basé à la Commission de l'Océan Indien à l'île Maurice. Ma volonté était de poursuivre les recherches sur une analyse socio-économique avec une approche socio-anthropologique. J'ai rejoint le laboratoire travaillant sur les Populations Végétales et les bioagresseurs dans les Ecosystèmes Tropicaux (UMR PVBMT), au CIRAD basé à l'île de La Réunion en mai 2015. Après discussion avec le CIRAD et l'Université de l'île de La Réunion, ma thèse a été orientée vers une approche pluridisciplinaire, incluant la recherche économique, écologique et socio-anthropologique. Ce projet a des objectifs pluridisciplinaires en vue de fournir des recommandations pour le prochain programme de lutte biologique dans le contexte de la conservation de la biodiversité à l'île de La Réunion. Le but de cette thèse est de décrire et d'analyser les facteurs économiques, écologiques et sociaux liés à la gestion et au contrôle de *R. alceifolius* à l'île de La Réunion, département français d'outre-mer (figure i). Une étude de la gestion de *R. alceifolius* a été entreprise (chapitre 1) avec la description des divers registres depuis l'introduction de la plante envahissante jusqu'à sa gestion, le besoin récent de subir un contrôle biologique jusqu'aux prémisses des controverses sociétales. Le but de l'analyse économique (chapitre 2) des différentes options de gestion a été d'évaluer tous les coûts encourus, y compris le coût du contrôle et le coût des invasions liées à l'agriculture, à la valeur du cadastre et au tourisme. Un soutien supplémentaire a été fourni par le *Centre for Invasion Biology* (Afrique du Sud), la *Business School* de l'Université de Nouvelle-Angleterre (Australie) et l'Université de Neuchâtel (Suisse). Le chapitre 3 souligne les avantages écologiques et le succès potentiel du programme de lutte biologique dans le parc national. Suite aux controverses entre les parties prenantes, il était impératif d'entreprendre une analyse économique et une étude écologique qui pourraient ensuite fournir des données pertinentes pour démontrer le succès du programme de lutte biologique. Cependant, l'étude des éléments nécessaires pour analyser la logique derrière de telles controverses était centrale afin de comprendre le point de vue des apiculteurs sur le choix du gouvernement local du centre de recherche CIRAD d'entreprendre ce programme de lutte biologique (chapitre 4). Le dernier objectif de la thèse (chapitre 5) est un travail collaboratif avec l'Université de Stellenbosch en Afrique du Sud sur la problématique des conflits des « parties prenantes » sur la gestion d'une plante invasive par le développement d'un cadre conceptuel. Ce chapitre se présente sous forme d'un article publié.

La description de la thèse

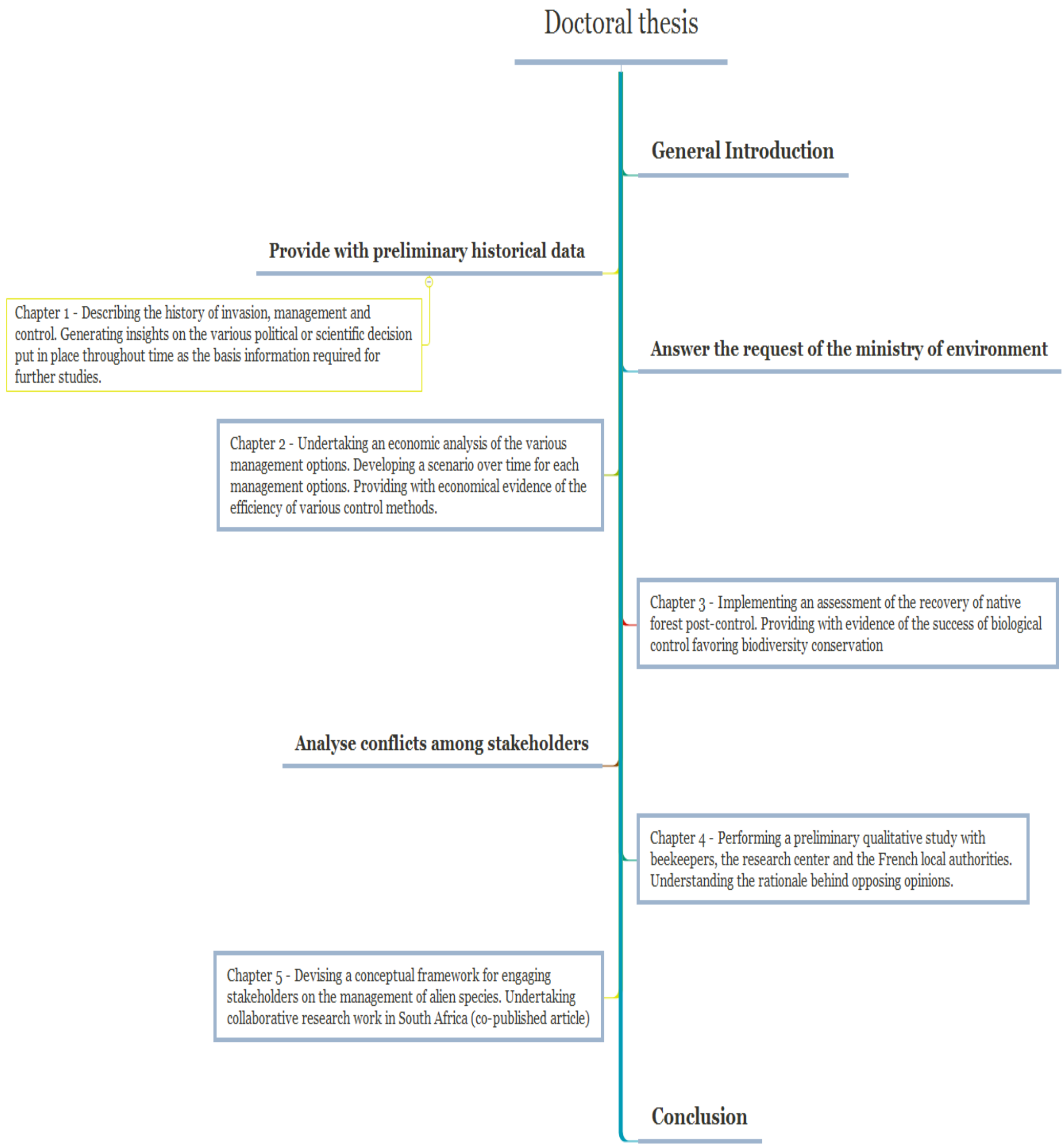

Figure 0-1: Les approches multidisciplinaires de ce travail de recherche et le lien entre chaque chapitre.

Chapitre 1

La gestion de l'introduction de *Rubus alceifolius* : une approche historique du rôle des acteurs à l'île de La Réunion (Archipel des Mascareignes)

Ce chapitre est destiné à être soumis à *Botany letters*

Ceci est une monographie de la gestion de *R. alceifolius* à l'île de La Réunion qui fournit le contexte historique. Je regarde comment et par qui l'espèce a été décrite et gérée. J'explore le travail de recherche entrepris sur les espèces cibles et son agent de lutte biologique *C. janthina*.

Chapitre 2

Une analyse économique des options de lutte contre l'arbuste exotique envahissant *Rubus alceifolius* (Rosaceae) à l'île de La Réunion, dans l'archipel des Mascareignes

Ce chapitre a été soumis à *PeerJ* le 12 mars 2018

J'estime les coûts de contrôle et le coût de l'invasion selon différentes options de gestion (Mécanique avec contrôle chimique, Contrôle biologique et pas de contrôle) au sein de deux strates dans deux communes de l'île. J'évalue la surface envahie par *R. alceifolius* dans les sites d'étude et j'estime son taux de propagation. Je compare les coûts encourus pour chaque option de gestion et fournis des prévisions en développant des scénarios.

Chapitre 3

Une évaluation de l'efficacité du contrôle biologique sur l'invasion de *Rubus alceifolius* : impacts sur la recolonisation des communautés forestières tropicales de l'île de la Réunion (archipel des Mascareignes)

Ce chapitre a été soumis à *PeerJ* le 20 mars 2018

Je mesure l'impact positif et négatif du programme de lutte biologique sur la reconstitution des plantes indigènes dans la réserve naturelle de Mare Longue sur une base de cinq ans. Pour les espèces indigènes et non indigènes, j'évalue la richesse et la récupération des espèces et j'étudie davantage le lien avec les facteurs environnementaux (superficie, élévation et emplacement dans la matrice forestière ou en lisière de forêt).

Chapitre 4

Comment un programme de lutte biologique classique est-il devenu une controverse chez les apiculteurs ? Une étude préliminaire sur la gestion de la plante envahissante *Rubus alceifolius* à l'île de La Réunion

Ce chapitre est un début d'éléments nécessaires en vue d'une analyse socio-anthropologique approfondie.

J'entreprends des études qualitatives pour étudier le problème perçu par les apiculteurs liés à la gestion et au contrôle de *R. alceifolius* en mettant l'accent sur le programme de lutte biologique. J'explore la construction sociale par rapport aux apiculteurs. Enfin, j'examine les liens entre la perception et les actions entreprises dans cette étude de cas controversée.

Chapitre 5

Un cadre pour impliquer les parties prenantes dans la gestion des espèces exotiques

(*A framework for engaging stakeholders on the management of alien species*)

> Novoa A., Shackleton R., Canavan S., Cybèle C., Davies SJ., Dehnen-Schmutz K., Fried J., Gaertner M., Geerts S., Griffiths CL., Kaplan H., Kumschick S., Le Maitre DC., Measey GJ., Nunes AL., Richardson DM., Robinson TB., Touza J., Wilson JRU. 2018. A framework for engaging stakeholders on the management of alien species. *Journal of Environmental Management* 205:286–297. DOI: 10.1016/j.jenvman.2017.09.059.

Après un atelier sur « l'engagement des parties prenantes dans la gestion des espèces exotiques » par le Centre for Invasion Biology en Afrique du Sud, j'ai travaillé avec le Dr Ana Nova qui a dirigé un travail de recherche en collaboration dans lequel un article a été publié.

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Chapitre 1

La gestion de l'introduction de *Rubus alceifolius* : une approche historique du rôle des acteurs à l'île de La Réunion (Archipel des Mascareignes)

L'arrivée de l'homme dans l'archipel des Mascareignes, à la fin des années 1600, a conduit à l'introduction d'espèces non indigènes. Dans ce nouvel environnement, sans leurs prédateurs naturels et leurs concurrents, certaines de ces espèces sont devenues envahissantes menaçant la faune et la flore endémiques de ces îles. L'Île de La Réunion a été témoin de l'invasion de plusieurs espèces, qui ont été enregistrées pour la première fois au milieu du XIX^{e} siècle. La notion d'espèces introduites, exotiques, non indigènes ou envahissantes a été décrite différemment selon les différentes parties prenantes du XIX^{e} au XXI^{e} siècle. La plante introduite, *Rubus alceifolius*, a été définie à partir de diverses perspectives de groupes d'individus identifiés comme les parties prenantes clés, représentées par des autorités locales, des institutions ou des chercheurs. Sa gestion s'est faite en fonction de la gouvernance, du développement et des priorités dans le temps. L'utilisation du contrôle biologique en tant qu'option de gestion a donné lieu à des controverses dans la société. Nous avons entrepris une rétrospective du processus de gestion de *R. alceifolius* à l'île de La Réunion. Le but de cette étude est d'évaluer le processus historique qui a mené au programme de contrôle biologique de *R. alceifolius*, l'une des plantes les plus envahissantes de l'île. Celle-ci a donné lieu à des opinions divergentes parmi les parties prenantes. Nous avons examiné l'histoire de *R. alceifolius* et son point de vue par les principales parties prenantes. Dans cette étude, nous avons décrit l'impact de l'invasion de *R. alceifolius* et passé en revue les travaux de recherche menés ainsi que les programmes de gestion et de contrôle mis en place pour contrôler cette espèce. Nous avons ensuite évalué les perceptions de la société civile et l'avons comparée à celle de la décision politique et scientifique mise en place pour contrôler *R. alceifolius*. Nous avons conclu en justifiant la nécessité récente d'une analyse socio-économique du contrôle de *R. alceifolius* comme étude de cas pour l'archipel des Mascareignes.

Mots clés: biodiversité, parties prenantes, conflits, controverses, espèces envahissantes

Chapitre 2

Une analyse économique des options de lutte contre l'arbuste exotique envahissant *Rubus alceifolius* (Rosaceae) à l'île de La Réunion, dans l'archipel des Mascareignes

Un contrôle biologique est souvent nécessaire pour compléter le contrôle chimique et mécanique des plantes exotiques envahissantes. De nombreuses espèces végétales exotiques envahissantes menacent les écosystèmes de l'île de La Réunion, un département français de l'archipel des Mascareignes. Malgré une longue histoire de contrôle chimique et mécanique de *Rubus alceifolius* Poir. (*Rosaceae*), l'une des espèces les plus envahissantes de l'île, elle est restée répandue et problématique. Ici, nous évaluons les coûts (de contrôle et de la valeur des impacts négatifs) associés aux différentes méthodes de contrôle. Les méthodes comprenaient un programme de lutte biologique avec l'introduction de *Cibdela janthina* (Hyménoptère : Argidae) en 2008 pour lutter contre *R. alceifolius* à l'île de La Réunion. Ce fut le premier programme français de lutte biologique ciblant une espèce végétale envahissante dans les habitats naturels plutôt qu'agricoles. Nous avons estimé la valeur actuelle des coûts liés à cinq scénarios de gestion :

1) contrôle mécanique en dessous de 800m

2) contrôle biologique (avec contrôle mécanique et chimique en cours dans les champs de canne à sucre) en dessous de 800m,

3) pas de contrôle en dessous de 800m

4) contrôle mécanique au-dessus de 800m,

et 5) aucun contrôle au-dessus de 800m.

Pour les coûts de contrôle, nous avons utilisé le coût de compensation pour chaque scénario de gestion de 1997 à 2007 avant la libération de l'agent de lutte biologique et de 2008 (lorsque le programme de

lutte biologique a commencé) jusqu'en 2016. Nous avons ensuite estimé les coûts d'invasion jusqu'en 2030. Pour évaluer les coûts engendrés par l'invasion, nous avons utilisé des rendements réduits en canne à sucre, la perte de valeur des terres agricoles et des pertes de revenus de l'écotourisme sur les terres forestières. Nous avons constaté que la lutte biologique réussissait à atteindre un contrôle complet en dessous de 800 m, et que c'était aussi l'option qui avait occasionné les coûts les plus bas. Le ratio des coûts du contrôle mécanique au contrôle biologique était de 12:1 en termes de valeur actuelle de 2008 à 2016. La lutte mécanique avec contrôle chimique entraînerait une invasion continue, car les plantes se répandent plus vite qu'elles ne peuvent être éliminées. D'autre part, le contrôle biologique a entraîné une réduction substantielle de la zone envahie en dessous de 800 m. Les taux annuels de propagation selon un scénario sans contrôle ont été estimés à 3,5% et 5,3% respectivement dans les forêts naturelles et les champs de canne à sucre. Après l'introduction du contrôle biologique, les taux de propagation sont devenus négatifs (-4,9% et -17,2% respectivement). Des recherches plus poussées sur la valeur de la biodiversité seraient nécessaires avant qu'une solide analyse coûts-bénéfices de l'effet net de la lutte biologique puisse être effectuée.

Mots clés : lutte biologique, analyse coût-efficacité, plante exotique envahissante, biodiversité, France

Chapitre 3

Une évaluation de l'efficacité du contrôle biologique sur l'invasion de *Rubus alceifolius* : impacts sur la recolonisation des communautés forestières tropicales de l'île de la Réunion (archipel des Mascareignes)

Le contrôle biologique peut être une stratégie de conservation efficace pour gérer les espèces envahissantes lorsque des moyens plus classiques ne peuvent être mis en œuvre, lorsque l'accessibilité pour contrôler les espèces cibles devient un problème, ou lorsque le financement est limité. Estimer les impacts de ces programmes en termes d'avantages pour la conservation de la biodiversité indigène reste souvent une tâche difficile. L'impact direct de l'agent de lutte sur les espèces envahissantes ciblées peut être facilement mesuré, mais les effets complexes au niveau de la communauté et les mécanismes sous-jacents restent mal compris. Nous avons évalué l'impact sur la recolonisation des communautés végétales indigènes post-biocontrôle, en termes d'augmentation de la richesse spécifique et du taux de recouvrement, sur une période de cinq ans durant le programme de lutte biologique de la ronce géante envahissante. Nous avons étudié la recolonisation de la végétation dans un ensemble de parcelles de *R. alceifolius* défoliées le long d'un gradient altitudinal. Pour mesurer les impacts positifs et négatifs d'un tel programme de lutte biologique sur la diversité des communautés végétales indigènes au fil du temps, nous avons également évalué le rôle des facteurs environnementaux. Nous avons étudié le recouvrement de *R. alceifolius*, la richesse spécifique et le recouvrement d'espèces non indigènes et d'espèces indigènes dans le parc national de l'île de La Réunion. La diminution du recouvrement de R. *alceifolius* suggère que le biocontrôle a eu un impact positif sur les communautés indigènes avec une augmentation de la richesse et du recouvrement des espèces indigènes. L'impact négatif du programme de lutte biologique était lié à l'augmentation de la richesse spécifique non indigène en réponse à la disponibilité des ressources terrestres après le programme de biocontrôle. La lutte biologique apparaît ici comme un moyen efficace pour gérer l'invasion de *R. alceifolius* et son efficacité a été influencée par l'aire de

répartition, la surface des parcelles et l'emplacement de chaque parcelle en bordure des zones forestières ou en matrice forestière. Nous examinons de la mesure dans laquelle l'utilisation du biocontrôle dans une approche intégrée peut optimiser les avantages pour la conservation de la biodiversité à long terme.

Mots clés: plantes exotiques envahissantes, île, biodiversité, succès, lutte biologique, *Cibdela janthina*

Chapitre 4

Analyser les controverses autour de la gestion et du contrôle de la plante envahissante Rubus alceifolius à la Réunion: éléments préliminaires d'une recherche sociologique

Dans le contexte de l'invasion biologique dans un écosystème insulaire, la perception réelle des plantes exotiques envahissantes par les citoyens affectera leur perception de la stratégie de contrôle choisie. La gestion et le contrôle de *R. alceifolius*, une herbe très envahissante à l'île de La Réunion, ont déclenché un grand débat parmi la communauté locale et ont radicalement mené à des opinions divergentes sur le statut envahissant de la plante. Au milieu du XIXe siècle, *R. alceifolius* a été enregistrée comme étant envahissante. *R. alceifolius* est apparue sur la première publication de la liste des plantes envahissantes de l'île de la Réunion en 1991 et a été répertoriée comme l'une des cinq plantes les plus envahissantes. La demande pour la production de bois a diminué et la propagation d'espèces envahissantes, y compris *R. alceifolius*, a ralenti le travail des services forestiers dans les années 1970. Les autorités locales ont financé les services forestiers pour lutter contre *R. alceifolius* depuis les années 1980 en exprimant la volonté d'utiliser un agent de lutte biologique. Du point de vue des autorités locales, *R. alceifolius* est considérée comme une plante exotique envahissante, même si ses baies sont consommées localement ou utilisées à d'autres fins traditionnelles. Un agent de lutte biologique, *Cibdela janthina*, a été sélectionné et une évaluation des risques environnementaux sur la spécificité de *C. janthina* en tant qu'insecte phytophage pour nourrir *R. alceifolius* a été réalisée. Le test de spécificité a démontré que *C. janthina* présente un risque mineur sur d'autres espèces à l'île de La Réunion. Les autorités locales ont donné leur accord pour libérer un agent de lutte biologique choisi, *C. janthina*, pour lutter contre *R. alceifolius* en 2007. L'omniprésence de l'agent de lutte biologique, une mouche bleu métallique, dans l'île en un an n'est pas passée inaperçue et a suscité un grand malentendu de la part du public. Une forte abondance de *C. janthina*, communément appelée la *mouche bleue*, a été observée sur les litchis (*Litchi* *chinensis*) et les poivriers brésiliens (*Schinus terebinthifolius*) pendant la floraison des litchis, créant ainsi des incertitudes sur la production de miel de litchi. Cette préoccupation a été la base d'un problème formulé au sein de la communauté locale et de groupes d'individus et a reçu une grande attention de la part des médias. La presse locale a publié de gros titres portant sur l'opinion des apiculteurs qui ont exprimé leurs préoccupations sur la diminution de leur production de miel aux autorités locales. L'association et le syndicat des apiculteurs ont été sollicités en réaction à ces positions controversées dans le but de défendre leur cause contre les autorités locales qui ont accordé l'autorisation au centre de recherche (CIRAD) qui a mis en place ce programme de lutte biologique. D'autres apiculteurs professionnels ont défendu leur cause en essayant de comprendre l'impact de l'agent de lutte biologique sur la production de miel et ont été considérés comme des entrepreneurs moraux. Ils ont collaboré avec le centre de recherche qui a obtenu l'accès à leurs ruches pour effectuer des recherches sur le lien entre *C. janthina* et la production de miel. En conséquence, nous avons réfléchi à ce problème dans une étude de cas qui était de déterminer la perception d'un programme de lutte biologique à partir de la perception des autorités locales, des apiculteurs et du centre de recherche. Nous avons étudié la perception des trois groupes d'acteurs identifiés à l'île de La Réunion en utilisant la notion de construction sociale. Nous avons identifié la perception divergente des autorités locales, des apiculteurs et du centre de recherche et des sujets d'interdépendance entre eux. Nous avons examiné les données disponibles dans les journaux et entrepris des enquêtes pour comprendre les différents points de vue dans le cadre du programme de lutte biologique. Nous avons étudié les émotions et les perceptions avant la libération de *C. janthina* qui a pu contribuer à une controverse, en raison de points de vue contrastés sur l'agent de contrôle biologique et le rôle ou les utilisations de la plante invasive.

Mots clés : Lutte biologique, formulation de problèmes, médias, conflits, biodiversité

Chapitre 5

Un cadre pour engager les parties prenantes dans la gestion des espèces exotiques

Les espèces exotiques peuvent avoir des impacts écologiques et socio-économiques majeurs dans leurs nouvelles classes et des actions de gestion sont nécessaires. Cependant, la gestion peut être litigieuse et créer des conflits, en particulier lorsque les parties prenantes bénéficiant d'espèces exotiques sont différentes de celles qui subissent des coûts. De tels conflits d'intérêts empêchent souvent la mise en œuvre de stratégies de gestion. Il y a, par conséquent, un intérêt croissant pour la participation des parties prenantes affectées par des espèces exotiques ou par leur gestion. Grâce à un atelier et à un processus de consultation facilités, comprenant des universitaires et des gestionnaires travaillant sur une variété d'organismes et dans différentes zones (urbaines et rurales) et des écosystèmes (terrestres et aquatiques). Nous avons développé un cadre conceptuel pour engager les parties prenantes dans la gestion des espèces exotiques. Le cadre qui explique l'engagement des parties prenantes comprend 12 étapes :

(1) identifier les parties prenantes ;

(2) sélectionner les parties prenantes clés pour l'engagement ;

(3) explorer les perceptions des principales parties prenantes et développer les objectifs initiaux qui concernent la gestion ;

(4) impliquer les principales parties prenantes dans l'élaboration d'un projet de stratégie de gestion ;

(5) réexplorer les perceptions des principales parties prenantes et réviser les objectifs de la stratégie ;

(6) co-créer les objectifs généraux, les objectifs de gestion et les échéances avec les principales parties prenantes ;

(7) co-concevoir une stratégie de gestion ;

(8) faciliter l'appropriation de la stratégie par les parties prenantes et l'adapter au besoin ;

(9) mettre en œuvre la stratégie et suivi des actions de gestion pour évaluer le besoin d'actions supplémentaires ou futures. Si une gestion supplémentaire est nécessaire après ces actions, des mesures supplémentaires doivent être prises ;

(10) identifier les nouveaux intervenants, avantages et coûts ;

(11) surveiller l'engagement ;

et (12) réviser la gestion de la stratégie.

Globalement, nous pensons que notre cadre fournit une approche efficace pour minimiser l'impact des conflits créés par la gestion des espèces exotiques.

Mots clés : Invasions biologiques, Conflits d'intérêts, Gestion des espèces envahissantes, Perceptions, Propriété des parties prenantes, Gestion de l'environnement

Conclusions générales et recommandations clés

Cette recherche visait à entreprendre une analyse socio-économique de la gestion et du contrôle de *R. alceifolius* à l'île de La Réunion. Pour ce cas-ci, j'ai passé en revue les résultats significatifs de chaque chapitre, décrivant l'impact positif et négatif du programme de lutte biologique. La posture de cette recherche est d'une haute importance, car elle implique une analyse du travail effectué par et pour le centre de recherche, afin d'évaluer son travail qui correspond à une forme d'auto-évaluation. Le bilan est affiché objectivement avec un ensemble de recommandations. Le résultat final de cette étude est de proposer une liste d'éléments-clés qui aideraient la fondation du futur programme biologique.

Principaux résultats

Les options de gestion du programme de lutte biologique contre *R. alceifolius* ont nécessité une approche multidisciplinaire pour aborder les questions économiques, écologiques et anthropologiques (figure ii). L'analyse économique de la lutte contre *R. alceifolius* (chapitre 2) a montré et prédit le rapport coût-efficacité de la lutte biologique par opposition au contrôle mécanique dans le gradient altitudinal inférieur (0-800 m) de 1997 à 2030. Une approche intégrée devrait être privilégiée. Le maintien du contrôle mécanique est obligatoire dans les altitudes supérieures (800-1500m), avec un financement sûr, à court et à long terme.

En termes de bénéfice écologique (chapitre 3), le programme de lutte biologique a été un succès dans les communautés forestières tropicales. Le programme de lutte biologique a entraîné une diminution du taux de recouvrement de l'espèce ciblée, *R. alceifolius*, d'une moyenne de 52% à 22%. L'impact positif de ce programme a été une augmentation de la richesse spécifique et du recouvrement des espèces indigènes. L'impact négatif qui devrait être pris en compte est l'augmentation des espèces non indigènes en lisière de forêt. L'ouverture de zones forestières pour des routes ou des sentiers augmenterait potentiellement l'invasion des voies par *R. alceifolius*.

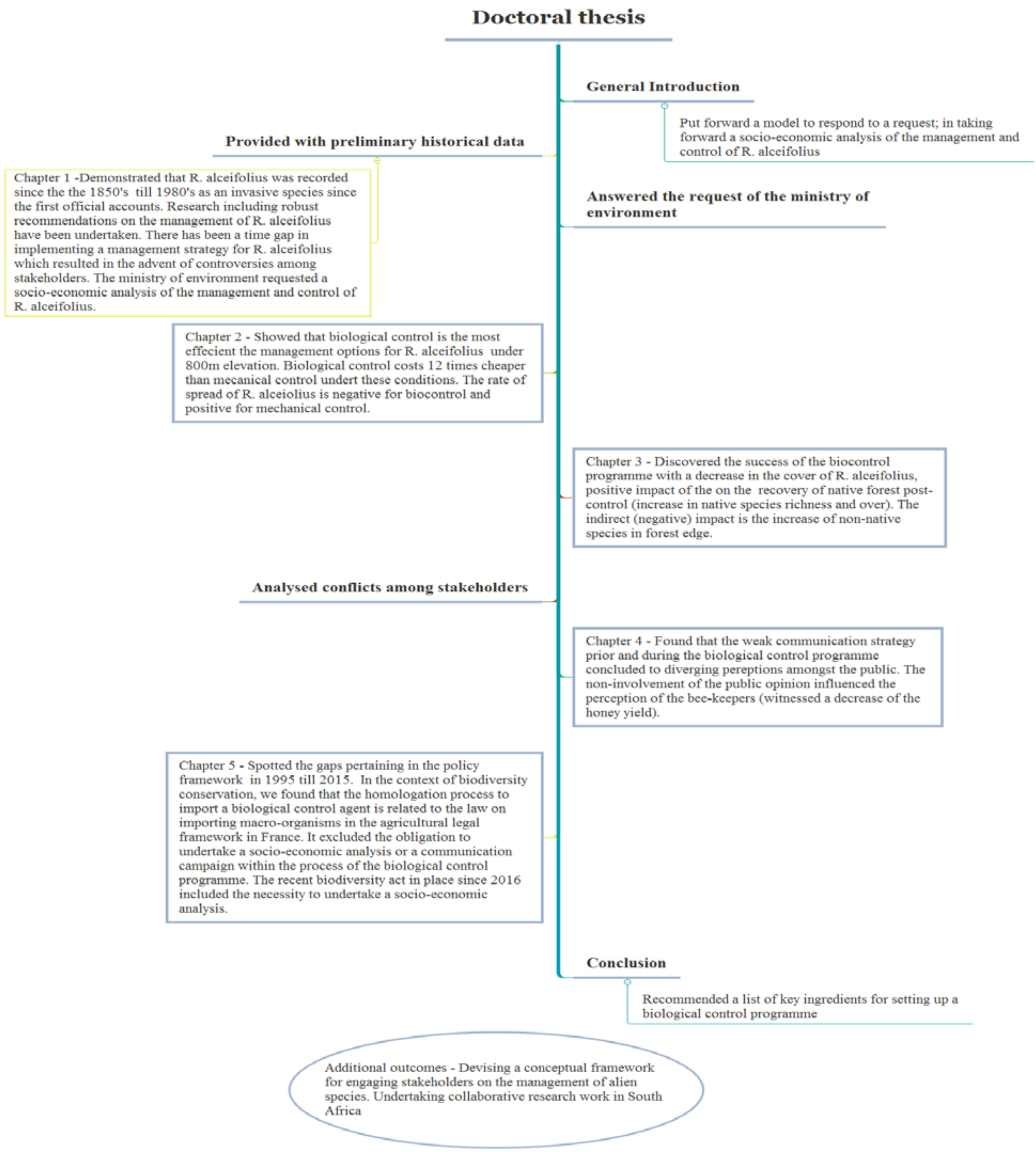

Figure 0-2: Les résultats pluridisciplinaires de ce travail de recherche et de conclusion.

Cette étude souligne l'importance d'impliquer les parties prenantes dans la gestion d'un programme de lutte biologique (Figure ii). Premièrement, la recherche socio-anthropologique a démontré qu'une faible implication des parties prenantes identifiées a généré des conflits dans le cadre du programme biologique (chapitre 4). Dans cette étude de cas, un manque de communication prévalait puisque, d'un point de vue légal, il n'existait aucune exigence contraignante pour établir une stratégie de communication pour un tel programme. Les politiques existantes lors de la mise en place et de la mise en œuvre du programme de lutte biologique n'ont pas répondu à la condition préalable d'un plan de communication. Les autorités locales, gouvernementales ou régionales représentées par le Conseil régional ou l'Union Européenne n'étaient pas tenues d'inclure un plan de communication dans la gestion de *R. alceifolius*. La mise en place et la mise en œuvre d'une stratégie de communication relèvent seulement de la gestion des espèces envahissantes dans le code de l'environnement (chapitre 4).

La posture adoptée tout au long de ce travail de recherche

Généralement, il y a plus de recherche biologique que de recherche sociologique sur le programme de lutte biologique. Il y a un manque de reconnaissance des résultats dans les études sociales liées à un tel programme. La restitution des résultats des chercheurs en sciences sociales aux chercheurs en science classique, sur les controverses scientifiques, est généralement fortement critiquée (Callon, 2005). Cette thèse a répondu à une demande du département de l'environnement, de l'aménagement et du logement de mener une analyse socio-économique de la gestion et du contrôle de la plante exotique envahissante *R. alceifolius*. Les principales difficultés rencontrées dans ce travail de recherche pluridisciplinaire ont été d'intégrer l'étude socio-anthropologique à une investigation biologique plus classique. Il était très difficile de garder une posture neutre tout en étant basée au CIRAD et d'écrire de façon objective et critique sur le rôle du CIRAD dans le programme de lutte biologique. Cette posture nécessitait des négociations avec des chercheurs en sciences biologiques, même si cela signifiait entraver une manière classique d'analyser le contrôle biologique. Cette approche novatrice comprend l'analyse de l'opinion publique, l'implication des parties prenantes et une étude sociétale dans son ensemble. Ceci est une nouvelle façon de faire de la recherche en menant une étude interdisciplinaire et pluridisciplinaire.

Les conclusions de cette thèse ont été résumées dans la liste suivante de recommandations ciblant les autorités locales, les gouvernements et les institutions liées à la fois aux sciences biologiques et aux sciences sociales.

Principaux éléments pour la mise en place d'un programme de lutte biologique

Ce travail de recherche a généré plusieurs résultats comprenant des conseils de premier plan dans la gestion des espèces envahissantes dans la phase préliminaire de concevoir un programme de lutte biologique et avant la libération de l'agent de contrôle identifié.

Entreprendre des études socioécologiques

Il est fortement conseillé d'entreprendre une étude socio-anthropologique pour identifier les principales parties prenantes liées aux espèces ciblées ou à l'agent de contrôle.

Cette étude a montré que les parties prenantes (principalement apiculteurs) étaient peu représentées dans le processus de prise de décision dans la gestion des espèces envahissantes et dans la conception d'un contrôle biologique jusqu'à la libération des espèces hôtes sélectionnées. L'opinion publique sur les faits liés à la description du caractère envahissant des espèces devrait être étudiée aux stades préliminaires de sa gestion (chapitre 4). Il est nécessaire d'avoir du recul pour comprendre la perception initiale du public, des autorités gouvernementales et des institutions d'une espèce envahissante et de sa gestion.

Conduire une analyse économique

Une analyse économique doit d'abord être mesurée pour évaluer le coût du contrôle, mais une mesure approfondie du coût de la biodiversité est nécessaire pour analyser en amont les coûts et les bénéfices.

Les différents coûts de contrôle d'une espèce ciblée doivent être estimés ainsi que les coûts d'invasion des activités génératrices de revenus (chapitre 2). Le coût lié à la biodiversité ou aux services écosystémiques devrait également être évalué pour pouvoir réaliser une analyse coûts-bénéfices des différentes options de gestion des espèces ciblées.

Mettre en place un forum hybride pour mobiliser l'opinion publique et identifier les parties prenantes clés

Les parties prenantes devraient être impliquées depuis la phase de démarrage du programme de lutte biologique. Il est crucial d'identifier et d'engager les parties prenantes clés à travers le programme.

Pouvoir identifier les parties prenantes représente une tâche difficile, car elles sont directement ou indirectement liées à une espèce ciblée. L'engagement des parties prenantes pourrait être une approche cruciale dans la gestion des problèmes permettant aux parties prenantes impliquées dans le processus d'agir en conséquence. Un forum hybride devrait être mis en place en tant que plateforme réunissant des acteurs techniques et sociaux, expliquant en termes de gouvernance le niveau d'implication de la société civile (Callon, Lascoumes & Yannick, 2001). Ce forum permettrait des dialogues préliminaires sur les implications des parties prenantes pour un dialogue plus approfondi sur la gestion d'une espèce ciblée.

<u>Concevoir une stratégie de communication solide</u>

Une stratégie de communication devrait être financée avant et après le programme de lutte biologique, avec un plan de communication et des outils identifiés.

L'analyse de l'instrument d'action publique à Lascoumes & Le Galès (2005) a montré comment la communication est au centre de chaque projet. Les conflits entre parties prenantes ont souvent surgi en raison d'opinions divergentes, car aucun plan de communication n'avait été mis en place (le cas des apiculteurs, voir le chapitre 4). En France, la nouvelle loi pour la biodiversité recommande la communication sur les espèces envahissantes.

<u>Renforcer le cadre politique et légal</u>

Il est fortement recommandé de travailler en étroite collaboration avec les institutions gouvernementales pour communiquer sur les forces et les faiblesses du cadre politique existant.

Cela permettrait de renforcer les politiques existantes pour améliorer les procédures d'analyse des risques au cours des étapes préliminaires de l'homologation de l'agent de contrôle jusqu'à la mise en œuvre du programme de lutte biologique.

Un écart dans le cadre politique en termes d'absence de lignes directrices visant à donner la priorité à l'impact sociétal dans un programme de lutte biologique pourrait entraîner des conflits entre les parties prenantes. Il est nécessaire d'inclure l'impact sociétal dans l'analyse de l’évaluation des risques lors de la mise en œuvre du processus d’homologation d’un agent de contrôle sélectionné avec le plan de gestion des espèces envahissantes.

La référence mondiale dans le cadre réglementaire national est la Nouvelle-Zélande qui a une loi sur la biosécurité depuis 1993 et une loi sur les substances dangereuses et les nouveaux organismes depuis 1996 (Simberloff, 2013). Ces actes correspondent à un cadre fort qui interdit l’arrivée de potentielles espèces. Un protocole rigoureux avec un haut niveau sécurité aux ports d’entrée (aéroports et ports maritimes) permet de prendre les précautions nécessaires pour éviter l’entrée des espèces. La Nouvelle-Zélande devrait être présentée comme un exemple à l’échelle mondiale, régionale et insulaire.

Avec l’avènement d’un tout nouvel acte pour la biodiversité, la France devrait renforcer le nouveau cadre juridique basé sur les échecs passés et le succès à l’échelle mondiale. Le premier exemple d’un programme de lutte biologique réussi, favorable à la protection de la biodiversité menacée, a eu lieu à l’échelle de l’île de La Réunion.

<u>Sécuriser le financement pour la gestion à court et à long terme</u>

Un financement devrait être assuré dans la gestion des espèces exotiques et envahissantes à court et à long terme. Le soutien des autorités gouvernementales est crucial pour éviter les controverses sur la lutte biologique.

Van Wilgen, Moran & Hoffmann (2013), ont démontré la nécessité d’assurer une budgétisation à long terme dans la stratégie de gestion des espèces invasives pour établir un impact positif. La stratégie devrait couvrir les mesures de contrôle, le programme de restauration, la gestion de l’utilisation des sols et le plan adapté en fonction de la priorité du site. Toutes les activités génératrices de revenus liées à la gestion des espèces invasives devraient être favorisées. Cela pourrait prendre la forme de création d'emplois ou de sites touristiques (s'ils sont liés à des zones de biodiversité).

<u>Une approche intégrative de gestion et de collaboration</u>

Il est obligatoire de veiller à ce que la gestion des espèces envahissantes soit effectuée en étroite collaboration avec toutes les organisations gouvernementales, les praticiens, les gestionnaires et les organisations non gouvernementales.

Une gestion intégrée devrait viser le contrôle optimal des espèces exotiques et envahissantes pour protéger la biodiversité menacée et pour une gestion adéquate de l'utilisation des terres, en travaillant ensemble dans un bon esprit d'équipe.

Une gestion intégrée à court et à long terme avec une solide collaboration au sein des institutions, y compris les administrateurs, les chercheurs et les praticiens, est requise

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Chapter 1: Management and biocontrol of the invasive *Rubus alceifolius*: a historical approach of stakeholder's role in tackling invasive plants in Réunion Island (Mascarene Archipelago)

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Abstract

Human settlement in the Mascarene Archipelago, in the late 1600's, led to the introduction of non-native species. In this new environment, without their natural predators and competitors, some of these species became invasive threatening the endemic fauna and flora of these islands. Invasive plant species invaded Réunion Island, most of which were introduced in the mid-19th century. The notion of introduced, exotic, non-native or invasive species, were described differently according to various stakeholders from the 19th to the 21st century. The status of *Rubus alceifolius*, one of the ten most invasive species in Reunion Island has been defined from various perspective of groups of individuals, represented by local authorities, institutions or researchers. Its management has occurred according to governance, development and priorities in time. The recent use of biological control as a management option resulted in controversies from the societal point of view. We undertook a retrospective of the process of management of *R. alceifolius* in Réunion Island. The aim of this study was to assess the historical process from its first record and notification of its invasion that lead to various control programmes of *R. alceifolius* one of the most invasive plant on the island, funded by the local authorities. We documented the different past technical and scientific programmes and publications on the study of R. alceifolius. In this study we described the impact of invasion of *R. alceifolius* and reviewed research work which were carried out as well as management and control programme that were put in place to control this species. We then associated the political and scientific decisions put in place to control *R. alceifolius.* We found that several publications were available on the invasion of *R. alceifolius* yet a gap between the published request to control its invasions and the first implementation in controlling of *R. alceifolius.* First mechanical control has been carried out and then biological control mean. This was due to a moderate prioritisation of policy and decision makers in the management of weed invasion in Réunion island for the case of biodiversity conservation.

Key-words: biodiversity, conflicts, policy, invasive species

Introduction

The history of human settlement in the Mascarene Archipelago

Island floras are among the most threatened in the world and harbour high levels of endemism. The Mascarene islands are biologically diverse and 72 % of the 959 native angiosperm species are endemic (Thébaud et al. 2009). Since human settlement in the late 1600's, Mascarenes native habitats have been transformed for agriculture and urbanisation and most of the native flora is now ranked in global IUCN Redlist. Among Angiosperms, between 50 to 82 % of single island species are endangered (Baider et al. 2010). Mascarenes native ecosystems are relatively preserved in Réunion island where it still covers 30% of the island area (Strasberg et al. 2005). Even if most Reunion island native habitats are protected into a national park, the native ecosystems and flowering plant flora (550 sp.) are severely threatened by a growing number invasive plants. Amongst which 49 vascular plants species are now considered extinct from the island (representing 5.4% of vascular plants) and 275 species are now threatened (representing 30.4%) (UICN France et al. 2013).

The first record of the existence of the Mascarene Archipelago were in the Arabian chart in the 13^{th} century (North-Coombes 1979). The first human settlement in the Mascarene Archipelago was recorded from 1598 in Mauritius (Cheke 2010). The long distance of the archipelago to maritime roads could explain the late colonization of archipelago. Before the 17^{th} century the islands were occasionally used to make provision when boats were shipping back from Asia to South Africa or Madagascar and needed water and food renewal. The first documented landing of human being in Réunion Island was the Portuguese in 1510 and the first permanent settlement by the French in 1665 (Defos Du Rau 1960). The intentional introduction of farm animals on Mauritius and Réunion Island was recorded in the early 16^{th} century (Cheke 2010).

The Mascarene Archipelago native habitats were dominated by tropical canopy forests that experienced a rapid transformation for agriculture across the 18th and 19th century (Vaughan and Wiehe 1937). The colonization of the Mascarene Archipelago by settlers rapidly occurred, aiming at commercial purposes and development. The intensive production of coffee and sugarcane was carried out for exportation.

Weed invasion in the Mascarene Archipelago

In less than 300 years, Réunion Island has witnessed the introduction of more than 3000 non-native plant species, mostly introduced and recorded in the mid-19th century of which 843 are naturalized (Boullet 2017). According to authors 50 to 100 species have become invasive, dominating native plant communities at large scale (Macdonald et al. 1991; CBNM 2018). In terms of weed invasion, invasive plant management of most invasive species is localised on small experimental plots, mainly performed mechanically and chemically by forest service.

Among the most invasive plant list, only one species, *Rubus alceifolius* has been targeted for a control programme by several groups of individuals, represented by local French authorities, institutions or researchers. This management option has occurred according to governance, development and priorities in the 2000s. More recently, the use of biological control as a management option resulted in controversies from the societal point of view.

The destruction of pristine habitats for development coupled with the introduction of Invasive Alien Plants (IAPs) have modified the natural landscape in Réunion Island (J Tassin et al. 2006). Non-native plants species have been introduced on the island and *R. alceifolius* is the most cited invasive plants in historical documents mentioning biological invasion associated with the native vegetation of the island. Most collections of report on introduced species were from the forestry services (*Office Nationale des Forêts*). The institutional reports of the forestry services entailed a follow-up of wood production in cultivated forest (Defos du Rau 1960; Miguet 1957; IUCN 2003). The economic failure of wood production, led them to curb its production and the ambitious forest clearing aiming at developing the Island. Miguet (1952) in his report expressed his concern about the decrease of annual economic revenue with wood production. The main goals of the forestry services, fell into the classical historical story of land use management which were recorded in the 1950's. The mission of the forestry services underwent a change in the late 1990's with the creation of a National Park in Réunion Island. The forestry services added biodiversity conservation within their mission and classified some forest areas as reserve (*Réserves Biologiques Domaniales*). The management of forest was oriented towards a strong control of invasive plants with the control of *R. alceifolius* since early 1980's up till today.

