Pacific Community
Communauté du Pacifique

RESCCUE

COMMERCIAL MARKET POTENTIALS OF INVASIVE ALIEN SPECIES IN THE PACIFIC ISLAND COUNTRIES AND TERRITORIES (PICTs)

Project Note

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INTRODUCTION

Invasive Alien Species (IAS) represent the second most important cause of global biodiversity loss after habitat destruction[1]. Introduced outside of their natural habitat, those species are causing damages by spreading in initially balanced ecosystems and negatively interacting with native species and their environment. Invasive species biodiversity impacts are an increasing international concern as reflected, among others, in Aichi target n°9 adopted at the 10th conference of the parties to the Convention on Biological Diversity[2].

In addition to being a major environmental problem, IAS have socio-economic consequences by notably impacting human health, food security, trade and all economic activities relying on ecosystem services, hence agriculture, fishery and tourism. Invasive species represents also a significant hindrance to ecosystems and societies resilience. Disturbed habitats and unhealthy ecosystems are more vulnerable to environmental disruptions and therefore lose their ability to adapt to climate change and cope with strong climatic events[3]. Overall, invasive species consequences go beyond biodiversity loss, altering progress towards achieving 10 of the 17 Sustainable Development Goals (SDGs)[4,5]. Managing invasive alien species appears therefore as a necessary condition to ensure both biodiversity conservation and climate change adaptation.

This statement is all the more relevant in the Pacific. As one of the world's most important biodiversity hotspot with 2,189[6] single-country endemic species recorded, the region is also experiencing one of the highest single-country endemic species extinction rate because of the invasive species issue[7]. Considering that Pacific Island Countries and Territories (PICTs) are among the most vulnerable nations to climate change, due to their insularity, limited resources and economic dependence on ecosystem services, invasive species management is a decisive aspect of their resilience strengthening. It is also a major challenge as controlling these species requires continuous financial and technical interventions that most PICTs cannot fully provide.

Well aware of this reality, many regional actors are already actively involved in non-native species management. CROP agencies have notably built the Pacific Invasive Partnership[8] and the Pacific Invasive Initiative[9] that aims to strengthen PICTs capacity to manage invasive species. Under these frameworks, several countries and territories of the Pacific were able to develop their national invasive species strategy[10] and many isolated policies encouraging pests and weeds harvesting have been

[1] https://www.iucn.org/resources/issues-briefs/invasive-alien-species-and-sustainable-development

[2] "*By 2020, invasive alien species and pathways are identified and prioritized, priority species are controlled or eradicated and measures are in place to manage pathways to prevent their introduction and establishment.*" *https://www.cbd.int/sp/targets/rationale/target-9/*

[3] SPREP (2016)

[4] https://www.un.org/sustainabledevelopment/sustainable-development-goals/

[5] https://www.iucn.org/resources/issues-briefs/invasive-alien-species-and-sustainable-development

[6] SPREP (2013)

[7] SPREP (2013)

[8] https://www.sprep.org/Pacific-Invasives-Partnership/invasive-partnerships

[9] http://www.pacificinvasivesinitiative.org/index.html

[10] See for example : National IAS strategy and Action plan of New Caledonia : http://www.cen.nc/documents/22209/82578/Strat%C3%A9gie+de+lutte+contre+les+EEE+en+Nouvelle-Cal%C3%A9donie.1/ba22c500-16fc-48e3-80b0-8aa0e649e6b0?version=1.10
Of Vanuatu : https://www.sprep.org/attachments/VirLib/Vanuatu/nissap-2014-2020.pdf

established. However, given the extent of the issue, these initiatives may not be sufficient and more management approaches shall be explored.

Market incentives to control invasive species are a topic of growing interest among international conservation debate. Facing the fact that many native or endemic species are threatened by human economic activities while invasive alien species with similar potentials are under-exploited, the hypothesis would be that if it is possible to drive native species to extinction due to over-exploitation, it should be possible to control or eradicate an invasive species with adequate economic and market incentives. With the exception of isolated initiatives, economic valorisation of these species remains relatively new in the Pacific with very few documentations existing on the subject.

The RESCCUE (Restoration of Ecosystem Services and Adaptation to Climate Change) project[11], implemented by the Pacific Community, aims at building the resilience of PICTs ecosystems and societies in the context of global changes. At the regional level, RESCCUE undertakes a number of capacity building activities on key topics of relevance to its seven pilot sites distributed in four PICTs: Fiji, French Polynesia, New Caledonia, Vanuatu. To this end, the project seeks to support the adaptation to climate change by reducing anthropic non-climatic pressures that weaken ecosystems and make them more vulnerable to major climatic events, resorting especially to economic analysis and economic and financial mechanisms.