The aim of this study is to assess the historical process that lead to the biological control programme of *R. alceifolius*, one of the most invasive plant on the island, which gave rise to diverging opinion amongst groups of individuals named as stakeholders. In this study we undertake a retrospective of the actions of management of *R. alceifolius* in Réunion Island. We describe historical facts documenting the spatial extent and impact of *R. alceifolius* and review research work which were carried out as well as management and control programme that were put in place to control this species. We try to put these historical facts in relationship to political decisions put in place to control *R. alceifolius* in order to better understand the process that lead to the release a biocontrol agent into native habitats on an oceanic island.

Methods

The biological records of *Rubus alceifolius*

We surveyed authors or institutions that early reported invasive species in Reunion island and we investigated when *Rubus alceifolius* has been cited and also we explain how the problem of invasion has been qualified; when documented the factors that favoured invasion and evidence of impact were integrated in the analysis. We took into account the whole process of naturalization, in native habitats, from introduction to invasion, based on the definition of Richardson et al. (2000), "*whereby an introduced species overcome several barriers within a natural habitat and establish itself*".

To do so we devised two tables to summarize the history of human settlement and that of invasion of our target species with a description of the control and management actions undertaken. Over the facts, we review available literature, whenever possible, the decision process involved.

In the management of natural resources, the terminologies used to relate to humans are group of individuals or the commonly used "stakeholders". The definition of the stakeholders has been given by (Freeman 2010)as "*any group of individual who can affect or is affected by the achievement of the firm's objectives*". The groups can be in the form of employees, media, competitors, environmentalists, supplier, governments, local community organisations, owners, consumer advocates, or customers all linked to an organisation (Freeman 2010). Stakeholders are connected to changes usually implicating several organisations and bringing about diverging perception. In the context of natural resources management or the biodiversity at threat, it is imperative to include the study the impact of humans on biological invasions management besides classical biological and ecological research studies.

Brief land use changes of Reunion island and historical phases of introduction of non-native plants

The South West Indian Ocean region was first discovered by the Arabian at least in the 13th century, including the Mascarene Archipelago. It was only in the 16th century that the Mascarene islands have been first colonized by the Portuguese and later the French.

Table 1-1: The records of human settlement throughout history in Réunion Island.

Date	Stakeholder	Action(s)	Fact(s)	Record(s)
13th - 14th century	Arabian	South West Indian Ocean Maps located and some islands have been named in the Mascarene Archipelago (San Apolonia for Reunion island)	The first map locating the Mascarene Archipelago (Réunion Island, Mauritius and Rodrigues)	(North-Coombes 1979)
1510	Portuguese travellers	Occasional landing of sailors for "stop over" on Réunion island	The first record of a human being on Réunion island	(Cheke 2010)
1665	French Colony	A French colony is set up in Réunion Island from Madagascar	The first human settlement	(Lougnon 1956)
1698	216 inhabitants	Autarkic agriculture and marginal productions of livestock and crops were undertaken for commercial companies shipping between Africa and Asia	Indicators or development	(Defos du Rau 1960)
1713	1171 inhabitants	Larger scale deforestation for coffee production and exportation	An increase in local population: 7500 inhabitants in 1732, 46017 inhabitants in 1788	(Defos du Rau 1960)
19th century	103 000 inhabitants	Sugar cane rapidly replaced coffee production	Technological progress in mechanization in sugar cane production (reaching 60 000 ha)	(Jacques Tassin 2002)
20th century	mid-20th century	Colonisation of inland, remote, steep places Lack of space for agriculture conducted the government to giveback land mainly in mountain areas	Large tracts of tropical mountain forest were deforested to develop new crops in higher elevation mainly sugar-cane and then vanilla, *Pelargonium* and cattle ranching	(Bertile 2000)

Subsistence farming

During the expansion of the colonial era in the 18th and 19th century, the United Kingdom, France and the Netherlands were considered as the dominant commercial nations in the Indian Ocean. The arrival of French colonizers along with labourers have brought about farming in Réunion island. Agricultural plants have been cultivated mainly for subsistence farming throughout the island, in which most of these cultivated plants have been introduced on the island. The French colonizer brought staple from Europe, the labourers from Madagascar and from India, simultaneously have gathered several crop species from the African sub-continent and Asia. They might have been responsible for few introduction of invasive species among the exotic crops.

Economic related plant species

Among the utilization of several crops or plants, the local community of Réunion island have also used the secondary purposes of plants. Few are known and used for their medicinal virtues among endemic and introduced species. Economic uses of plants also entailed fodder for farmed animal or plants used to dye textile products. Since the 19th century, the production of coffee, vanilla then geranium and later banana, pineapple and sugar cane were the main crops produced on large scale on the island for export in continental France. The island has known an increase in the development of agricultural export bringing revenue to the island's economy. Nowadays, mainly sugar cane is cultivated on large scale with subsidy provided to farmers from the European Union.

To promote trade and develop export-based agriculture, the governments hired commercial and even military expedition to survey, collect and propagate any useful exotic plants in the tropics. They supported savants' societies, described the flora; collected and exchanged plant species with the creation of botanical gardens within various countries of the Southern hemisphere (Gaillard 1999). The society's aim and willingness at that time was to extensively develop and use the resources of the overseas territories (Gaillard 1999). The sister island, Mauritius is host to *Pamplemousses* botanical garden which is known for its richness in introduced plant species. During the French colonization in the Mascarene Archipelago, it was believed that several botanical exchanged were carried out between *Pamplemousses* botanical garden created in 1736 and La Réunion Island to the garden named *Jardin de l'Etat* (Dequaire 1984; Rouillard and Guého 1999). The aim of the exchanges of plants were mainly for spices plants and the crops (Dequaire 1984).

In terms of ornamental plants, several species were introduced in the beginning of the 19th century to extend botanical gardens in Mauritius and Réunion island, by the Secretary General governing these islands (Trouette 1898). The advent of a rapid globalization in the late 19th century and the beginning of the 20th century have brought the exchanges of goods and services.

The records of *R. alceifolius* in Réunion Island

Table 1-2: The records of introduced plant that later became invasive in the history in Réunion Island

Date	Stakeholder	Action(s)	Fact(s)	References
1837	French botanist	Described the introduced plants of the Mascarene Islands	Introduction in 1837 based on Bojer, in the Pamplemousses Garden as many exotic species in the 19th century	(Rouillard and Guého 1999)
1861	State Botanic Garden	Catalogue of useful plants Acclimation societies	*Reports on Rubus 2 sp. described but no mention of R. alceifolius*	(Roussin 1860)
1883	General Council	Recorded the status of invasion of *R. alceifolius*	*R. alceifolius was* identified as a threat for agricultural practices and wood production	(Miguet 1980)
Mid-19th century	French botanist	Surveyed the native plants of Réunion island and published the first flora	*R. alceifolius* was considered as a highly invasive plant which has invaded a considerable part of Réunion Island	(De Cordemoy 1895)
1952	Forestry officer	Was head of the national forestry department (ONF) in Réunion island	*R. alceifolius* was recorded in 1949 in the forest of "Bélouve" and was covering 100 ha through a thick and densely patch which was rendering impossible access in the forest. The invasive *R. alceifolius* was squeezing the trees, with fallen dead wood. *R. alceifolius* was reported to be a highly invasive species.	(Miguet 1952)
1952	French researcher	Described the vegetation and habitat of Réunion Island	*R. alceifolius* was described as an invasive species present in various part of the island	(Rivals 1952)
1952	Botanist	Recommended the use of biological control of *R. alceifolius*	Based on the work of Rivals(1952), the use biological control as a solution to manage *R. alceifolius* was mentioned	(Friedmann 1997)
1957	Forestry officer	Reported on the enhancement of forest in Réunion Island	In a report on the reforestation of Réunion Island, (Miguet 1957) expressed his disagreement on the research work undertaken by Rivals (1952) whereby the latter explained that the complex forest has a slow growth and the species richness of potential commercial woods decreased with increasing elevations. Rivals (1952) explained that most species are of low economic value and that none of the forestry area is of value at the scale of a human life-time.	(Miguet 1957)
1960	PhD research	Described the geography of Réunion island	Mentioned that following the clearing of pristine forest, the land is rapidly invaded by the	(Defos du Rau 1960)

			prickly *R. alceifolius.* The dense invasion of *R. alceifolius* made the area difficult to access.	
1975	National research centre	Described the topography of Réunion Island	*R. alceifolius* was mentioned as being an invasive plant	(Centre National de la Recherche Scientifique, 1975)
1989	The Réunionese Society for the study and protection of the environment and the Ministry of Environment	*R. alceifolius,* commonly named “raisin marron” was reported as being a highly invasive species among a list of 20 species. A scientific mission was organised with the International Union for the Conservation of Nature to study the forest habitats and ecosystem of Réunion Island	A mission was financed by the Regional council and Departmental council of Réunion Island on a survey of the level of threat towards biodiversity and the impact of IAPs	(Doumence and Renard 1989; Galland 1991)

Legris (1963) in Baret (2002) explained that *R. alceifolius* was probably present in the Botanical garden of Calcutta in India in the late 19th century. The presence of *R. alceifolius* in Reunion Island was first recorded in 1895 by De Cordemoy (1895). Imported from Asia around the mid-19th century, it was described to be highly invasive up to the point that De Cordemoy (1895) cited that it nearly invaded the entire island (Table 2). It was known by the binomial nomenclature “*Rubus moluccanus”*. Its rapid naturalisation in the wild, growth, form and leaf shape explains its various common names: *“Raisin marron, Vigne marronne, Grosse ronce, Grosse framboise marronne”*. It was described as an invasive alien plant occurring in dense patches (Rivals 1952; Cadet 1977). The forestry services of Réunion Island (*Office National des forêts*) expressed their concern about the level of invasiveness of *R. alceifolius* appearing in thick, prickly patches in native forests and was highlighted as a threat by the General Council Commission in 1883 (Miguet 1952).

The destruction and the fragmentation of pristine habitats combined with the introduction of IAPs have severely modified the natural landscape in Réunion Island. Around 20 invasive species largely dominated in abundance or biomass the native plant communities and the human-disturbed habitats (UNESCO World Heritage Centre 2010; DEAL 2010b).

The spatial extent and impact of *Rubus alceifolius* in native ecosystems

In terms of level of invasion, *R. alceifolius* was formally attested as an invasive species due to its dominance over native and non-native species in Réunion Island since the 19th century (De Cordemoy 1895). It was already considered as a fully invasive species with dispersal and reproduction occurring on a greater range around the island. In terms of environmental factors, it highly impacted the native flora in Réunion Island through a rapid dispersal and growth (Friedmann and Cadet 1976; Cadet 1977). Moreover, several conservation assessment reports or books on the flora and vegetation of Reunion and Mascarenes, have been issued and cited *Rubus alceifolius* among the most impacting introduced species (Table 3).

Table 1-3 Publication showing R. alceifolius is usually ranked among the top ten invaders at the island scale.

Title	**Aim**
(Cadet 1977)	An inventory of the vegetation present in Réunion Island
(Lavergne 1978)	The description of plants of Réunion Island
(Dupont, Girard, and Guinet 1989)	A description of threatened plants in Réunion Island through the creation of a red list
(Dupont 2000)	An inventory of flora species in Natural Area of Ecological Interest Floristic and Fauna (ZNIEFF)
(Macdonald et al. 1991)	The first inventory of invasive plants in Réunion Island

(Stephane Baret et al. 2006)	The current distribution and extent of the most invasive plants in Réunion Island
(Boullet 2017)	The index of vascular plants of La Réunion from the botanical garden “Botanical Conservatory of Mascarins”(Conservatoire Botanique des Mascarins)

R. alceifolius is the most cited invasive plants in historical documents mentioning biological invasion associated with the native vegetation of the island. *R. alceifolius* is also invasive in Mauritius, Madagascar, Mayotte and in Australia (Amsellem et al. 2000).

Research study related to *Rubus alceifolius* invasion (biology, extent, impact, management)

Over the past few decades, various publications on the invasiveness of *R. alceifolius* were produced (Jacques Tassin et al. 2009). Thébaud (1989) unpublished report from the regional and the forestry services explained the importance to control the invasive *R. alceifolius* and recommends biological control as a management option. Macdonald *et al*. (1991) published a list of IAPs, their relative abundance and carried out an impact assessment, ranking *R. alceifolius* among top five IAPs. Amsellem (2000) undertook PhD study on a molecular study of *R. alceifolius* and compared the genetic diversity of introduced populations to that present in its native range (Amsellem et al. 2000) . He showed that the invasion pathway of *R. alceifolius* started from Madagascar and from there to Réunion island. Baret (2002) conducted a research on the developmental pattern of *R. alceifolius* which showed that it has a heteroblastic development pattern and is considered as a bush and a liana. The results also indicated that its high floral stage occurred in the early development of *R. alceifolius,* allowing the invasive species to draw light to grow. Moreover, Baret et al. (2008) found than an opening in the canopy (which brings more light) increased the germination and growth rate of *R.alceifolius*. Baret, Le Bourgeois, and Strasberg (2005) studied the dispersal of *R. alceifolius*' seeds in tropical lowland forest of Réunion island and found that when the species occurred in monospecific patches, a single plant could generate more than 10 000 seed/m^2 which are mainly dispersed through running water. They concluded the high level of invasiveness of that *R. alceifolius* is due to its biological traits such as a considerable sexual reproduction with a rapid rate of germination and a large seedbank in the soil. They showed that the main invasion pathways are through open track and trail in forest areas of Réunion Island. Long-distance dispersal are due to frugivorous birds (Stéphane Baret 2002). Le Bourgeois (2004) organised a regional workshop in Réunion Island on the threatened biodiversity. The biological control agent, *C. janthina* was released in 2008 after Le Bourgeois, Baret, and de Chenon (2011) presented the biological control programme at the 8th International Symposium on Biological Control of Weeds. Mathieu et al. (2014) studied, post biological control of *R. alceifolius*, the reproduction cycle of its control agent *C. janthina* which is limited within higher altitudinal range in Réunion Island.

The socio-economic context to understand the management of forests and IAP control actions (*R. alceifolius* in particular)

Forestry production and *R. alceifolius* management

The institutional reports of the forestry service entailed a follow-up of wood production in cultivated forest (Miguet 1957). Réunion Island has a typically colonial history of forestry, highly dependent on the Ministry of Agriculture, initially dedicated to timber production (Miguet 1952). Miguet (1957) published a study on the regeneration of natural forest of Réunion island and described sylviculture as a valuable economic objective because of the island's previous economic dependence on forestry products and trees in the 1950's. The annual production of forestry in Réunion Island in the 1950's was 10 000 m^3 of sawing tree (Miguet 1957). Miguet 1952 in his report expressed his concern about the decrease of annual economic revenue with wood production.

In 1989, Miguet explained to IUCN International during a Congress that the forestry services were saving the forests of Reunion by clear-cutting the primary forests to allow the regeneration of the native Acacia (*Acacia heterophylla*) for future timber production. More recently the decrease in demand and resources in timber production oriented the forestry services towards the management of invasive plant species during the 1980's (Jacques Tassin et al. 2009). The last clear-cutting and forestry road was built in native tropical forest by ONF with public funding, which was recorded in 1992 (in the area of Plaine des fougères).

The growing economic difficulties of wood production, led ONF to curb its production and to give up with the ambitious native forest clearing planned for exotic tree cultivation. The forestry services have initiated the premises for a possible biological control programme to control *R. alceifolius.* The forestry services devised a project for funding request to look for potential biological control agents in the 1990's. The mission of the forestry services underwent a change in the late 1990's with the launching of the pre-project for the National Park in Réunion Island. The forestry services added biodiversity conservation within their mission and classified more and more forest areas as reserve (*Forêt Domaniales*). The management of forest was oriented towards a strong control of invasive plants (Triolo 2005) with the control of *R. alceifolius* since early 1980's up till today.

The selection of biological control to manage the invasion of *Rubus alceifolius*

Cadet (1977) in his research work on the vegetation of Réunion Island recommended biological control as the only method to control *R. alceifolius.* The first official decision upon the possible use of a biological control agent was in the early 1980's amongst the governmental institutions, the Regional Council and among research institutions (IRAT 1981). The plant protection sub-committee in 1981 reported on their investigation to find potential host species to control the targeted species, namely *R. alceifolius,* and recommended a specific sub-committee in partnership with the forestry services and any related institutions to devise a strategy for the management of invasive alien plants (IRAT 1981). In 1989, under the request of the local government (*Régional council*), a field work mission was undertaken which provided eight key recommendations as phases to be developed upon the research strategy and long-term management of invasive plants in Réunion Island (Macdonald 1989). One of the fundamental recommendations of the report was the need to undertake an economic assessment of biological invasions for Réunion Island and it specified that a cost-benefit analysis should be undertaken for invasive plants subject to a conflict of interest. The report later gave rise to one of the crucial research work on the impact of IAPs in Réunion Island (Macdonald et al. 1991) to later develop the first strategy for the management of IAPs in Réunion Island which was implemented only in 2010. Macdonald (1989) mentioned in his report that a socio-economic analysis should be undertaken if any IAP is used by the public. However, the non-inclusion of the public opinion on the biological control programme have raised disputes among stakeholders post-control. There is a need to study the societal dimension of the management of *R. alceifolius* in the form of an ex-ante socio-economic analysis to understand the opinion of stakeholders.

Discussion

A look in the history of *R. alceifolius* showed that since the end of 1890's till 1980's various research study and records expressed the urge to control *R. alceifolius.* Though Macdonald (1989) constructed a full report on the key procedures to devise and implement a IAP strategy in Réunion Island, his recommendations were not fully taken into account by the Regional council or the forestry services. It was only in 2010 that it was undertaken by the French Ministry of Environment (DEAL 2010a).

In terms of governance, the forestry services were mainly concerned about management of cultivated forests for timber production (ONF as institution in charge of forest management for the Departmental council, the owner of the forest) till they changed their focus in 1990's to the control of IAPs. The national and European decentralized policy in Réunion Island, together with a decrease in wood production have driven the forestry services to move towards the management of IAPs in the late 1980's. The forestry services, after unsuccessful efforts in mechanical control comprising substantial costs and few control success, requested funding from the regional council for the biological control of *R. alceifolius* (IRAT 1981), without taking into account the previous research recommendations from Macdonald (1989).

A supplementary reason behind the challenges in controlling *R. alceifolius* was due to the fact that policy and decision makers took substantial time in considering the recommendations of published articles or reports since (De Cordemoy 1895), then (Cadet 1977) and (Dupont, Girard, and Guinet 1989).

The historical records showed the level of invasion of *R. alceifolius* have been detected since the mid-19th century but the implementation of its control was undertaken a century after. It is necessary to look into the policy framework that was in effect when the programme was created in the 1990's till the release of the control agent with subsequent reaction of the society. An examination of the policy framework is mandatory to understand possible gaps in the guidelines that would assist in devising a list of key ingredients for a control programme. In terms of decision making, late political decisions in the face of such environmental problems can only generate anachronisms, misunderstandings and non-acceptance by different audiences since mechanical control started first around 1970's and then the biological control programme have been implemented 20 years after its initial request. In terms of past records, the first available scientific publication of Macdonald (1989) was to control the level of invasion of *R. alceifolius*. Macdonald (1989) mentioned in his report that a socio-economic analysis should be undertaken if any IAP is used by the public. To be able to provide in-depth data that would later be used in the prioritization framework, in terms of economic records, it is classically recommended to perform an economic analysis. This would allow the acquisition of the various costs incurred in terms of costs of control and the cost of invasion of *R. alceifolius.* The native species are at stake due to the invasion of *R. alceifolius*. A knowledge of the positive and negative impact of the biological control on the recovery of the threatened native forest is significant to demonstrate the success of such biological control programme.

Available recommendations and the way forward

The introduction of a metallic blue-sawfly (*Cibdela janthina)* as a biological control agent was visible amongst the local communities and on nectariferous and pollineferous trees in Réunion island. The unexpected decrease in honey production have created misunderstandings which later transformed into protests amongst beekeepers. However, there is a further need to understand stakeholders' knowledge and perception; to comprehend their protests and various forms of conflict. A sociological or anthropological approach is required to identify key social actors' and analyse their perception of the management option for *R. alceifolius* with a focus on the biological control programme. Nonetheless, this biological control programme was built on existing legal and policy framework, and acted in accordance with the prevailing guidelines. The arousal of controversies amongst the French authorities (as main funders), the research centre (implemented the biological control programme) and beekeepers (protested to understand their loss in honey production) established the immediate need to assess the success of the biological control programme and necessitated further study on a socio-economic perspective.

Recent research work on the identification of future invasion in various habitats, following a rapid increase of plant invasion already incurred, are recently being studied in Réunion island and should also consider any social dimension related to it and take into account policy and decision makers in implementing and funding programmes.

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Chapter 2: **An economic analysis of control options for the invasive alien shrub *Rubus alceifolius* (Rosaceae) in Réunion Island, Mascarene Archipelago**

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Abstract

Biological control is often needed to complement the chemical and mechanical control of invasive alien plants. There are many invasive alien plant species that threaten ecosystems on Réunion Island, a French department in the Mascarene Archipelago. Despite a long history of chemical and mechanical control of *Rubus alceifolius* Poir. (*Rosaceae*), one of the most invasive species on the island, the species remained widespread and problematic. Here we assess the costs (i.e. the cost of control and the value of negative impacts) associated with different control methods. The methods included a biological control programme which introduced *Cibdela janthina*, (Hymenoptera: Argidae) in 2008 to control *R. alceifolius* on Réunion Island. This was the first French biological control programme that targeted a plant species that invaded natural, rather than agricultural, habitats. We estimated the Present Value of the costs linked to five management scenarios*:* 1) mechanical control below 800 m 2) biological control (with ongoing mechanical and chemical control in sugar cane fields) below 800 m, 3) no control below 800 m 4) mechanical control above 800 m, and 5) no control above 800 m. For control costs, we used the cost of clearing for each management scenario from 1997 to 2007 prior to the release of the biocontrol agent and from 2008 (when the biological control programme started) to 2016. We then estimated the costs of invasion till 2030. To assess the costs caused by the invasion we used reduced sugar cane yields, lost value of agricultural land and losses in eco-tourism revenue in forest land. We found that biological control was successful in achieving complete control below 800 m above sea level, and it was also the option that incurred the lowest costs. The cost ratio of mechanical control to biological control was 12:1 in present-value terms from 2008 to 2016. Mechanical with chemical control would result in ongoing invasion, as the plants spread faster than they can be cleared. Biological control, on the other hand, resulted in a substantial reduction in the invaded area below 800 m asl. Annual rates of spread under a scenario of no control were estimated to be 3.5% and 5.3% in natural forests and sugar cane fields respectively. After the introduction of biological control, spread rates became negative (-4.9% and -17.2% respectively). Further research on the value of biodiversity would be needed before a robust cost-benefit analysis on the net effect of biological control could be conducted.

Key-words: biodiversity, biological control, cost effectiveness analysis, invasive alien plant

Introduction

Given the escalating problem of invasions at global scale, improving the cost-effectiveness of control methods remains a key priority (Simberloff, 2005). Knowing the costs and benefits of the management of invasive species would help decision-makers to evaluate various management scenarios for such species (Reaser et al., 2007). Among the different control measures, biological control has been widely used to complement chemical and mechanical control (Van Driesche, Hoddle & Center, 2008) and is considered to be less costly (de Lange & van Wilgen, 2010). The biological control of Invasive Alien Plants (IAPs) has an excellent record of safety, and many notable successes over two centuries (van Wilgen, Moran & Hoffmann, 2013). Although biological invasions pose a major threat to biodiversity in the Western Indian Ocean islands, very few studies have been conducted on the socio-economic implications of invasive species at island scale (Kueffer, C. and Mauremootoo, 2004).

On Réunion Island, a biological control programme was initiated in 1997 to deal with the invasion of *Rubus alceifolius* (Rosaceae) in native habitats and cultivated forests (Le Bourgeois, Baret & de Chenon, 2011) by the Regional council. *R. alceifolius* was introduced in the mid-19th century from Southeast Asia, and rapidly invaded various habitats up to 1500 m; invasion was assisted by deforestation for agriculture and extraction of wood for fuel from native forests on Réunion Island (De Cordemoy, 1895; Rivals, 1952) and Mauritius (Cheke, 1987; Strahm, 1993). Considered as one of the most invasive plant species in Réunion Island and the Mascarenes Archipelago, *R. alceifolius* has negative impacts on the native vegetation, the services it provides (Macdonald et al.; Strahm, 1999; Baret et al., 2008), and the cost of attempting to control it is very high (Triolo, 2005). Despite the long history of chemical and mechanical control measures, *R. alceifolius* has remained problematic. In Réunion Island, *R. alceifolius* has been controlled for decades by the forestry services. First, mechanical control was initiated in the early 20th century in selected areas of the island, in the form of manual cutting with machetes as well as specialised tractors that uprooted and removed plants from areas with dense invasions of *R. alceifolius* along with other IAPs (Soulères, 1991). Herbicides were used until the early 21st century to complement mechanical removal of *R. alceifolius*. Because these operations were expensive and largely ineffective, it was decided to release in 2008 the control agent, from Southeast Asia, *Cibdela janthina* Klug (Hymenoptera: Argidae) commonly called the blue sawfly (Mathieu et al., 2014). Despite its negative impacts, *R. alceifolius* does provide some benefits, and is occasionally used by local communities as fodder for honey-bees (Baret, 2002), jam-making and medicine (Lavergne, 1978). The existence of these uses has made the biological control programme controversial (Baret et al., 2013). This was the first biological control of a species that threatened natural ecosystems on Réunion Island, and it proceeded without any *ex-ante* economic analysis prior to its release. It therefore became important to undertake such analysis after the biocontrol programme (*ex-post*) to evaluate its performance and to inform future programmes.

This paper describes a partial economic analysis of alternative control scenarios for the period 1997-2030. Five management scenarios of *R. alceifolius* on Réunion Island were considered: mechanical and chemical control, with and without biological control, and no control. The outcome was examined separately for areas above and below 800 m altitude above sea level, because the biological control agent is only effective below this altitude and cannot reproduce effectively at higher altitudes (Mathieu et al., 2014). We estimated present values of the costs associated with each management scenario; costs included the cost of control and the monetary value of impacts associated with each scenario.

Materials & Methods

Study area

The Mascarene Islands are included in the Malagasy biodiversity hotspot (Myers et al., 2000). Remnant natural areas cover 18% of the Mascarene Archipelago, within which Rodrigues has less than 1%, Mauritius less than 2%, whereas Réunion Island has 40% (Safford, 1997; Thébaud et al., 2009). Réunion is a volcanic island of 2512 km^2 with a highest peak of 3070 m (Strasberg et al., 2005). The island has two volcanic systems with an active and a dormant volcano (Lénat, Vincent & Bachélery, 1989; Michon & Saint-Ange, 2008). Mean annual rainfall ranges from > 8000 mm in the windward mountain areas to <500 mm at the leeward coast. Mean annual temperature range from 12^0C to 24^0C depending on altitude (Lagabrielle et al., 2011). The centre of Réunion Island is a World Heritage Site and a National Park, with a high biodiversity value, and is composed of rugged mountainous areas, cliffs, gorges, and one active volcano (UNESCO World Heritage Centre, 2010). The National Park covers 40% of the island, and hosts many endemic species, which are threatened by IAPs, including *R. alceifolius* (Baret et al., 2006). Outside of the National Park, 48% of the island has been transformed by agriculture, principally sugarcane (22%), secondary forests (14.4%), and urbanization (11%) (Lagabrielle et al., 2011).

R. alceifolius became invasive in the late 19th century, and rapidly spread across the island (De Cordemoy, 1895; Rivals, 1952). It is listed amongst the most invasive plant species of the island (Macdonald et al., 1991; Baret et al., 2006), occurring in the lowlands, sub-mountain and mountain habitats (Baret et al., 2006). Our study took place in the municipalities of Saint-Benoit and Plaine des Palmistes (referred as study sites hereafter), where the biological control agent was disseminated. Prior to the release of the biological control agent, the management of *R. alceifolius* was carried out by several institutions who employed a set of techniques that evolved over decades (Tassin et al., 2006). Control began with mechanical methods, which were combined with chemical control after 1985 (Sigala, 1998; Roussel & Triolo, 2016) in forest areas, and earlier in the agricultural sector. Cultivated forest or sugar cane fields are easily accessible for such control compared to steep mountainous areas. Most recently these methods were supplemented by biological control (Mathieu et al., 2014).

Study design

Our study examined five management scenarios (Table 2-3). For each management scenario, we collected data on the extent and impacts of invasion and the costs of control from 1997 on the study sites, and pooled these for analysis. We then estimated (1) the area occupied by *R. alceifolius* in 1846 (the date of introduction), and again in 1997, 2008 and 2016 (dates for which satellite images were available); (2) the area that would eventually become invaded, assuming that abandoned land, a buffer of up to 1 m into all sugar cane fields and in all natural forests, that shared a common boundary with projected invaded areas would become invaded under no control; and (3) the rate at which the plants would spread under the different treatments, based on historical spread rates between 1846 and 2016. Costs to agriculture associated with invasion by *R. alceifolius* were estimated as decreases in sugar cane yield and loss of value for agricultural land, and as losses of ecotourism income in natural forests.

The Forestry Services (*Office National des Forêts*), and the sugar cane producers, have both incurred costs for the mechanical and chemical control of *R. alceifolius* on Réunion Island. We used their records to estimate the costs of control. Detailed spatial records of the cost of control operations of the whole island were available from the Forestry Services for the years 2000 to 2016. It was possible to identify the proportion of funds that was spent on the study area for those years. We assumed that funds spent in each year for which we had no data (i.e. 1997 – 1999) were equal to the average spent in years for which cost data were available. Data from control carried out in sugar cane fields was available for the portion of the island where the crop is grown and we used the cost of control per hectare estimated by experts (Cyathea, 2011). In the case of biological control, the costs included the development of a detailed proposal for the required research, and the costs of the research itself from the regional council (la Région Réunion), the French Ministry of Environment (DEAL) and the Centre for Agricultural Research for Development (CIRAD). The costs of biological control were proportionately adjusted to the study sites.

Table 2-1: Management scenarios used for assessing the Present Value of costs associated with the control and impact of Rubus alceifolius in Réunion Island between 1997 and 2030.

Elevation range	**Mechanical and chemical control**	**Biological control**	**No control**
Below 800 m	Scenario 1. Mechanical and chemical control only.	Scenario 2. Biological control introduced in 2008. Mechanical and chemical control until 2008 only in sugar cane fields,	Scenario 3. No attempts at control

		continuing at reduced rates after that.	
Above 800 m	Scenario 4. Mechanical and chemical control only.	Not considered, as biological control was ineffective above 800 m.	Scenario 5. No attempts at control

Historical and current invaded area

Very few existing data were available on the area occupied by *R. alceifolius*. The initial area was set at 1 hectare in 1850, to provide a starting point for the estimation of spread rates (see below). The extent of invasions in the districts of Saint-Benoit and Plaine des Palmistes was mapped in 1997, 2008 and 2016 using satellite image data. We delineated polygons of invaded areas on these images, and used QGIS software (QGIS Development Team, 2017) to estimate the area of the polygons. The full description of the approach can be found in Annex 1.

Potential invadable area

The area suitable for invasion was estimated by subtracting the area occupied by urban settlements, forestry plantations and agricultural fields from the total area of the study site. We assumed that all abandoned land (i.e. previously cultivated or planted land that is no longer under active management) would eventually become invaded if no effective action was taken to reverse the invasion by *R. alceifolius*. We further assumed that all invaded areas that abutted on sugar cane fields, would result in an invasion into the sugar cane fields and in natural forests of up to 1 m, under a scenario of no control, and increased the potential invaded area accordingly. We estimated the surface area of *R. alceifolius* 1) at its full potential, 2) within forests and 3) in sugar cane fields (Annex 1).

Rates of spread under different management scenarios

The area occupied by an invasive alien species follows a sigmoid curve over time. Initial growth is slow, but becomes exponential as the species becomes well-established, and slows again as the occupied area approaches the potentially invadable area (van Wilgen et al., 2004).

In our study timeline, we fitted an exponential model assuming the growth at each site was in the exponential stage:

$$A_t = c(1 + r)^t \qquad (1)$$

A_t is the area occupied by *R. alceifolius* in year t (ha)

t is the time (years)

r is the annual rate of spread

c is the area invaded at t=0.

Spread rates at each of the management scenarios were then estimated based on the area occupied by *R. alceifolius* at different stages for which estimates were available (1850, 1997, 2008 and 2016).

Estimating total costs

For each management scenario, we generated estimates of the area occupied by *R. alceifolius* for each year from 1997 (the year in which the decision was made to initiate biological control) to 2030. Each management scenario had a different set of costs associated with the combination of control methods, and each resulted in a different outcome in terms of costs of invasion (the additional flows of income lost from land that becomes invaded in the absence of control) (Brown & Daigneault, 2014). The net cost of each control option was calculated as a Present Value (PV) with the equation:

$$C = \sum_{t-0}^{T} \left(CC_t + CA_t + CF_t\right)\left(1+\delta\right)^{-t} \qquad (2)$$

Where CC_t is the cost of control, CA_t and CF_t are the costs that the invasion imposes respectively on agriculture land and forest land in year t, and δ is the discount rate; we used a discount rate of 4% (Lebègue, 2005). All the costs for the years 1997 to 2030 were converted to real prices by correcting for inflation using the annual consumer price index reported by OECD for Europe, with a base year of 2010.

The total cost of control including mechanical control, biological control and no control is represented by CC_t, the costs to agriculture (CA_t) associated with invasions of *R. alceifolius* included reductions in sugar cane yields and in land values. We used the area of planted sugar cane to estimate the potential sugar yield losses. For land values, we adopted the approach used by van Wilgen et al. (2004), and assumed that every hectare of land that became 100% invaded would lose 2% of its value. We obtained land values and sugar cane yields based on expert's knowledge of the price of land and sugar cane production (Cyathea, 2011). The costs to natural forests (CF_t) consisted of reductions in eco-tourism income. *R. alceifolius* is a prickly bramble at high density, reducing the access of tourists to the forest areas and it is reasonable to expect that increases in invasion by this plant would prevent or discourage entry by tourists resulting in decreases in tourism income. We obtained the price that people pay for the privilege of hiking in natural forest areas from the French National Institute of Statistics and Economic Studies (François Legros, 2016) and proportionally adjusted them to the study sites. We then related the amount of expenditure based on the surface area of natural forests and level of invasion within the two elevation strata. Although invasions by *R. alceifolius* would almost certainly impact negatively on biodiversity values, we were unable to assign values to this impact. Annual costs for each management scenario were estimated for each year up to 2030. We assumed that the cost of biocontrol ended in 2016 and that the biological control agent would be self-sustaining. Based on the rate of spread, we estimated the surface area invaded and predicted the cost of control within the five scenarios till 2030 to further compare the strength of the different control methods.

Sensitivity analysis

We carried out a sensitivity analysis on the rates of spread and the discount rate because they have a strong influence on the level of invasion through time and its costs. We selected six hypothetical rates of spread through a range of around ± 2% (Cacho et al., 2006). We selected six discount rates between 3% and 8% and tested their effect for each scenario. We calculated the costs of each scenario as a PV for 1997 to 2030 and assessed the efficiency of the control methods by calculating the PV of costs for five scenarios: 1) mechanical control below 800 m 2) biological control (with ongoing mechanical and chemical control in sugar cane fields) below 800 m, 3) no control below 800 m 4) mechanical control above 800 m, and 5) no control above 800 m. There is a dearth of information for the evaluation of the success of mechanical control in natural forests; we undertook a complementary sensitivity analysis enabling us to estimate the level of invasion depending on the efficiency of the mechanical control for both strata. We tested a range of 1% to 6% for the rate of spread for mechanical control and 0% to 5.3% for no control (as a rate added to the actual rate of spread).

Results

Reduction of rates of spread

Between 1850 and 1997, *Rubus alceifolius* spread at rates estimated between 1% and 3% per year at the two study sites. Mechanical and chemical control marginally slowed the annual rate of spread of *Rubus alceifolius* in natural forests from 3.53% with no control to 3.47% with control (Table 2-2). Corresponding figures for sugar cane fields were 5.37 and 0.98%, indicating more effective control. Only biological control (scenario 2) resulted in negative rates of spread (shrinkage) after introduction (Table 2-2). In natural forests, annual spread rates were changed from 3.53 to -4.9%, and in sugar cane fields the annual spread rates changed from 0.98 to – 17.21% following the introduction of biological control. Above 800 m, invasions increased under all management scenarios, with mechanical control (scenario 4) resulting in slower rates of spread than no control (scenario 5) (Figure 2-1). Above 800 m, mechanical control (scenario 4) reduced annual rates of spread from 3.09 to 2.97% in natural forests, and from 10.66 to 5.88% in sugar cane fields (Table 2-2)

Table 2-2: Estimates of area invaded by Rubus alceifolius on Réunion Island at different stages, and rates of spread for five scenarios (different elevations and management approaches) for sugar cane fields and natural forest areas.

Altitude range		Whole study site (ha)	Management scenario	Area invaded in 1997 (ha)	Area invaded in 2016 (ha)	Potential invadable area (ha)	Rate of spread from 1997- 2008	Rate of spread from 2009-2016
Below 800 m	**Forest**	10836	Mechanical and chemical	34.6	66.7	2500	3.47	3.47
			Biological	34.6	34.0		3.53	-4.90
			None	34.6	66.9		3.53	3.53
	Sugar Cane		Mechanical and chemical	74.9	99.4	3542	0.98	0.98
			Biological	74.9	18.4		0.98	-17.21
			None	74.9	170.6		5.37	5.37
	Abandoned land					3433		
Above 800 m	**Forest**	3395	Mechanical and chemical	16.3	27.3	1680	2.97	2.97
			None	16.3	29.0		3.09	3.09
	Sugar Cane		Mechanical and chemical	4.2	15.5	163	5.88	5.88
			None	4.2	22.9		10.66	10.66
	Abandoned land					1527		

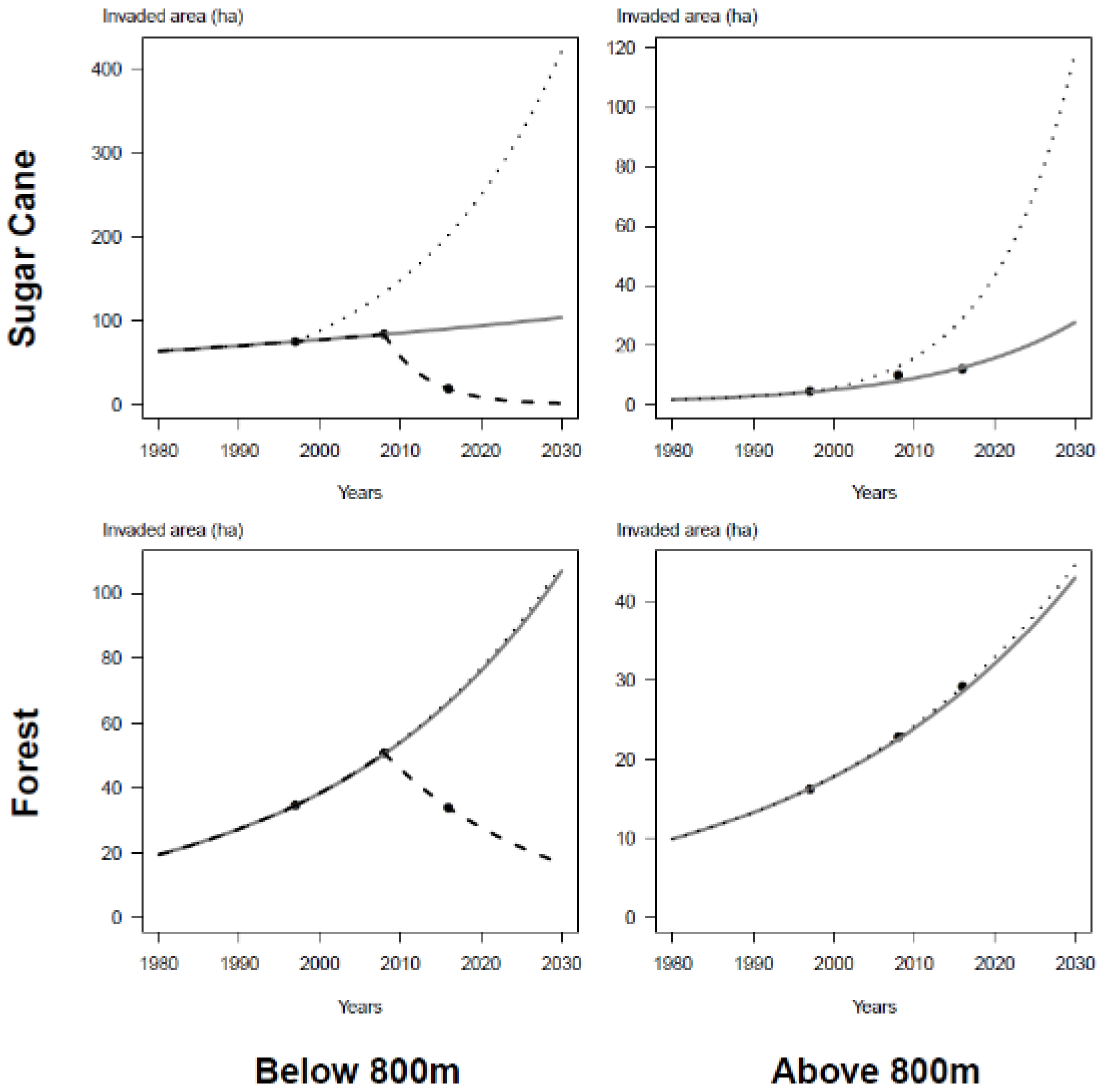

Figure 2-1: The mapped extent of R. alceifolius invasions in two study sites in Réunion Island in 1997, 2008 and 2016 (dots), with trajectories of the estimated invaded area of R. alceifolius for the five scenarios (Mechanical control in grey solid line, biological control in black dashed line and no control in black dotted line within the elevation range (below 800 m to the left and above 800 m to the right) from 1980 to 2030 for both sugar cane fields (above) and natural Forest areas (below).

Present value of Control Costs

Control costs associated with mechanical control below 800 m (scenario 1, see Table 2-3) amounted to 1 302 000 € between 1997 and 2016 (Table 2-4). Control costs associated with biological control below 800 m (scenario 2) amounted to 575 000 € between 1997 and 2016, and included research and development costs of 31 000 €, with control costs in sugar cane fields falling from 411 000 € between 1997 and 2007 to 133 000 € between 2008 and 2016, after the introduction of biological control. Above 800 m, the costs of mechanical control (scenario 4) amounted to 395 000 € between 1997 and 2007, falling to 90 000 € between 2008 and 2016. There were no control costs associated with scenarios 3 and 5, but the costs of impacts under no control were over €3 million for both periods (1997 – 2007, and 2008 – 2016, Table 2-4).

Table 2-3: Estimated total Present Value (C) in € of the cost of invasion calculated as the sum of the cost to agriculture (CAt), cost to Forest (CFt), and the Cost of control (CCt) of R. alceifolius in study sites of Réunion Island subjected to the five scenarios between 1997 and 2016 (before and after the release in 2008 of the biological agent).

Elevation range	**Management approach**		***CCt***		***CAt***		***CFt***		***C***	
			1997-2007	**2008-2016**	**1997-2007**	**2008-2016**	**1997-2007**	**2008-2016**	**1997-2007**	**2008-2016**
Below 800 m	Scenario 1: Mechanical and chemical	Forestry Services	548,810	92,342	2,638,191	1,605,595	12,742	7,060	3,610,398	1,954,921
		Sugar cane producers	410,655	249,923						
	Scenario 2: Biological control	Research & development	13041	17,711	2,638,191	855,186	12,784	5,953	3,074,671	1,011,966
		Ongoing control in sugar cane fields	410,655	133,116						
	Scenario 3: No control		0	0	3,252,416	3,032,880	12,784	7,135	3,265,200	3,040,015
Above 800 m	Scenario 4: Mechanical and chemical	Forestry Services	365873	61,561	186,940	182,835	8,495	4,707	590,407	277,562
		Sugar cane producers	29,099	28,460						
	Scenario 5: No control		0	0	237,297	358,922	8,523	4,757	245,819	363,678

Cost of impacts on sugar cane and natural forests

Below 800 m, the costs of impact on sugar cane fields, between 1997 to 2016, amounted to 4 244 000 € with scenario 1, to 6 285 000 € with scenario 3 and 3 493 000 € with scenario 2 (Table 2-3). In scenario 2 the cost of impact on agriculture fell from 2 638 000 € between 1997 and 2007 to 855 000 € from 2008 to 2016 due to the impact of biological control. Above 800 m, for scenario 4, the cost of impact on agriculture between 1997 and 2016 amounted to 370 000 € as opposed to 596 000 € for scenario 5.

There was no important difference in cost of impact on natural forests within the scenarios and between the two time intervals considered (1997 to 2007 and 2008 to 2016).

Table 2-4 : Predicted outcomes and estimated total Present Value (C) in Euros of the cost of invasion calculated as the sum of to the cost to agriculture (CAt), cost to Forest (CFt), and the Cost of control (CCt) associated with the five management approaches for the study sites invaded by Rubus alceifolius in Réunion Island from 2008 to 2030.

Elevation range	**Management approach**	**Outcome**	**Stakeholders**	***CCt***	***CAt***	***CFt***	***C***
Below 800 m	Scenario 1: Mechanical and chemical	Less effective, area predicted to increase given a high rate of spread	Forestry Services	144,464	3,393,093	19,223	4,084,943
			Sugar cane producers	528,162			
	Scenario 2: Biological control	Highly effective, invasion brought down to minimal levels and maintained there in perpetuity at minimal cost (periodic monitoring)	Research & development	17,711	975,919	12,269	1,157,809
			Ongoing control in sugar cane fields	151,909			

	Scenario 3: No control	Considered as a control group		0	8,522,725	19,527	8,542,253
Above 800 m	Scenario 4: Mechanical and chemical	Less ineffective, area predicted to increase with a high rate of spread	Forestry Services	96,310	532,787	12,816	724,845
			Sugar cane producers	82,932			
	Scenario 5: No control	Considered as a control group		0	1,520,133	13,018	1,533,151

Total Present Value (C)

Between 1997 and 2007, the overall costs (control costs plus the cost of impacts) were similar for scenarios 1, 2 and 3, but after the introduction of biological control in 2008, the present value for no control was 56% higher than for mechanical control, and 300% than for biological control (Table 2-3). Above 800 m, the Total Present Value for scenario 4 (mechanical control) was 868 000 €, while it was 610 000 € for scenario 5 (no control).

Future Cost Predictions

The predicted future costs of impact on natural forests were low for all scenarios (present values between 12000 and 19000 €), but the costs of impact on sugar cane fields changed dramatically between scenarios 1, 2 and 3. For mechanical and chemical control below 800 m (scenario 1), this cost was reduced by 60% (from 8.5 to 3.4 million €) compared to scenario 3, while for scenario 2, the cost reduced by almost 90% (from 8.50 to 0.98 million €, Table 2-4).

Sensitivity analysis

The PV of the costs of invasion was selected as the main reference for each scenario. Here we selected 6 rates which showed a strong difference in PV out of the 12 (Figure 2-3). When we tested for discount rate Figure 2-2A and Figure 2-2D showed that an increase in discount rate would decrease the PV for all scenarios. An increase in discount rate also can reduce the PV differences between management options: a discount rate of 8% showed that the PV mechanical control and no control declined heavily above 800 m (Figure 2-2D). The value of the rate of spread in sugar cane fields below 800 m for no control (scenario 3) is defined as the rate (0.98%) under mechanical control (scenario 1) plus 4.39% (Table 2-3). This means that any variation in the rate of spread of mechanical control impacted that of the no control option from 2008 to 2030 for the two strata (Table 2-3). Therefore, an increase in the rate of spread would raise the PV of costs for the three management scenarios but less for biological control below 800 m (Figure 2-2B). Similarly, an increase in the rate of spread would raise the PV of mechanical control and no control above 800 m (Figure 2-2E). An increase in rate of spread for no control in sugar cane fields for both strata increased the PV (Figure 2-2C and Figure 2-2F). When the rate of spread is at its lowest values, the PV of mechanical control is equal or slightly less than under no control for both strata (0.98% versus 2.02% below 800m, 5.88% versus 8.02% above 800 m).

We estimated the rate of spread in forest areas below 800 m for mechanical control (scenario 1), 3.47%, in 2030 with 107 ha being invaded (Figure 2-3A). If the rate of spread was 1.01%, 48 ha would be invaded and if it was at 6.18%, 251 ha would be invaded. We calculated the rate of spread in forest areas above 800 m for mechanical control (scenario 4), 2.97%, in 2030 with 43 ha being invaded (Figure 2-3B). If the rate of spread was 1.01%, 23 ha would be invaded and if it was at 6.18%, 118 ha would be invaded (Figure 2-3B).

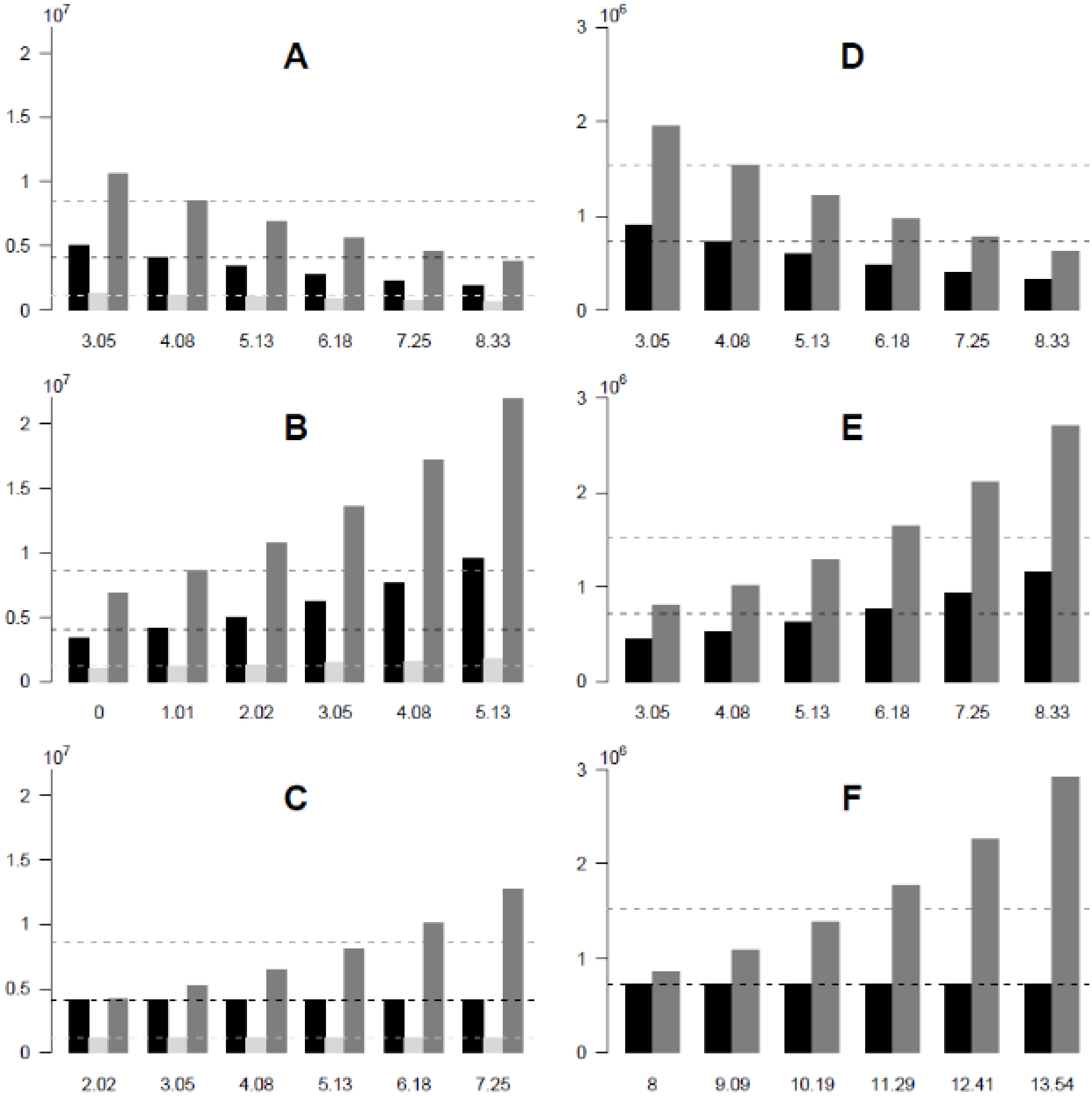

Figure 2-2: The sensitivity analysis of the estimated Present Value (PV) for the five scenarios in the study sites for the years 2008-2030, for the six rates showing strong differences in PV among scenarios: discount rate (3-8%) and rates of spread (actual value ± around 2%). The left side of the figure (A, B, C) indicates results below 800 m and the right side (D, E, F) above 800 m. In black is mechanical control, in light grey biological control and in dark grey no control. The y-axis shows the PV in Euros (€) and the x-axis the tested rates (%). A and D represent the Discount rate, B and E the rate of spread of mechanical control for sugar cane, C and F the rate of spread for no control for sugar cane. The dotted lines represent the PV for the actual rates.

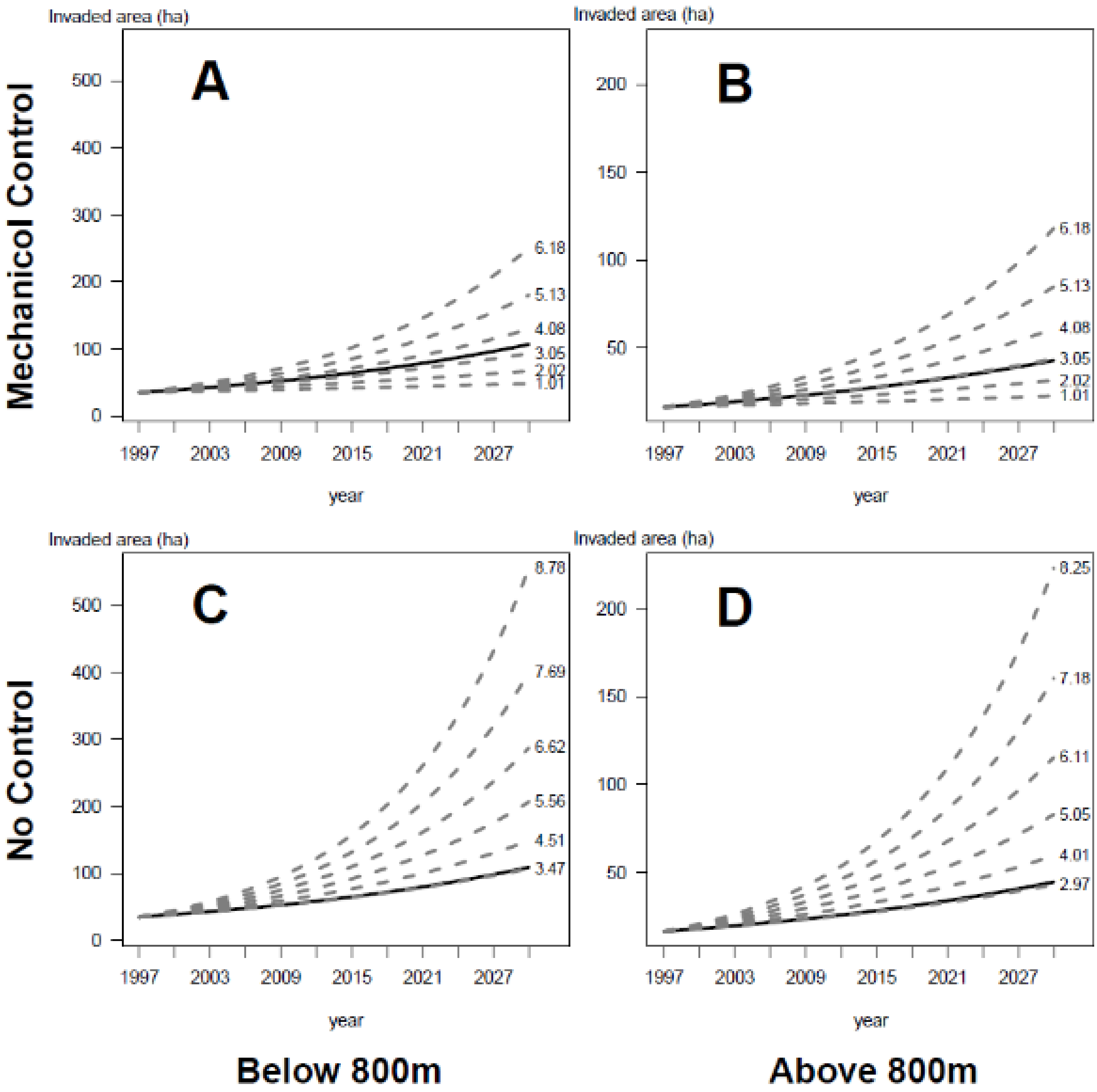

Figure 2-3: A sensitivity analysis of the estimated rates of spread of R. alceifolius in forest areas of the study sites for mechanical control and no control with a starting estimated rate (in black line) of 3.47% (A) for mechanical control below 800 m and 2.97% (B) above 800 m; and of 3.53% (C) for no control below 800 m and 3.09% (D) above 800 m. A range of 1% to 6% was used for the rate of spread of mechanical control and a range of 0% to 5.3% for no control (added to the actual rate of spread for mechanical control).

Discussion

The relative effectiveness of biological control

This study has clearly demonstrated, in this case, the effectiveness of biological control compared to other methods of control. It has resulted in a shrinkage of the area covered by *Rubus alceifolius* to almost negligible proportions below 800 m, whereas invasions continued to grow despite substantial expenditure using other methods. Although the biological control agent was released with the initial aim of controlling *R. alceifolius* for biodiversity conservation, it has been highly efficient in the agricultural sector as well. Nevertheless, mechanical control should be maintained for plantation in agricultural fields, for conservation work in targeted natural forest areas, and will need to be ongoing above 800 m where the biological control is ineffective.

The need for a comprehensive economic assessment

Our study has clearly shown that the costs associated with the biological control management scenario are less than those of either mechanical and chemical control, or no control. However, this is not a comprehensive economic assessment, as we have not considered the benefits of control in the form of, for example, avoided losses of biodiversity and ecosystem services associated with uninvaded areas. In addition, it would also be necessary to consider the loss of benefits associated with the target weed itself. The only quantifiable benefit associated with invasions of *R. alceifolius* was the possible contribution that it made to fodder for honey-bees. Following the release of the biological control agent, beekeepers protested between 2009 and 2010 against the negative impact of this control on honey harvest. CIRAD assessed the relationship between the honey harvest and the biological control agent and found that the biological control agent gathered pollen but had no link to honey harvest (Reynaud et al., 2010). In Réunion Island, the three main honey harvest, in order of highest harvest, are “Brazillian Pepper honey” (*Schinus terebinthifolius*), “Litchi honey”, (*Litchi chinensis*) and “forest honey”. They have been estimated from 2001 to 2012, showing a variable (Esnault et al., 2014) with an increase from 2008 to 2010. For the case of “Litchi honey”, we assume that most of the variability was explained by the impact of the weather on flowering of litchi trees (Menzel, 2001). A consideration of these issues would have to form part of a full economic assessment, which should ideally be completed on an island scale.

Lessons for the implementation of future biological control projects

The release of a biological control agent against *R. alceifolius*, and its subsequent success in controlling the weed, was a significant event in alien plant management of Réunion Island. The release was not without controversy, and there are a number of aspects that could have been handled differently; with hindsight, these can be seen as lessons to guide any future releases. Such additional releases would be essential if ecosystem managers are to achieve effective control of other aggressive invasive alien plant species, for example *Ulex europaeus* and *Hyptage benghalensis*.

First, the question of host-specificity needs to be carefully considered. One of the potential risks of the introduction of *C. janthina* was that it might have attacked a congeneric endemic *Rubus* species, *Rubus apetalus*, which occurs on higher altitudes above 1000 m on Réunion Island (Baret et al., 2007). *C. janthina* was selected since it is ineffective at this altitude, so the issue has been resolved. However, a comparison of the value of the endemic *Rubus* species to the harm generated by the invasive *Rubus* could have been used to guide a decision on whether or not to release the agent, had this not been the case.

Secondly, the issue of public resistance to biological control needs to be considered. In the case reported here, controversies arose because of misperceptions on the biological control agent pullulating on nectariferous and pollineferous trees. The local press carried headlines against the biological control agent and conflicts emerged between beekeepers and CIRAD post release of the biological control agent (C. Cybèle unpublished data). The development of a communication strategy with targeted audiences, could have helped to manage this situation, and much of the controversy might have been avoided. The avoidance of controversies due to misperceptions is one of the largest challenges to biological control (van Wilgen et al. 2013), and it is necessary to gain the political support that will be needed in future.

Thirdly, the issue of rehabilitation needs to be considered. Many alien plant control programmes rely on passive restoration, in which it is considered that the natural vegetation will return unaided following removal of the alien species. A strategic plan with an action plan on the restoration work was lacking prior and post control of *R. alceifolius* on Réunion Island, yet the forestry services has been undertaking restoration with endemic trees post-control. There is a need to follow the restoration work undertaken in forest areas to evaluate the biodiversity value and to determine its associated ecosystem services.

Finally, the government and institutions of Réunion Island have a global responsibility to effectively manage the UNESCO World-Heritage site that covers 40% of the island. The value of ecosystems services linked to the management of IAPs in general and for the case of the control of *R. alceifolius* has not been estimated. In Réunion Island, studies related to biodiversity value are lacking and should be undertaken. France needs to accelerate the management of invasive species and the local authorities should anticipate short and long term management.

Conclusions

The aim of this paper was to undertake an economic analysis to assess the various costs of invasion incurred for five management options from 1997 to 2030, to control the invasive *R. alceifolius*. Based on our estimation of the surface area of *R. alceifolius,* we calculated its rate of spread for each scenario and predicted the costs of invasion under each scenario, till 2030. Our study demonstrated that biological control is a successful cost-effective choice compared to decades of mechanical and chemical control. The peak of this study was the efficiency of the biological control agent in sugar cane fields, generating available land for plantation and bringing supplementary sugar cane yield. To further evaluate a robust cost-benefit analysis of this biological control programme, an ex-post assessment of the conservation value or ecosystem services related to the natural resources of Réunion Island would be required.

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Chapter 3: An assessment of the biocontrol efficiency on *Rubus alceifolius* invasion: impacts in the recovery of the tropical forest communities of Réunion Island (Mascarene Archipelago)

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Abstract

Biological control can be an effective conservation strategy to manage invasive species when more classical means cannot be implemented, when accessibility to control the target species becomes an issue, or when funding is limited. Estimating the impacts of such programmes in terms of benefits for the conservation of native biodiversity often remains a challenging task. The direct impact of the control agent on the target invasive species can be easily measured but complex effects at community level and underlying mechanisms remain poorly understood. We assessed the impact on native plant communities' recovery post biocontrol, in terms of increased species richness and cover, over a five-year period during the biological control programme of the invasive giant bramble, *Rubus alceifolius* in Réunion Island (Mascarene Archipelago). We studied the vegetation recovery within a set of defoliated *R. alceifolius* patches along an elevation gradient. To measure the positive and negative impacts of such biocontrol programme on native plant communities' diversity across time, we also assessed the role of environmental factors. We investigated *R. alceifolius* cover, species richness and cover of non-native species and native species in the National Park of Réunion Island. The decrease in *R. alceifolius* cover, suggested that biocontrol positively impacted on native communities with an increase in native species richness and cover. The negative impact of the biocontrol programme, was related to the increase in non-native species richness in response to the availability of land resources post-biocontrol. Biocontrol appears here as an effective means to manage the invasion of *R. alceifolius* and its efficiency was influenced by the elevation range, the surface area of the patches and the location of each patch in the edge of forest areas or in forest matrix. We discuss the extent to which the use of biocontrol within an integrated approach can optimize benefits for biodiversity conservation in the long term.

Key-words: biodiversity, biological control, *Cibdela janthina,* invasive alien plants, island, success

Introduction

Islands often host unique biota with a high level of endemism due to their remote biogeographical settings promoting speciation and diversification among colonizing lineages. In relation to the history of high extinction rates of island flora and fauna, insular biota is often hypothesized to be more vulnerable to non-native species introductions and invasions (D'Antonio & Dudley, 1995; Daehler, 2006). Rapid land-use changes combined with biological invasions are widely acknowledged as the two main causes of insular biodiversity loss at global scale; biological invasions are particularly significant for the case of oceanic islands (Kueffer et al., 2010). Tropical islands offer optimum climatic conditions in the establishment and spread of introduced plant species threatening native biodiversity (Vtousek, 1988; Denslow, Space & Thomas, 2009). On islands, plant invasions can lead to a decrease in biodiversity especially in protected areas which become inefficient to maintain unique endemic species and native communities (de Poorter et al., 2005; Baret et al., 2013).

The management and control of Invasive Alien Plant (IAPs) species in insular ecosystems are of utmost priority both for biodiversity conservation and socio-economic development

(Caujapé-Castells et al., 2010). Several control methods exist and there is a need to evaluate the success and failure of these different methods (Reaser et al., 2007). Among them, biocontrol appears as a relevant approach for areas with high topographical complexity, such as volcanic islands (Fowler, Syrett & Hill, 2000) with mountain areas having steep slopes. Large proportions of the surface area of these islands remain inaccessible for the use of mechanical or chemical control, reducing the efficiency of the approaches. The use of a biological control agent along with mechanical control as an integrated management could be a potential solution on islands (Lorence & Sussman, 1986; Strahm, 1996).

The efficiency of biological control to manage IAPs has been poorly studied quantitatively with unknown impact (Thomas & Reid, 2007). In the process of biocontrol, the introduction of a biological agent might trigger alterations in ecosystem functioning, biotic interaction networks and abiotic factors while impact of non-native species control or eradication must be conducted at ecosystem level (Zavaleta, Hobbs & Mooney, 2001). One of the main challenges in evaluating the efficiency of a biocontrol programme is the choice of approaches and indicators of success (Barton et al., 2007; Meyer & Fourdrigniez, 2011). Most studies focused on changes in the target species' distribution, abundance and demography (Syrett, Briese & Hoffmann, 2000). Recent research compared the recovery success of local native plant communities post biological control programme (Pearson & Callaway, 2005; Flory & Clay, 2010). Others evaluated the success of biocontrol on ecosystem services (Dixon M, 2015), e.g. water supply in South Africa (Van Wilgen & Richardson, 2012). The well-known examples of biocontrol in island ecosystems in tropical regions are documented in the Pacific in Hawaii where biocontrol using fungal pathogens has been successful since 1967 to control invasive weeds *Senna surattensis*, *Ageratina riparia*, *Clidemia hirta* and *Passiflora tarminiana* (Trujillo, 2005). In Society islands, (Meyer & Fourdrigniez, 2011) evaluated the conservation benefits on the highly endangered plant species *Ophiorrhiza subumbellata* on the island of Tahiti. Conservation benefits was calculated there based on the success of the effect of the biological control agent on the invasive *Miconia calvescens* in relation to the increase of the endemic *Ophiorrhiza subumbellata*. In the subtropical regions, in New Zealand, the success of biocontrol against *Ageratina riparia* has been evaluated based on the benefits to native species too (Barton et al., 2007).

Positive and negative impacts on biodiversity can occur after biocontrol. The main aim of a biocontrol programme is to successfully control its targeted species (Hoffmann & Moran, 2008). A positive impact improves native biodiversity's conditions and status, with an increase in native species abundance. When competition with native plants is the major impact of the targeted IAP, the positive impact of the biocontrol strategy on native biodiversity may be due to the availability of space and resources previously utilized by the invasive species. However, re-invasion by non-target IAPs can occur after biocontrol (Erskine Ogden & Rejmánek, 2005) and can hamper the desired benefits.

Evaluating conservation benefits post biocontrol is far from straightforward in most situations. Expected direct impacts of the released control agent can be easily quantified, as the target host species decreases in number of population, demographic rates or spatial extent for instance. The potential indirect impacts of biological control on native biodiversity are ecosystem services or other aspects of ecosystem functioning, which measure the actual conservation benefits gained from the control programme. Ecological indicators are thus needed in this context, so that their variation in time or space can be used to assess the impacts of implemented actions. Here we chose to focus on community metrics of biodiversity, namely composition, quantified by species richness, and structure, assessed through species cover (Franklin &

Hemstrom, 1981; Noss, 1990). Species richness is generally considered as an indicator of community resilience to biological invasions.

Tropical islands are rich in biodiversity but have not been the focus of many biocontrol programmes. In Hawaii, biocontrol programmes for biodiversity conservation have been in place since 1970's (Vitousek et al., 1997). Data on biocontrol efficiency is limited to few geographic regions and Hawaii has more recorded data on various control techniques for IAPs management than other archipelagos. In the Mascarene Archipelago, Mauritius implemented the first biocontrol programme in 1914 for the conservation of coastal lowland vegetation (Manrakhan, 1997; Fowler et al., 2000). There is a dearth in studies focusing on positive and negative impacts of native plant recovery post control programmes in the Mascarene Archipelago (Macdonald et al., 1991; Tassin et al., 2006; Baider & Florens, 2011) .

Réunion Island is part of the Mascarene archipelago with Mauritius and Rodrigues. The Mascarenes are included in the biodiversity hotspot of Madagascar (Myers et al., 2000a). Most terrestrial Mascarene taxa exhibit high level of endemism like the flowering plants with 72% of endemic species (among 959 native plant species). In Réunion Island, the vascular flora hosts 871 native species among which 246 are endemic to Réunion Island (Boullet, 2017). Since human settlement started in 17th century, more than 3000 non-native plant species have been introduced, to Réunion Island. At present 856 vascular plant species are naturalized among which 105 invasive in native or human-disturbed ecosystems (Kueffer et al., 2010; Boullet, 2017). Among these, *Rubus alceifolius* Poiret (Rosaceae), a bramble native from South East Asia and frequent island invader, was introduced in few countries of the Indian Ocean region (Réunion Island, Mauritius, Madagascar and Australia) in the mid-nineteenth century (De Cordemoy, 1895)

In Réunion Island, *R. alceifolius* is considered as one of the five most invasive species, forming dense patches up to 15 m-high (Baret et al., 2006). Intensive management has been implemented during the past three decades by the Forestry services (*Office National des Forêts*) through a costly and intensive work programme for mechanical and chemical control at island scale, up to 2000 m on rugged mountainous areas (Le Bourgeois, Baret & de Chenon, 2011)). A biocontrol programme was launched in the island during the late 90's to limit the spread of *R. alceifolius* and control its impact on the island's biodiversity and ecosystem services. A biological control agent native from Sumatra, the defoliating blue sawfly namely *Cibdela janthina* (Argideae), was released on Réunion Island in 2008 to control of *R. alceifolius* (Le Bourgeois, Baret & de Chenon, 2011; Mathieu et al., 2014). It was the first biocontrol agent released in a native tropical habitat and in an island ecosystem in France. The aim of this paper was to evaluate the benefits of this biocontrol programme in Réunion Island in lowland tropical rainforest. We assessed the efficiency of the biocontrol programme in terms of positive and negative impacts on biodiversity on an annual basis during five years in relation to the elevation above sea level (a.s.l), the location of each *R. alceifolius* patch in forest or forest edges, and the initial area of *R. alceifolius* patches. Specifically, we asked a) what has been the change in *Rubus alceifolius* cover over time; b) how vegetation cover and species richness for native and non-native species have changed; and c) which environmental factors explain the variation in biocontrol efficiency.

Material and methods

Study site

The study was conducted in Mare Longue Nature Reserve, part of the National Park southeast of Réunion Island in the Mascarenes archipelago (Baret, Le Bourgeois & Strasberg, 2005).

Mare Longue Nature Reserve is the last remnant of lowland tropical rainforest in the Mascarenes archipelago. It is therefore of critical conservation value for the region. The nature reserve provides a suitable experimental zone as *R. alceifolius* patches of various size occur in this forest matrix along an elevation range of 100 to 700 m. The study site consists of 68 ha and is located on a 500-year-old basaltic flow with an irregular and thin layer of soil (Kirman et al., 2007).

Mare Longue Nature Reserve is often disturbed by natural hazards through cyclones resulting in tree falls. Canopy opening after tree falls triggers the germination of *R. alceifolius* (Baret et al., 2008). This bramble colonized forest gaps spreading in the form of lianas or patches (Baret et al., 2003). Seed bank of *R. alceifolius* is abundant within *R. alceifolius* patches. (Baret, Le Bourgeois & Strasberg, 2005) showed, in Mare Longue Nature Reserve, that soil seed count was greater under *R. alceifolius* patches (more than 10 000 seed/m^2) than in understoreys not colonized by the bramble where approximately 3000 seed/m^2 were present. Baret et al., (2004) showed that the seed bank decreased with elevation and was not present at 1200 m a.s.l. They concluded that the decrease of fruit set in upland areas might be compensated by an increase in vegetative growth. In 2008, the biocontrol agent *C. janthina* was released in two locations on Réunion Island. Preliminary ecological *in-situ* and laboratory studies of *C. janthina* showed that the insect range is limited to lower elevations (0-1500 m) in Réunion Island. Low temperature during winter season on the island disrupt the insect's life-cycle (Mathieu et al., 2014).

Vegetation survey

After an initial survey, in 2009, of the distribution of *R. alceifolius* within the reserve, 37 patches were selected for the study of vegetation recovery in Mare Longue Nature Reserve.

Prior to the release of the control agent, these areas were densely invaded by *R. alceifolius*. The 37 patches were selected over a range of elevation, from 140 to 700 m a.s.l, and were located either in tree fall gaps within the forest, or on the forest edges adjacent to roads, trails or sugar cane fields. The surface area of each patch, defined as the gap size in the forest due to tree fall (Baret et al., 2008), varied between 8 to 1500 m^2. We assessed the vegetation by monitoring woody plant species' cover and abundance (Chytrý et al., 2008) in each patch. In order to restrict errors in plant identification, we excluded epiphytes since they are not easy to identify directly in the field, and because they are mostly located off the ground and are found in few numbers. To estimate species, cover and followed the assessment of *R. alceifolius* undertaken in (Dafreville et al., 2015) we used a semi-quantitative (ordinal) scale using Braun-Blanquet (Braun-Blanquet, 1932; van der Maarel, 1979, 2007). In 2010, 2011 and 2012 we included all plants below 1m and at 2013 and 2015 we added plants between 1-2 m and 2-4 m to account for the growth of seedlings following biocontrol. Plant cover was recorded for each stratum (0-1, 1-2, 2-4 m) and for a given species, cover can theoretically exceed 100%. The surveys were conducted yearly during austral summer starting in 2010 until 2015, excluding 2014 as no survey was undertaken. Native and non-native species were recorded except for 2010 where the initial protocol involved non-native species only.

Community metrics and environmental factors

Species richness and total cover

The analysis of ordinal data can be challenging because of its multinomial nature. We converted the ordinal cover classes into numerical values using the average value of the corresponding cover interval (van der Maarel, 2007). In order to monitor the vertical changes in the vegetation, we summed up the recovery using the total recovery per species from 3 strata

(0-1 m, 1-2 m and 2-4 m). For each surveyed patch on a yearly basis, the cover values were summed separately for native versus non-native species to estimate each total cover (noted as TC_t at time *t*) excluding *R. alceifolius*. We estimated the cover of *R. alceifolius* (noted as R_t) and considered the changes in R_t as a direct impact of biocontrol. We evaluated the species richness (noted as S_t) for native versus non-native species. We measured changes in non-native species richness as indirect impact to biodiversity conservation. We quantified benefits to conservation in terms of increase in native plant species richness and native vegetation cover. We then compared the species richness and total cover on a yearly basis for each patch (Dew et al., 2017).

Bayesian framework to estimate the impact of environmental factors

We then analyzed the effects of three environmental factors on vegetation dynamics: the elevation a.s.l (noted *E,* in meters), the location of each *R. alceifolius* patch (noted *L,* factor with 2 levels: forest or forest edges), and the initial area of *R. alceifolius* patches (noted *A*, in m^2).

We developed a hierarchical Bayesian approach to estimate the temporal trends in species richness, vegetation covers and the effects of environmental factors on them. We built Hierarchical Bayesian Models and use Monte Carlo Markov Chains (MCMC) to estimate parameters (Gelman et al., 2004) and to test for hypotheses. In the Hierarchical Bayesian Models (HBM), framework complex models are defined, with moderate effort, as hierarchical series of hypotheses are considered at three primary levels: data, processes and parameters (Wikle, 2003). The models include autocorrelation to temporal dynamics to estimate uncertainty in parameter values (Clark et al., 2003; Flores, Rossi & Mortier, 2009). It also allows to account for missing information in the data (Gelman et al., 2004).

Based on the HBM framework, statistical models were built for each of the following response variables measured over time (t); 1) *R. alceifolius* cover(R_t), 2) Species richness (S_t) and 3) Total cover(TC_t). We included a yearly timeline in the model. In the models for S_t and TC_t, we estimated the response of native and non-native species to the three environmental factors (E, L, A) separately.

The model variables

Y_t is the response variable measured at time t and X is the matrix containing the three explanatory environmental factors, $X = (E, L, A)$, independent of time. We present here a generic version of the models for species richness (S_t) and total cover (TC_t) without taking into account whether the species are native or not.

For R_t and TC_t the response was devised using a Gaussian distribution. At data and process levels, which define respectively the response distribution and the effects of explicative variables on the expectation of the response variable, μ_t, the model is written as:

$$Y_t \sim N(\mu_t, \sigma^2)$$

$$\mu_t = \beta \boldsymbol{X} + \delta \times \boldsymbol{T} + \gamma_p + C$$

where *N* is the Gaussian normal distribution with mean μ_t and standard deviation σ, $\boldsymbol{X}$ is the matrix of environmental explicative variables, β is a vector of regression coefficients (β_1 for linear trend and β_2 for quadratic) for each variable in $\boldsymbol{X}$, δ is a vector of regression coefficients (δ_1 for linear trend and δ_2 for quadratic) for time , γ_p is an individual effect of patch p, a random effect in the frequentist approach, and C accounts for temporal autocorrelation in the response.

Regarding the impact of location L, we use sum to zero contrasts to ease coefficients interpretation (Schielzeth, 2010), the overall average patch effect being null ($\beta_1^{L,F} + \beta_1^{L,E} = 0$). The patch effect γ_p is modelled as:

$$\gamma_p \sim N\left(\beta_{1\,L}^{L}, \sigma_\gamma^2\right)$$

where the expected mean patch effect, β_1^L is either $\beta_1^{L,F}$ or $\beta_1^{L,E}$ depending on the location of *R. alceifolius* patch and σ_γ the standard deviation of patch effect, with the constraint where $\sum_{p=1}^{37}\sum \gamma_p = 0$.

The patch effect, γ_p accounts here for differences in environmental local conditions and history across patches that are not accounted for by variables in $\boldsymbol{X}$.

The term C estimates the autocorrelation in the response Y_t due to persistence through time. Temporal autocorrelation challenges the classical hypothesis of independent observations. It is due to the characteristics of ecological communities to persist through time. This persistence implies that community metrics, such as richness or total cover, vary over longer time periods than the annual survey scale. The term for autocorrelation, C, is defined as:

$$C = \begin{cases} \alpha, & t = 0 \\ \rho \times \mu_{t,} & t > 0 \end{cases} (1)$$

where α estimates the intercept of the model at $t = 0$ (initial time), and ρ is a correlation coefficient measuring autocorrelation.

For species richness S_t, we build a generalized linear model based on the Poisson distribution P:

$$Y_t \sim P(\lambda_t)$$

$$\log(\lambda_t) = \beta X + \delta \times t + C$$

where λ_t is the parameter for the Poisson distribution, that is the expected (mean) species richness at time t: $\lambda_t = E[S_t]$. In this case, the autocorrelation term C is defined by replacing μ_{t-1} by $\log(\lambda_{t-1})$ in equation (1).

We run MCMC sampling using JAGS, a Bayesian Graphical modelling programme (Plummer, 2003) implemented through R software (R Core Team, 2016) with burn-in phases of 2×10^4 iterations and sampling chains of length 10^4 for posterior distribution estimation. All model parameters were assigned weakly informative or uninformative prior distributions initially. We assigned normal distributions N (0, 10^6) as priors for the intercept (α), regression coefficients (*β*) and trend coefficients (*δ*). We assigned to correlation coefficients *ρ* a uniform distribution on the interval [0,1] as prior. We run three Markov Chains for each model. Models were first evaluated by visual inspection to ensure that the chains were well-mixed, with constant variance, and showing no trend, ensuring convergence of the sampling algorithm. Posterior distributions were checked for unimodality and regularity. Bayesian data analysis does not provide classical probabilities for Type-I errors (p-values) or inference based on hypothesis testing. It allows however to estimate credible intervals and provides with Bayesian analogs of confidence intervals used in the frequentist approach. Here we base our conclusions on parameters using 95 % credible intervals and consider effects as significant when zero was found out of the credible intervals for the corresponding parameters.

Due to small sample size, we performed limited model comparison to compare models to evaluate potential differences between native and non-native species. We used the mean penalized deviance (Plummer, 2008) as criterion for model comparison as it is better adapted than Deviance Information Criterion to small sample sizes.

Results

Changes in *Rubus alceifolius* cover

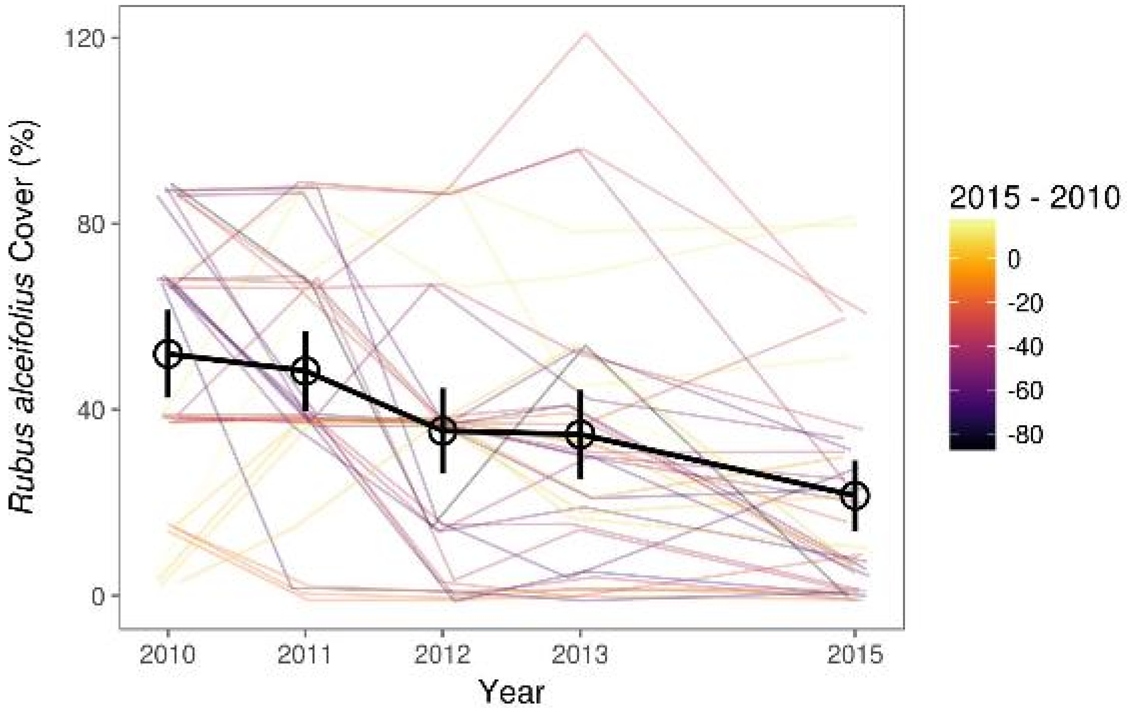


Figure 3-1: Cover dynamics of R. alceifolius cover (%) estimated for the 37 study patches where x-axis shows the time per year from 2010-2013 and 2015. The lines indicate individual patch trajectory (jittered for better visibility), with colors indicating the value of net absolute variation between 2010 and 2015. The average trajectory, mean cover values for the given year and standard errors are shown with a black line.

R. alceifolius cover declined over time (Figure 3-1). Its cover decreased from an average of 52 % to 22 %. A strong decrease occurred between 2011 and 2012 (-13 %) indicating a major direct impact of the biocontrol agent soon after its arrival in Mare Longue Nature Reserve. The reduction of *R. alceifolius* cover occurred in 29 patches (78 %). In the HBM related to *R. alceifolius* cover, the coefficient for the temporal trend was significantly negative (δ = -5.51, Table 3-1), expressing a linear mean decrease of 5.51% per year. We found no significant difference in cover between patches locations (forest / edge), though in forest, the patches showed a relatively higher cover compared to those in edges (5.5 versus -5.5). The cover of *R. alceifolius* increased with elevation ($\beta_1^E = 9.12$, significantly) and with the surface area ($\beta_1^A = 5.89$, not significantly, Table 3-1). The influence of temporal autocorrelation (ρ = 0.0524) indicated a slight occurrence of *R. alceifolius* through time, the maximum possible value being 1.