Under this project, the present document aims at establishing a review of the potential of commercial markets for invasive species management in the Pacific and beyond, in order to identify opportunities they may hold for the PICTs.

I. LITERATURE REVIEW

Harvest incentives to control invasive species are various and can have many different structures. The most common are presented and reviewed in a paper from Pasko and Goldberg published in 2014[12]:

- Bounty Program: A financial incentive program in which an individual receives financial compensation of a predetermined amount for any evidence of the targeted species harvest.
- Contract Operation: A program that provides direct payment to the public or service provider to remove or harvest a species.
- Commercial Market: Initiatives, usually private, to economically valorise a species through commercial market where the species is harvest and offered for sale.
- Recreational Harvest: Actions that promote recreational removal of invasive species based on the individual's own initiative. It comprises actions such as conducting outreach, modifying hunting or fishing seasons, changing license requirements or bag limits.

[11] https://www.spc.int/resccue
[12] Pasko S., Goldberg J., (2014)

The present work focuses mainly on commercial market harvest incentives. It is the only method among those described above that directly involves the private sector and does not necessarily require continuous public funding. This method also stands out with its inherent operating rationale: instead of only considering the non-native species as a pest to eradicate, economic valorisation would turn the species into a resource out of which it would be possible to benefit from. As invasive species mainly thrives because of a scarcity of enemies in their introduced range, economic potential would encourage harvest, creating negative pressure on invasive species population and thus potentially "rebalancing" ecosystems. Commercial valorisation to manage invasive alien species is one of the many existing methods to control or eradicate invasive species such as biological control, mechanical or physical removal or chemical application[13,14].

Economic valorisation of invasive species hence represents all initiatives, both public and private, that suggest to harvest invasive species in their native range with a perspective of an economic outcome[15]. Depending on the species considered, possible commercial uses can be very diverse and the market more or less challenging to develop.

Among all the existing uses, promoting human consumption is a promising management strategy that is gaining in popularity within government agencies, conservation groups and medias[16]. Eating invasive species, or "invasivorism", to combat invasion was notably promoted by the conservation ecologist Joe Roman in its article "Eat the invaders"[17] where several recipes made with invasive species were presented. Since then, the article has led to the creation of the IAS recipes websites eattheinvaders.org and many similar initiatives have launched[18]. The development of invasive species human consumption is nevertheless facing some challenges such as the absence of initially existing market and the need to change consumers' behaviour towards those species. For instance, some invasive species can have a poor reputation, as it is the case of the Asian Carp or the Lionfish[19]. To cope with this phenomenon, many public campaigns to encourage invasive species consumption have been run, notably in the United States[20].

Apart from human consumption, most common commercial initiatives comprise energy production, (notably through bioenergy[21]), cosmetics products[22], fur harvest[23], or even animal feedstock[24].

[13] Stafford W., Blignaut J. (2017).
[14] As an example : The case of the feral goat eradication on islands : Campbell K., Donlan J., (2005)
[15] IUCN. (2018)
[16] Snyder M (05/26/2017).
[17] Roman J. (10/2004).
[18] See for examples, among many more :
http://invasivore.org/
« They're Cooked: Recipes to Combat Invasive Species », Institute of Applied Ecology :
https://appliedeco.org/product/theyre-cooked-recipes-to-combat-invasive-species/
« The New York State invasive species cookbook » R.Nelson and al.
https://issuu.com/esfknothole/docs/eatinginvasives
[19] Huth W.L., et al (2018) ; and Varble S., Secchi S. (2013).
[20] Nuñez M.A, *et al* (2012).
[21] For example among others : Lu J *et al* (2010). ; and O'Sullivan C., *et al* (2010).
[22] Video : « Research team comes up with cosmetics made of invasive plants », Arirang News :
https://www.youtube.com/watch?v=T69CS39fBcs
[23] Jones C., *et al* (2012).
[24] Wall T. (08/30/2017) ; and Zimmerman G. (02/04/2015).