*Table 3-1: Summary of the statistics for the model of cover dynamics for R. alceifolius. Mean values shows the estimated mean effect of model components. Int. = model intercept, s.d. = standard deviation, s.e = standard error, *= indicates whether the coefficient differs from 0 at 95%-confidence level, when zero is not in the corresponding highest posterior density interval. Numbers are given with three significant digits. See methods for the full description of the parameters.*

Coefficients		Mean	s.d.	s.e.	Low.	Upp.
α	Intercept	49.6*	2.41	0.0197	44.8	54.1
β_1^E	Elevation Linear	9.12*	3.57	0.0291	2.41	15.6
ρ	Autocorrelation	0.0524*	0.0405	0.000331	1.47e-05	0.133
δ	Time Linear	-5.51*	0.756	0.00617	-6.95	-4.07
$\beta_1^{L,F}$	Forest patch Effect	5.5	3.38	0.0276	-1.03	12.2
$\beta_1^{L,E}$	Edge patch Effect	-5.5	3.38	0.0276	-12.2	1.03
β_1^A	Area of patch	5.89	3.44	0.0281	-1.43	12.4
σ_γ	Patch effect standard deviation	18.6*	2.87	0.0234	13.7	24.1
σ	Observed standard deviation	18.1*	1.06	0.00868	16	20.2

Changes in plant communities' richness

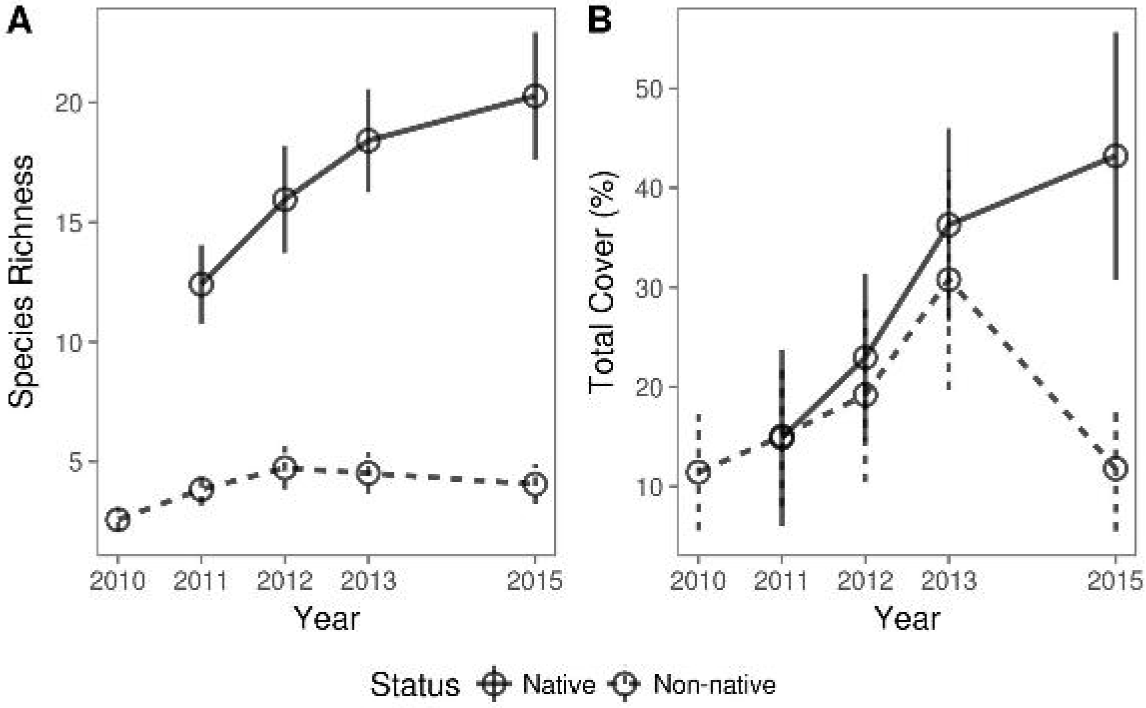


Figure 3-2: Community metrics across time for native and non-native species: x-axis shows the time per year from 2010-2013 and 2015, the species richness (A) and the percentage of species cover where the y-axis represents the number of patches (B). Native species were not sampled in 2010.

The surveys showed that 168 plant species were present, among which 114 were native and 46 were non-native (see Annex 2). We could not determine 8 species named as unknown. Native species richness increased over the study time from an average of 12.4 ± 0.8 (mean ± s.e.) species observed per patch in 2011, to 20.3 ± 1.3 in 2015 ($\delta_1^{Nat} = 0.255$, Table 3-2 and Figure 3-2A). This positive trend was general as native species richness declined or stagnated in only 3 of the 37 patches surveyed (8 %). During the same period, non-native species also increased, from an average of 2.57 ± 0.2 species per patch in 2010, to 4.05 ± 0.4 in 2015 with a maximum in 2012 (4.73 ± 0.4) and a positive (not significant) coefficient for non-native species ($\delta_1^{Non} = 0.0106$, Table 3-2, Figure 3-2A). The trend for each patch showed that non-native species were more variable than native ones, as 20 patches (54 %) increased in species richness and 17 patches (46 %) decreased in species richness. The final HBM for species richness, S_t, the mean coefficient with a positive value are α_{Non} , α_{Non} , $\beta_1^{E,Nat}$, $\beta_1^{L,F}$,δ_1^{Nat}, β_1^{A}, σ_γ and with a negative significant value are $\beta_1^{E,Non}$, $\beta_1^{L,E}$. The effect of elevation differs for native and non-native species richness. S_t for native species increased linearly with elevation while S_t for non-native species declined (Table 3-2, Figure 3-3A and C). Patches location (forest versus edges) had an influence on community recovery (Figure 3-4A and C). Species richness was higher in patches located within forest compared to patches on edges, as shown by the significantly positive impact of forest versus forest edges in the HBM model ($\beta_1^{L,F} = 0.0777$, Table 3-2), mostly due to native species within forest compared to edges (Figure 3-4A). However, Figure 3-4C shows that non-native species' richness was slightly greater in edges than in forest. The initial surface of a patch had a significant impact on species richness ($\beta_1^{A} = 0.082$, Table 3-2), and was consistent across the two species groups. The HBM for S_t also showed significant variability in the patch effect ($\sigma_\gamma = 0.155$, Table 3-2) interpreted as unobserved variation in patch local conditions leading to differences on species richness.

*Table 3-2: Summary of the statistics for the model of species richness, St, with coefficients relative to status of native species (Nat) and non-native (Non). Mean values shows the estimated mean effect of model components. Int. = model intercept, s.d. = standard deviation, s.e = standard error, *= indicates whether the coefficient differs from 0 at 95%-confidence level, when zero is not in the corresponding highest posterior density interval. Numbers are given with three significant digits. See methods for the full description of the parameters.*

Coefficients		Mean	s.d.	s.e.	Low.	Upp.
α_{Nat}	Intercept for native species	1.91 *	0.0414	0.000239	1.83	1.99
α_{Non}	Intercept for non-native species	1.55 *	0.0769	0.000444	1.4	1.7
$\beta_1^{E,Nat}$	Elevation Linear for native species	0.24 *	0.0357	0.000206	0.172	0.313
$\beta_1^{E,Non}$	Elevation Linear for non-native species	-0.32 *	0.0467	0.00027	-0.416	-0.233
$\beta_1^{L,F}$	Forest patch Effect	0.0777 *	0.0316	0.000182	0.0153	0.143
$\beta_1^{L,E}$	Edge patch Effect	-0.0777 *	0.0316	0.000182	-0.143	-0.0153

δ_1^{Nat}	Time Linear for native species	0.255 *	0.0118	6.83e-05	0.232	0.277
δ_1^{Non}	Time Linear for non-native species	0.0106	0.0242	0.00014	-0.0366	0.0587
β_1^{A}	Area of patch	0.082 *	0.0321	0.000185	0.0193	0.147
σ_{γ}	Patch effect standard deviation	0.155 *	0.0313	0.00018	0.0993	0.22

Changes in plant communities' cover

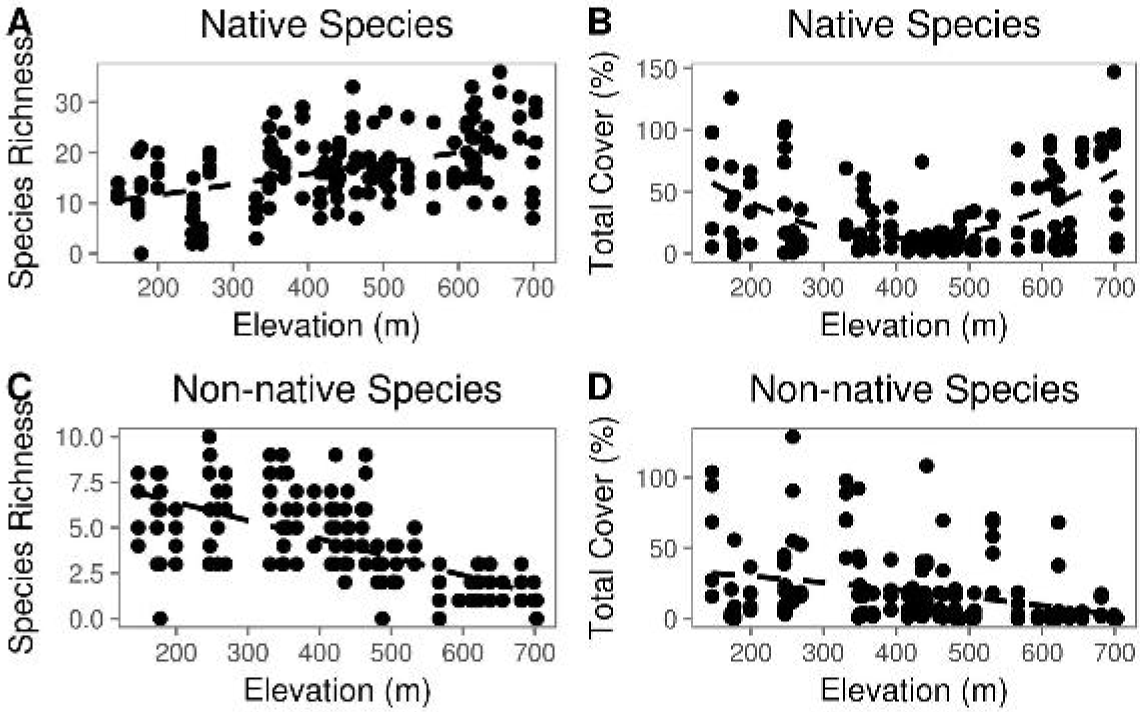


Figure 3-3: Changes in community metrics in relation to elevation measured in meters for native and non-native species; species richness identified within the amount of patches (left) and total species cover expressed in percentage (right).

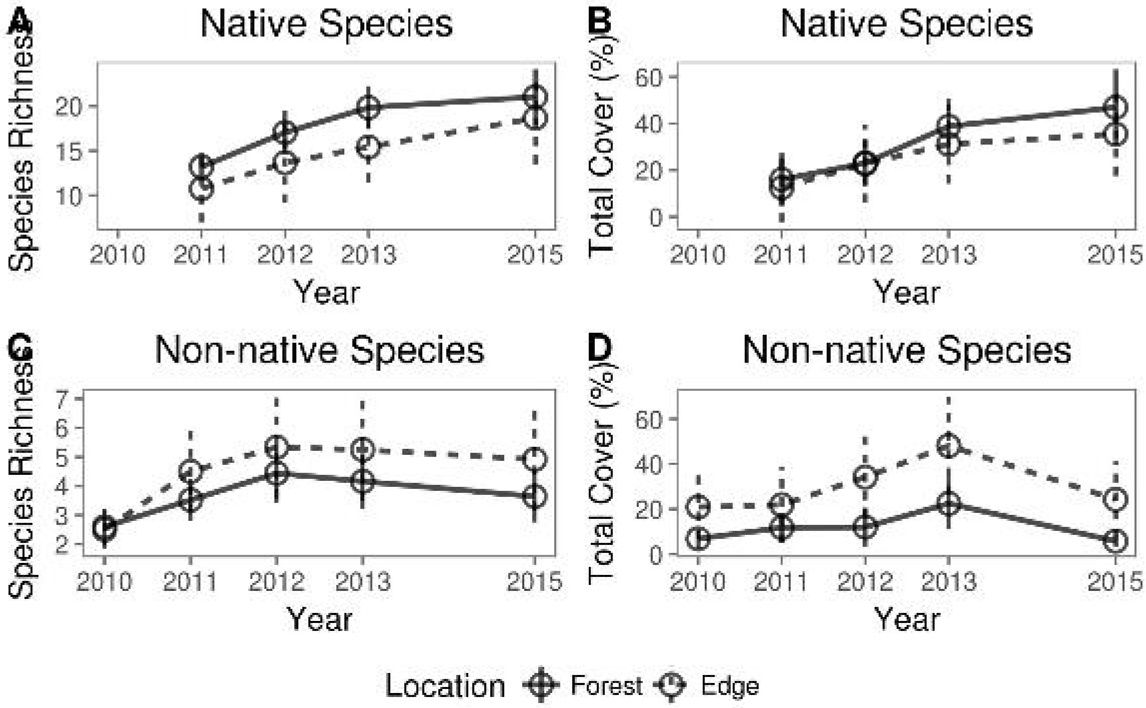
A positive trend was observed for native species, with mean cover extending from an average of 14.8 %±4.5 to 43.2 %± 6.2 over the study period (Figure 3-2B). Regarding non-native species, their average cover increased from 11.4 ± 2.9 % per patch in 2010 to 30.8 % ± 5.5 in 2013 and then decreased to 11.8 ± 3.1 in 2015 (Figure 3-2B). The main species with cover decreasing over time were *Clidemia hirta*, *Psidium cattleianum*, *Ardisia crenata*, and *Syzygium jambos*.

The HBM for total cover (TC_t) confirmed strong differences in time across the two species groups as observed in Figure 3-2B on the studied period: native species only showed a large increasing and significant linear trend ($\delta_1^{Nat} = 10.9$, Table 3-3), compared to non-native species which showed an increasing and significant linear trend ($\delta_1^{Non} = 10.4$) and a significant hump-shaped trend ($\delta_2^{Non} = -2.04$) over time. Regarding autocorrelation, the best model included only one term common to both groups as it is significant but low ($\rho = 0.199$, Table 3-3).

Regarding the effects of environmental factors, native species cover showed an overall significant quadratic U-shaped relationship with elevation (Figure 3-3B and $\beta_2^{E,Nat} = 13$, Table 3-3). High cover values tend to occur at lowest and highest elevation, whereas total cover was low with an elevation height between 400 and 500 m. Non-native species showed more variable results than native species. The linear impact of elevation on non-native species' TC_t indicated a significant posterior mean value of -9.47 (Table 3-3). This showed that TC_t for non-native species declined linearly with increasing elevation (Figure 3-3D).

Patch location in edges increased significantly with mean total cover ($\beta_1^{L,E} = 3.89$, Table 3-3), mostly due to non-native species (Figure 3-4D). The HBM also showed a significant patch effect ($\sigma_\gamma = 8.15$, Table 3-3) on total cover.

Figure 3-4: Changes in species cover and richness where x-axis shows the time per year from 2010-2013 and 2015, within the forest and on edge for native and non-native species, with the position of patches (A) and where y-axis indicates the percentage and total species cover where y-axis indicates the number of patches (B).



A
Native Species
Species Richness
Year
B
Native Species
Total Cover (%)
Year
C
Non-native Species
Species Richness
Year
D
Non-native Species
Total Cover (%)
Year
Location
Forest
Edge

*Table 3-3: Summary of the statistics for the model of overall species cover, TCt , with coefficients relative to species status, native (Nat) and non-native (Non). Mean values shows the estimated mean effect of model components. Int. = model intercept, s.d. = standard deviation, s.e = standard error, *= indicates whether the coefficient differs from 0 at 95%-confidence level, when zero is not in the corresponding highest posterior density interval. Numbers are given with three significant digits. See methods for the full description of the parameters.*

Coefficients		Mean	s.d.	s.e.	Low.	Upp.
α_{Nat}	Intercept for native species	-8.65	6.27	0.0362	-20.5	2.64
α_{Non}	Intercept for non-native species	9.67 *	3.82	0.0221	2.34	16.9
$\beta_1^{E,Nat}$	Elevation Linear for native species	3.58	2.29	0.0132	-0.697	8.27
$\beta_1^{E,Non}$	Elevation Linear for non-native species	-9.47 *	2.52	0.0145	-14.5	-5.04
$\beta_2^{E,Nat}$	Elevation Quadratic for native species	13 *	2.95	0.017	7.53	18.4
$\beta_2^{E,Non}$	Elevation Quadratic for non-native species	-2	2.17	0.0125	-6.16	2.29
$\beta_1^{L,F}$	Forest patch Effect	-3.89 *	1.83	0.0106	-5.1	2.06
$\beta_1^{L,E}$	Edge patch Effect	3.89 *	1.83	0.0106	1.3	20
ρ	Autocorrelation	0.199 *	0.161	0.000927	4.27	17.3
δ_1^{Nat}	Time Linear for native species	10.9 *	4.94	0.0285	-2.36	0.739
δ_1^{Non}	Time Linear for non-native species	10.4 *	3.82	0.0221	-3.29	-0.95
δ_2^{Nat}	Time Quadratic for native species	-0.87	0.821	0.00474	-7.64	-0.523
δ_2^{Non}	Time Quadratic for non-native species	-2.04 *	0.67	0.00387	0.523	7.64
β_1^{A}	Area of patch	-1.25	1.79	0.0103	1.94e-06	0.47
σ_γ	Patch effect standard deviation	8.15 *	2.18	0.0126	20.2	23.7
σ	Observed standard deviation	21.9 *	0.928	0.00536	4.42	12.6

The abundance of native and non-native species

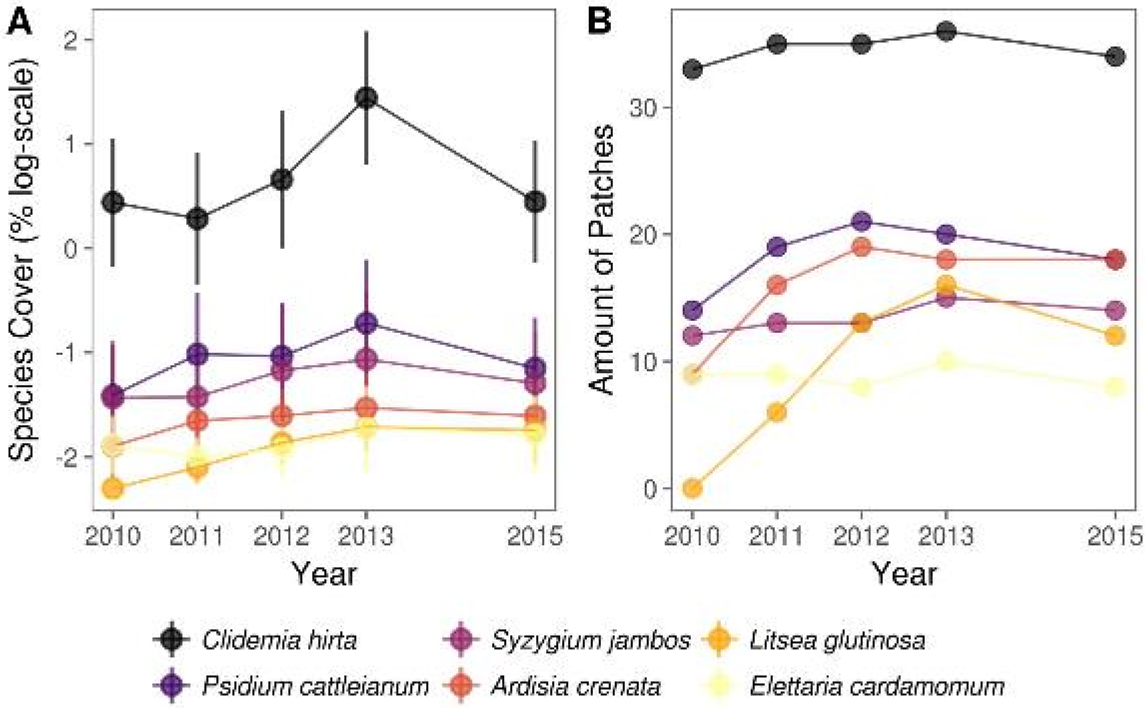


Figure 3-5: The abundance of non-native species at study scale for the six highest species with mean cover at T5 are shown, where x-axis the time per year from 2010-2013 and 2015, y-axis indicates standard error across sites. The species cover in y-axis indicates the log-scale for the mean cover and variability across patches with vertical bars indicating standard error (A), and the number of patches in which the survey non-native species were present (B).

At species level, we evaluated the trend in their cover and the numbers of patches colonized (Figure 3-5 and Figure 3-6) by non-native species. Cover for the following species decreased: *Clidemia hirta*, *Psidium cattleianum*, Syzygium Jambos, *Ardisia crenata*, *Litsea glutinosa*, *Elettaria cardamomum*, *Boehmeria macrophylla*, *Diospyros digyna*, *Boehmeria penduliflora*, *Aphloia theiformis*, *Lantana camara*, *Hiptage benghalensis*, *Cyathea cooperi*, *Ruellia brevifolia* and *Solanum mauritianum*. The pool of non-native species was dominated by *Clidemia hirta* (Figure 3-5A), a small shrub that was initially present in all patches (Figure 3-5B) and classified as invasive. However, the dynamics of species cover and of the amount of colonized patches, of this light-demanding species, has changed after 2013 from a high to low trend. The native species showing the highest species cover in 2015 were *Nephrolepis* *bisserata*, *Machaerina iridifolia*, *Antirhea borbonica* (Figure 3-6A) as well as *Aphloia theiformis* and *Pandanus purpurascens*. Out of 6 native species recorded, 5 showed an increasing species cover in time; except for *Nephrolepis bisserata* which expressed a slight decrease from 2013. In terms of the amount of colonized patches (Figure 3-6B), *Gaertnera vaginata* (27 patches), *Nephrolepis bisserata* (17 patches), and *Machaerina iridifolia* (11 patches) stagnated while the three other indicated species expressed a high increase in time, with a stronger increase for *Piper borbonense*.

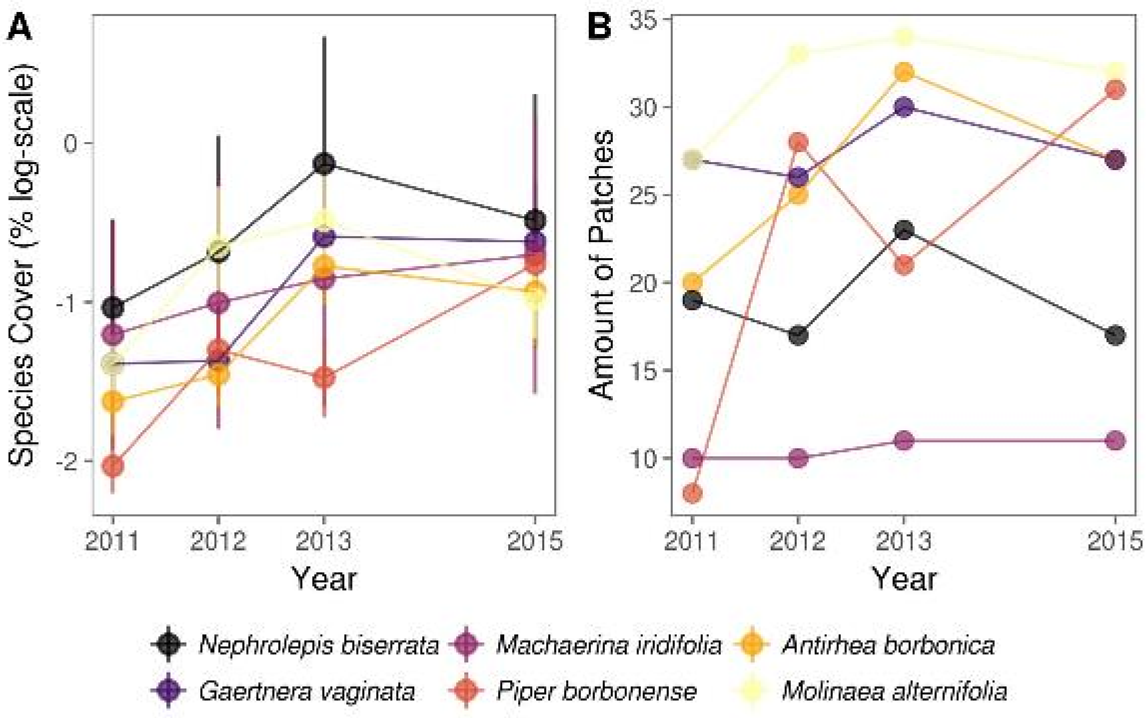


Figure 3-6: The abundance of native species at study scale for the six highest species with mean cover at T5 are shown, where x-axis the time per year from 2010-2013 and 2015, y-axis indicates standard error across sites. The species cover in y-axis indicates the log-scale for the mean cover and variability across patches with vertical bars indicating standard error (A), and the number of patches in which the survey non-native species were present (B).

Discussion

Key results

Our results pointed out a strong benefit for biodiversity conservation as the biological programme assisted native species recovery. In addition to decrease in plant target cover, we documented here other positive impacts of the biocontrol programme on studied plant communities. Native species richness increased, indicating ongoing recruitment of those species after the release of the biocontrol agent induced by a decrease in *R. alceifolius* cover from 2010 to 2015. The total cover and species richness of native species outweighs that of non-native species. The most important increases in native species cover at patch scale were mainly related to two species that tend to spread in dense cover in habitats surrounding the study area in 2015, namely *Nephrolepis bisserata (Oleandraceae)* found in the undergrowth of the forest at low elevation, and *Machaerina iridifolia* (Cyperacae) at higher elevation and in more open places.

Prioritizing where to establish a biocontrol programme

The conservation value of a site can be taken into account to estimate the benefits of a biocontrol programme but this has been indirectly assessed in our study. Here we provided evidence of the benefits brought to biodiversity conservation of the last remnants of tropical rainforest at the Mascarene Archipelago scale. Analog ecosystems are remnant in the sister islands of Réunion Island, Mauritius and Rodrigues which are seriously threatened (Cheke, 2010; Cheke & Hume, 2010) since they are included in the Madagascar biodiversity hotspot (Myers et al., 2000b). The peculiar composition, structure, and functioning, of these ecosystems make them unique at global scale, as no representative of continental analogs exist in this biogeographical setting. Their conservation value can therefore be considered as very high. Conservation benefits gained from IAPs control in this context are consequently of critical importance, at least at island scale where management programmes are more feasible than on continents (Veitch & Clout, 2002; Glen et al., 2013). When weeding through mechanical or chemical control becomes inefficient, biological control programme could be an efficient tool for conserving island biota threatened by invasive plants. Our case study may be useful in islands within the Western Indian Ocean like Mauritius, Seychelles, and the southern oceanic islands.

The influence of environmental factors on biocontrol success

The success of biocontrol usually depends on several biotic and abiotic factors, in addition to the management option in place. It is imperative to consider a strategic planning prior and post biocontrol programme. We found that success of the biological control (as measured by a decrease in *R. alceifolius* cover) depended on the surface area of the patch, the elevation and the location whether the patch was located in the forest matrix or on trails or road tracks on forest edge. This result highlights the significance of including environmental factors in assessing the success of biological control project. A better understanding of these factors might assist in setting additional control measures where biological control efficiency is low. On our case, mechanical control will be needed in high elevation sites to compensate the low efficacy of the biocontrol agent.

We also found that the variation in both native and non-native species with edge effects versus forest matrix on forest communities tends to limit biodiversity by favoring the opening on an ecological niche for invasive plants (Otto et al., 2014). Management options should be prioritized in sites that are prone to enhance invasion to avoid these potential injurious consequences (McGeoch et al., 2016). Nowadays the level of invasive alien plants is now considered as a global issue, affected by the increase in invasion pathways (Seastedt, 2015) explained that the assessment of the success of a biological control project should include global environmental drivers (climate change, nitrogen depositions, CO_2) that could have substantial direct or indirect impact on the ecological interactions between the insect as a biocontrol agent towards the targeted invasive plant. (Seastedt, 2015) used the example of the control of *Cardus nutans* commonly called the nodding thistle, which has highly invaded North America and New Zealand over a century ago, and recorded in New Zealand in 1940. North America started biocontrol of the nodding thistle with a total of selected six insect species and few were release in Australia and New Zealand. The interactions between the targeted species and the biological control agents were different in these three countries due to differences in various biotic and abiotic factors. In North America, for instance, the biocontrol agent affected the native thistly, in New Zealand biocontrol agents acted as seed feeders, and in Australia these insects had an effect on growth forms of the nodding thistle. (Rai, 2015) explained how the management of invasiveness needs to be assessed by devising a unified framework to bring about features related to global change; climate change, land-use, atmospheric carbon dioxide level or nitrogen deposition. (Hovick & Carson, 2015) found that supplementary biotic factors such as soil fertility could influence the level of success of a biological control project, whereby a low soil fertility would favor a better biocontrol efficacy.

Long-term effects and monitoring of biocontrol programme

Our study showed the importance of long-term monitoring of invasive control programmes. If we had only a two-year step to estimate the benefit of the biocontrol programme, the result would have demonstrated a failure. This study has been undertaken over 5 years and have allowed to evaluate the trends in vegetation cover and richness. We concluded that the biocontrol agent was a success on controlling *R. alceifolius*. Studies evaluating the impact post control are generally undertaken over a limited time-frame of one to three years (Guido & Pillar, 2017). (Kettenring & Adams, 2011) demonstrated through a meta-analysis on IAPs control that the time scale selected in studies are usually within one growing season or less and focus only on the success of the control of the invasive plant and not enough on the recovery of native species. Funding availability is required to measure the impact of different control measures on a short and long term. This will allow the possibility to investigate on supplementary biotic or abiotic factors liked to the global changes highly impacting on the invasiveness traits and the invasion pathways.

Implications for management and monitoring

A comprehensive evaluation of biocontrol success is needed beyond change in target species cover. A crucial recommendation for the management that can be drawn from our results is that as other control means, biological control may not provide an all-inclusive solution to invasive species management, but needs to be supported by other restoration and control actions. Biological control alone might not be sufficient, depending on site environmental conditions. Among these, an integrative management strategy need to be set up, through complementary mechanical control of all other invasive alien plant species and planting of fast-growing native species originated from the vicinity (to maintain the genetic pool). A strategic plan including an integrated management, on short and long term, including restoration and regular monitoring, should be favored with availability of funding. However, invasive alien plants species tend to favor large perturbations. Although the observed trends need to be assessed over a longer period of time, the species cover for non-native species show stable or decreasing trend. The management of buffer zones along edges to limit invasive propagules pressure or limitation of road width could help to reduce those effects.

Conclusion

The aim of this study was to undertake an assessment post-biocontrol programme of the invasive *R. alceifolius* by the host insect *C. Janthina.* We found that the biocontrol programme was successful with a positive impact on native species recovery. The positive impact (species cover and richness) was greater than the negative impact. Few negative impact expressed was an increase in cover of other invasive species but limited to specific environmental conditions (forest edge, lower elevation). These results highlight the importance of opting for an integrated control management with restoration programme, following the clearing of non-native species. We recommend assessing biocontrol after five-year to have a broader overview of the efficiency of the biocontrol agent in reducing *R. alceifolius* cover. A comprehensive assessment should include a socio-economic impact with in-depth sociological study as the next process of this control programme.

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Chapter 4: Unpacking the controversies around the management and control of the invasive plant, *Rubus alceifolius*, in Réunion Island: preliminary elements for a sociological research

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Abstract

The perception of invasive plants by citizens is often underlooked in control programs. The management and control of *R. alceifolius,* the giant bramble, highly invasive in Réunion Island, triggered a great debate among the local community and contributed to diverging opinions about the invasive status of the plant. Although it is occasionally used for medicinal and food purposes, *R. alceifolius* is considered as an invasive alien plant by the local government and forest service in Reunion island. In 2008, a biological control agent, *Cibdela janthina*, a phytophagous sawfly was introduced to control *R. alceifolius* with approval from the French authorities here represented by the state, regional council, ministries, agencies and institutions. The omnipresence of the biological control agent, a blue-metallic looking fly around the island within a year’s time did not go unnoticed and aroused great misunderstanding by the public. A high abundance of *C. janthina*, commonly called the "blue fly" was recorded on litchi trees (*Litchi chinensis*) and Brazilian pepper tree (*Schinus terebinthifolius*), during litchi flowering season raising uncertainties among beekeepers of its impact upon litchi honey production. This concern was broadcasted amongst the local community and it received great media attention. The local press published headlines expressing the opinion of beekeepers who voiced out their concerns on the decrease of their honey production to the French authorities. We reflected on the controversy around the release of a biological control agent in Réunion island. The aim of this study was to determine the different perceptions of this biological control programme from the French authorities, the beekeepers and the research centre. We selected the emergence of the transformation of disputes to determine the rationale behind the controversies on the biological control programme. We looked into the available data through newspapers, scientific committee meetings reports, decrees, orders and undertook surveys to understand the various point of views which brought about disputes as part of the biological control programme. We studied the perceptions due to contrasting views on the biological control agent and the invasive *R. alceifolius*, focusing on beekeepers. We found out that a weak communication and involvement of beekeepers prior to the release of the biological control agent have generated discontentment. The none-involvement of beekeepers during the scientific decisions later generated controversies. The research centre was requested to investigate on the issue of the reported decrease in honey production and concluded that *C. janthina* had no link with honey production. The research centre has later collaborated with professional beekeepers, as allies, to undertake the study.

Keywords: Biocontrol, perception, media, conflicts with beekeepers

Introduction

Contrasting perceptions in the context of biological invasion control

The knowledge and perception of an invasive plant may differ for any person, group of individuals, local community or governmental institutions. Few perceive a plant as part of “nature” (Kueffer and Kull 2017) while a given plant could be defined by others as an invasive species that should be controlled (Simberloff 2013). The general public often have a contesting view of methods of control of invasive species that can lead to its interruption or suspension of its management and control plan (McNeely 2001). Misunderstandings or misperceptions due to opposing level of perception regarding the economic use of an invasive species can lead to contests (Genovesi 2005). The perception of the controlled species by the general public can also be problematic as it could be considered in a contrasted manner, either as a common "naturalised" species appreciated by the general public in the form of an income generating, medicinal, aesthetic species, or as a harmful species to be controlled.

In terms of the perception of environmental issues, whether derived from a political point of view, or managers or the general public, the perceived issues appear in their respective context (policy, management, cultural, natural) and can be therefore seen as different realities. A "discourse" is considered as the study of the meaning attributed to social and physical occurrences given in the form of set of ideas, concepts and categories which are created over a set of identified practices (Hajer and Versteeg 2005) . The definition of discourse analysis, according to Hajer and Versteeg (2005) is built around the existence of multiple realities and is defined as "*socially constructed reality instead of a single reality, governed by immutable natural laws*." Since reality is regarded as being socially constructed, for the case of environmental research, the most important aspect is the way the society makes sense of a given phenomenon and less the environmental phenomenon itself. These diverging realities or discourse based on various level of knowledge and perception usually generate conflicts and controversies for the case of the management of invasive species.

Quéré (2012) provided with a case study of the emergence of an invasive algae with toxic characteristics in the East of France, which created a highly controversial situation with disputes, profound emotions around unforeseen consequences. This was due to the fact that the perception of the appearance of an invasive algae was different between various groups of individuals, the state, researchers headlined by the media (Quéré 2012). Few members of the general public and of non-governmental organisations protested against the excessive algae in rivers and the sudden death of animals and of a man due to toxic gas release by algae. They questioned farming practices but farmers claimed that they used fertilizers according to rules recommended by the national authorities. The state went unnoticed since the farmers were in the dock in court. In Quéré (2012), the diverging opinions brought about affects and emotions that lead into actions in the form of demonstrations among various organisations and also a case in court against the French state. In general, the invasive species as a subject of debate is not considered as being native and the meaning of the term "native" and "natural" brings about uncertainties when it comes to understanding the concept of invasion of a given "alien" species (McNeely 2001). Chapter 5 showed that having disputes can also amend strategies put in place to manage invasive "alien" species and it is necessary to identify key audiences (individuals either using the species or controlling it) in the process of building strategies. In the control of invasive cactus in South Africa, cactus users who depend on this invasive plant as a socio-economic resource were in conflict with those aiming at eradicating the invasive cactus, since it had economic value as a revenue for a few (Chapter 5) . These recent problematics required further research study on controversy and conflict linked to the management of invasive species. Réunion Island, found in the South West Indian Ocean region undertook a biological control programme which rapidly went through controversies and misperceptions. This case study comprised of a case study upon the rationale behind controversies and more specifically how can we avoid such controversies.

Research undertaken in managing the invasive *Rubus alceifolius*

The use of biological control to manage invasive alien plant has been promoted since late 19th century on islands ecosystems, with Hawaii as a main showcase (Funasaki et al. 1988). In Reunion Island (France) the first use of biological control aiming at biodiversity conservation was undertaken in 2008 to control the invasive giant bramble *Rubus alceifolius*. The French authorities perceived the spread and impact of *R. alceifolius* as a threat to agriculture, wood production and biodiversity conservation, due to the rapid invasion of *R. alceifolius* and the limited success of mechanical control. The perceived status of a given species can be considered as part of nature or as a biological invader, depending on the profile of the audience among the overbroad general public, researchers or managers (Simberloff 2013).

From the perspective of the French authorities, *R. alceifolius* is considered as an invasive plant that should be controlled. Few occasional uses of *R. alceifolius* have been recorded *R. alceifolius* could be used for its berries in preparing jam (Lavergne 1978). Mechanical control combined with chemical control have been undertaken by the forestry services (*Office National des Forêts*) through manual and automated cutting, uprooting and the use of glyphosate based herbicides (Triolo 2005; Roussel and Triolo 2016) for biodiversity conservation and in the agricultural sector mainly in sugar cane production since the 1980's. During the late 1990's, after 30 years of manual and chemical control the Forestry Services suggested finding an alternative means of control (Tassin et al. 2009). Research into alternative control measures (such as biological control) started in the late 80s (Tassin et al. 2009). In 2000, a Ministerial decree established a list of invasive species (based on scientific research and risk assessment), subject to compulsory control measures. The decree declared *R. alceifolius* as a priority pest to be controlled on the territory of Réunion island under a EU act (European Union 2000) . This order was necessary from a legal point of view since it stated that *R. alceifolius* as a species with obligation of control recommending the use of biological control.

The Regional Council started to fund research and development and established a scientific committee to identify possible biological control agents for *R. alceifolius*. The role of the scientific committee was to provide scientific support and advices to the regional council on the biological control research programme implemented by the research centre (CIRAD). It is therefore important to be able to understand the objectives of the different local authorities in controlling *R. alceifolius.* It is also important to consider the perception of the beekeepers who claim the utilities of this invasive plants. This study should assess the discourse in the management of *R. alceifolius*. We looked into the rationale behind discontentment among the public in Réunion Island on a biological control programme to mitigate an invasive plant, *R. alceifolius.* We tried to first look into how the problem has been set up and why it resulted in a public problem from identified stakeholders; the French authorities, the research centre (CIRAD) and the beekeepers. We investigated on the perception of the biological control programme from the identified groups of individuals. In this study on contrasting perceptions of biological control programme we investigated on: 1) the rationale behind the biological control programme which transformed into a public problem, 2) the contrasting perceptions of the French authorities, the research centre and the beekeepers of biological control programme and; 3) the broadcasted messages by the media expressing the views of identified groups.

Methods

The social problem theory

A social problem is considered as the transformation of any social fact into a concern for public debate with/without the intervention of a given state (Neveu 1999). Neveu (1999) showed how a problem is a transformation of any social fact of concern at the heart of a public debate with a probable state action. Any social fact might become a public problem if it is accompanied by the voluntary intervention of institutions (the press, social movements, parties, lobbies or intellectual) as part of voluntary actions, based on public operations in the form of rules or budgets. Neveu (1999) made explicit that some problems can generate greater public interest when they received different prioritisation. Diverging opinions in policy implementation or decision-making and misunderstanding in the context of environmental management often brings controversies. A controversy is defined by Lascoumes (2014) "*in a scientific context to designate a discussion on a theoretical and / or empirical issue. Controversy is part of the process of validating scientific discoveries, with peer judgment establishing the validity or error of a theoretical model or demonstration.*" Therefore, in this context, a situation is considered as problematic when a normal course is interrupted, entangled and difficult to interpret, depending on the basis of belief of related individuals besides scientists. Spector and Kitsuse (1973) further showed that social problems are a process within which individuals either as groups or societies declare their complaints and express their alleged circumstance. Spector & Kitsuse (1973) gave an explanation of a social problem, which happens when a group of individual declared an actual offense within their environment and context. Felstiner, Abel, and Sarat (1980) demonstrated the conception and transformation of problems among parties, commonly called, disputes in the form of claimed grievances which aroused from a given problem. The theory of a social problem is the justification in setting-up, and perpetuating misunderstandings which are voiced out and expressed (Felstiner, Abel, and Sarat 1980). Neveu (2017) interprets the theory of 'social problem' emerged in the early 1970s and started to establish research on the rationale behind the creation of issues among the public and the impacts related to the conception of problems. A public problem is generated when social problems are identified in a political agenda (Lascoumes, Pierre 2012). Public problem, for the most part, holds an unstable nature since the mobilization of people evolved (in thoughts or actions) when it comes to priorities (Lascoumes and Le Galès 2005). In terms of platform used for explanations, in the 1980's Gusfield (1989, 2012) added the description of the ownership of the object of issues and disparity among groups of individuals able to voice out in the public arena, is sometimes undertaken as an opposition between a moral conflict or politics.

Steyaert *et al.* (2007) enquired on the implementation of natural resources management policy using a collaborative knowledge sharing between various identified individuals, namely practitioners, including researchers. The involvement of a panel in decision making process has demonstrated the ethical dilemma posed by the classical biological researchers. In the case study of the amendment of the European environmental policy called Natural 2000 on wetlands biodiversity richness, comprising the involvement of researchers on the biological aspect. The latter could weakly resolve the issue on how to recreate the bond between human activities and nature conservation. This limitation of classical biological researchers in the field of social science generated a gap in the understanding of the involvement of individuals in natural resources management. Based on Quéré (2012), we considered that unplanned social matters usually arose requiring to make clear that the initial environmental problem by providing more clarifications to the general public with the consequential reaction of disputes. Quéré (2012) explained through an environmental issue in the form of invasive algae releasing toxic gases has generated opposing views from the farmers, researchers, local authorities and the non-governmental organisations against the use of pesticides. Furthermore, the problem formulated around the domestication of the scallops in St-Brieuc Bay (France), following the decrease in local scallops, brought about a framework developed by Michel Callon (1984) on the mandate of the researchers in trying to find a solution in the artificial rearing of scallops and the attachment of fishermen to continue to fish scallops. The researchers were inexperienced in the domestication of scallops while fishermen were in need of scallops to pursue their work. Similarly, novel approach undertaken by researchers in using biological control programme of *R. alceifolius* by selecting a peculiar and innovative biological control agent *Cibdela janthina* could bring about controversies among the local populations.

From a social problem to a public problem in Réunion Island

A social problem was generated when a group of beekeepers advocated against the introduction of a biocontrol agent in Réunion Island. The management and control of an invasive plant in Réunion island has been the main focus of the French authorities and managers in the early 2000 following few decades of mechanical and chemical control and later the use of a biological control agent in 2008. However, beekeepers found a decrease in the production of honey due to the biological control of *R. alceifolius* since the beekeepers considered *R. alceifolius* as a resource for bees. The main honey production is from the Brazilian pepper tree, litchi and forest trees (Esnault et al. 2014). Following the biological control programme, the beekeepers expressed their concern on the control agent *C. janthina*

interacting with bees and the reduction of *R. alceifolius.* Beekeepers claimed a reduction of honey production since the bees feed on *R. alceifolius* during the winter season. The sudden control of the invasive *R. alceifolius,* with the introduction of a biological control agent, created an imbalance in the production of honey according to the professional beekeepers.
For the case of the biological control programme of *R. alceifolius*, in Réunion Island, the use of biological control over mechanical control was the entire making of the French authorities along with the research centre and hasn't been a request of the local community. The beekeepers declared the control of *R. alceifolius* as a fault of the research centre and the French authorities. The use of biological control for *R. alceifolius* without the implication of beekeepers created a feeling of discontentment among the beekeepers against the local authorities and the research centre. The public did not receive any information upon the use of a phytophagous insect to feed on *R. alceifolius* and reacted sharply to its sudden appearance. The metallic blue colour of the control agent pullulated and was therefore visible to the general public in Réunion island. Another delicate circumstance was the fact that the beekeepers went into court against the local authorities and the research centre to claim for their loss in honey production due to the biological control of *R. alceifolius* and the introduction of *C. janthina* as control agent.

The media was a platform used by the beekeepers and the research centre to express their concern and provide with related information by defending their cause. The media was used as a form of public arena where beekeepers, researchers from CIRAD or the local authorities could voice out their opinions and justify their views. The public expressed their opinions through the media to convey their concern to the media and the press was used as a public arena to express their discontentment against a political decision. The press broadcasted headlines with highlights on beekeepers, local authorities and CIRAD's position on the biological control programme, thus exposing to the general public the concern of each parties.

Scope and approach for analysing diverging perceptions

Following a request of the ministry of environment of France to undertake a cost-benefit analysis of the management and control of *R. alceifolius* in Réunion Island, my main mandate was to carry out the evaluation of the different cost incurred for each control method and to evaluate the recolonization of native or non-native species post biological control programme in forest areas. I suggested an additional research chapter to be able to enquire on the perception of local communities following the strong opinions which has been voiced by beekeepers. My tasks were primarily directed towards understanding the problematics behind these contrasting perceptions among the identified groups of individuals.

This supplementary field of research required the use of a reflexive posture in enquiring on contrasting views between the French authorities, the research centre and beekeepers but being based at the research centre. A reflexive posture entails the analysis of the problem by taking no position and working on the objectivity of the problem to be understood. In this study of the biological control of *R. alceifolius,* being based at the research centre, I struggled to adopt a neutral standpoint, by taking into account the positions of the employees of the research centre and transcribing it without generating any discourse through misunderstandings from beekeepers or the research centre. The employees of the research centre had different versions upon the release of the biological control agent and few were reluctant to communicate fully and freely on this subject matter. My role entailed a very close listening while creating a zone of trust for the employees to explain their experience in a social science manner with open-ended answer rather than the typical classical and biological manner using facts. It was a challenging task to be able to bring about a social science approach in a classical biological science work at the research centre. The employees of the research centre found it complicated to describe this court in case since it would be potentially recorded in the study and also show a possible negative representation of the biological control programme. This matter brought before a court would not be discussed in this study since it is targeting the different perception of the biological control programme and derivated problems. Due to these numerous accounts, it was important to remain objective throughout my research work while collecting and analysing data in enquiring on diverging opinions of the management of *R. alceifolius.*

Semi-structured interviews with beekeepers and analysis of media content

Quantitative study is not sufficient to analyse the diverging opinions among the general public and researchers (Selge, Fischer & van der Wal, 2011). A combination of qualitative and quantitative study was necessary, and was imperative to understand the perception of the identified groups, acceptability of management option in invasive species management associated to built-in values that needs to be studied (Selge, Fischer, and van der Wal 2011). Here the regional council, the French Agency for Food, Environmental and Occupational Health & Safety, the ministry of environment, the ministry of agriculture and the forestry services are referred to as “the French authorities”. The researchers are the Centre for Agricultural Research and Development (CIRAD) and few complementary research work by CABI bioscience (none-profit inter-governmental development and information organisation). The beekeepers are professional, semi-professional and amateur. We investigated changes on the perception of beekeepers, the French authorities, the research centre. We initially undertook a quantitative study (n=28) on the principle sources of information and media usage of beekeepers (Annex 4), then undertook semi-structured qualitative study (n=12) among professional beekeepers (Annex 5). We used in-depth semi-structured interviews (Newing 2010) to focus on beekeepers. We also looked into media publications by a qualitative study of headlines and citations with a particular look of the published press articles on the biological control programme of *R. alceifolius.*

It was challenging to be able to adopt a neutral posture being based at the research centre CIRAD and having to objectively analyse the perception of the identified stakeholders and the role of CIRAD as a research centre. My posture has been oriented towards an active listening of the identified stakeholders, while keeping a standpoint, mainly influenced by the directive of CIRAD. It was very straightforward to undertake semi-structured interviews among beekeepers, once the aim of the interview has been explained. It was challenging to obtain a clear story from the colleagues in the research centre (CIRAD) since they had different personal history of the biological control programme and had to keep a diplomatic position. However, the main challenges I encountered was in conveying the importance of a social science analysis to the classical science researchers at CIRAD. I attempted to undertake an analytical perspective of the controversy in the perception of the biological control programme of *R. alceifolius.*

Looking into the problematizations of the biological control programme

In this analysis we first consider a public problem constructed by beekeepers opposed to the research centre (CIRAD) and the French authorities. We designated the public problem here by the beekeepers, who contested against the biological control programme. This initial step was preferred among other choices since the beekeepers have expressed their opinions and took actions which necessitated an in-depth study. The viewpoint of researchers differed from that of beekeepers and a future complementary study would be necessary. Few data were available on the experiences of the researchers of the biocontrol programme. We looked into the discourse generated through diverging or contradictory opinions of beekeepers as opposed to the goal set by the local authorities to undertake a biological control programme. The biological control programme of *R. alceifolius* entailed researchers working classically on biological research who had to deal with unexpected reactions of beekeepers, which necessitated more of a social study. We previously categorised our description of problems by defining the actors, the union and links shared (Callon 2013). We aimed at describing how the beekeepers perceived, and responded to the biological control programme initiated against the IAP *R. alceifolius*.

We selected the analysis devised by Spector and Kitsuse (1973) in which the analysis of social problems to be able to classify social problems corresponding to interactions between the beekeepers with researchers, policy and decision makers. It would allow us to first define the discourse in the form of conflicts due to different opinions and facts. We categorized the social problem of beekeepers which later transformed to a general national public problem in Réunion Island. In this framework, we included the theory of the emergence of the transformation of disputes to describe the actions and responses of the identified stakeholders based on Felstiner, Abel, and Sarat (1980). We considered that we named the issues according to the statement and point of view of the three identified groups of stakeholders. Wolt *et al.,* (2010) explained that problem formulation has been used in environmental risk assessment mainly in the form of questioning the risk in policy, scope and assessment of future problem that might arise. The scope of the study is to determine the impact of such biological control programme and the response of the identified groups of individuals. Neveu (2017) explained that the media could diffuse both a political plan and related tragedies in the case studies of depleting natural resources management. Moreover, we included the highlights of published press articles to express the voice of the identified stakeholders.

We devised our analysis into three steps: in step 1 the group of stakeholders try to proclaim fact(s) considered as being detrimental, by declaring the complaints which encouraged controversy and generating a public/political dispute(s). In this stage we associate the naming of the identified issue by the identified groups of individuals (Felstiner, Abel, and Sarat 1980), with a focus on the description given by the beekeepers. Step 2 involved the claims by the groups showing their resentment with the initiated measures to solve claimed circumstances, the administrative supervision of the grievances, the none-fulfilment of the formation of an environment of trust and assurance in dealing with the actions in line with the grievances. In the final step 3, we constructed the claiming of the group as they requested for change and solutions to the set plan of action from the administrative authorities in charge of their pleas keeping a record of its dramaturgic sense. Based on this first analysis of this controversy, we then examined the rationale behind the formulated problems.

Results and discussions

Factors leading to the controversies

The description and perception of *R. alceifolius* and its biological control agent

The first glimpse of the presence of the biological control agent *C. janthina* was very surprising since they are metallic blue looking sawfly and appeared in numbers. The arrival of such uncommon insect aroused suspicion amongst the local communities. The blue sawfly appeared on its host species *R. alceifolius* as clouds of sawfly, arousing even more distrust amongst the beekeepers. "*…, there was more maroon vine. And there was some sawfly, if you want and there was a moment when… because of the maroon vine, the surfaces were* *hugely covered. So the sawfly had swarms of whole cloud of swarms. When I told you it was impressive, it was impressive!"* (Professional beekeeper, 2017).

The French authorities and the research centre could not have guessed that the introduction of a biological control agent would have resulted in such a sudden reaction from the society. *Rubus alceifolius* is commonly known as "*raisin marron*" by the creole community in Réunion Island, a name which has been transformed into a French related common name in the early 70's to "*la vigne marronne*" with a French pronunciation (Lavergne 1978). The term "*raisin marron*" in Creole mean the maroon vine, an escaped vine proliferating and hiding in the forest to escape from the sabre and the lash. The name denotes the past history of hiding life of escaped communities (Lavergne 1978). These various common names attributed to *Rubus alceifolius* have been highly contested by the local community, in Réunion island, who proclaimed that the local name is indeed "*raisin marron*" and that it has later been transformed by French intellectuals to "*la vigne marronne*". The duality between local communities in French Réunion Island and continental French on various perceptions often pertains including the management of *R. alceifolius.* The propagation of *R. alceifolius,* since its first records around 1850, has been very quick, and the local community has identified the plant for its juicy "wild berries". "*R. alceifolius* has been used by the local community for its fruit and as fodder for bees according to beekeepers. Several beekeepers had the conviction that *R. alceifolius* is a pollineferous and nectariferous resources in strengthening their hives during the winter season "*… for the hive, as soon as the maroon vine bloomed, or, even if one did not produce honey on certain places, the hive was in good health. The maroon vine had honey, the maroon vine had pollen and everything."*

(Professional beekeeper 2017)

A controversy arose amongst the beekeepers who requested a compensation from their loss in honey production to the research centre and the French authorities. The beekeepers were the actors directly involved with the biological control agent *C. janthina* since they were surprised by the clouds of *"blue sawflies"* around their bees during the production of honey from litchi trees. The beekeepers named *C. janthina* as the blue sawfly and proclaimed the appearance of an alien fly as a major catastrophe for the production of honey in 2008 and 2009. The upcoming and creation of social misunderstandings aroused with its arrival, a metallic-blue sawfly defoliating the invasive *R. alceifolius.* This invasive plant occurs in urban areas, agricultural fields and forest areas. The first appearance of the biocontrol agent has immediately created a sense of chaos among the general public. The conflicts were both linked to the presence of the blue sawfly, its omni-presence on nectariferous and pollineferous trees along with honey bees and its perceived impact on the production of honey.

The biological control programme was perceived differently by few beekeepers who were aware of the introduction of the control agent. These members of the beekeepers' syndicate were informed of the biological control but the information was not communicated to other beekeepers. Therefore, most beekeepers have missed the opportunities of being aware of a potential control programme of *R. alceifolius*. According to the professional beekeepers, they have been ignored prior to the process of introducing *C. janthina*. They have subsequently enrolled the beekeepers syndicate, and have defended their position in this public arena in the management of *R. alceifolius*. They later joined the syndicate of beekeepers named the Apicultural Syndicate of La Réunion (SAR) and Association for the development of beekeeping (ADAR) to be able to voice out their opinion and concern about their loss in honey production. As a response to this problem formulated, the beekeepers have understood the empirical voice of an institution that enabled them to be upfront along with other institutions in any decision-making process that are directly or indirectly related to honey production in Réunion island.

Honey yield in Réunion Island

Following the release of the biological control agent, the media have published headlines about the control agent and its visible presence. The key messages broadcasted by the media have aroused deep fear nourished by the fact that the honey production had decreased and blamed CIRAD for its release. The newspapers published the claims of the beekeepers that the high reduction of honey production was linked to the presence of the biological control agent. The beekeepers explained that they experienced a period of drastic decrease in honey "*the sharp decline in honey production in 2009…*" (Le Quotidien de la Réunion 30/01/2010). The honey production has decreased two years following the biocontrol programme creating a sense of havoc among honey producers. The beekeepers believed that the decrease in honey production was linked to the introduction of the blue sawfly. It was understood that the blue sawfly was feeding on the nectar of litchi and Brazilian pepper tree, leaving few resources for the bee to pollinate these plants *"the pollination of the flowers is threatened…" (*Le Journal de l'Île, 04/09/2009)

"In this plant that produces nectar, it was a significant percentage of production in the eastern region of the island. But above all, it is a plant that flowers in offseason between the Brazilian pepper tree and litchi. It allowed us to prepare the honey of litchi and Brazilian pepper tree honey. The disappearance of the vigne marronne compelled beekeepers in the east to feed their bees. Artificially feeding hives will never replace natural nectar and natural pollen. With that regard, there is already a prejudice". (Professional Beekeeper 2017).

A researcher from the CIRAD showed that the pollination of bees was ongoing in the presence of the blue sawfly. The CIRAD undertook research and found that the decrease in honey yield was not linked to the presence of *C. janthina* but most probably to irregular climatic variations (Reynaud et al. 2010). The report also indicated that there was no decrease in resources for honey bees (Reynaud et al. 2010). However the risk analysis preliminary report mentioned that *R. alceifolius* is a pollineferous plant (Le Bourgeois 1997). In general, few studies of risk analysis assessment have been undertaken on the effect of biotic factors in the production of honey such as pollen or nectar as food sources or competition with other species (Boivin et al. 2006). The interactions of the blue sawfly *C. janthina* with honey bees on nectariferous and pollineferous trees, haven't been included on the risk analysis of *C. janthina.* According to the researchers, the biological control agent is not responsible for the loss of honey production (Reynaud et al. 2010). From the perspective of the beekeepers, the researchers are responsible for the loss of honey production due to the introduction of *C. janthina* competing with honey bees. This dichotomy between the researchers and beekeepers on the reason behind the reduction in honey production created a perpetual conflict between the two groups of stakeholders.

The impact of the media as a public arena

The results of our quantitative study showed that the media was an important mean of communication for the professional beekeepers. The beekeepers were asked by which mean of communication they heard about the blue sawfly and the majority answered "*But it was mostly by the press*". The quantitative study showed that over (n=28), 82% respondents got informed mainly by the media. The quantitative study disclosed that 82% of beekeepers were informed by the media and according to the qualitative study since most beekeepers did not receive any information regarding the blue sawfly prior to its release.

The preliminary stories covered by the news headlines were against the biological control agent "*The blue sawfly, the pet hate of beekeepers*" (Liberation 18/09/2009). The general public heard of *C. janthina* via the media through striking headlines. The press described the introduction of the blue sawfly as an "*ecological catastrophe with irreversible consequences*" (Philipe Madubost, Le Journal de l'Île, 02/09/2009).

The local press expressed the interest of the beekeepers disapproving the biocontrol agent and named the problem "*The blue sawfly: the beekeepers condemn a state scandal"* (Jérôme Talpin, Journal de l'Île, 02/09/2009). Several newspapers published headlines providing with journalists' opinion on the biological control agent. The destruction of *R. alceifolius,* considered as a local plant named "*raisin marron*" by the communities, created a reaction among the public. Journalists have also articulated their views about the discontentment by groups of individuals around the biological control agent *"Réunion Island is experiencing a tragedy. Introduced in December 2006 in our island, the blue sawfly is provoking damages"* (Manuel Marchal, Le Témoignage, 14/08/2009). The local press accused the authorities and research centre for bringing an alien species to eradicate *R. alceifolius,* perceived as being a "*local plant*" according to the public (Jérôme Talpin, Journal de l'Île, 02/09/2009). The general public identified *R. alceifolius,* as a common plant in Réunion Island, which was not in need of control due to invasion. On the other hand, the blue sawfly was described as an introduced and "*alien*" species in Réunion island which is causing disturbance against *R. alceifolius*. The local press was used as a platform by the 3 groups of identified individuals, and here the beekeepers expressed their concern about this newly introduced biological control agent, the blue sawfly.

The local press created discontentment among the beekeepers, as they felt negligence on behalf of the state towards their profession. The local press displayed a headline explaining that the biological programme funded by the French authorities as being a loss, "*A waste of public money"* (Le Journal de l'Île, 02/09/2009). "*The state decided to introduce the blue sawfly without any consultation… condemned the beekeepers*" (Jérôme Talpin, Journal de l'Île, 02/09/2009). "*The* CIRAD *tested under a greenhouse and showed that there is no interaction between the bees and the blue sawfly*…" (Le Quotidien de la Réunion 09/10/2009). The press published according to the point of view of the beekeepers "*the chamber of agriculture has been accused of being in cahoots with the administrative authorities' in granting permission to release the biological control agent*".

The President of the chamber of agriculture replied through the press: "*The Chamber of Agriculture has been present at almost all meetings and press conferences organized by the apicultural trade union (ADAR*) …" "As *for beekeepers, I just want to remind them that: The Chamber of Agriculture was the first to call on the authorities with regards to the release this fly."* (Jean-Yves Minatchy, Clicanoo, 30/10/2009).

A few years later, the key messages released by the press were in favour of the biological control agent *"The blue sawfly, more fear than harm"* (Le Quotidien de la Réunion 25/06/2013). The blue sawfly here appeared to be an icon with a past representation of fear amongst the beekeepers. The control agent now was later considered by the press as a positive control programme for the invasive *R. alceifolius.*

Moving from a social problem to a public problem

The reaction of the beekeepers with the naming, blaming and claiming of the situation

The beekeepers' requested for support from the syndicate of beekeepers (SAR) and the newly established Association for the development of beekeeping (ADAR). Moreover, the first naming of the problem was undertaken by the beekeepers and were carried out in the form of complaints. The protests usually arise from an organization with social workers or any related field and groups of the same field, who might have taken the initiative for their own interest. In Réunion island, the beekeepers found a weakness in their representation amongst the governmental institutions. The beekeepers opted for the support of the SAR that would potentially back-up their grievances and support their voices during meetings with the local authorities and the governmental institutions.

The close collaboration of beekeepers resulted into an instrument of power, as the actors were part of the public. Various forms of rallying are required to stand up to fight the cause of the needy and the beekeepers reinforced their cause by setting up the ADAR. *"We had taken a little control of the sector and we had created the ADAR, the association of professionals…around 2009-2010".* (Professional beekeeper 2017)

The blaming of the French authorities by the beekeepers

In the process of homologating the biological control agent, several institutions, amongst the French authorities, were involved and the Chamber of Agriculture was included in the scientific committee meeting prior to the release of *C. janthina.* In this process, the Chamber of Agriculture were representing the beekeepers, but the beekeepers were not informed of such biological programme by the chamber of agriculture. It seemed that a top-down approach has been carried out by the chamber of agriculture during the decision-making process of the homologation of *C. janthina*. The beekeepers later investigated on the decision process of the homologation of *C. janthina*. They were disappointed to learn that they had been represented by the Chamber of Agriculture who provided a positive agreement to release the biological control agent. The beekeepers were represented by few members of the Chamber of Agriculture and perhaps by the beekeepers' syndicate or association but the key information regarding the implementation of the biological control agent were not shared with the majority of beekeepers. They felt excluded in the process.

The beekeepers wondered whether the impact assessment prior to the release of the biological control agent had been undertaken following the norms in place "*I saw the experimentation protocol … It is absurd…*" The voice of the beekeepers was heard by the local media, creating a misunderstanding on the island. The local press also commented and criticised the experimentation protocol of the research centre through the headlines "*The CIRAD and the state in their collimator*" (Le Journal de l'Île, 04/09/2009).

The local government failed to tackle the situation around the decrease in honey production and the misperception of the blue sawfly. According to beekeepers, a solution in this controversy is to look towards the preliminary objectives of the local government, "*Well, my experience, if you want, is that you have to ... (hesitates) It's not really up to me to have that experience. Because, in the end, it is the state too that you have to see…*" (Professional beekeeper 2017). The French authorities had an environmental agenda in favour of the control of invasive species. This political agenda has been set up with a financial perspective in order to minimise the various costs of control, within which biological control has been opted for *R. alceifolius*.

Moreover, the public arena had diverging point of views at the inception of the release of the biological control *C. janthina*. "*I know that it is a fly which comes from Asian countries, we brought it here to pretend to eradicate a plant and pest which we call the marron vine…but I don't think if it is a benefit or not but from my point of view it is not a good thing that they did, to bring this pest over here*" (Professional beekeeper 2017). The beekeepers imputed the researchers and the government for bringing an alien species that destroys their natural and cultural heritage as well as impacting on their revenue. They pictured the scientist as the "creator" of the blue sawfly and blamed them for their loss. The beekeepers claimed that the research centre had no right to introduce an alien species that would be responsible for the loss of honey yield. "*We even asked ourselves it didn't come from the laboratory? What did they do in the laboratory*? … *The first laboratory studies were botched and the outdoor trials were botched*." (Professional beekeeper 2017). The beekeepers have an iconic idea of the research centre as being the sole responsible party in the introduction of the biological control agent.

A retrospection on the chikungunya crisis

According to beekeepers, the production of honey was dramatically reduced. The beekeepers remembered the very recent proliferation of the virus *Chikungunya* transmitted to the population by infected mosquitoes and caused death among the local population. The government undertook an island-wide campaign to exterminate the mosquitoes by using strong insecticides in 2005-2006 (Flahault et al. 2007). The beekeepers saw a side effect of the use of the pesticides and the decline in bee population. They were worried and alarmed the government to notify them prior to any future vaporization of insecticides to be able to take preliminary precaution in protecting their hives. Following the Chikungunya phase, from the perspective of the beekeepers, the latter were very aggrieved to know that the government once more undertook a decision related to bees according to them, but without provision of information. "*During the massive application of insecticides that was a weak selection for fighting mosquitoes during the chikungunya period, the bees had already had to endured early problems of a method that did not take into account the fragility of our biodiversity.*" (Manuel Marchal, Le Témoignage, 14/08/2009). *"Afterwards, it is above all a moral prejudice. Indeed, after the chikungunya crisis in 2006, treatments had destroyed a large part of their hives. The state had promised them that it would not happen again, that the beekeepers would be informed next time."* (Professional beekeeper 2017). *"We have not been informed. Personally I have not been informed about anything on the introduction of this blue sawfly. I discovered about it live in the field"* (Professional beekeeper 2017).

Moon, Blackman, and Brewer (2015), explained that in the process of devising policies against eradication policies, the opinion of scientists were that local communities should help and support the local government in the management and control. This case-study demonstrated that the involvement of stakeholders was essential to be able to undertake a successful control programme. Opposingly, the scenario of policy-making in the selection of the use of pesticides to combat mosquitoes by policy-makers in Réunion Island without including the beekeepers made them feel underprivileged in the process. The previous experience of insecticides used to control mosquitoes which also, according to beekeepers, affected their hives, forged mistrust towards the local authorities. *"Because there is an* *introduction like that of insects or plants, or something else, you really need everybody, we should be involved directly or indirectly in this matter, if I can…we should all be summoned around a table to discuss that. To see, to weigh the pros and cons!"* (Professional beekeeper 2017). They blamed the CIRAD and the blue sawfly as the main cause of their loss in honey production and loss of revenue.

The claiming of beekeepers in their representativeness during decision-making

The lack of involvement of beekeepers during the decision process prior to the release of the biological control programme was claimed by the beekeepers. The governmental structure, responded by establishing a compensation scheme against the loss of honey yield from 2009 to 2014. The loss of honey production, the presence of the biocontrol agent and the sensational news headlines gave rise to a feeling of mistrust and suspicion towards the French authorities and the researchers as the only information available during the crisis on the blue sawfly was by the local press. The beekeepers held accountable the French authorities (the regional council, the French Agency for Food, Environmental and Occupational Health & Safety, the ministry of environment, the ministry of agriculture and the forestry services are referred), on the mean of control of invasive species as they no trust in the French authorities.

"Before I trusted biological control, now I'm wary of biological control as well as chemical control…" (Professional beekeeper 2017). The members of the beekeepers' syndicate often have to face misunderstandings prevailing from diverging opinions. *"The only problem is the syndicate who is putting a spoke on our wheels. They want to lead, they are incompetent and they decide everything, they themselves are the biggest problem."* (Professional beekeeper 2017). A contingency among professional beekeepers appeared, whereby those who were in

favor of research work on the decrease of honey yield were in contradictions with the majority who wanted to continue to strike against the French authorities and the research centre to obtain justice for their loss and recognition from the local authorities for the honey sector. A disagreement between the heads of the organization resulted in the dismissal, against the willingness, of those working in collaboration with beekeepers to find the truth. *"We created the ADAR and from one day to the next, we were expelled from the ADAR and we were expelled from the syndicate."* (Professional beekeeper 2017). Few beekeepers who were pro-research wanted to save a common cause but the main concern of the majority of the beekeepers outnumbered their principles. The majority of beekeepers were against the setting-up of a collaboration with the researchers, considered as being a betrayal.

"*Well now I've moved on, I'm not interested, the damage is already done. We as beekeepers have to find other ways to get by. We have more work to do. I found the solution. But some beekeepers have not found the solution it always goes through nourishment. Me what I do I will work in the forest. Many in the forest. And I deserted the coast because there are no more maroon vines, I know that the bees will suffer a lot. And what is that? I found this solution I touch wood it works. After you have to have the courage to move hives. It gave us more work. To have honey now you have to work four times more. Otherwise there are no results*" (Professional beekeeper 2017). Some beekeepers had to change their technical practice and were forced upon feeding their hives. Others, were compelled to carry out the transhumance of their hives which necessitated great effort. The members of the syndicate complained to the state for their loss of production and later claimed subsidies as compensation "*…expected a compensation of 115 euros per hives…*" published by the newspapers (Laurent Decloitre, Liberation, 18/09/09).

The words used in the media exposed the sentiments and emotions of the group of individuals. The beekeepers expressed their emotions towards their non-involvement in the protocol of controlling *R. alceifolius* and took actions for their lost. "*We had meetings, vis-à-vis the prefecture, the region, the General Council, the Department of agriculture, we were going to complain about them, there was even a day of protest, we brought a hive up there to tell them that it's not right, things are missing here. It's the fact that it's been so brutal that everyone has reacted…*" (Professional beekeeper 2017). Similarly, the beekeepers went into court against the research centre and the French authorities to request for compensation from their lost in honey production. They were later provided with allowances and sugar to feed the honeybees by the French authorities.

The way forward

Nine years after the release of the blue sawfly and the disputes, few beekeepers are collaborating with CIRAD for research on the content of their honey. The beekeepers have moved on the conflicts on the biological control of *R. alceifolius*, and have evolved towards new perspectives.

"*by working with CIRAD, we can better know our honey is* …" (Professional beekeeper 2017)

The beekeepers still produce honey from endemic species in forest areas where there used to be invasive Rubus.

"Now we have honey from Bois de Jolicoeur which is also an endemic plant and is medicinal", "we have an endemic forest with medicinal plants and as a matter of fact the honey has medicinal virtues…" (Professional beekeeper 2017). Few beekeepers believe in the

importance of replanting endemic nectariferous and pollineferous trees post control of *R. alceifolius*. *"We worked on it, with ADAR, the ONF (forestry services), to see what we can put in place of the brown grapes. Indeed, the marron vine was a constraint, but it was necessary to try at that time, to replace this constraint by two opportunities. First, we know the unemployment rate on the island. Give work to people, and it's feasible to do mechanical work. The second opportunity was to replant. We remove and immediately we put something else in the place. It was not done. After the fact, studies were done to try to restore but it takes a lot of work and money to do it. Moreover, the ONF did a study on ... where they have, on a plot of a little over half a hectare ... it works well, but it has a cost…La Liane papillion and other plants are now invading, and they are killing endemic melliferous plants…"* (Professional beekeeper 2017). The beekeeper at the head of the beekeepers' syndicate provided recommendations in terms of biodiversity conservation indicating that the forestry services should undertake more restoration of endemic plants post control of invasive plants. However, a lack of funding is restraining the restoration work by the forestry services. *"Before starting to control, we must preserve, we must protect; and that unfortunately, it is not always well done. For example, we forbid a passenger with seeds on the island, but we allow horticulturists, or massive imports of plants on the territory. I think that…often ornamental species which have been introduced legally"* (Professional beekeepers 2017). The biosecurity measures in Réunion island contains gap in law enforcement and in awareness. It is imperative for the French authorities to take action amongst horticulturists in awareness raising and giving penalties.

The beekeepers later received allowances for sugar as a compensation for fodder for honeybees from the French authorities. Moreover, the professional beekeepers received supplementary funding to help to develop the honey sector. They were also granted access for the transhumance of their hives in the National Park. Few beekeepers have branded their honey from the National Park, an added value for developing the honey sector. The benefits provided to the beekeepers by the French authorities increased their visibility upon the honey sector in Réunion Island.

The importance of understanding public problems

The involvement of stakeholders in each step of strategic decisions in the management of invasive species is necessary (Chapter 5). The novel form of social response to the formulated problem is to bring reform to the social construct by the setting-up of a formal institution that could be identified and seen within the public arena and in the future. The inclusion of the general public during scientific decisions are undertaken, it should be in an explicit and transparent manner. Simberloff (2013) investigated the impact of biological invasions highly recommended the impact of public perception is taken into consideration in the management of invasive species. Existing research work on disputes have shown that the gaps in management of invasive species entailed a study of the importance to engage stakeholders during any decision making process. The benefits or inconveniences directly or indirectly impacting on the invasive species have to be identified and measured. The process put in place should include such measures with the identification of key stakeholders amongst the civil society. The social construct of the society related to the invasive species have to be studied, along with the study of practices of beneficiaries. This would enable to better recognize perception attached to the invasive species from various standpoints, researchers, the government, the institutions, the practitioners, syndicates and the society. There is a supplementary need to look into the policy framework related to a biological control programme to analyses any existing gaps in the process of importing a control agent till its release. The analysis of the policy framework should also look into the involvement of stakeholders (Annex 3).

The actors and the links related to the perception of the formulated problem

We oriented our understanding of stakeholders towards the notion of public arena without manipulating the cognitive and normative meaning of their perception enabling the recognition of the practicality of the role of stakeholders (Cefaï 1996). The main social actors involved in this dispute are the beekeepers, the bees, the blue sawfly, the French research Centre (CIRAD), the French State and the media. Each stakeholder had a specific point of view of the outcome of the biological control programme.

The beekeepers were the actors directly involved with *C. janthina* since they were surprised by the clouds of *"blue sawflies"* around their bees during the production of honey from litchi trees. The beekeepers named *C. janthina* as the blue sawfly and proclaimed the appearance of an alien fly as a major catastrophe for the production of honey in 2008.

The impact of the media

The results of our qualitative study showed that the media is an important mean of communication for the professional beekeepers. The beekeepers where asked by which mean of communication they heard about the blue sawfly and the majority answered "*But it was mostly by the press*". The qualitative study showed that over (n=28), 82% respondents got informed mainly by the media.

The stories covered by the news headlines were against the biological control agent "*The blue sawfly, the pet hate of beekeepers*" (Liberation 18/09/2009). The general public heard of *C. janthina* via the media through striking headlines. The local syndicate in Réunion Island described the introduction of the blue sawfly as an "*ecological catastrophe with irreversible consequences*" (Philipe Madubost, Le Journal de l'Île, 02/09/2009).

The local press accused the state and research centre for bringing an alien species to eradicate *R. alceifolius*, perceived as being a "*local plant*" according to the public (Jérôme Talpin, Journal de l'Île, 02/09/2009). The blue sawfly had thus been identified as an object of dispute by the local press and the beekeepers.

The naming of the blue sawfly is indistinctly related to the naming of the problem

The beekeepers expressed their disapproval of the biocontrol agent and named the problem "*The blue sawfly: the beekeepers condemn a state scandal"* (Jérôme Talpin, Journal de l'Île, 02/09/2009).

The destruction of *R. alceifolius*, considered as a common property by the communities, created a reaction among the public.

"Réunion Island is experiencing a tragedy. Introduced in December 2006 in our island, the blue sawfly is provoking damages" (Manuel Marchal, Le Témoignage, 14/08/2009).

The biological control agent *C. janthina*, a sawfly commonly called "*la mouche bleue*" for the "blue sawfly" is a highly controversial story in the management of an IAP in Réunion Island. The controversy is around the introduction of the blue sawfly, an exotic species from the perspective of the local community in Réunion Island. The blue sawfly could be seen everywhere. The upcoming and creation of social misunderstandings aroused with its arrival, a metallic-blue sawfly defoliating the invasive *R. alceifolius.* This invasive plant occurs in urban areas, agricultural fields and forest areas. The first appearance of the biocontrol agent has immediately created a sense of chaos among the general public.

The description and perception of *Rubus alceifolius*

"…, there was more maroon vine. And there was some sawfly. if you want and there was a moment when… because of the maroon vine, the surfaces were hugely covered. So the sawfly had swarms of whole cloud of swarms. When I told you it was impressive, it was impressive!" (Professional beekeeper, 2017)

The French state and the research centre could not have guessed that the introduction of a biological control agent would have resulted in such a sudden reaction from the society. *Rubus alceifolius* is commonly known as "*raisin marron*" by the creole community in Réunion Island, a name which has been transformed into a French related common name in the early 70's to "*la vigne marronne*" with a French pronunciation (Lavergne 1978). The term "*rézin maron*" in Creole mean the maroon vine, an escaped vine proliferating and hiding in the forest to escape from the sabre and the lash. The name denotes the past history of hiding life of escaped communities (Lavergne & Honoré 2015). The propagation of *R. alceifolius*, since its arrival around 1850, has been very quick, and the local community has identified the plant for its juicy "wild berries". "*R. alceifolius* has been used by the local community for its fruit and as fodder for bees by beekeepers.

"… for the hive, as soon as the maroon vine bloomed, or, even if one did not produce honey on certain places, the hive was in good health. The maroon vine had honey, the maroon vine had pollen and everything." (Professional beekeeper 2017).

Honey yield in Réunion Island

The key messages broadcasted by the media have aroused deep fear nourished by the fact that the honey production had decreased. They named the *C. janthina* as the blue sawfly and blamed CIRAD for its release. The news linked the high reduction of honey production to the presence of the biological control agent, which was stated to have a main role to play in this issue "*the sharp decline in honey production in 2009…*" (Le Quotidien de la Réunion 30/01/2010). The honey yield has decreased two years following the biocontrol programme creating a sense of havoc among honey producers. The beekeepers believed that the decrease in honey yield was linked to the introduction of the blue sawfly. It was understood that the blue sawfly was feeding on the nectar of litchi and Brazilian pepper tree, leaving few resources for the bee to pollinate these plants *"the pollination of the flowers is threatened…" (*Le Journal de l'Île, 04/09/2009)

"In this plant that produces nectar, it was a significant percentage of production in the eastern region of the island. But above all, it is a plant that flowers in offseason between the Brazilian pepper tree and litchi. It allowed us to prepare the honey of litchi and Brazilian pepper tree honey. The disappearance of the vigne marronne compelled beekeepers in the east to feed their bees. Artificially feeding hives will never replace natural nectar and natural pollen. With that regard, there is already a prejudice". (Professional Beekeeper 2017)

A researcher from the CIRAD showed that the pollination of bees was ongoing in the presence of the blue sawfly. The CIRAD undertook research and found that the decrease in honey yield was not linked to the presence of *C. janthina* but most probable to irregular climatic changes.

The reaction of the beekeepers following the arrival of the blue sawfly

For the case of the semi-professional and professional beekeepers, they responded quickly and organized a meeting within their organizations. The beekeepers' set-up the syndicate of beekeepers named the Apicultural Syndicate of La Réunion (SAR) and Association for the development of beekeeping (ADAR). Spector and Kitsuse (1973) explained in the case of naming of an issue, through the a weakness of a welfare system which resulted in a loss of trust from its beneficiaries. Moreover, complaints usually arise from an organization with social workers or any related field and groups of the same field, who might take the initiative for their own interest.

The close collaboration of beekeepers building strength resulted into an instrument of power, as the actors were part of the public (Lascoumes & Le Galès 2005). Various forms of rallying are required to stand up to fight the cause of the needy (Lascoumes 2012) and the beekeepers reinforced their cause by setting up the ADAR.

"we had taken a little control of the sector and we had created the ADAR, the association of professionals…around 2009-2010". (Professional beekeeper 2017)

"The blue sawfly case is now in the hands of the administrative court" (Le Journal de l'Île, 04/09/2009).

The blaming of the French authorities by the beekeepers

The public arena had diverging point of views at the inception of the release of the biological control *C. janthina.*

"*I know that it is a fly which comes from Asian countries, we brought it here to pretend to eradicate a plant and pest which we call the marron vine…but I don't think if it is a benefit or not but from my point of view it is not a good thing that they did, to bring this pest over here"* (Professional beekeeper)

*The state decided to introduce the blue sawfly without any consultation… condemned the beekeepers***"** (Jérôme Talpin, Journal de l'Île, 02/09/2009). The local press created discontentment among the beekeepers, as they felt negligence on behalf of the state towards their profession. The local press displayed a headline explaining that the biological programme funded by the state as being a loss, "*A waste of public money"* (Le Journal de l'Île, 02/09/2009).

"*The* CIRAD *tested under a greenhouse and showed that there is no interaction between the bees and the blue sawfly*…" (Le Quotidien de la Réunion 09/10/2009).

The press published according to the point of view of the beekeepers "*the chamber of agriculture has been accused of being in cahoots with the administrative authorities' in granting permission to release the biological control agent*".

The President of the chamber of agriculture replied through the press:

"*The Chamber of Agriculture has been present at almost all meetings and press conferences organized by the apicultural trade union (ADAR*) …" and

"As *for beekeepers, I just want to remind them that: The Chamber of Agriculture was the first to call on the authorities with regards to the release this fly."* (Jean-Yves Minatchy, Clicanoo, 30/10/2009).

In the process of homologating the biological control agent, several institutions, amongst the French state, was involved and the Chamber of Agriculture was included in the scientific committee meeting prior to the release of *C. janthina.* In this process, the Chamber of Agriculture were representing the beekeepers, but the beekeepers was not informed of such biological programme by the chamber of agriculture. It seemed that a top-down approach has been carried out by the chamber of agriculture during the decision-making process of the homologation of *C. janthina* (Cybèle et al. 2018, unpublished data). The beekeepers have investigated on the decision process of the homologation of *C. janthina*. They were disappointed to learn that they had been represented by the Chamber of Agriculture who provided a positive agreement to release the biological control agent.

The beekeepers imputed the researchers and the government for bringing an alien species that is destroying their natural and cultural heritage as well as impacting on their revenue. They pictured the scientist as the "creator" of the blue sawfly and blaming them for their loss. The beekeepers exclaimed that the research centre had no right to introduce an alien species that would be responsible for the loss of honey yield.

"*We even asked ourselves it didn't come from the laboratory? What did they do in the laboratory*? … *The first laboratory studies were botched and the outdoor trials were botched*." (Professional beekeeper 2017). The beekeepers have an iconic idea of the research centre as being the sole responsible party in the introduction of the biological control agent. They felt excluded in the process.

The beekeepers wondered whether the impact assessment prior to the release of the biological control agent has been undertaken following the norms in place "*I saw the experimentation protocol … It is absurd…*" The voice of the beekeepers was heard by the local media, creating havoc in the island. "*The CIRAD and the state in their collimator*" (Le Journal de l'Île, 04/09/2009).

The local government failed to tackle the situation around the decrease in production of honey and the misperception of the blue sawfly. According to the beekeeper, we should look towards the preliminary objectives of the local government, "*Well, my experience, if you want, is that you have to ... (hesitates) It's not really up to me to have that experience. Because, in the end, it is the state too that you have to see*…" (Professional beekeeper 2017).

The words used in the media guided the intellect of the reader towards its sentiments and emotions (Quéré 2012). In the dispute entitled the "*green tide"*, in Quéré (2012), due to an invasion of an algae, thought to be the result of the excess use of pesticides by farmers (allowed by the government). The stakeholders looked like a victim as some had lost a member of their families or have witnessed the death of animals due to toxic gases released by the invasive algae. This aroused a thorough clash among various group against the researchers, the state and the farmers. The predominance and repetition of conflicts with emotions draws a parallel between the disputes in the (invasion of algae), the “green belt” and that of the beekeepers oriented towards an environment of fear, anger, guilt and victim. Similarly, the beekeepers expressed their emotions towards their non-involvement in the protocol of controlling *R. alceifolius*.

“We had meetings, vis-à-vis the prefecture, the region, the General Council, the Department of agriculture, we were going to complain about them, there was even a day of protest, we brought a hive up there to tell them that it's not right, things are missing here. It's the fact that it's been so brutal that everyone has reacted.” (Professional beekeeper 2017)

A retrospection on the *Chikungunya* crisis

“*During the massive application of insecticides that was a weak selection for fighting mosquitoes during the chikungunya period, the bees had already had to endured early problems of a method that did not take into account the fragility of our biodiversity*.” (Manuel Marchal, Le Témoignage, 14/08/2009).

From the perspective of the beekeepers, the production of honey was dramatically reduced. The beekeepers remembered the very recent proliferation of the virus Chikungunya transmitted by mosquitoes and caused death among the local population. The government undertook an island-wide campaign to exterminate the mosquitoes by using strong insecticides in 2005-2006 (Flahaut et al. 2007). The beekeepers saw a side effect of the use of the pesticides and the decline in bee population. They were worried and alarmed the government to notify them prior to any vaporization of insecticides to be able to take preliminary precaution in protecting their hives. Following the Chikungunya phase, from the perspective of the beekeepers, the latter were very aggrieved to know that the government once more undertook a decision related to bees according to them, but without provision of information.

"*Afterwards, it is above all a moral prejudice". Indeed, after the chikungunya crisis in 2006, treatments had destroyed a large part of their hives. The state had promised them that it would not happen again, that the beekeepers would be informed next time*." (Professional beekeeper 2017)

Our society has a common belief system which tolerates the elucidation of what is explained and not what is unexplainable (Goffman 1991).

"*We have not been informed. Personally I have not been informed about anything on the introduction of this blue sawfly. I discovered about it live in the field*". (Professional beekeeper 2017)

The beekeepers were not informed about the introduction of the biological control agent and discovered it while working. Moon, Blackman, and Brewer (2015), explained that in the process of devising policies against eradication policies, the opinion of scientists were that local communities should help and support the local government in the management and control. This case-study demonstrated that the involvement of stakeholders was essential to be able to undertake a successful control programme. Opposingly, the scenario of policy-making in the selection of the use of pesticides to combat mosquitoes by policy-makers in Réunion Island without including the beekeepers made them feel underprivileged in the process. The involvement of stakeholders in each step of strategic decisions in the management of invasive species is necessary (Novoa et al. 2018). The previous experience of insecticides used to control mosquitoes which also, according to beekeepers, affected their hives, forged mistrust towards the local authorities.

"*Because there is an introduction like that of insects or plants, or something else, you really need everybody, we should be involved directly or indirectly in this matter, if I can…we should all be summoned around a table to discuss that. To see, to weigh the pros and cons!*" (Professional beekeeper 2017). They blamed the CIRAD and the blue sawfly as the main cause of their loss in honey yield and loss of revenue. Moreover, the analysis by the word-mapping based on the node entitled "beekeepers", the key cluster of words is; denounce, tribunal, recognize, mistake, loss and future

"*it was sad what to see all the blue sawfly…, at a certain moment, so they were many, they even managed to get into the hives, to take the nectar and the bees had nothing to eat because that they were also going on flowers to bite the nectar…there was an impoverishment of our hives*". (Professional beekeeper 2017). The beekeepers' strike against CIRAD received a high media coverage, leading to the diffusion of uncontrolled messages on the biological control agent and the research Centre. The "semi-professional beekeeper" have at least 60 hives declared to the state institutions, and in the case of the Réunion Island, the chamber of agriculture.

The claiming of discontentment of beekeepers

The governmental structure, responded by establishing a compensation scheme against the loss of honey yield from 2009 to 2014. The key linkages between the loss of honey yield, the presence of the biocontrol agent and the sensational news headlines gave rise to a feeling of mistrust and suspicion towards the state and the researchers as the only information available during the crisis on the blue sawfly was by the local press. The beekeepers held accountable the local authorities on the mean of control of invasive species as they no longer know what or whom to trust.

"Before I trusted biological control, now I'm wary of biological control as well as chemical control." (Professional beekeeper 2017)

The members of the beekeepers' syndicate often have to face misunderstandings prevailing from diverging opinions.

"The only problem is the syndicate who are putting a spoke on our wheels. They want to lead, they are incompetent and it is them who decide everything, they themselves are the biggest problem." (Professional beekeeper 2017)

A contradictory version of the decrease in honey yield during the biological control programme was experienced by some beekeepers who followed the introduction of the control agent. They were aware of the biocontrol programme as a representative of the beekeepers' syndicate and reported to their colleagues but the latter did not consider such information as being valid.

"I was doing a lot of meetings with CIRAD from whom I heard about that. Well, I warned the syndicate, but they did not move because they had predicted it would not be more than six hundred meters." (Professional beekeeper 2017)

Another beekeeper, considered as a leader to defend the cause of beekeeping wanted to understand, through research work, the interaction between the biological control agent with the bees. A moral entrepreneur is considered as someone who takes the lead in finding a solution for an issue as part of a group or community (RED). The moral entrepreneur collaborated with the researchers but was expelled from the syndicate and association. (perceived as a traitor for collaborating with the research centre).

"we created the ADAR and from one day to the next, we were expelled from the ADAR and we were expelled from the syndicate." (Professional beekeeper 2017)

A contingency among professional beekeepers appeared, whereby those who were in favor of research work on the decrease of honey yield were in contradictions with the majority who wanted to continue to strike against the state and the research centre. A disagreement between the heads of the organization resulted in the dismissal of the moral entrepreneurs against their willingness to find the truth. The moral entrepreneurs wanted to save a common cause but the main concern of the majority of the beekeepers outnumbered the principles set by the moral entrepreneurs.

"*Well now I've moved on, I'm not interested, the damage is already done. We as beekeepers have to find other ways to get by. We have more work to do. I found the solution. But some beekeepers have not found the solution it always goes through nourishment. Me what I do I will work in the forest. Many in the forest. And I deserted the coast because there is no more marroon vines, I know that the bees will suffer a lot. And what is that? I found this solution I touch wood it works. After you have to have the courage to move hives. It gave us more work. To have honey now you have to work four times more. Otherwise there are no results*" (Professional beekeeper 2017). Some beekeepers had to change their technical practice and were forced upon feeding their hives. Others, were compelled to carry out the transhumance of their hives which necessitated great effort.

The members of the syndicate complained to the state for their loss of production and later claimed subsidies as compensation "*…expected a compensation of 115 euros per hives…*" *(Laurent Decloitre, Liberation, 18/09/09)*

Lack of communication

The elaboration of a new political action is not often linked to solving an issue but formulating problems (Lascoumes 2012). For the case of the biological control programme, a weak monitoring of the native and non-native species recovery post-control with a lack of restoration plan generated problem through re-invasion and formed additional disputes (Cybèle C. *et al.* 2008, unpublished data). Following the control of *R. alceifolius*, the beekeepers noted that other invasive lianas have invaded. The problem of invasion has not been properly solved by the local authorities according to them.

The beekeepers claimed that *"no nectariferous species have been planted after the biological control programme"*. (Professional beekeeper 2017)

The initial issue emerged with the release of the blue sawfly without any communication strategy prior to the release.

The cause of emotion generated as cross-cutting issues

The role played by the local authorities (regional council) in the management of the biological control crisis was known post-release of *C. janthina* and there was no existing press article prior to the release. The non-existence of a communication strategy or plan, in the form of a press release or sensitisation campaign contributed to a wide range of headlines and demonstrations by key stakeholders. Quéré (2012) showed how the sudden death of animals with the presence of excessive algae in association with a lack of sensitization from the local authorities among the public has brought about doubts and fear and a sudden reaction from the civil societies such as ecologists and non-governmental organisations.

Kull *et al.* (2011) showed with the example of the introduction of Australian Acacia around the world during the last 200 years by researchers, gardeners mainly as a source of benefit or for wood production. This issue was subject to various social perceptions and thus formulating problems. The rapid invasion of *Acacias,* is considered as a social and ecological issue. Human intervention in planting more *Acacias* has facilitated its rate of spread. It is now a problem for researchers who initially introduced acacias as a resource, and is now considered as being highly invasive. The perception of *R. alceifolius* from the perspective of professional beekeepers in Réunion Island is reflected as being a plant of natural heritage and of great pollineferous resources for bees during the two main yearly honey production. The beekeepers were perplexed to see *C. janthina* along with local bees during litchi harvest season as *C. janthina* is a phytophagous insect that defoliates the leaves of *R. alceifolius.* The advent of a potentially successful biocontrol programme, from the perspective of the research centre, was perceived negatively by other actors. When compared to the case study of Quéré (2012) whereby anger developed by the civil society on the invasive algae releasing a toxic gas, fear from the farmers using pesticides in their cultivation generating the invasive algae, the stakeholders manifested their emotions which strengthened with the support of media, by providing accusations towards farmers, the state and researchers.

The press provoked feelings of resentment towards the government and the researchers. The beekeepers started their grievances against this introduced alien fly as a biocontrol agent mingling with their bees since they first heard from it through the media.

"*And there in 2009, we learn through the press that an insect was released in the wild to destroy a nectariferous plant. We did not really appreciate*". (Professional beekeeper 2017)

The bees are icons, symbols of revenue to beekeepers, they reacted with deep resentment "*we will harden the movement. We will not go down the street to construct barriers. But our hives will land on the administrations*" (Le Quotidien de la Réunion 06/10/09).

“*I'll tell you something, and if the problem is bombing the mosquito repellent all the time…. this is the government… after Chikungunya*.” (Professional beekeeper 2017).

The historical choice of the state using insecticides to control the virus Chikungunya hosted by mosquitoes had a negative impact on the population of bees.

“*There have been a lot of pesticides used against Chikungunya that impacted bees…*” (Professional beekeepers 2017)

“We took the initiative to go out and do our work ourselves because at the level of CIRAD, we no longer had confidence in them and there was a climate of suspicion.” (Professional beekeeper 2017).

The link between the common classes and interconnectedness

The analysis of the common classes (the impact of media, the biological control agent, the beekeeper’s reaction to the biological control programme and the decrease in honey yield) allowed to build linkages between them. We found that emotions were expressed mainly to misperception of the biological control agent. The common classes are based on culture to assist in discerning between and among events, people and situations and are named (Schatzman and Strauss 1973). The effects of the agenda setting indicated that a crucial message in the headlines created a set of feelings as an immediate response of beekeepers. Dewey explained how emotions are delineated out of the function provided by the type overall situation in which we react and in the context of this controversial biological control programme, doubt and fear have emerged among the beekeepers due to miscommunication. Dewey 1993 displayed the emergence of emotions due to the modifications of practices. The invasion of algae in water sheds in Britany, France, affected animal and people implicating various stakeholders, the farmers, non-governmental organizations, the state and researchers

(Quéré 2012). The driving force of each group of stakeholders was often brought into oppositions with immense feelings but all based on the invasive algae. The contrasting view of the issue and the fact that farmers defended their agricultural practices blaming the state in allowing them to use pesticides generated emotions among the stakeholders. The ecologists in turn blamed the farmers while the state was hung upon the researchers and their findings (Quéré 2012). Likewise, we found that the past dispute following the use of insecticide to control the mosquito propagating the deadly disease Chikungunya in 2006, the beekeepers formally requested to be involved in any decision process related to bees at large. The professional beekeepers expressed their concern on their non-involvement though they conveyed to the local authorities their knowledge and experience of beekeeping with any subject related to beekeeping's environment in 2006. Despite the insight of professional beekeepers on the sphere of beekeeping, its ecosystems and habitats they felt forgotten or denied by the local government in the protocol to select biological control as a mean of managing *R. alceifolius.* Some beekeepers, reluctantly, had to change their technical specifications and provide supplementary nourishment to the bees.

Key recommendations

In terms of communication, few existing sensitization or awareness had been undertaken by any institutions of the French authorities to the media prior to the release of the blue sawfly in late 2007 or 2008. There should have been imperative press conference to inform the media and also release awareness information to general public in form of television and radio shows. There is a need to devise a mechanism that would allow the identification of key stakeholders in any future biological control programme. The beekeepers should be involved as collaborators for such future programme since their inception. For the case of innovative biological control programme, particularly involving species with few scientific publications, preliminary socio-ecological study prior and post future biological programme, should be set-up to identify key stakeholders, their perception and possible uses of target species. The efficiency of the awareness campaign needs pre and post needs to be assessed to better inform policy and decision makers on the willingness of targeted audience to further such programme. An economic analysis post biological control programme for *R. alceifolius* showed that biological control has been efficient at 0 to 800m above sea level and that there is a need to select an integrated management including mechanical control to be able to slow the spread of *R. alceifolius* (Chapter 2).

Our investigation on the impact of local media through the headlines and interviews of newspapers exposed that the key messages conveyed a negative image of the biological control agent by various stakeholders, at the advent of the problem being formulated. The semi-structured interviews showed that professional beekeepers have a thorough experience of the biological control programme with conflicts that brought them to adapt. Some were against the use of a biological control agent or the research center and others were curious to help the research center to investigate whether there is a connection between the decrease of production of honey yield and *C. janthina.*

The evolution of the policy and legal framework related to biological control programme aiming a biodiversity conservation in France

During the 1990's the risk assessment protocol in the introduction of a biocontrol agent in France, was applied to the policy text for agricultural practice as none was in place for biodiversity conservation. Prior to 1990 no law related to the management of biodiversity, invasive species or the use of biological control agent was in place until later. Very few components on the introduction of non-native species appeared in the *"Barnier"* act of the 2nd February 1995 and was applicable to the invasive species control programme (Legifrance 1995). The *"Barnier"* act have relevance to the protection of the environment, its habitat, the landscape, flora, fauna and the biological equilibrium. Their protection, restoration, and management should be in the interest of the sustainable development. There is no mention of control measures or risk assessment protocol as such in the act. The precautionary principle is applied if the necessary measures should be put in place if damages to the environment prevails, in absence of scientific certainty. The European Union (EU) adopted the draft on the prevention and management of the introduction of invasive species in 2014 (European Union. 2014). The spread of invasive alien species in the EU are listed since 2017 for EU ultra-peripheral Region within which include Réunion Island. In France, including in Réunion island as an oversea-department, since 2016 with the advent of the new Biodiversity act (*loi Biodiversité*) under the code of environment and up to date since the Article L 411-3, there is now more detailed environment policy (Legifrance 2016). It includes the compulsory consultation of the public with information approved research institutes to be able to elaborate of a national management plan on invasive species. The management plan has to take into account socio-economic and cultural heritage (Legifrance. 2017, 2016). The code of environment now includes a full section on the management of invasive species through Article L411-5 to L411-9 on its prevention and spread (Legifrance. 2016). It also provides the introduction of species except in the case of biocontrol and after an impact assessment (Annex 3). The policy framework in France has now evolved to include the necessity to manage and control invasive species. This involved the prerequisite for controlling from the perspective or "social reality" of policy and decision-makers. Supplementary case studies are required to better inform the existing policies and provide with recommendations upon the short and long term management on invasive species in France.

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Chapter 5: A framework for engaging stakeholders on the management of alien species

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A framework for engaging stakeholders on the management of alien species

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ABSTRACT

Alien species can have major ecological and socioeconomic impacts in their novel ranges and so effective management actions are needed. However, management can be contentious and create conflicts, especially when stakeholders who benefit from alien species are different from those who incur costs. Such conflicts of interests mean that management strategies can often not be implemented. There is, therefore, increasing interest in engaging stakeholders affected by alien species or by their management. Through a facilitated workshop and consultation process including academics and managers working on a variety of organisms and in different areas (urban and rural) and ecosystems (terrestrial and aquatic), we developed a framework for engaging stakeholders in the management of alien species. The proposed framework for stakeholder engagement consists of 12 steps: (1) identify stakeholders; (2) select key stakeholders for engagement; (3) explore key stakeholders' perceptions and develop initial aims for management; (4) engage key stakeholders in the development of a draft management strategy; (5) re-explore key stakeholders' perceptions and revise the aims of the strategy; (6) co-design general aims, management objectives and time frames with key stakeholders; (7) co-design a management strategy; (8) facilitate stakeholders' ownership of the strategy and adapt as required; and (9) implement the strategy and monitor management actions to evaluate the need for additional or future actions. In case additional management is needed after these actions take place, some extra steps should be taken: (10) identify any new stakeholders, benefits, and costs; (11) monitor engagement; and (12) revise management strategy. Overall, we believe that our framework provides an effective approach to minimize the impact of conflicts created by alien species management.

1. Introduction

Over the past centuries, humans have moved species to regions

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Abstract

Alien species can have major ecological and socioeconomic impacts in their novel ranges and so effective management actions are needed. However, management can be contentious and create conflicts, especially when stakeholders who benefit from alien species are different from those who incur costs. Such conflicts of interests mean that management strategies can often not be implemented. There is, therefore, increasing interest in engaging stakeholders affected by alien species or by their management. Through a facilitated workshop and consultation process including academics and managers working on a variety of organisms and in different areas (urban and rural) and ecosystems (terrestrial and aquatic), we developed a framework for engaging stakeholders in the management of alien species. The proposed framework for stakeholder engagement consists of 12 steps: (1) identify stakeholders; (2) select key stakeholders for engagement; (3) explore key stakeholders' perceptions and develop initial aims for management; (4) engage key stakeholders in the development of a draft management strategy; (5) re-explore key stakeholders' perceptions and revise the aims for management; (6) co-design general aims, management objectives and time frames with key stakeholders; (7) co-design a management strategy; (8) encourage stakeholders' ownership of the strategy and adapt as required; and (9) implement the strategy and monitor management actions to evaluate the need for additional or future actions. In case additional management is needed after these actions take place, some extra steps should be taken: (10) identify any new stakeholders, benefits, and costs; (11) monitor engagement; and (12) revise management strategy. Overall, we believe that our framework provides an effective approach to minimise the impact of conflicts created by alien species management.

Keywords: Biological invasions; conflicts of interests; invasive species management; perceptions; stakeholder ownership; environmental management

Introduction

Over the past centuries, humans have moved species to regions outside their native ranges. This has been done for a range of reasons including purposefully for agriculture, aquaculture, forestry, ornamental horticulture, the pet trade, and recreation; and accidentally through ballast water, fouling or concealment in transported goods (Mack, 2003). Many of these introductions were, and remain, desirable (indeed indispensable) for humans, and include the staple food crops in most countries. These can be called "desirable species" due to the benefits they provide and the low or no costs they have (Ewel et al., 1999). Other introduced species provide few or no benefits (Shackleton et al., 2007; van Wilgen and Richardson, 2014) and are environmentally inconsequential – e.g. insects that are transported by boats between continents and do not survive in the introduced area (Figure 5-1).

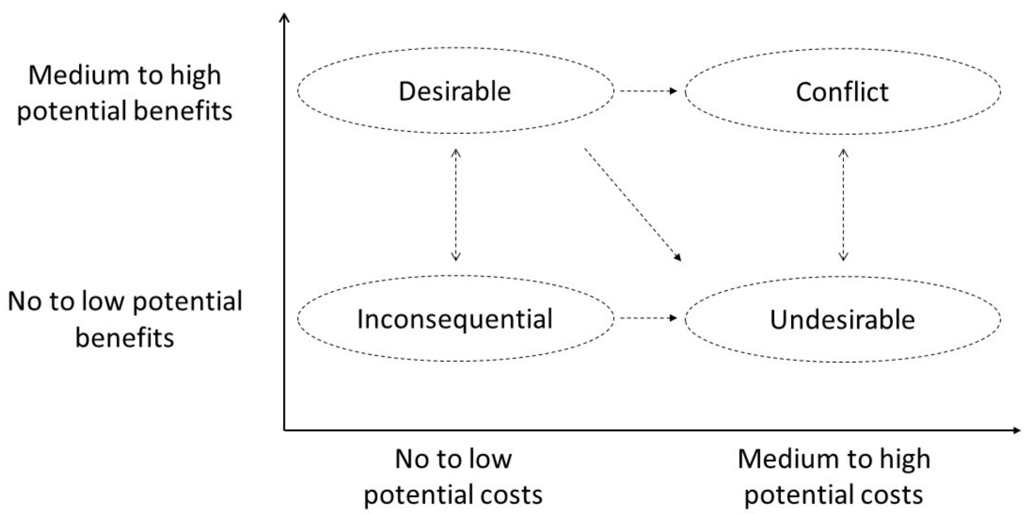

Figure 5-1: Classification of alien species based on their potential benefits and costs for society. Arrows indicate potential category changes for a particular species over time.

However, a small proportion of all alien species become invasive (i.e. reproduce and spread over substantial distances from introduction sites; Blackburn et al., 2011). Such growth and spread sometimes results in negative impacts, but even if there is no spread, alien species can be "undesirable" (Figure 5-1). Impacts caused by invasive species (and occasionally alien species which are not invasive) include changes to ecosystem services (such as water or grazing supply), changes to ecosystem processes (such as fire and nutrient cycling), reductions in biodiversity, and negative effects on local economies and livelihoods (Levine et al., 2003; Le Maitre et al., 2011; Jeschke et al., 2014; Shackleton et al., 2014). For example, the perennial herb *Chromolaena odorata* in South Africa prevents the establishment of native plants, reduces grazing ground for native animals, alters natural ecosystem processes, alters features of fire regimes, causes negative impacts on forestry and crop plantations, reduces pasture carrying capacities, and is toxic to humans and animals (Goodall and Erasmus, 1996; Te Beest et al., 2015). In New Zealand, the black rat (*Rattus rattus*) causes substantial declines in native plant and animal populations (Caut et al., 2008), damages agricultural crops and carries human-threatening diseases (Russell et al., 2008). Effective management of such undesirable species often requires the engagement of all stakeholders, to ensure that all relevant ecological and socioeconomic dimensions influencing the management are addressed (Liu and Cook, 2016). A management strategy designed and implemented without engaging all stakeholders can be controversial and might be challenged, ultimately reducing the efficiency of management efforts (Crowley et al. 2017a). For example, an aerial spraying program aimed at eradicating the light brown apple moth (*Epiphyas postvittana*), a major threat to agriculture in northern California, was challenged by a popular opposition movement which was concerned that the spray might pose a risk to human health (Lindeman, 2013). In this case, the strategy adopted for the management of the alien species created a conflict.

Some alien species, in addition to incurring costs, provide benefits and are, therefore, embraced by certain stakeholders (e.g. Dickie et al., 2014; Kull et al., 2011; Novoa et al., 2015a; Shackleton et al., 2007; Shackleton et al., 2014; van Wilgen and Richardson, 2012). Alien species with both benefits and costs ("conflict species", Figure 5-1) usually lead to conflicts around both their use and management (Dickie et al., 2014; Novoa et al., 2015b; Shackleton et al., 2014; Stanley and Fowler, 2004; van Wilgen and Richardson, 2012, 2014; Woodford et al., 2016). For example, several tree species in the genera *Acacia*, *Pinus* and *Prosopis*, which are highly invasive in many areas of the world, are extensively used in the forestry industry and for agroforestry and silviculture by farmers and rural communities (Kull et al., 2011; Moran et al., 2000; Shackleton et al., 2014). Furthermore, many alien plant invasions that have arisen from 'escaped' horticultural introductions (e.g. the jacaranda tree *Jacaranda mimosifolia* in South Africa, the African tulip tree *Spathodea campanulata* in Fiji and the saltcedar *Tamarix ramosissima* in the USA), have substantial intrinsic and aesthetic value for some stakeholders (Dehnen-Schmutz and Williamson, 2006; Dickie et al., 2014). Several invasive animals [e.g. the Mediterranean mussel (*Mytilus galloprovincialis*) in South Africa and feral pigs (*Sus scrofa*) in the USA] and plants [e.g. prickly pear (*Opuntia* spp.) in Australia and Spain, guava (*Psidium* spp.) in Mauritius and brambles (*Rubus* spp.) in Australia, New Zealand and the USA] are used for food (Cole et al., 2012; Naylor et al., 2001; Novoa et al., 2014a; Robinson et al., 2005; Stanley and Fowler, 2004;) and numerous invasive fish species [e.g. the rainbow trout (*Oncorhynchus mykiss*) in Australia, Europe or South Africa] are popular both for food and for sport fishing (Cambray, 2003).

The categorisation of species as inconsequential, desirable, undesirable, or conflict can also change over time (Shackleton et al. 2007). For example, the following species have all become undesirable over time as they have started to spread and caused negative impacts: (1) inconsequential species [e.g. parthenium (*Parthenium hysterophorus*) in eastern and southern Africa (McConnachie et al., 2011) and the red imported fire ant (*Solenopsis invicta*) in the USA (LeBrun et al., 2012)], (2) desirable species [e.g. boneseed (*Chrysanthemoides monilifera*) in Australia (Downey, 2010) and the erect prickly pear (*Opuntia stricta*) in South Africa (Foxcroft et al., 2004)], and (3) conflict species [e.g. mesquite (*Prosopis* spp.) in South Africa (Shackleton et al., 2014) and the acacia bernier (*Acacia dealbata*) in Spain (Lorenzo et al., 2010)]. Similarly, a desirable species might become a conflict species [e.g. the prickly pear (*Opuntia ficus-indica*) in Spain and Turkey (Novoa et al. 2015a) and the Mediterranean mussel (*Mytilus galloprovincialis*) in South Africa (Branch and Steffani, 2004)].

Achieving workable management strategies for such conflict species depends, to a large extent, on acceptance (if not cooperation and support) from all stakeholders — both those supporting the use of the species, and those supporting its control. A lack of acceptance across stakeholder constituencies often has a negative influence on implementation actions and policy making (Ford-Thompson et al., 2012; Gárcia-Llorente et al., 2008; Reed et al., 2009). For example, in South Africa's Table Mountain National Park, the invasive tree karri gum (*Eucalyptus diversicolor*) has some negative impacts on water resources. However, it is perceived as beneficial by hikers, cyclists and tree enthusiasts. Due to this conflict of interests, plans to remove the species and restore invaded areas in the National Park were halted (Gaertner et al., 2016). Another example is the blue gum (*E. globulus*) in Galicia, Spain. Although considered by many stakeholders in the region as one of the most problematic invasive plants, it also has important benefits for the forestry sector (Dehnen-Schmutz et al., 2010). Consequently, the local government excluded the species from the list of invasive alien plants in the area.

The importance of engaging multiple stakeholder groups in management of alien species (both undesirable and conflict species) has been highlighted before (Kueffer, 2010) and the need for such engagement is stipulated by the Convention on Biological Diversity and in strategies to combat biological invasions in many parts of the world. For example, in 2004, the Invasive Alien Species Strategy for Canada identified a range of stakeholders (including academic researchers, industry, NGOs, and the general public) as "essential players for successfully responding to the challenge of invasive alien species" (Environment Canada, 2004). Similarly, the Guiding Principle 6 (Education and public awareness) of the *European Strategy on Invasive Alien Species*, has the need to "work with key stakeholders to produce and disseminate information and guidance on best practices for those using or affected by [invasive alien species]" (Brunel et al., 2013) as a key action. And codes of conduct dealing with the role of horticulture, pet trade, plantation forestry, and zoological gardens and aquaria in disseminating alien species in Europe all stipulate the need for stakeholder engagement (e.g. Brundu and Richardson, 2016 for planted forests). Such engagement is essential for elucidating the factors that shape stakeholders' perceptions and practices i.e. for "framing" the problem (Woodford et al., 2016). It is also essential for identifying valuable local knowledge and practices, promoting awareness and social learning, reaching consensus and gaining support, and formulating co-management programs (Dehnen-Schmutz et al., 2010; Forsyth et al., 2012; García-Llorente, 2008; Moon et al., 2015; Novoa et al., 2015b; Reed et al., 2008, 2009; Sharp et al., 2011; Stokes et al., 2006). Therefore, the importance of participatory approaches in alien species management has been increasingly recognised (García-Llorente, 2008; Shackleton et al., 2015; Crowley et al., 2017b) and the number of studies aiming to understand stakeholders' perceptions to facilitate decision-making in alien species management is growing (e.g. Liu and Cook, 2016; Novoa et al., 2016; Rout et al., 2014). Studies that discuss stakeholder involvement on alien species management are, however, still scarce. To facilitate such work in future, we develop a step-by-step approach to engaging stakeholders in the management of alien species. This approach is based on adaptive management, i.e. a flexible management strategy that can be adjusted as more information (e.g. on stakeholders' perceptions or on outcomes from management actions) becomes available or better understood (Linkov et al., 2006; Williams, 2011).

Methods

To better understand the issues pertaining to stakeholder engagement in alien species management, we organized a two-day workshop in Cape Town, South Africa, in August 2015. It involved 20 participants working on biological invasions and representing different organizations in South Africa and France (governmental institutions, universities and other scientific institutions). Participants included academics and managers working in different capacities on a variety of invasive organisms and in different areas (urban and rural) and ecosystems (terrestrial and aquatic). South Africa has major problems with biological invasions in freshwater, marine and terrestrial ecosystems and has a long history of scientific study and management of invasions (Richardson et al., 2011). The cross-section of invasive organisms and management issues in the workshop therefore covered many of the most pressing global issues with alien species management.

On the first day of the workshop, participants presented eleven different case studies of conflicts that they had experienced around the management of alien species. Presentations covered: (1) species benefits and costs; (2) affected stakeholders; and (3) attempts to engage stakeholders (if any) (Table 1). The case studies were chosen with the aim of representing a wide variety of groups—bamboos, cacti, forestry species, freshwater species, amphibians, terrestrial invertebrates, and mesquite. This led into various round-table discussions. Based on participants' experiences, and feedback from the group work, we constructed a first draft of a stakeholder-engagement framework for dealing with conflicts in the management of alien species.

On day two of the workshop, participants were separated into break-out groups of 4-6 people and were asked to write down all the steps they found necessary to include in the framework, and the reasons for these. In a following feedback session, participants summarized their discussions. All discussions were videotaped. A revised framework was then developed. The workshop ended with a group discussion and a detailed analysis of each step of the revised framework.

Building on the workshop and incorporating perspectives from elsewhere in the world, this framework was further discussed through additional meetings and e-mail communications involving a collaborative group of researchers interested in the optimum control of invasive species with participants from Australia, La Reunion Island (France) and the United Kingdom. Each step of the framework was further improved by reviewing and drawing on information from various literature sources and by visiting the taped discussions from the workshop.

Table 5-1: Examples of "conflict species", their costs and benefits, stakeholders' perspectives and outcomes of engagement presented by workshop participants

Species group	Benefits	Costs	Stakeholders opposed to management	Stakeholders for management	Conflict	Attempts to engage stakeholders	References
Bamboos	• Ornamental • Timber • Used as food • Used as fodder • Carbon sequestration projects • Water filtration	• Establishes in riparian areas • Supresses regeneration of surrounding trees	• Commercial cultivators • Nursery owners	• Commercial growers • Nursery sellers • Private landowners	Use and management	Mostly successful	Canavan et al., 2016

Species group	Benefits	Costs	Stakeholders opposed to management	Stakeholders for management	Conflict	Attempts to engage stakeholders	References
Cacti (Cactaceae)	• Aesthetic value • Used as food • Used as fodder • Used as fences • Biofuel	• Cause injuries to humans, wild animals and livestock • Reduce grazing potential • Prevent access to land • Displace native biodiversity	• Nursery owners • Farmers • Food scientists • General public	• Farmers • Game reserve owners • Land-managers • General public	Use and management	Successful	Novoa et al., 2016

Species group	Benefits	Costs	Stakeholders opposed to management	Stakeholders for management	Conflict	Attempts to engage stakeholders	References
Commercial forestry trees/species	• Timber • Pulp • Employment opportunities	• Widespread invasions of adjoining land (often watersheds) leading to substantial reductions in streamflow • Biodiversity losses	• Commercial forestry companies	• Conservation agencies • Landowners • General public	Use and management	Largely unsuccessful (failure to agree on ownership of the problem and management options)	Van Wilgen and Richardson, 2012, 2014; McConnachie et al., 2015, 2016

Freshwater species	• Recreational/fishing tournaments, • Major income for fishing/boat shops • Used as food • Aesthetic value/pets • Cultural	• Threats to aquatic biodiversity (through predation, competition, habitat alteration, disease transfer and hybridization)	• Angling clubs • Fishermen • Inland fisheries societies • Aquaculture sector	• Managers • Conservation agencies	Use and management	Largely unsuccessful for some species, such as rainbow trout (failure to agree on the areas to be managed). Largely successful for other species, such as bass.	Hargrove et al., 2015; Taylor et al., 2015; Weyl et al., 2015
Amphibians	• Aesthetic value • Natural pest control	• Very noisy calls • Parasite and pathogen transfer	• Collectors • Animal rights activists	• Collectors • Conservation agencies	Management actions	Some success, but some	Measey et al., 2014,

Species group	Benefits	Costs	Stakeholders opposed to management	Stakeholders for management	Conflict	Attempts to engage stakeholders	References
		• Predation • Toxicity to predators • Damage to infrastructure				private properties not accessible to management/conservation staff	2015, 2016, 2017; Vimercati et al., 2017

Species group	Benefits	Costs	Stakeholders opposed to management	Stakeholders for management	Conflict	Attempts to engage stakeholders	References
Mesquite (*Prosopis* spp.)	• Fodder • Fuelwood • Honey • Shade • Aesthetic value	• Negative health effects to humans and livestock • Water uptake • Loss of grazing areas • Breakage of infrastructure • Biodiversity impacts • Economic losses • Encroachment Loss of land	• Some farmers and community members	• Some farmers and community members • Managers • Conservationists	Use and management Management actions	Successful	Shackleton et al., 2014, 2015, 2016, 2017

Species group	Benefits	Costs	Stakeholders opposed to management	Stakeholders for management	Conflict	Attempts to engage stakeholders	References
Terrestrial invertebrates	• >20 uses were recently identified, e.g., biocontrol, silk production, human food, animal feed, pets, pollination, waste processing or bait for fishing	• Large damage to native environments. Most impacts and risks have however not been studied.	• Not studied, but dependant on use. Probably pet holders, animal farmers, etc.	• Not studied, but likely conservationists,	Not studied	Not known	Kumschick et al., 2016

The framework

The framework proposed here is designed to be followed by any entity tasked with responding to a concern raised about an alien taxa. The concerns might be raised due to environmental change, the detection of a new incursion, the result of a decision made to address a long-standing issue, or in response to criticism of current or historical control efforts. The overall aim of the framework is to ensure that stakeholders are appropriately considered (and where possible included) in the subsequent decision making process. The framework consists of 12 steps and 6 decision points. Each of these steps and decision points are discussed below.

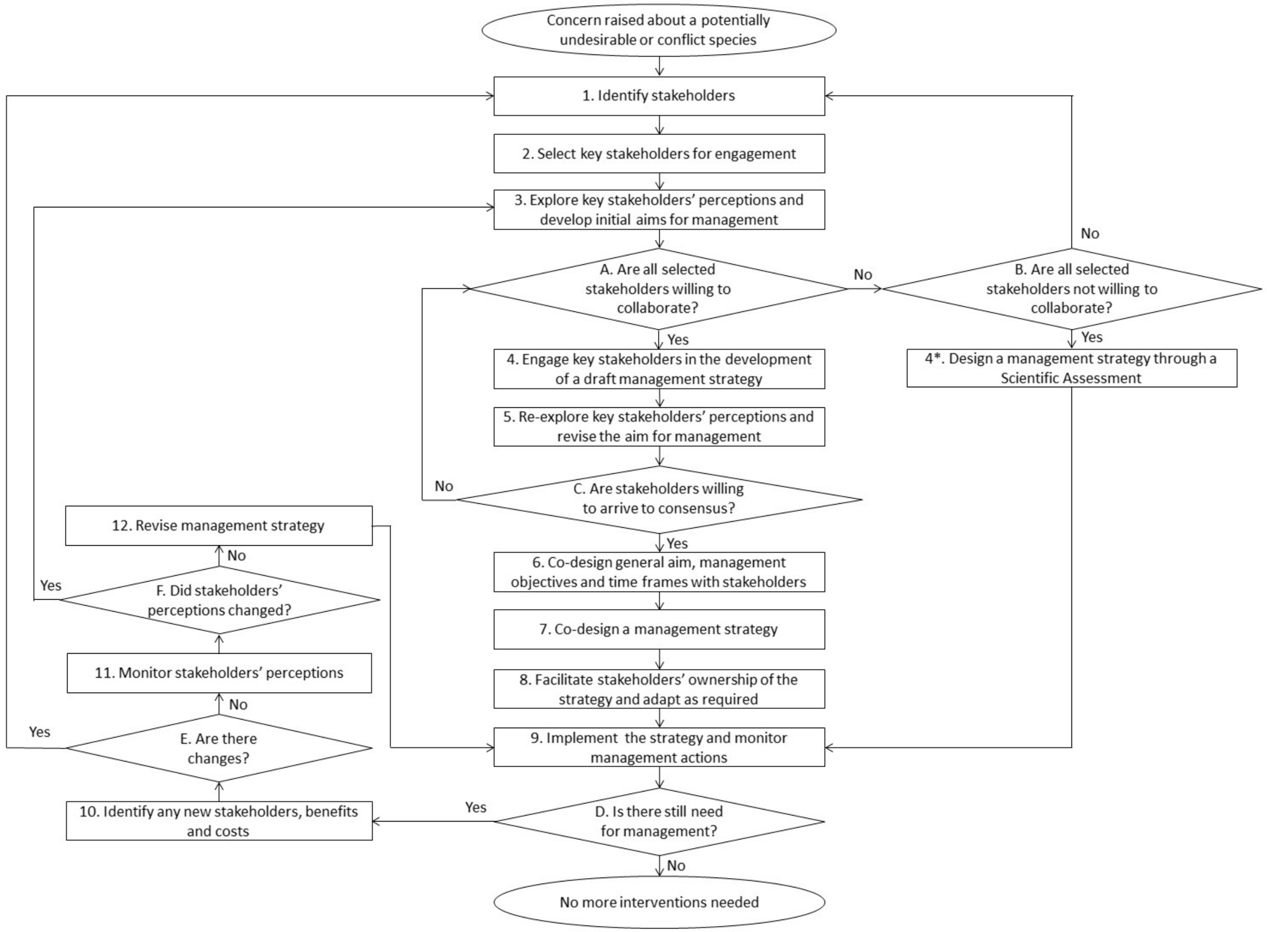

Figure 5-2: Proposed framework for engaging stakeholders when developing management practices for alien species. Numbers (1-12) indicate the different steps and letters (A-F) indicate decision points.

Step 1. Identify stakeholders

When there is a need for managing undesirable or conflict species (“target species”) – i.e. due to a legislative requirement or to address particular impacts, –it is essential to identify stakeholders that might play a role during the course of the management initiative (Reed et al., 2009). The identification of stakeholders at this stage should aim to be as broad and inclusive as possible, and should consider groups and individuals that might either benefit or experience negative impacts from the target species, as well as those that might experience impacts or risks associated with the actual management intervention.

Many techniques are available for identifying stakeholders. These include network analyses (Scott, 2012) and historical, demographic and geographic techniques (e.g. Babiuch and Farhar, 1994). However, the most popular is the snowball technique (Biernacki and Waldorf, 1981), which involves identifying a small initial pool of stakeholders – through peer recommendation or literature review (including books, scientific articles, newspaper articles, social media or meeting minutes) – and asking them to nominate other stakeholders until no new ones are identified (e.g. Bardsley et al., 2007; Kumschick et al., 2012; Urgenson et al., 2013). For example, Urgenson and colleagues (2013) aimed to understand the perceptions of stakeholders regarding the control of invasive alien plants on private land in South Africa’s Western Cape province. Although they could identify affected landowners through a land management agency, they effectively used the snowball technique to find conservation professionals involved in the management of the target species.

Each target species or group of species will require the engagement of different stakeholders and, depending on the species, most stakeholder groups are often obvious. Table 5-2 shows some examples of different stakeholder groups that can be expected to be involved in the management of different groups of alien species.

Table 5-2: Example of stakeholders that are expected to have influence on or be affected by the management of different groups of alien species.

	Plants	Freshwater species	Marine species	Vertebrates	Terrestrial invertebrates	Amphibians
Managers & policy makers	x	x	x	x	x	x
State agencies	x	x	x	x	x	x
NGOs	x	x	x	x	x	x
Agricultural sector	x	-	-	x	x	x
Forestry sector	x	-	-	-	x	-
Aquaculture sector	-	x	x	-	-	x
Pet shop owners	-	x	x	x	x	x
Collectors	x	x	x	x	x	x
Nursery owners and plant wholesalers	x	-	-	-	x	-
Land owners	x	X	-	x	x	x
Food industry	x	X	X	x	x	x
Landscapers	x	-	-	-	-	-
Fishermen	-	X	X	-	-	-
Recreational ocean users	-	-	X	-	-	-

Academics	x	X	X	x	x	x
General public	x	X	X	x	x	x

Step 2. Select key stakeholders for engagement

Although all identified stakeholders should ideally be engaged in the management actions, sometimes this might be impractical (e.g. due to lack of funding, capacity, or time). In such cases, all stakeholders should be categorized, and only those that are most likely to affect the functioning of the management strategy should be engaged (Grimble et al., 1995).

Various approaches have been used to categorize and identify key stakeholders for engagement (Babiuch and Farhar, 1994; Reed and Cruzon, 2015). The most widely used is the impact-influence matrix, which categorizes stakeholders according to their level to influence management actions and the impact of the management on them (e.g. Liu and Cook, 2016; Newcombe, 2003; Olander and Landin, 2005; Reed and Curzon, 2015; Walker et al., 2008). This approach, often referred to as stakeholder mapping (Reed, 2009), contemplates four stakeholder categories: "Key players", with high influence on the management actions and that are highly impacted by the management; "Context setters", with high influence, but are not impacted much; "Subjects", who are highly impacted by the management actions, but have little or no influence over the actions; and the "Crowd", who have little influence and are not heavily impacted by the management (Figure 5-3).

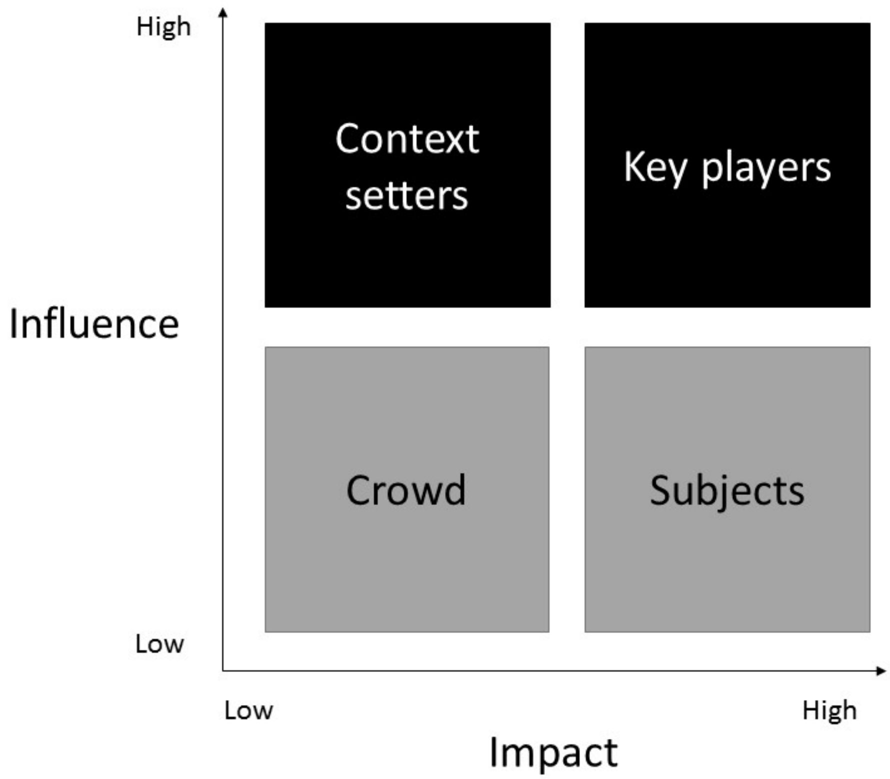

Figure 5-3: Impact-influence matrix categorizing stakeholders affected by undesirable species into four groups.

When developing management actions, it is tempting to only focus on stakeholders with high influence (key players and context setters), as they will have the highest impact on management decision outcomes (Liu and Cook, 2016; Newcombe, 2003; Olander and Landin, 2005; Reed and Curzon, 2015). For example, in South Africa's Table Mountain National Park, a population of invasive Himalayan tahrs (*Hemitragus jemlahicus*) was targeted for eradication. There was strong resistance from some members of the public to controlling these mammals (Gaertner et al., 2016), but gaining backing from some influential NGOs and conservation authorities was enough to solve the conflict. The challenge, however, is to also empower those that are most affected by the decisions (the subjects), and some case studies have shown that mobilising stakeholders with low influence can be an effective way of building mass support for management initiatives. For example, a large-scale eradication programme of the invasive American mink (*Neovison vison*) in north-eastern Scotland was possible due to the engagement of not only scientists, government agencies and national park authorities, but also local fisheries boards and local communities (Bryce et al., 2011). Likewise, in South Africa, engaging the public on the management of bass (*Micropterus dolomieu*) resulted in the bass angling fraternity providing full support for extirpation actions within selected sites of high conservation value (Weyl et al., 2014).

Step 3. Explore key stakeholders' perceptions and develop initial aims for management

By studying stakeholder perceptions and levels of awareness of the invasions, factors influencing management can be uncovered and explored (Eiswerth et al., 2011; García-Llorente et al., 2008; Shackleton and Shackleton, 2016). Moreover, people's views on alien species can be better understood (Urgenson et al., 2013) and their wants and needs for management gauged (Kreuter et al., 2005; Shackleton et al., 2015a). Finally, the level of cohesion and consensus between stakeholders can be identified (Fischer et al., 2014; Novoa et al., 2015). Fischer et al. (2014) highlight that understanding stakeholders' beliefs (i.e. their subjective knowledge) about a particular species provides a good basis for gauging possible attitudes towards different management strategies. Therefore, having a broad overview of key stakeholders' beliefs and attitudes towards management of target alien species can help managers develop a shared aim for the management strategy and design a successful engagement process. A variety of techniques can be used to study stakeholders' perceptions, including questionnaires, phone calls, e-mails, site visits and workshops (Reed et al. 2009; Malatinszky, 2016). Using face-to-face interviews, Schüttler and colleagues (2011) explored the perceptions of stakeholders (Chilean Navy members, indigenous Yaghan people, fishermen, public service employees, civilian residents and nature conservationists) regarding two invasive species, the American mink (*Neovison vison*) and the North American beaver (*Castor canadensis*), for which management plans, including co-management, needed to be developed in Chile. Although stakeholders had positive attitudes regarding the control of the invaders, there was disagreement about the goal of the management actions (control or eradication) and the appropriate management method (killing or castration). This suggests that, although the engagement of identified stakeholders and the aim of controlling both invaders were achievable, during the engagement process, information about the feasible control methods and their trade-offs should be provided. In this case, discussion of the option of establishing a no-control area for *C. canadensis* might have been helpful.

Decisions A-B. Are all selected stakeholders willing to collaborate?

Once the perceptions of all selected stakeholders are known, we can proceed to engagement (Step 4). However, the results of Step 3 might show that some stakeholder groups are not interested in participating further in the process, or are against any form of management. In such situations, a smaller group of stakeholders may be selected (Step 2). Alternatively, if the selected stakeholders do not agree, it can be essential to have a formal process, e.g. a scientific assessment (Step 4*; Scholes et al., 2017).

Step 4. Engage key stakeholders in the development of a draft management strategy

Engaging stakeholders is one of the most important steps of the proposed framework. A key aim of engagement is to increase levels of trust and establish collaborations among stakeholders, promote social learning and information sharing. Moreover, solving the potential differences between stakeholder groups is crucial. Engagement can be achieved by promoting dialogue among stakeholders through an open and fair participation process — through workshops or social media, such as blogs or Facebook pages, where stakeholders can share their perceptions (e.g. Estévez et al., 2015; Ford-Thompson et al., 2012; Gilmour et al., 2013;). For example, Novoa and colleagues (2016a) organized a workshop with stakeholders who either benefit from or suffer the costs of invasive cacti in South Africa. Before the workshop, some stakeholders were not fully aware of the benefits and negative impacts of cacti in South Africa. In the workshop, stakeholders listened to each others' perceptions, wants and needs. The workshop was shown to increase different stakeholders' knowledge and understanding of the species' benefits and adverse impacts, and improved their acceptance and willingness to collaborate on the proposed management actions.

If the strategy aims to provide the basis for managing alien species across different regions (with different climates, land uses, economies or demographics), a different engagement process might need to be carried out in each region. For example, Friedel and colleagues (2011) aimed to engage governmental and non-governmental organisations on the management of buffel grass (*Cenchrus ciliaris*) in Australia. They ran workshops in four regions, each of them having a different climate, land use and pastoral dependence on buffel grass. Overall, they found regional differences in stakeholders' perceptions of the benefits and costs of buffel grass and identified a need for different management objectives in the different regions.

A key requirement of the engagement process is having a facilitator to lead the process and balance any competing interests of stakeholders. Such a facilitator or mediator should ideally be a neutral third party with expertise in conflict resolution, and should assist stakeholders to voluntarily reach consensus on the approaches to be adopted for managing the target species (Lampe, 2001).

Step 4. Design a management strategy through a scientific assessment

When achieving acceptance from all stakeholders is not possible, a formal scientific assessment process can be set up. Such a scientific assessment is an evaluation of information, done by experts on the field, aiming to guide decision-makers on the management of the target species (Scholes et al., 2017). Management then proceeds (Step 9), with decisions ultimately enforced through legislation (van Wilgen and Richardson, 2012). However, this approach might create conflicts, since stakeholders might feel excluded from the management process and seek alternative ways of achieving their goals (Crowley et al., 2017). For example, on Lord Howe Island (Australia), members of the public opposed a program to eradicate rodents from the island because they felt excluded from the design of the management strategy (Lord Howe Island Community Liaison Group, 2013).

Step 5. Re-explore key stakeholders' perceptions and revise the aim of the management strategy

After the engagement process, it is important to re-assess the perception of stakeholders to determine whether the engagement process has built cohesion and trust, or if further engagement is needed. The techniques available for exploring whether stakeholders' perceptions and attitudes towards the target species have changed are those described in Step 3. However, in the current step (5), additional efforts should be targeted to explore stakeholders' attitudes towards the other stakeholders. This should be done with the help of the facilitator or mediator mentioned in Step 4 and through open and individual dialogue between each stakeholder and the facilitator.

Decision C. Are stakeholders willing to arrive at a consensus?

In some cases, consensus is easily reached. For example, Novoa and colleagues (2016) showed, through the results of questionnaires, that only one session of interaction and dialogue between stakeholders affected by cactus invasions was enough to improve their willingness to collaborate on cactus management actions. This shows how engagement and information exchange can change stakeholders' beliefs (subjective knowledge) about a target species and subsequently change their attitudes towards management interventions.

However, sometimes, multiple engagements are needed before stakeholders are prepared to arrive at a consensus in the management process. For example, in the Cape Floristic Region (South Africa), several meetings had to be organized to engage the public (especially anglers, the main stakeholder group responsible for the introduction of freshwater fishes) on the extirpation of non-native fish from priority rivers. However, opposition to the project still remains.

Conservation managers, through a Freshwater Angling Forum, are still working closely with local angling groups to achieve engagement (Marr et al., 2012).

Unfortunately, in certain situations it might not be possible to achieve consensus. For example, in Cape Town (South Africa), European mallards (*Anas platyrhynchos*) were targeted for eradication, as they interbreed with indigenous yellow-billed ducks (*Anas undulata*). However, efforts to engage the public were not successful, because arguments to control the European mallards failed to convince the opposing stakeholders (Gaertner et al., 2016). The presence of powerful stakeholders in each of these cases has hindered the engagement process and progress towards management implementation (Figure 5-3). In such cases, the management strategy might need to be designed through a scientific assessment (Step 4*), and the management goals might need to be adapted to accommodate partial or complete tolerance of the target species – i.e. little management targeting the species could be designed and implemented. For example, in South Africa, the invasive river red gum (*Eucalyptus camaldulensis*) is an attractive ornamental tree. In the case of public social opposition and lack of willingness to arrive to a consensus regarding the clearing of river red gums, an appropriate management goal would be to tolerate large individuals in public parks and gardens, but to remove plants from protected areas and river courses (Gaertner et al., 2016).

Step. 6. Co-design general aim, management objectives and time frames with key stakeholders

Once consensus among key stakeholders is achieved, the aim of the management strategy must be revised, in order to incorporate stakeholders' wants and needs. Workshops in which team decision-making techniques are applied can be used to translate stakeholders' knowledge and needs into alien species management objectives that are broadly supported by all stakeholders. For example, Novoa and colleagues (2016) organized a workshop at which biological control researchers, farmers, food scientists, fruit pickers, game reserve owners, invasion biologists, invasive species managers, land managers and nursery owners co-designed aims and objectives for a national strategy for managing cactus species in South Africa (Kaplan et al., 2017). Similarly, Shackleton and colleagues (2016) held several workshops with academics, farmers and managers during which, in order to improve management interventions, they identified barriers and potential solutions (adaptation responses) for the management of invasive mesquite (*Prosopis* species) in South Africa.

There are many techniques than can be used in such workshops. For example, the Round Robin Brainstorming Technique (RRBT) involves giving each stakeholder a fixed number of sheets of paper and asking them to write one management recommendation on each paper (Brilhart and Jochem, 1964). Stakeholders are then asked to present (one at a time) their written recommendations to the full group. Another example is the Charette Procedure (CP), which is especially useful when many stakeholders are involved (Manktelow, 2009). It involves separating stakeholders into several small groups, preferably mixing stakeholder types (e.g. as categorized in Figure 5-3). Stakeholders then brainstorm and discuss potential management recommendations until consensus is reached within the group. A representative of each group then presents their recommendations to all stakeholders. Although the RRBT and CP techniques are generally successful (e.g. Novoa et al., 2016), some stakeholders may find it difficult to share their knowledge and opinions openly. In these situations, the use of a Metaplan (Ramshaw, 1989) would be recommended. This technique is similar to the RRBT, but once the recommendations are written, each stakeholder anonymously places his or her papers on the wall. A potential difficulty of all these techniques is to separate personal views of people involved in the engagement process from those of the organizations, constituencies or stakeholder groups they represent.

Moreover, discussing management recommendations under high levels of uncertainty (such as unknown effectiveness of control actions) can be difficult. Under such conditions, scenario planning is an effective approach to guide the co-design of management objectives (Peterson et al., 2003). For example, Roura-Pascual and colleagues (2010) used scenario planning for guiding the management of invasive plants in the Cape Floristic Region (South Africa) under several uncertainties (e.g. "how is funding going to change?" or "is the institutional capacity going to increase or decrease?").

Once all recommendations are presented (independently of the technique used), they should be discussed until every stakeholder agrees to a final set of management objectives. To achieve consensus and avoid conflicts, once again the facilitator of these discussions should be neutral (Deelstra et al., 2003; Kaner, 2014) and capable of mitigating tensions (Morris and Baddache, 2012), since certain topics can be controversial or provocative, creating unexpected dynamics or rivalries between stakeholders. Finally, all management objectives should be documented in writing, and the facilitator should agree with stakeholders on their time frames and when they will be updated (Morris and Baddache, 2012).

Step 7. Co-design a management strategy

The final set of management objectives documented in Step 6 must be incorporated into an effective management strategy. Such a strategy can be drafted by a core group of scientific and/or management experts, and it should clearly state the management objectives, facilitate the implementation of all available management practices needed to achieve those objectives, and define clear areas of responsibility for implementation at all levels (national, provincial or municipal) (e.g. Kaplan et al., 2017; Leeuwen et al., 2014; van Wilgen et al., 2011). This means that the strategy should clearly state what is going to be done and when, who is going to do it, how it will be paid for, and how the success of its implementation will be determined (Wilson et al., 2016). Moreover, the management strategy should include a communication plan that will help to target the audience with identified communication tools. Finally, all the process of designing the management strategy should be transparent and accessible to all stakeholders (Malatinszky et al., 2013).

Step 8. Facilitate stakeholders' ownership of the strategy and adapt as required

After producing a management strategy, it is important to present it to all stakeholders, so they can validate the information collectively. This will inform stakeholders how their feedback has been used, help mitigate misunderstandings, and build co-ownership and mutual trust. Moreover, this process can help eliminate linguistic uncertainties, so that stakeholders share a common understanding of each action (Liu and Cook, 2016).

For example, Novoa and colleagues (2015b) organized a workshop in which they followed a consultative process with stakeholders to design a list of potentially invasive cactus species whose introduction and use should be prohibited in South Africa. After the workshop, the list was compiled by researchers and then presented to all stakeholders for validation and adaptation. The resulting list was adopted in the final version of the National Environmental Management: Biodiversity Act, Alien and Invasive Species regulations that came into force in October 2014. This process encouraged stakeholder ownership and ensured the buy-in of all stakeholders into the national regulations. Being able to demonstrate that participants can potentially influence decisions will likely increase willingness to be engaged in the process in future.

Step 9. Implement and monitor management

Once a management strategy is accepted and published, it can be implemented (e.g. Borja et al., 2010; van Leeuwen et al., 2014; Vreysen et al., 2007). Essentially, coordinated and collaborative partnerships with capacity and funding are almost always necessary to successfully implement a management strategy. Moreover, there must be the involvement of a champion to ensure that, when underway, management is implemented and the objectives and time frames are met (Wilson et al., 2017).

If the management strategy was co-designed and accepted by all key stakeholders, conflicts around the implementation should be minimal. However, during implementation, other stakeholders with views against management actions might materialise. As such, if the management strategy was co-designed with stakeholders or if it was designed through a scientific assessment, providing sufficient information during management interventions (e.g. explanatory billboards in the managed area, websites or Facebook pages) might help to reduce conflict with potential stakeholders previously not involved in the engagement process. Therefore, this step must include ongoing communication between different parties to make sure that, as much as possible, all stakeholders are informed about actions taken, so that their trust is maintained.

The effectiveness of the management actions needs to be measured at appropriate intervals. Monitoring should be established based on a set of target actions with related indicators of success/progress associated to the main objectives stated in the management strategy (Shackleton et al., 2017). However, limited resources can make it difficult to effectively monitor management actions across large areas (Crall et al., 2010). In such cases, this process can be facilitated by engaging different stakeholders (e.g. through citizen science initiatives), making it time and cost effective. Involving stakeholders through citizen science for monitoring and surveying alien species has been used in numerous instances and shown to encourage participation and ownership (Delaney et al., 2008). For example, in Texas, citizen scientists are trained to detect the dispersal of invasive species and report them into an online mapping database. This program, known as "Invaders of Texas" is focused on long-term surveying and monitoring of invasive species (Gallo and Waitt, 2011). Another example is "Invasoras.pt", a Portuguese program that engages the general public to support the management of invasive species. One of its core elements is a WebMapping platform that intends to engage volunteers to geolocate invasive plants in Portugal (Marchante et al., 2016). A similar web-based platform encourages citizens in different regions of Canada and the United States to use their smartphones to report invasive species sightings (eddmaps.org).

Decision D. Is there still need for management?

If monitoring results indicate that there is no longer need for management, no further interventions are needed. However, if only a subset of the management objectives has been achieved, if unanticipated conflicts occur during implementation, or if new management objectives have to be designed, further steps need to be followed (i.e. proceed to step 10).

Step 10. Identify any new stakeholders, benefits, and costs

During the implementation of the management strategy, new stakeholders, new benefits and new costs of the target species and its management might arise. Some key stakeholders, particularly among the general public, only emerge after the management intervention is implemented. These are often highly motivated and influential stakeholders that can help or hinder management programmes. Examples of newly emerging stakeholders are residents in areas that are treated for invasive plants removal, who are fearful of being affected by chemical spraying (e.g. Myers et al., 2000).

Decision E. Are there changes?

If any changes are detected, a new engagement process (Step 2) should be initiated. In case no changes are detected, step 11 should be followed.

Step 11. Monitor stakeholders’ perceptions

During implementation, stakeholders might lose or gain interest in the management strategy – e.g. satisfaction with the participatory process may be affected by management outcomes

(McKinney and Field, 2008). In this case, stakeholder perceptions need to be re-assessed following the same approach as in Steps 3 and 7.

Decision F. Are stakeholders willing to collaborate?

If the assessment reveals that stakeholders' perceptions changed during implementation, it is important to understand why (Step 3). However, if stakeholders' perceptions did not change, one can proceed to step 12, in order to revise the management strategy adopted.

Step 12. Revise management strategy

Before continuing with the implementation of the proposed management strategy, all management objectives, lines of responsibility and time frames should be revised. If all of these are still appropriate, implementation can continue. However, if they are deemed to be no longer adequate, before implementation, they should be adapted with the key stakeholders or the scientific assessment team.

Discussion

Acceptance of the management of alien species by all stakeholders — from the decision makers that allocate funding for management, to organizations that help implement management actions, to the industries that might lose commercial opportunities, to local people who care — is needed if costly conflicts are to be avoided. However, many stakeholders are often not aware of the suite of impacts caused by alien species and the potential benefits of management, which results in a lack of collaboration and support for management (Courchamp et al., 2017). Moreover, since the management of alien species often involves restrictions on trade, the use of chemicals or biological control agents or the extermination of valued species, management actions are regularly challenged by social conflicts among stakeholders (Crowley et al., 2017a).

Aiming to minimize such conflicts and promote collaboration, we propose a framework based on the principles of stakeholder engagement – i.e. the process by which an organization involves all who may be affected by or can influence the implementation of its decisions in a decision making procedure (Carroll et al., 2005). The framework we propose includes information on the steps that can be followed, and the techniques that can be applied, to engage stakeholders in issues relating to the management of alien species. The proposed framework provides opportunities for collaboration, in order to further align management practices with stakeholders' needs and expectations. Therefore, we believe this framework can help managers and policy makers develop and implement conflict-reduced management strategies with the buy-in of stakeholders.

This framework was developed in part on the basis of what has already been done in real-world situations (see for example Novoa et al., 2016 for steps 1, 3, 4, 5, 6 and 7). However, the proposed framework still needs to be implemented in its entirety and tested for its applicability. Nonetheless, we envisage that it will be of great help for practitioners to develop successful alien species management strategies.

When using the proposed framework, some factors need to be taken into account. Firstly, we acknowledge that the management of each alien species or group of alien species involves a unique configuration of stakeholders, context and issues. Therefore, we caution that, in some cases, due to a lack of funding or capacity, or to the presence of unavoidable conflicts, it might not be possible to achieve collaboration among all stakeholders. In such cases, options include proceeding with legal measures to ensure compliance with actions approved by relevant authorities, promoting various levels of tolerance of the target alien species, or setting up a formal scientific assessment process (Scholes et al., 2017). As previously mentioned, these approaches might trigger management conflicts, which can drain resources and create distrust (Crowley et al., 2017a). Therefore, they should only be used when engagement is absolutely not possible and they should incorporate deliberative and participatory processes such us structured decision-making or social impact assessment (Crowley et al. 2017b).

Finally, the scale and duration of the engagement process are also influenced by the available resources (both human and monetary). It can be costly to organise several workshops or certain stakeholders might not be able to afford attendance. But we would strongly argue that this process should not be seen as an optional extra. The costs of a conflict arising later in the management process will likely vastly outweigh the costs of considering stakeholders early in the process. Moreover, such conflict can prevent any form of management and hamper any future attempts.

Conclusion

Conflicts between stakeholders can hamper environmental management actions (Cole, 1993; de Wit et al., 2001; Airlanghaus, 2005). Stakeholder engagement, by considering more comprehensive information inputs (Reed et al. 2008), is recognized as essential for developing effective, equitable, sustainable and conflict-free environmental management strategies (Grimble and Wellard, 1997; Jolibert and Wesselink, 2012; Colvin, 2016). Therefore, by placing stakeholders at the centre of the development and implementation of the decision process dealing with conflicts of interest in alien species, our framework provides a workable and effective approach to reduce the risk of failing to implement alien species management strategies.

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General Conclusions and key recommendations

This research aimed at undertaking a socio-economic analysis of the management and control of *R. alceifolius* in Réunion Island. Here, I reviewed the significant findings of each chapter, describing the positive and negative impact of the biological control programme. The posture taken in this research study is of utmost consideration, as it entailed an analysis of the work undergone by and for the research centre, in order to assess its work which corresponded to a form of self-appraisal. The evidence is displayed objectively with a set of recommendations. The final outcome of this is to propose a list of key ingredients that would assist the foundation of future biological programme.

Key results

The management options of the biological control programme of *R. alceifolius* necessitated a multi-disciplinary approach to address economic, ecological and anthropological questions (**Error! Reference source not found.**). The economic analysis of the control of *R. alceifolius* (Chapter 2) showed and predicted the cost-efficiency of biological control as opposed to mechanical control in lower elevation range (0-800 m) from 1997 to 2030. An integrated approach should be favored and maintaining mechanical control is mandatory in upper elevation range (800-1500 m), with a secure funding on the short and long term.

In terms of ecological benefit (Chapter 3), the biological control programme was a success in tropical forest communities. The biological control programme resulted in a decrease in the cover of the targeted species, *R. alceifolius*, from an average of 52 % to 22 %. The positive impact of this programme was the recovery of native species' richness and cover. The negative impact that should be taken into account is the increase of non-native species on the forest edge. The opening of forest areas for roads or trails would potentially increase the invasion of *R. alceifolius* pathways.

This study highlights the importance of involving stakeholders at large in dealing with a biological control programme (**Error! Reference source not found.**). First, the socio-anthropological research demonstrated that a weak involvement of identified stakeholders in biological programme generated conflicts (Chapter 4). In the case study, a lack of communication prevailed since from a legal prospective, there were no binding requirements to establish a communication strategy for such a programme. The existing policies during the setting-up and implementation of the biological control programme did not cater for the prerequisite of a communication plan. The local, governmental or regional authorities represented by the Regional council or the EU had no obligation to include a communication plan within the management of *R. alceifolius*. The setting-up and implementation of a communication strategy would fall under in the management invasive species within the code of environment (Chapter 5).

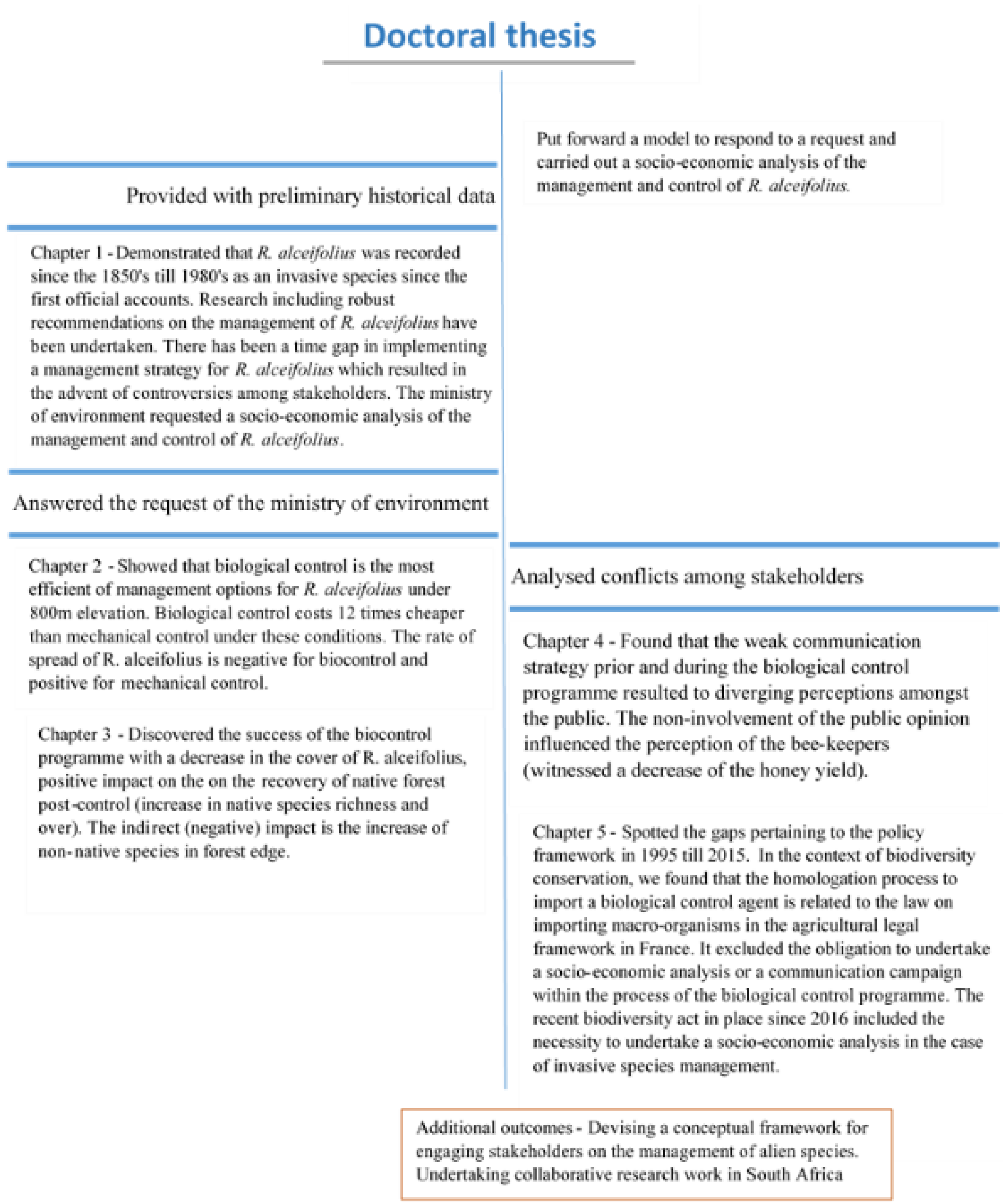

Figure 6-0-1: The multi-disciplinary results of this research work and conclusion.

The posture adopted throughout this research work

Generally, there are more biological research than sociological research on biological control programme. There is a lack of recognition from findings in social studies related to such programme. The restitution of social scientist findings to researchers on their investigation of scientific controversies are usually highly criticized (Callon 2005). This thesis answered a request from the French Ministry of environment to conduct a socio-economic analysis of the management and control of the invasive alien plant *R. alceifolius*. The main difficulties encountered in this multi-disciplinary research work was to integrate socio-anthropological study with a more classical biological investigation. It was highly challenging to keep a neutral posture based on CIRAD and to write objectively and critically about the role of CIRAD within the biological control programme. This posture required negotiations among researchers in biological sciences, though it meant impeding on a classical way of analyzing biological control. This novel approach includes the analysis of public opinion, stakeholder's involvement and a societal study at large, a novel way to do research by conducting an inter-disciplinary study.

The findings of this thesis was summed-up into the following list of recommendations targeting local authorities, governments and institutions related to both biological sciences and social sciences.

Key ingredients for setting up a biological control programme

This research work has generated several results comprising of prime guidance in the management of invasive species in the preliminary phase of devising biological control programme and prior to the release of the identified control agent.

Undertake socio-ecological studies

It is strongly advised to undertake a socio-anthropological study to identify key stakeholders related to the targeted species or the control agent.

This study has shown that the stakeholders (mainly beekeepers) were poorly represented in the process of decision-making in the management of invasive species and in devising a biological control till the release of the selected host species. The public opinion on facts linked to description of invasiveness of species should be studied at the preliminary stages of its management (Chapter 4). It is required to take a step backward to comprehend the initial perception of the public, the governmental authorities and institutions of an invasive species and its management.

Conduct an economic analysis

An economic analysis should first be measured to assess the cost of control, but an in-depth measure of the cost of biodiversity is needed to further analyze cost and benefits.

The various costs of control of a targeted species should be estimated as well as the costs of invasions on income-generating activities (Chapter 2). To be able to undertake a cost-benefit analysis of the management options of the targeted species, the cost linked to biodiversity or ecosystem services should also be evaluated.

Set-up hybrid forum to engage the public opinion and identify key stakeholders

Stakeholders should be involved since the inception phase of the biological control programme. It is crucial to identify and engage key stakeholders through the programme.

It could be a challenging task in being able to identify stakeholders who are directly or indirectly, linked to a targeted species. Engaging stakeholders might be a crucial approach in managing problems allowing stakeholders involved in the process to act upon it. A hybrid forum should be set-up as a platform gathering technical and social actors, explaining in terms of governance the level of involvement of the civil society (Callon, Lascoumes, and Yannick 2001). The forum would allow preliminary dialogues with the implications of stakeholders that would provide with further dialogue on the management of a targeted species.

Devise a robust communication strategy

A communication strategy should be funded pre and post biological control programme, with identified communication plan and tools.

The analysis of Public Action instrument in Lascoumes & Le Galès (2005) showed how communication is in the centre of each project. Conflicts among stakeholders often arose due to diverging opinions since no communication plan has been put in place (in the case of beekeepers see chapter 4). In France, the new biodiversity act (*loi biodiversité*) recommend for communication on the invasive species.

Re-inforce legal and policy framework

It is highly recommended to work closely with governmental institutions as a collaborative work to communicate on strengths and weaknesses of existing policy framework.

This would allow the strengthening of existing policies to enhance risk analysis procedures during the preliminary steps of the homologation of the control agent till the implementation of the biological control programme.

A gap in the policy framework in terms of no guidelines to put the societal impact as a priority in a biological control programme, could result into conflicts among stakeholders. There is a need to bring a bridge to include societal impact in risk assessment analysis when undertaking the homologation process of a selected control agent with the management plan for invasive species.

One way to re-inforce the policy framework is by looking into efficacious case studies. The worldwide reference in national regulatory framework is New Zealand having a Biosecurity act since 1993 and a hazardous substance and new organisms act since 1996 (Simberloff 2013). These acts correspond to a strong framework that prohibits the arrival of potential species. A rigorous protocol with trained boarder security at entry ports (airports and seaports) allow the necessary precautions to avoid and entry of species. New Zealand should be put forward as an example at global, regional and island scale.

With the advent of a very new act for biodiversity, France should re-enforce the new legal framework based on past failures and success at global scale. The first example of a successful biological control programme favoring the protection of threatened biodiversity, took place at island scale in Réunion Island.

Secure funding for short and long term management

Funding should be secured in the management of IAPs on the short and long term. The support from the governmental authorities is crucial to avoid controversies on biocontrol.

Van Wilgen, Moran & Hoffmann (2013), demonstrated the necessity to ensure a long term budgeting in the strategy of IAPs management to establish its positive impact. The strategy should cover the control measures, restoration programme, land-use management and adapted plan depending on the site's priority. Any income-generating activities in relation to the IAPs management should be favored. It could be in the form of job creation or tourist's sites (if related to biodiversity areas).

An integrative management and collaborative approach

It is compulsory to ensure that the management of IAPs is carried out in a close collaboration with all governmental organisations, practitioners, managers, non-governmental organisations.

An integrative management should be aiming at the optimum control of IAPs to protect the threatened biodiversity and for an adequate land-use management, by working together in a good team spirit. A good knowledge of IAPs is required in terms of its biology, its control and distribution.

An integrated management on the short and long term with a robust collaboration within institutions including administrators, researchers and practitioners is required

(a) Beekeeper's syndicate providing training.
(b) National Park staff undertaking surveys with CIRAD and the Université de La Réunion.
(c) CIRAD researcher analyzing data.

(d) Regular field work with CIRAD and National Park staff.
(e) Forestry services undertaking mechanical control.
(f) Beekeeper expressing his concern on invasive plants.

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Annex 1

The estimated surface area of *Rubus alceifolius*

Mapping

As no estimate of the surface area of *R. alceifolius* was available, we mapped the surface of *R. alceifolius* in time. We used orthophotography images (Table 1) from the French National Mapping Agency (IGN) maps prior to the possible efficacy of biocontrol, for the years 1997 and 2008 based on natural colours Blue Green Red (BGR) photography and Near Infra-Red (NIR) with a resolution of 1m and 0.5m respectively. We selected SPOT 6-7 Satellite Sensor images based on spectral bands for 2016 with a resolution of 1.5m after compiling BGR and NIR images with panchromatic ones.

For the districts of Saint-Benoît and Plaine des Palmistes, the criteria used to detect *R. alceifolius* were based on a fine scale within which the yellowish-green colour of the invasive plant was discriminated with a unique squared scratch pattern that is easy to detect from mapping images. We chose eCognition software (Trimble Germany GmbH, 2014) to extract, from images of 2008 and 2016, homogeneous pixels generated by a multiresolution segmentation algorithm (Blaschke et al., 2000; Blaschke, 2010). The objects, then created, were imported in R software (R Core Team, 2016) as a table with 46 variables based on topological features. We classified these objects with a Support Vector Machine (SVM) supervised classification algorithm (Tong & Koller, 2001; Dupuy, Barbe & Balestrat, 2012) with kernlab package (Karatzoglou et al., 2004). The learning data base used for the SVM algorithm was created manually with QGIS software (QGIS Development Team, 2017) by a committee of experts. Finally, visual validation was undertaken on the whole detected patches of *R. alceifolius.*

Based on detected polygons in 2008, we then manually constructed polygons from the image of 1997 by modifying, adding or removing them accordingly.

This approach estimated the evolution of *R. alceifolius* in time for scenario 2 (which is equivalent to scenario 1 before 2008) and scenario 4. For the no control scenarios (3 and 5), we estimated the evolution of the surface area of *R. alceifolius* by calculating buffers around polygons of 1997.

Table 1 shows the mapping systems used to detect *R. alceifolius* before biocontrol and post biocontrol.

Year	**Spectral band**	**Spatial resolution (m)**	**Type**	**Mapping techniques**
1997	Blue Green Red (BGR)	1	Airborne-IGN	GIS mapping
2008	BGR and NIR	0.5	Airborne-IGN	GIS mapping and remote sensing
2016	BGR and NIR	6	Satellite Spot6-7 constellation	remote sensing
2016	Panchromatic	1.5	Satellite Spot6-7 constellation	remote sensing

Estimated surface area under each scenario

Scenario 1

In both forest areas and sugar cane fields, scenario 1 has been mapped for 1997 and 2008 since during these years, it was the only control method prevailing. However, scenario 2 with biocontrol is considered as the actual referred scenario, and since biological control worked best in lower altitudes, we could not have mapped scenario 1 for 2016.

Scenario 2

In both forest areas and sugar cane fields, for 1997 and 2008, we used the available map of scenario 1, since the biological control agent has been released and was efficient after 2008. Therefore, scenario 2 has been mapped for 2016.

Scenario 3

In forest areas, we selected the mapped areas for scenario 1 in 1997 and 2008 to estimate the surface area of *R. alceifolius*. Since the forestry services have potentially eradicated 0.03ha of *R. alceifolius* per year we added a cumulative amount of 0.03ha from 1997 to 2008. In sugar cane fields, we selected the mapped areas for scenario 1 in 1997 to estimate the surface area of *R. alceifolius.* For 2008, we first undertook an intersection between a buffer 11m created around the polygons of *R. alceifolius* in 1997 and intersected with polygons of sugar cane fields. We used the result to join with the polygons of *R. alceifolius* in 2008.

Scenario 4

In both forest areas and sugar cane fields, scenario 4 has been mapped for 1997, 2008 and 2016 since above 800 m, it was the only control method prevailing.

Scenario 5

We selected the mapped areas for scenario 4 in 1997 and 2008 to estimate the surface area of *R. alceifolius* for no control. Since the forestry services have potentially eradicated 0.03ha of *R. alceifolius* per year we added a cumulative amount of 0.03ha from 1997 to 2008. In sugar cane fields, we first undertook an intersection between a buffer 11m created around the polygons of *R. alceifolius* in 1997 and intersected with polygons of sugar cane fields. We used the result to join with the polygons of *R. alceifolius* in 2008.

Forest areas

We used the official Maps of forest areas form the National Park and the forestry services (*Office National des Forêts*) to investigate on the surface area of *R. alceifolius* explained in the table below:

	1997	**2008**	**2016**
Scenario 1	Mapping	Mapping	NA
Scenario 2	Mapping	Mapping	Mapping
Scenario 3	Mapping	Mapping We used the polygons of *R. alceifolius* in 2008 and added 0.03ha annually (success in mechanical control of 0.03ha per year)	NA
Scenario 4	Mapping	Mapping	Mapping
Scenario 5	Mapping	Mapping We used the polygons of *R. alceifolius* in 2008 and added 0.03ha annually (success in mechanical control of 0.03ha per year)	Mapping We used the polygons of *R. alceifolius* in 2008 and added 0.03ha annually

Sugar cane fields

We intersect the following maps of *R. alceifolius* with sugar cane fields obtained from the department of agriculture food and forest (*Direction de alimentation agriculture et forêt*) shown in the table below:

	1997	**2008**	**2016**
Scenario 1	Mapping	Mapping	NA
Scenario 2	Mapping	Mapping	Mapping
Scenario 3	Mapping	We first undertook an intersection between a Buffer 11m created around the polygons of *R. alceifolius* in 1997 and intersected with polygons of sugar cane fields. We used the results to join with the polygons of *R. alceifolius* in 2008	NA
Scenario 4	Mapping	Mapping	Mapping
Scenario 5	Mapping	We first undertook an intersection between a Buffer 11m created around the polygons of *R. alceifolius* in 1997 and intersected with polygons of sugar cane fields. We used the results to join with the polygons of *R. alceifolius* in 2008	We first undertook an intersection between a Buffer 8m created around the polygons of *R. alceifolius* in 2008 and intersected with polygons of sugar cane fields. We used the results to join with the polygons of *R. alceifolius* in 2016

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Annex 2

Species name

Name	**Status**
Acalypha integrifolia	Native
Acanthophoenix rubra	Native
Adenanthera pavonina	Non native
Agarista salicifolia	Native
Allophylus borbonicus	Native
Alocasia sp.	Non native
Ananas cf.bracteatus	Non native
Ananas sp.	Non native
Antirhea borbonica	Native
Antidesma madagascariensis	Native
Aphloia theiformis	Native
Apodytes dimidiata	Native
Ardisia crenata	Non native
Artocarpus heterophyllus	Non native
Asplenium cf.nitens	Native
Badula barthesia	Native
Badula borbonica	Native
Badula grammisticta	Native
Badula sp.	Native
Begonia cucullata	Non native
Begonia salaziensis	Native
Bertiera borbonica	Native
Bertiera rufa	Native
Boehmeria macrophylla	Non native
Boehmeria penduliflora	Non native

Calophyllum tacamahaca	Native
Casearia coriacea	Native
Cassine orientalis	Native
Chassalia corallioides	Native
Chionanthus broomeana	Native
Citrus aurantiifolia	Non native
Citrus aurantium	Non native
Claoxylon glandulosum	Native
Claoxylon parviflorum	Native
Clematis mauritiana	Native
Clidemia hirta	Non native
Cnestis glabra	Native
Coffea mauritiana	Native
Coix lacryma-jobi	Non native
Cordemoya integrifolia	Native
Cordyline mauritiana	Native
Cyathea borbonica	Native
Cyathea cooperi	Non native
Cyathea excelsa	Native
Cyathula prostrata	Unknown
Danais fragrans	Native
Desmodium incanum	Non native
Desmodium repandum	Native
Dioscorea alata	Non native
Diospyros borbonica	Native
Diospyros digyna	Non native
Dombeya sp.	Native
Doratoxylon apetalum	Native
Drypetes caustica	Native
Elatostema fagifolium	Native
Elettaria cardamomum	Non native
Elephantopus mollis	Non native
Erythroxylum laurifolium	Native
Ficus lateriflora	Native
Ficus mauritiana	Native
Ficus reflexa	Native

Forgesia racemosa	Native
Gaertnera vaginata	Native
Geniostoma angustifolium	Native
Geniostoma borbonicum	Native
Hernandia mascarenensis	Native
Hiptage benghalensis	Non native
Hippobroma longiflora	Non native
Homalium paniculatum	Native
Hubertia ambavilla	Native
Humbertacalia tomentosa	Native
Hyophorbe indica	Native
Impatiens sp.	Non native
Impatiens walleriana	Unknown
Isachne mauritiana	Native
Justicia gendarussa	Non native
Labourdonnaisia calophylloides	Native
Lantana camara	Non native
Lantana sp.	Non native
Leea guineensis	Native
Litsea glutinosa	Non native
Ludwigia octovalvis ?	Native
Machaerina iridifolia	Native
Mangifera indica	Non native
Melicope borbonica	Native
Melicope obscura	Native
Melicope sp.	Native
Memecylon confusum	Native
Mimusops balata	Native
Molinaea alternifolia	Native
Monimia rotundifolia	Native
Mussaenda arcuata	Native
Mussaenda landia	Native
Nephrolepis abrupta	Native
Nephrolepis biserrata	Native
Nuxia verticillata	Native
Ochrosia borbonica	Native
Ochropteris pallens	Unknown

Ocotea obtusata	Native
Pandanus montanus	Native
Pandanus purpurascens	Native
Piper borbonense	Native
Pittosporum senacia	Native
Poaceae sp.	Unknown
Polyscias repanda	Native
Procris pedunculata	Native
Psathura borbonica	Native
Psiadia boivinii	Native
Psidium cattleianum	Non native
Psiadia laurifolia	Native
Psiloxylon mauritianum	Native
Rubus alceifolius	Non native
Rubus rosifolius	Non native
Ruellia brevifolia	Non native
Schinus terebinthifolius	Non native
Scleria sieberi	Native
Secamone dilapidans	Native
Setaria barbata	Non native
Sideroxylon borbonicum	Native
Smilax anceps	Native
Solanum americanum	Non native
Solanum mauritianum	Non native
Stachytarpheta jamaicensis	Non native
Stachytarpheta sp.	Non native
Stenotaphrum dimidiatum	Non native
Syzygium borbonicum	Native
Syzygium cordemoyi	Native
Syzygium cumini	Non native
Syzygium cymosum	Native
Syzygium jambos	Non native
Syzygium sp.	Unknown

Tabernaemontana mauritiana	Native
Tambourissa elliptica	Native
Terminalia bentzoë	Native
Toddalia asiatica	Native
Trema orientalis	Non native
Tristemma mauritianum	Unknown
Turraea ovata	Native
Turraea sp.	Native
Vanilla planifolia	Non native
Vepris lanceolata	Native
Vernonia fimbrillifera	Native
Weinmannia tinctoria	Native
Xylopia richardii	Native

Annex **3**

Diving into the policy framework for a biological control programme in managing alien species: a case study in the Mascarene Archipelago

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Abstract

The use of control methods to mitigate invasive alien species can be highly controversial depending on the perception of the invasive species and its relative management options. In the process of using biological control method to manage and control invasive species for natural resources management, the preliminary steps are related to the existing legal framework in the setting up of a given control programme. Public, scientific and governmental visions on such biological control programme or the introduction of a control agent are usually diverging. Following past conflicts world-wide in the management of invasive species, stakeholders' involvement is key to understand conflicts. School of thoughts in social science, anthropology and analytical science have been working independently in the field of alien species management. Biological control programme often lacks a socio-anthropological perspective that could impact positively or negatively on the expected results of the programme. When the control of an invasive species is related to an economic outcome, it is imperative to assess the impact of controlling such species classically in the form of a socio-economic analysis. However indirect impact linked to the same anthropogenic services are very difficult to detect and might be identified through in-depth studies or only when conflicts aroused post-biocontrol. We use the principle of Public Action Instrument to understand the relationship between the governmental decision and the response of the public transformed into disputes within a public arena. We inquired on the causes of problem formulation among the state and the general public, including committed local institutions, which enabled us to determine the background for disputes. We first assess the grey literature on the homologation procedure, its amendments till 2016 and identified the gaps related to implementation of a biological control programme. We then looked into the techniques and rational behind the choice of the biological control agent till its release. We then identified the driving factors around the biological control programme to provide with recommendations for upcoming control programme to avoid societal disputes. We found out that there is a need for public awareness prior and in the course any biological control programme. In addition, the policy framework in place to release the biological control lacked risk assessment procedures in mid-2000. The new French biodiversity law of 2016 (*Loi biodiversité* 2016) has modified past policies and has now the preliminary procedures on risk analysis and safety concerns necessitating authorizations for future biological control release.

Keywords: beekeepers, disputes, invasive species, public action instrument, risk assessment, stakeholders.

Introduction

During the 1990's the risk assessment protocol in the introduction of a biocontrol agent in France, was applied to the policy text for agricultural practice as none was in place for biodiversity conservation. The policy framework had no mandatory elements in including any socio-economic or socio-anthropologic studies prior to the selection or release of the biocontrol agent. Here we describe the gaps in the policy framework which lead to a dispute post-biocontrol programme. The control agent *Cibdela janthina* (Hymenoptera: Argidae) was selected to manage the invasive plant, *Rubus alceifolius* in Réunion Island, a French department located in the Mascarene islands. An economic analysis was carried out to estimate the cost of invasions under management options from 1997-2016 with predictions till 2030. The economic analysis showed than under 800 m above sea level (a.s.l) biological control was 12 times cheaper than mechanical with chemical control and the sugar can industry benefited from avoided cost of invasions (Cybèle C. et al. 2018, unpublished data). A five-year assessment of the positive and negative impacts of the biocontrol programme on native forest recovery was undertaken.

Risk assessment procedures for biological control

Biological control can be linked to other control strategies such as mechanical or chemical control to optimize the management needs. Since its advent in the late 19th century, the use of a biological control agent to reduce the population of an invasive species was usually seen as a risky option. The use of an alien species to counter another invasive alien species brought uncertainties on the robustness of such measures put in place. The beginning of the strengthening of risk assessment methods for the selection of a host specific control agent was brought about in 1974. Wapshere (1974), introduced a robust procedure on the establishment of specificity tests for the biological control of weeds. Wapshere (1974) explained the importance of undertaking a centrifugal phylogenetic or taxonomic studies to be able to choose non-target species in testing potential entomophagous control agents. Indeed, the paucity of studies on the impact of biological control on non-target species has been noted with the arrival of failures (Howarth and Koebele 1991). There are few cases of failures of using biological control in Australia where the introduction of Bufo marinus (Cane toad) 80 years ago to control insects, has proved to be unsuccessful since the Cane toad became highly invasive (Phillips et al. 2006). Hawaii has witnessed an important amount of introduction of biological control agents. (Messing and Wright 2006) explained that Hawaii is an outstanding area of biological control programme in the world as, out of the 243 host species, 53 attacked non-target species. One of the most studied failure of biological control in Hawaii is that of the small Indian mongoose (*Herpestes javanicus*) brought to control the rats but unfortunately predated on the endemic bird (Messing and Wright 2006). The small Indian mongoose was also introduced in Mauritius, Fiji and in the West Indies for the target species which also impacted on non-target native species. Scarce research on the impact of the control agent post-biocontrol might result in unforeseen consequences through competition with native species or effects on ecosystem. Simberloff & Stiling (1996) showed that the introduction of *Myxdoma* virus to control rabbits in Great Britain was successful except for the fact that the rabbits in turn were previously creating open zone within which ants were nesting. The loss of ants, due to the control of rabbits, resulted in the extinction of endemic butterfly (Simberloff and Stiling 1996). If there are necessary records of a host species with its habitat, it is imperative to create an initial valuation of the possibilities of the host species' range (Sands and Driesche, n.d.). The centrifugal phylogenetic testing of the host species has to be studied, as a preliminary precaution for safety issues, by putting related plants (of the same phylogenetic level) which are closely related to the targeted plant species as it would allow the determination of the host species' probable polyphagous traits (Wapshere 1974). The test should also include the feeding niche, ecology and ecosystem effects (Simberloff and Stiling 1996). The host-range and the feeding behavior of the biological control agent potentially attacking target or non-target species should be studied (Messing and Wright 2006). Few biological control agents could be niche specific or habitat oriented with potential effect to non-target species (Howarth and Koebele 1991; Kuhlmann et al. 2006). In North America the biological control agent was used to control *Ceutorhynchus obstrictus* the cabbage seedpod weevil, of the same *Ceutorhynchinae* subfamily as other insects' pests present (Kuhlmann et al. 2006). Knowing possible non-target species would mainly allow to anticipate the host specificity of the selected biological control agent (Kuhlmann et al. 2006).

The premises of risk assessment in the homologation of a biological control agent in Europe has been established based on the International Plant Protection Convention and the Food and Agriculture Organization which published a Code of conduct in 1996 providing procedures on the process of releasing a biological control agent. This code of conduct is the basis of the safety guidelines for a biological control agent by the European and Mediterranean Plant Protection Organization (Schulten 1997). Countries within Europe now follows the guidelines of the European Union (EU) put in force in 2014, (Regulation No 1143/2014), providing with specific articles related to the risk assessment procedures on the management of invasive alien species. In the EU regulations, no policies are related to risk assessment on the homologation of a biological control agent et EU level but only at country level (European Union 2014). This would allow a country specific management of homologation of control agent. The French protocol in the mid-2000 complies with the EMPPO (2000) and FAO (1996) as main reference in complementary to the country code of environment (L413-1 to 5) and the rural code (L213-1 to 5 and R213-2 to 213-22). The updated biodiversity act in France is based on the rural code in 2015 (code rural - article R258-2 (V). Few studies have notified the importance of including risk analysis of the selected biocontrol agent. Andow, Lane & Olson (1995) described how undertaking a risk analysis on the candidate parasitoid and knowing their population dynamics might be important to avoid threatening endangered native species. Barratt et al., (2010) showed the amendments in New Zealand's regulation, are long and tedious, to investigate on risks towards non-target species including compulsory tests on behavioral reactions between candidate agents, targeted hosts and indigenous or other non-target species. Gibbs et al. (2011) demonstrated through a thorough environmental risks for EU countries that selecting the biocontrol agent, *Torymus sinensis* to control the chestnut gall wasp *Dryocosmus kuriphilus* required a step-wise approach tacking into account possible risks to other native gall wasp hosts or native *Torymus*, though the biological control programme was already successful in Italy.

Stakeholders' perception of a biological control agent in the management of invasive species

Most literature related to environmental risk assessment before any potential use of biological control in the management of Invasive Plant Species (IAPs) do not include an ex-ante socio-ecological analysis. Very few studies are focusing on a social, anthropological perspective on stakeholders' perception of biological control but rather on the management of IAPs (Novoa et al. 2018; Selge, Fischer, and van der Wal 2011a; Moon, Blackman, and Brewer 2015). Very few research has been undertaken on the perception or willingness of the general public to accept or refuse a biological control agent in the context of biodiversity conservation. Some studies have explained the different level of understanding on invasion or the need to manage invasion. (Selge, Fischer, and van der Wal 2011a) showed that the perception of non-native species is diverging and opposing from the perspective of the public opinion. Novoa et al (2018) is an example of research study with the involvement of stakeholders in the management and control of invasive species. The risk-perceptions related to invasive species management are being studied (Estévez et al. 2015), the public knowledge (Selge, Fischer, and van der Wal 2011b; Moon, Blackman, and Brewer 2015), public perception (Bardsley and Edwards-Jones 2006), public preference (Sharp, Larson & Green, 2011) or the study of societal dimension (Schüttler, Rozzi, and Jax 2011) with an emotional affect (Quéré 2012).

Stakeholders involvement in the context of managing alien species can create controversies since the benefits incurred from controlling an alien species might differ from those who benefits from the invasive species (Novoa et al. 2018). The management of invasive alien species could generate conflicts amongst stakeholders beneficiating from them as opposed to practitioners or managers who control them.

The inception of problem formulation between stakeholders in the management of invasive species

The civil society has its opinion of “invasiveness” and closely associated definitions to nature (McNeely 2001) or a “biological control programme”. The notion of invasiveness is seen by (Robbins 2010) from the action of human being himself as invasive and the consequences of landscape modifications rendering more opportunities for biological invasions. While Gröning & Wolschke-Bulmahn (2003) showed how the designation of a native plants as in Germany is a sense of patriotic identity. Therefore, exotic species are considered as foreign and shouldn’t be present within the country. (Fall 2013) provided with a most discursive opinion on the concept of “nativism” by policy making for conservation and the society’s consent of its link to nature. The link is defined contrastingly for biosecurity purposes with the case of the invasion of *Centaurea maculosa* in North America (Fall 2013). The panacea associated with human-environment synergy is often applied to a monospecific governance regime of governmental authorities, privatization or community project used by scholars to explain the link between social-ecological systems. These systems generate shaped solutions allowing the excess use of resources in times of uncertainty (Ostrom, Janssen, and Anderies 2007). To hinder gaps among scholars on social-ecological systems; Social, Economic and Political systems (S) impact positively or negatively on the interactions to outcomes of Related Ecosystems (ECO) (Ostrom 2007). The (S) and (ECO) act by a multitier framework which can be adapted to problematic (in turn generating as much descriptive variable for (S) and (ECO) (Ostrom 2007). Societal conflicts in the context of biological invasion usually become apparent when any definitions (invader, exotic or weed) are shaped due to cultural or political factors (Robbins 2010). Moon, Blackman & Brewer (2015) described the importance of undertaking qualitative survey to obtain the perception of scientists on identified stakeholder's knowledge involvement. This would allow the set-up to devise to put in force policy on invasive species management and recommended that including stakeholders would limit public conflicts (Moon, Blackman, and Brewer 2015). Wolt et al. (2010) explained how problem formulation can be used in devising scenarios in the context of environmental risk assessment with the case of genetically modified plants. This approach underpins risk analysis in finding weaknesses on sensitive subjects for instance genetically modified crops as part of environmental risk assessment (Gray 2012) and could also be used to identify gaps in risk assessment of the homologation of a biological control agent.

The procedural steps to set-up a biological control programme in Réunion Island

Réunion Island, a French department located in the Mascarene Archipelago has undertaken the first release of a biological control agent in favor of biodiversity conservation in 2008 to manage the invasive *R. alceifolius* reported to be highly invasive on the island since 1850's (De Cordemoy 1895). The French state, through the regional council, provided funding to the French Agricultural Research Centre for International Development (CIRAD) to undertake research for potential biological control agents in late 1980's till its release. CABI Bioscience, a leading institution in biological control of IAPs, was appointed to provide with scientific expertise based on the preliminary analysis available from CIRAD. They reported that further specificity tests were needed in terms of the feeding behavior of *C. janthina* to verify survival and larval development previously undertaken in Sumatra, it's country of origin. The specificity tests should have been replicated under identical environmental conditions Réunion Island (CIRAD unpublished report). The guidelines were to undertake more specificity tests for *C. janthina* with other *Rubus species* in outdoor conditions which was a challenge since it had to be in the form of cages within living plant species. CABI Bioscience conclusions were that more rigorous scientific specific tests are needed but the final decisions upon the release of the selected control agent *C. janthina* have to be taken by the decision makers in Réunion Island. The Regional Scientific Council of Natural Heritage (CSRPN) used the precautionary principle of the existing law (La loi du 2 février 1995) whereby in case of lack of certainty, taking into account current scientific and technical knowledge, should not delay the adoption of effective and proportionate measures. This would prevent the risk of serious and irreversible environmental damage having adequate economic cost. This precautionary principle could be used in uncertain situations in favor or economic purposes or environmental threats. The CSRPN issued a favorable decision in mid-2006 in favor of the introduction of *C. janthina* in natural environment with a period of experimentation under tunnel. The release of the control agent was undertaken in 2008 via two introductions (Mathieu et al. 2014) with pullulating of the biological control agent due to the availability of the host species *R. alceifolius.*

Bringing sociology in understanding public's opinion in biological control programme

When controversies involving the study undertaken by researchers or scientist have been analysed in the sociology of translation, it is important to set the methodology (Callon 1984). Callon (1984) explained that in trying to understand a dramatic circumstance. There is a need to take into account the diverging identities of stakeholders (researchers, organizations, syndicates) with their relative problematic stories. This would allow us to understand that each actor evolves in a specific context, linked to its activity or its responsibilities. Perception are put in perspective when we look at innovation which change routine daily activities (Callon 1984). When the subject of controversies is related to nature, a classical methodological selection for sociologist has to be reconsidered where an in-depth analysis of each audiences' opinion should be carried out. Thus data collected or observed should be free of judgement, should contain contradictory point of views and maintain any social or technical transcriptions without altering its source of register (Callon 1984). Involving stakeholders is a mean to share a given governmental programme with a view to gaining the confidence of people and create a sense of social acceptability of the programme (Steyaert et al. 2007).

Public problem, for the most part, holds an unstable nature since the mobilization of people evolved (in thoughts or actions) when it comes to priorities (Lascoumes and Le Galès 2005). This could be shown in this case-study of the biological control programme in Réunion Island. The stakeholders in this programme encompassed a research centre (CIRAD), the governmental authorities (the ministry of environment, the Regional council), beekeepers (professional and syndicates) and the media. The reality perceived from the public (Goffman 1974) is different from rationale of the decision makers or the work undertaken by the research centre in the of the biocontrol agent.

For conservation and management purposes of native forests, mechanical and chemical control have been used as management option to control invasive plants in Réunion Island (Tassin et al. 2009). Mechanical control to manage *R. alceifolius* was initiated in the 1950's by the forestry services to clear land for wood production (J. Miguet 1952). Previous research study on the biological traits of *R. alceifolius* were undertaken (Amsellem 2000; Baret 2002). Biocontrol was later used for the first time in France in 2008 in Réunion Island (Mathieu et al. 2014). A recent multi-disciplinary study of the economic, social and ecological aspects of the biological study was conducted ex post, with a view to identifying the positive and negative impact of the biocontrol programme (Cybèle C. et al. 2018 unpublished data).

The introduction of a detectible biocontrol agent, without the involvement of stakeholders would potentially arouse questions among the public society. If no preliminary awareness campaign has been carried out, a lack of communication would pertain. A socio-anthropological study was engaged in understanding the controversies from key stakeholders. This study now addressed the recommendations on the importance of involving stakeholders, at the present time, referred to decision-making level since the inception phase of the biocontrol programme (Cybèle C. et al. 2018, unpublished data). We then looked into the evolution of the legal framework from late 1990's till mid-2000 to understand the decision taken in the risk assessment procedures in homologating the biocontrol agent, the governance related and any inconsistency. The key stakeholders involved in this procedural conflict are the state, the research Centre and participants within a scientific committee meeting.

First we analyzed the strength and weaknesses in the risk assessment of the introduction of the candidate biological control agent *C. janthina* and its target species *R. alceifolius* in Réunion Island. Secondly we categorized our identified group of social and technical actors as instrumentation in the analysis of the disputes (Lascoumes & Le Galès 2005). The social actors here are beekeepers and the technical actors were the research centre and decision-makers. We then analyzed the reaction of the public opinion towards the decision of the technical actors that later provoked disputes. We investigated on the link between opinion that might have provoked disputes.

Methods

When dealing with controversies on new technologies and innovation adopted in the case of the biological control over classical mechanical control, the problematic with the role of the social and technical actors have to be clearly defined. The aim of the research is to identify and describe the cause of disputes among the public at large in the context of a biological control programme. We used the management of *R. alceifolius* by the phytophagous *C. janthina* in Réunion Island. We first look at the risk assessment protocol implemented in this case study during 1990-2006 and compared with existing protocols. We then looked into how the public's action represented by the beekeepers has been instrumented through the decisions of the technical actors. In this study of the policy framework of France during the 1990's, introducing a biological control agent in the context of natural resources management was a novel initiative. We had to go back to the preliminary decisions linked to the choice of using biological control to manage the invasive *R. alceifolius*. We investigated on the selected protocol through the scientific reports, regional scientific committee reports and official correspondences. We undertook a qualitative study and divided the available data into two main categories; the scientific and technical approach in the biocontrol programme and the sociological angle of such issue. We established the categories into institutions, its causes and related driving factors.

Here we define the sociological position by taking into account the stakeholders involvement throughout this process. We first look into the preliminary suggestion till the decision taken from the local authorities to implement the biocontrol programme. We undertook semi-structured interviews amongst professional beekeepers in Réunion Island and experts of the CSRPN the scientific group providing recommendations (Beaud and Weber 2010). Each interview is transcribed then analyzed using the process of instrumentation. In this process the technical actors reacted to the voiced out disagreement of social actors in their opposition in the implementation of the biological control programme. The division of the core-text of the transcribed interviews generates various fields of common thematic, which are of a general overbroad common aspect. The core-text include minor sensitive thematic that are usually forgotten or suppressed. The conceptual framework adopted is based on Lascoumes & Le Galès (2005) on the public action instrumentation (PAI). It is defined as a group of formulated questions through means of selected tools. Techniques, mode of operations or plan aiming at materializing and putting into place a governmental action. PAI enables to understand the rationale behind an instrumentation of a given public action, in the form of policy implementation, rules and regulations, economic perspectives, communications or information-based. PAI is a socio-political space built around techniques and instruments rather than as a consequence of stakeholders' projects. Functionalism methods are in favor of the objectives set by public policy but PAI transcends this approach in the form of instruments which structures public policy programmes. The actions of government bring the instrumentation of the public as governmental decisions put individuals into a frame allowing to remotely guide their behavior (Foucault 1994 in Lascoumes & Le Galès (2005)). The advent of "newly negotiated governance" whereby the civil society, in the form of organizations gaining power to influence public policy, has also its strength in framing the decision taken under governmental liabilities, at the stake of a government refuting the potential impact of social interest (Salamon 2002). In this analysis, we identified social actors with contradictory point of views thus with controversial version of the disputes for case of the use of a biological control agent in the control of an invasive plant species. We then investigated the components of this dispute allowing the smallest yet key components to be highlighted. The dispute included the research Centre (CIRAD), the French state, beekeepers and experts of the scientific panel (CSRPN). We looked into the published reports since 1988 when the decision of selecting biocontrol was undertaken. Here we tried to establish possible links between the sources of disputes to the homologation process. We divided the analysis of PAI into three categories of instruments in the form of (1) institutions having rules and regulations, (2) The rationale behind the biological control programme and (3) The driving factors expressed as an emotional detector (Figure 4-1). We avoided any stepwise retrospection that might miss or include uncertainties or misinterpretations. Based on the packs of data generated and deconstructed through the PAI, we attempted to understand the divergences of opinions generated by the key actors. From Callon (1984), we established the elementary relationships to show the interest or impairing links that might be obvious or unobvious among the identified problematize institutions (here described as the state, the protocol involving risk assessment, the beekeepers syndicate), the reasons behind the selection of biocontrol and driving factors (identifying emotions).

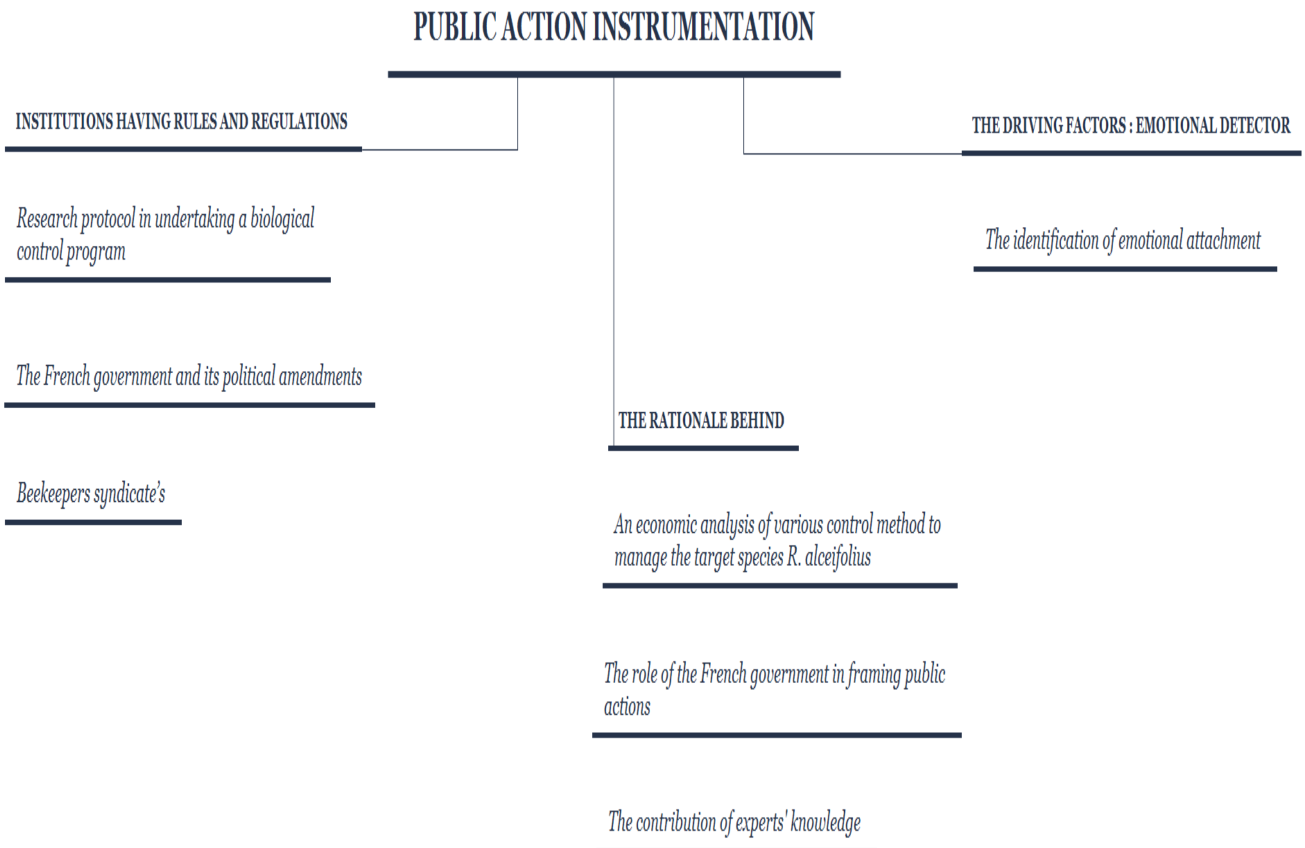

Figure 6-1 : The analysis of the public action instrumentation of the case study of the management of the invasive R. alceifolius in Réunion Island

Figure 4-0-1: The analysis of the public action instrumentation of the case study of the management of the invasive R. alceifolius in Réunion Island

Results and discussion

The scientific and technical approach: policy and legal framework in Réunion Island

It is important to describe the governance system in this context, since the late 1990's when the decision of using biocontrol as a management options for *R. alceifolius*. We looked into the laws enforced related to the use of a biological control agent to manage invasive plant species from 1988 to 2017. Here we describe the governance system and its legal framework to understand how the issue of the management of invasive plant species was dealt with by local institutions and local authorities depending on the policies in place. Réunion Island is classified as a French Overseas Department, "*Département d'Outre-mer Français*", and is under the management of the Departmental council, a sub-region that falls under the Regional council.

In terms of history, at the beginning of human settlement in the 17th century, the mandate of colonizers were to develop the island resulting in rapid deforestation (J. Miguet 1980).

The forestry services was in charge of the management of forest areas with a mandate to develop the island in the mid-20th century through wood production (J. Miguet 1952). It is not until the 1970's that the demand for wood production has decreased (J.-M. Miguet 1957). The forestry services has gradually included management of invasive species in their activities recorded in the 1980's (J. Miguet 1980). The only record of a management of invasive species was devised by (Macdonald 1989) which listed *R. alceifolius* amongst the highly IAPs and provided with a clear set of recommendations on how to manage and control a strategic plan. (Macdonald 1989) stressed on the fact that depending on the impact of the invasive species, priority action of control should be devised and carried out. Such strategic plan has been set-up 26 years later by the forestry services (Triolo 2015) and should have been put in place earlier. A faster strategy might have reduced the impact of the level of invasion in threatened biodiversity areas or reduce its associated cost of control. (Macdonald 1989) also mentioned that in the case of conflicts on the management of an IAP, a socio-economic analysis should be carried out. The recommendations of (Macdonald 1989) have perhaps not been taken into account during the process and implementation of the biocontrol programme nor has it be questioned. It was effective in 2010, when the ministry of environment decided to fund a research programme, post conflict (which arose in 2009) (DEAL 2010).

At the beginning of the project in the 1990's the legal framework in France didn't have a specific biodiversity or wildlife act that included policy on biological control. Prior to 1990 no law related to the management of biodiversity, invasive alien species or the use of biological control agent was in place until later. Very few components on the introduction of non-native species appeared in the *"Barnier"* act of the 2nd February 1995 and was applicable to the programme (Legifrance 1995). The *"Barnier"* act have relevance to the protection of the environment, its habitat, the landscape, flora, fauna and the biological equilibrium. Their protection, restoration, and management should be in the interest of the sustainable development. There is no mention of control measures or risk assessment protocol as such in the act. The precautionary principle is applied if the necessary measures should be put in place if damages to the environment prevails, in absence of scientific certainty. The EU adopted the draft European regulation on the prevention and management of the introduction of invasive species in 2014 (European Union 2014). The spread of invasive alien species in the EU are listed since 2017 for EU ultra-peripheral Region within which include Réunion Island. Since 2016 with the advent of the new Biodiversity act (*loi Biodiversité*) under the code of environment and up to date since the Article L 411-3, is a more detailed environment policy (Legifrance 2016b). It includes the compulsory consultation of the public with information approved research institutes to be able to elaborate of a national management plan on IAS. The management plan has to take into account socio-economic and cultural heritage (Legifrance 2017, 2016a). The code of environment now includes a full section on the management of invasive alien species through Article L411-5 to L411-9 on its prevention and spread (Legifrance 2016a). It also provides the introduction of species except in the case of biocontrol and after an impact assessment. The establishment of an economic analysis was completed by (Cybèle C. et al. 2018, unpublished data) and provide with the premises in the management of IAPs with the case of *R. alceifolius* only.

The homologation process and its political influences

Recalling the first step was to find a biological control agent, located in the country of origin of the invasive plant, in South-East Asia. CIRAD's scientific report complied with FAO 1996 code of conduct for introduction and release procedures of exotic biological control agents (Schulten 1997). This code of conduct has been strongly revised by the European and Mediterranean Plant Protection Organization (EPPO/OEPP) to a later version in 2010 to make it consistent with outcomes biocontrol programmes.

The researchers undertook specificity test on identified pathogens and insects for 4 years. The CIRAD worked in collaboration with the Université de la Réunion, the Indonesia Oil Palm Research, the National Biological Control Research Centre in Thailand. The first step of the regional council was to create the scientific advisory body with scientific competence in the field of natural heritage under the authority of the Prefecture, known as CSRPN (*Conseil Scientifique Régional du Patrimoine Naturel*).

The regional council set-up a step-wise action, since no legal procedures or guidelines were available. It was the first biocontrol programme for natural resources management and biodiversity conservation. The legal framework didn't contain any precise guidelines or strategic documents that could be the basis of the Regional council's actions to set-up the scientific advisory body. The regional council provided funding to set up a project. A bi-monthly meeting was held with a pool of experts from the Université de la Réunion, the Ministry of agriculture (DAF), Ministry of environment (previously DIREN now DEAL), the forestry services (ONF), the botanical museum (CBNM) and the French Agency for Food, Environmental and Occupational Health & Safety (ANSES). Few members commented on the:

"uncomplete analysis of the necessity to undertake the biological control programme. No restoration plan was devised post control, no discussion prevailed on the land-use post-control" (Anonymous expert, December 2017).

Other member explained their perception of the meeting:

"it was more about expert's showing that one knows more than others…its wasn't constructive discussions" (Anonymous expert, November 2017)

In terms of local authorities, a responsible authority has been identified locally in the late 1990's. The preliminary list of identified species as potential biological control agents that would further undergo specificity test of was presented to a Steering Committee of the scientific advisory body. In early 1998, the steering committee helped to provide with expertise, required an official mandatory Ministerial order allowing the control of *R. alceifolius.* In the French legal system, the ministerial order is the official answer by the government for a given request. The CSRPN was appointed as consultative body with scientific competence in the matter of natural heritage falling under the authority of the Prefecture. The members of the CSRPN committee meeting were the Regional Council, DAF, Ministry of environment (DEAL), (ONF), (CBNM), the National Park, Réunion island Environment Organisation (SREPEN), external institutions (FDGDON) and CABI bioscience. Following a meeting held at the CSRPN, with a presentation of the technical file with the report explaining the rationale behind the choice of the potential biological control agent. Two biocontrol agents were identified, *Cibdela janthina and Cleorina Alcidodes* with need to undergo complementary specificity test in Sumatra. All the protocols were developed in consultation with the members of the project team and in partnership with external specialists according to each theme or species studied. *C. janthina* was selected by CIRAD due to its elevation limit to avoid the endemic *Rubus* is found at higher altitudes (Mathieu et al. 2014). The CSRPN found out that the specificity test undertaken by CIRAD was insufficient in terms of testing the biocontrol agent in Réunion Island without any available larvae of *C. janthina*. The CSRPN recommended parallel monitoring of the biocontrol agent and its impact of the control on its contained environment. The CSRPN also recommended for an awareness campaign aimed at the general public in Réunion Island. CABI bioscience provided with their expertise as an external opinion before any final decisions were taken.

The management of environmental affairs previously under the Regional council and now under the General council. The change in governmental structure has modified the procedure for biological control and the project. The General Council a higher instance is now in charge of the homologation of a biocontrol agent and the prefect of the department of Réunion Island is the highest authority in 2005. In May 2006 the Minister of Ecology of the Environment and Sustainable Development visited Réunion island urging the Prefecture urged CIRAD for a synthesis of the results of the biological control research programme of *R. alceifolius.*

"*The minister visited the forest areas of Réunion island with unequipped shoes…her shoes were scratched by the prickly R. alceifolius. She asked why were there so much of the invasive R. alceifolius if the government have been funding so much project to control it and specially a biocontrol programme*" (Anonymous expert, August 2017).

The regional council consulted with the CSPRN committee and requested for an update. Based on the available report from CABI bioscience, the final conclusion was not to release the biological control agent. CABI bioscience explained that CIRAD haven't compared the results of specificity tests (non-target attack, host shift) of the biological control agent conducted in Sumatra with that conducted in Réunion Island. CABI bioscience provided with specific gaps in CIRAD's testing, amongst which the creation of outdoor greenhouse boxes should be more solid, animal proof and should be re-enforced with a double cage. CIRAD was also requested to use larvae from both quarantine reared or natural reared using the same conditions in both Sumatra and Réunion Island. Therefore, CABI bioscience stated that more rigorous scientific testing is required before the release of the biocontrol agent. Despite, CABI Bioscience report, a prefectural authorization was provided for the introduction and release of *C. janthina* end of 2006. A first tunnel was built to enable the acclimatization of *C. janthina* was installed in the Grand Brulé, a barren area in the east area of the island of previous lava flow. The authorization to release the biocontrol agent was granted by the Prefecture of Réunion Island in 2006. The release programme was held with the support of the forestry services and the Municipality of Saint Philippe. There was no public awareness campaign on the release of *C. janthina* as the candidate control agent for *R. alceifolius* though the CSPRN meeting. The report of CABI bioscience mentioned the importance of enquiring for possible risks or benefits of this biocontrol programme.

There was a second assumption around the possible rapid release of the biocontrol agent in 2008. It entailed the possible release of the biocontrol agent, earlier than expected, with all due legal authorization. The sudden volcano eruption of 2007 was bigger than usual and impacted the greenhouses biocontrol testing site:

"*The Volcano in Réunion Island was active and diverted its usual route to close to the greenhouses thereby burning them and releasing the biological control agent.*" (Anonymous experts, August 2017).

The strength and weaknesses of the homologation process of the biological control agent

Here we investigated on the legal procedures for the homologation process in bringing a biological control agent in Réunion Island. Since the advent of the decision for a biocontrol in 1988, no existing law was in place in the code of environment but only for the code of agriculture. The introduction of biocontrol agent is linked to the introduction of a macro-organism to control pest and diseases in the agricultural sector. It included clauses applicable for the environment in the case of biodiversity conservation before 2016 (Legifrance 2017) . In France, the introduction of a non-native species is first linked to the legislatives and regulatory text at order level but no existing law prevailed. Except if an order is issued at the ministerial or prefectoral level. The existing order of 26 February 1195 established the list of non-indigenous macro-organisms useful for plants, in particular in the context of biological control, are exempt from applications for authorization to enter a territory and introduction into the environment. For the case of the introduction of *C. janthina,* a prefectoral order was issued in allowing its introduction for testing in a laboratory only first and then its release.

If the protocol has to be set in 2017, an exotic macro-organism that is not present in Réunion, which is not on an appendix, listing the insects authorized before 2012, the line of action would be different (Legifrance 2014). The first policy framework related to the homologation of macro-organism was put in place first by a decree in 2012 and then in the rural code in 2014 (Legifrance 2012, 2014). First there is a file that should be completed to answer to the health-related organizations. It implied a veterinary organization with a technical vocation, regional health associations and the conditions for delegation of missions related to health controls. If the proposed biological control agent is intended for release in the wild, there is a whole risk assessment analysis that should be done, entailing a long procedure that will take into account all elements set by the ministry of agriculture, the ministry of environment and the ministry of forest. Once this file is completed, it would not go to the CSRPN as it was previously done. The file would be assessed by a committee of experts, the committee of scientific experts of the ANSES in the biological commission, which would gather a panel of French, European experts, covering different fields, botany, entomology and natural resources management. After the reports given by the committee, the Ministry of Agriculture and Ecology would grant the final decision. If we take into account this new protocol, in place as opposed to the ones in the late 1990's, to reintroduce the host species (*C. janthina*) to Réunion Island, we would have to prove that we are going to bring is identical to the one that is present. The procedure are in place and would no longer allow the external decisions based on facts as was the case in 2006 (Legifrance 2014). However, in the pre-requisite of the present risk assessment, there is no direct request to investigate potential risks of the selected biocontrol agent or its targeted species on the public perception. In addition, there are no obligations to find any risks to natural or cultural heritage or economic value.

The social perspective of the biocontrol agent and the honey-bee

A missing point in the protocol in favor of selecting and releasing a biocontrol agent is that the Regional council did not undertake a procedural approach in involving stakeholders. The use of *R. alceifolius* as fodder for bees wasn't thought to be included in the risk assessment studies before the release of a biological control agent.

"During the CSPRN time we did not think about the honey-bee or pollination…but since the issues of conflicts with beekeepers, the questions of honey-bee interaction with a host species is nearly compulsory" (Anonymous expert, December 2017).

Lack of communication

We found that the general public wasn’t involved during the process of selecting a potential agent. Formal institution meeting was initiated in the late 1980’s within which scientific committees was set up to follow the process of the selection to the release of the biocontrol agent.

“*I followed the previous polemic on the news… Well, what is a pity is that there was no communication to warn the people of this front. People were afraid to see blue sawfly everywhere. So I was told that it stung. That people were horribly stung by that while it does not sting. So I was also told of spades, there was the blue sawfly, there were lots of maggots in the dog bowl, while it does not have maggot. That is to say, there is a whole speech, people began to speculate on it without knowing the biology, without knowing and especially they were afraid to see blue flies everywhere. And in fact, I think there was a lack of information. We should have warned them, tell them "take care we set up a biological control device ... There will be some areas with a blue sawfly, so it's normal. Do not worry*.” (Anonymous expert, December 2017).

The weak communication campaign, followed by conflicts among stakeholders, the evolution of existing policies on the management of IAPs have been the driving factors to avoid further gaps in managing IAPs. In response to the request of the French Ministry of environment in 2015, the CIRAD worked on analyzing the social, economic and ecological impact of the control of *R. alceifolius* in Réunion Island (Cybèle C. et al. 2018, unpublished data).

Experts’ knowledge and opinion

The scientific meeting was composed of expert on ecology, biological control, invasive plants from governmental institutions, the chamber of agriculture, the ministry of agriculture, and the non-governmental organizations. The opinions of experts during the committee meeting were very mitigated since they felt that their voices were not being heard during the meetings,

“*The experts provided with recommendations, guidance with contrasting point of views. It was a showcase of experts trying to express their expertise rather than working in a collaborative way*” (Anonymous expert, December 2017)

The role of the beekeepers’ syndicate as instrumentation

The release of the biological control agent in 2008 was undertaken in the east side of the country. The sawfly spread prolifically in the country and could easily be seen on flowering pollineferous and nectariferous trees with a major occurrence on litchi trees (*Litchi chinensis*) and Brazilian pepper tree (*Schinus terebinthifolius*). The presence of *C. janthina* was noticeable by the general public and particularly on pollineferous and nectariferous trees. The high increase of population of *C. janthina* with bees on litchi trees and Brazilian pepper trees has created havoc amongst beekeepers. The local media has broadcasted headlines with key messages against the biological control programme and explaining that a reduction of honey production was indistinctly linked to the presence of *C. janthina.* The actions of the local authorities in this management of IAPs has generated problem amongst the public (Cybèle & Aebi 2018, unpublished data). The more a public action is defined by their instruments, the higher the stakes in generating conflicts between stakeholders, organizations and public interest (Lascoumes & Le Galès 2005 p.28). The causes of the first dispute are the misunderstandings of the presence of an unusual metallic blue colored sawfly on flowering litchi tree. According to Weber, each domination (to the public) is manifested and works as administration (local authorities) and each administration needs a form of any domination. The administration is best adapted form of practices with a legal rational domination (Chazel 1995 p. 179-198 in Lascoumes & Le Galès (2005)). If the civil society takes the lead upon their opinions, it is compulsory to set-up an administrative authority that would support their views, requiring their participation amongst governmental policy decisions. The beekeepers recognized their none-inclusion in the decision-making process prior to the release of the host species (Cybèle C et al. 2018, unpublished data). The professional beekeepers, as social actors, decided to collaborate and set-up a legal institution which would allow them to voice out their concern. The beekeepers syndicate has been created by the beekeepers as a direct reaction of the lack of communication from a top-down direction in explaining the link between the omni-presence of the biological control agent and the bees with the sudden decline in the honey production.

The lack of information has allowed the beekeepers to presume that the blue sawfly was responsible for the decrease in honey production. The beekeepers as a social actor has instrumented in the form of driving factors (honey production) which has later been expressed as an emotional detector in the form of anger and fear (Cybèle C et al. 2018, unpublished data). The beekeeper syndicate went into court against CIRAD, to context on the decrease of the honey-production in 2009. The research centre undertook experiments and found that the *C. janthina* had no impact on honey-production (Reynaud et al. 2010).

Conclusion

The risk assessment for the introduction of selected agents have been undertaken by a researcher of Cirad during the late 1990's till 2006. A very basic protocol has been put in place with imported larvae of the selected agent *C. janthina* from Sumatra. The shortfall in the protocol established, has led to a probable early release of the biocontrol agent. However, the procedure in France in introducing a biological control agent as part of a biodiversity conservation project now entails a scientific research on the level of invasiveness of the species to be controlled, the identification of potential biological control agents with details of their origin.

The dispute among social actors was mainly due to the exclusion of stakeholders in the decision-making process. In the legal framework the risk assessment analysis in the homologation process of a biological control agent, does not require the justification of potential risks to a societal impact such as natural heritage, cultural value, economic value. The new biodiversity law provides with the obligation to request for public opinion on the management of invasive species in addition to undertaking socio-economic analysis. There should be a policy text linking the societal impact within the risk assessment protocol to strengthen the gap between the societal impact and the biological impact.

Communication was a driving factor of the Public Action Instrument that generated speculations among the public opinion. At least two causes of dispute have been identified amongst the social actors of this research study. First is that the social actors have not been mobilized in this decision-making. Secondly the perception of beekeepers thinking that the blue sawfly might be interacting with honey-bees generated speculations. The disagreement among social actors was a result of a lack of communication. Furthermore, this very weak communication strategy to inform the public opinion on the biological control programme showed the reaction of the beekeeper syndicate to claim for information and proof from the research centre.

Our findings demonstrated that it is compulsory to start an analysis including social science, if it is in interests of selecting instruments (Peters 2005). A socio-economic analysis pre-biocontrol programme with a risk assessment studies are imperative for future biological control programme. A communication strategy should be included. This analysis will provide recommendations in the management of IAP in the form of lesson learnt to stakeholders.

The driving factors that have disrupted the biological control programme are the weak communication strategy and the gaps within the policy framework of France. Lascoumes & Le Galès (2005) provided us with a framework to analyze the possible causes of controversies seen from the technical actors and the social actors. However, there is a need to consider the strength and weakness within the new biodiversity act for future homologation process for importing biocontrol agents in France.

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Annex 4

Semi-structured interviews

Entretien semi-directives

Bonjour

« Icebreaker » et présentation générale

1. Pouvez-vous vous présenter s'il vous plait ?
2. Comment vous êtes-vous intéressé à l'apiculture ?
3. Depuis quand êtes-vous apiculteurs ?
4. Est-ce votre activité professionnelle principale ?
5. Etes-vous adhérents à des associations apicoles ? Lesquelles ? Votre rôle ?

Inspiration

6. "Pourquoi vous intéressez-vous aux abeilles ?" Est-ce votre passion ?
7. Avez-vous d'autres passions (activités ludiques entre autre) dans la vie ?
8. Quel est la source de communication que vous préférez ? Et les médias ?
9. Auquel faites-vous confiance ?

Production

10. Et en ce moment, à quel stade de votre production êtes-vous ?
11. Combien de ruches avez-vous ?
12. Quelle quantité de miel produisez-vous ?
13. Ou vendez-vous votre miel ?
14. Quel type de miel produisez-vous ?
15. Comment se présente l'évolution de votre production pour cette année?
16. Pouvez-vous me décrire les problèmes que vous rencontrez en apiculture ?

17. Depuis quand ?
18. Comment trouvez-vous des solutions ?

Connaissances

19. Avez-vous entendu parler de la mouche bleue ?
20. Que connaissez-vous de cette mouche ?
21. Le rôle de la mouche bleue ?
22. Que représente la vigne marronne (ou raisin marron) pour vous ?

Vécu-attitude

23. En 2008-2009 pouvez-vous me raconter votre expérience vécue de la mouche bleue ?
24. Que pensez-vous de la mouche bleue à cette période ?
25. Et 2015-2016 pouvez-vous me raconter votre expérience vécue de la mouche bleue ?
26. Que pensez-vous de la mouche bleue en ce moment ?

Connaissances

27. Comment avez-vous entendu parler de la mouche bleue ?
28. Par quel moyen de communication avez-vous fait votre suivi sur la mouche bleue ?
29. Quelle est la source de communication la plus fiable pour vous ? (Et en terme des médias ?)

La presse, les médias et les acteurs utilisent souvent des mots clés et je souhaiterai savoir ce quels évoquent pour vous :

30. Pouvez-vous me donner votre compréhension de la « lutte biologique » ?
31. Des exemples de la lutte biologique
32. Que comprenez-vous par « une plante envahissante » ?
33. Pouvez-vous me nommer quelques plantes envahissantes à la Réunion ?
34. Connaissez-vous la liane papillon ?
35. Après la lutte contre la vigne marronne (ou raisin marron), quelle(s) espèces a pris de l’avant selon votre expérience ?
36. « La biodiversité » représente quoi pour vous ?
37. Connaissez-vous la notion « d’endémicité », de plante dite endémique ? Pouvez-vous me donner quelques noms ?

Annex 5

Questionnaire survey

<u>Questionnaire aux apiculteurs</u>

Identifiant :

Localité :

Informations générales

1. Prénom et nom:

2. Tranche d'âge :

18-35	36-50	51-60	61-70	>71

3. Depuis combien de temps êtes-vous apiculteur ?

4. Quelle est votre profession principale ?

5. Si retraité, quelle était votre profession principale ?

6. Avez-vous

un jardin	des champs	rien ?

7. (Si jardin ou champs) quelles plantes cultivez-vous?

Les ruches

8. Combien de ruches possédez-vous ?

9. Combien de ruchers possédez-vous ?

10. Dans quel milieu placez-vous vos ruchers ?

	Milieu urbain		Milieu périurbain

	Forêt		Autre (ex. : parc)

11. A quelle altitude ?

12. Dans quelle région placez-vous vos ruchers ? (précisez commune ou quartier si possible)

Nord	Est
Sud	Ouest

13. Pratiquez-vous la transhumance ? Oui Non

14. Si oui, depuis quand ?

Apiculture et médias

15. Comment vous informez-vous sur l'apiculture ?

	Médias		GDS
	Ch. Agri		ADA

	Formations		Autre :

16. Quels médias utilisez-vous pour vous informer sur l'apiculture ? (Par ordre d'importance si possible)

	Presse écrite		Radio
	Télévision		Internet
	Sms		Autre :

Télé

17. Regardez-vous le journal télévisé ? Oui Non
18. À quelle heure?
19. Sur quelle chaîne?
20. Regardez-vous « Terre d'ici » sur Antenne Réunion ? Oui Non
21. Si oui, avez-vous déjà regardé une émission sur l'abeille ? Oui Non
22. Si oui, avez-vous déjà regardé une émission sur le varroa ? Oui Non

Presse écrite

23. Quel est votre magazine ou journal préféré ?
24. Connaissez-vous le magazine « La santé de l'abeille » ? Oui Non

25. Avez-vous entendu parler de l'article « Caractérisation de l'apiculture réunionnaise : chiffres-clés, pratiques et typologie » ? Oui Non

26. Si oui, qu'en avez-vous retenu ?

Radio

27. Quelle radio écoutez-vous le plus pour vous informer sur l'apiculture ? (Par ordre d'importance si possible)

1	
2	
3	

Internet

28. Sur quel(s) site(s) vous informez-vous sur l'apiculture ? (Nom de(s) site(s))

Lutte biologique

29. Avez-vous déjà entendu parler du mot « biodiversité » ? Oui Non

30. Avez-vous déjà entendu parler de la lutte biologique ? Oui Non

31. Comment définiriez-vous la lutte biologique ?

32. Connaissez-vous les intérêts de la lutte biologique ?

33. Connaissez-vous des inconvénients à la lutte biologique ?

Interactions avec l'agriculture

34. Connaissez-vous les « ravageurs » et les maladies des cultures ? Oui Non

35. Si oui, pouvez-vous en citer quelques-uns ?

36. Avez-vous déjà entendu parler du ver blanc de la canne à sucre ? Oui Non

37. Si oui, connaissez-vous les moyens de lutte qui ont été mis en place contre le ver blanc ?

38. Avez-vous déjà entendu parler de « Betel » ou « Beauveria » ? Oui Non

39. Avez-vous déjà entendu parler de la mouche bleue ? Oui Non

(Si non passez directement à la question 51)

40. Si oui, connaissez-vous les raisons de son introduction ?

41. Comment avez-vous entendu parler de cette mouche ? (Plusieurs réponses possibles)

	Vu		Bouche à oreille
	Médias : **Lesquels** ?		Autre :

42. Comment vous êtes-vous tenus au courant de l'évolution de cette lutte biologique ?
(Plusieurs réponses possibles)

	Presse écrite		Radio
	Télévision		Internet
	GDS		Ch. Agri
	ADA		Autre :

43. Votre production a-t-elle été affectée par la mouche bleue ? Oui Non

44. Si oui, sur quels ruchers ?

45. Si oui, à quelle époque ? (année, saison, …)

46. Quel a été l'impact de la mouche bleue sur les abeilles ?

47. Quel article de la presse écrite vous a le plus marqué ? (le sujet, le titre, le nom du journal/magazine)

48. Quelles sont les dernières informations sur la mouche bleue que vous avez prise en compte ?

49. Quelle en était la source ?

50. De quand (quelle année) date ces informations ?

Soutien à l'apiculture

51. Recevez-vous de l'aide pour l'apiculture ? Oui Non

52. Si oui sous quelle forme recevez-vous de l'aide, par qui et depuis quand ?

UNIVERSITÉ DE LA RÉUNION

Pôle Recherche
Ecoles doctorales

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Fait à Saint-Denis le : 03/04/2018

Signature :

Extrait du Règlement intérieur de l'Université de La Réunion
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