The economic benefits from invasive species products could be greater than for similar products made from "conventional" species. A study carried out by William L. Huth and al.[25] shows that these products could indeed be more market competitive due to their "environmental friendly" nature. Once consumers are informed of the potential ecological benefits that can result from the consumption of an invasive species product, consumers can adopt a behaviour specific to 'Impure Public Goods", i.e private goods with public goods attributes[26]. In this case, consumers respond positively to public goods attributes by changing their consumption behaviour and even accept to pay more for these products. Therefore, in addition to outreach campaigns, instruments such as an invasive species label to inform consumers about the positive aspects of IAS products consumption are being developed[27].

Economic valorisation of invasive species with an objective of population regulation could be expected to bring many environmental and economic benefits[28]. In a study published in 2018, the International Union for Conservation of Nature (IUCN) and the Groupe de Travail National Invasion Biologiques en Milieux Aquatiques (GTIBMA) have presented a description of the main positive impacts expected from the development of invasive species commercial markets[29].

The main driver of invasive species management through commercial markets is the direct positive impacts that should occur on biodiversity and ecosystem health. Invasive species population reduction allows a relief of the pressures initially brought by those species on ecosystems and related services. In some cases, this strategy could also transfer initial harvest pressures on native species to invasive species with the same economic potential. It should be noted, however, that apart from some very specific cases, these direct ecological benefits have, for the most part, never been reported in practice[30].
Market incentives to control invasive species also imply some indirect environmental benefits. Harvest incentives and product certification can educate program's participants and consumers about the invasive species issue[31,32]. In the meantime, programs and activities encouraging people on consuming invasive species can support identification of these species by the non-scientific community and therefore have the potential to facilitate Early Detection and Rapid Response initiatives (EDRR)[33].

In addition to the environmental benefits directly linked with invasive species management, market-based harvest incentives also lead to positive economic outcomes. Although very difficult to estimate, invasive species economic costs are considerable, in the range of millions of dollars for the Pacific region each year[34]. Among the main motivations for invasives commercial development the potential to offset the economic losses caused by invasive species is thus prevalent. Commercial exploitation can also significantly benefit the local economy. Depending on the economic model chosen, markets development can be a source of job creation and income generation for the local population[35].

[25] Huth W.L., et al (2018)
[26] Huth W.L., et al (2018)
[27] See as an example the Green Anchor certification, still in development: https://www.green-anchor.com/
[28] Nuñez M.A, *et al* (2012).
[29] IUCN. (2018)
[30] IUCN. (2018)
[31] Hunting Contest, RESCCUE (2018), information accessible online at www.spc.int/resccue/publications
[32] Nuñez M.A, *et al* (2012).
[33] Nuñez M.A, *et al* (2012).
[34] SPREP (2016)
[35] IUCN (2018)

Commercial valorisation to control invasive species therefore appears at first a promising mechanism that could combine biodiversity conservation and economic development. In reality, this remains a very controversial topic among biodiversity conservation debates. Indeed, with the exception of a the IUCN and GTIBMA report, very few studies have critically assessed the success of these market-based programs. Instead, several potential problems and unexpected challenges associated with this approach have been identified.

Firstly, as for other invasive species management strategies, the harvest must consider the entire biological and ecological characteristics of the species to be efficient. These include, for instance, an understanding of the species population structure, demographic aspects, inter and intra-species interactions, life history traits, reproduction specificities etc. If the necessary precautions are not taken, programs may fail in achieving their population control objectives[36] or even lead to counter-productive effects in terms of biodiversity conservation. For example, a wrong understanding of the demographic structure and density-dependant processes can lead to a phenomenon of biological overcompensation where an increased mortality allow an increasing overall number of individuals in the population[37]. In the case of weeds, the collection of the species can also unintentionally promote further invasion by facilitating the dispersal of reproductive parts[38]. Moreover, if the local ecosystem is not fully understood, the harvesting of the targeted invasive species can lead to the spreading of new invasive alien species that was previously inhibited[39]. Finally, some cases of invasive species control through economic valorisation were reported to have negative impacts on non-targeted species, in particular when collection methods are non-selective and lead to bycatch[40].

In addition to adverse environmental effects, the commercial valorisation of invasive species can present socio-economic risks. Indeed, the exploitation of a commercial potential raises the need to make the market sufficiently profitable and sustainable be economically viable and ensure a return on investment for private partners. The optimal population harvest level to meet these economic requirements may be differ from the harvest level needed to efficiently reduce the species population. Therefore, market incentives can be incompatible with the ecological requirements of invasive species management[41]. More than that, once the invasive species has become an income-generating resource, it may be more challenging to promote population control. Market creation can generate incentives to maintain the invasive species population instead of reducing it. It may even lead to the development of breeding in places where the species was not initially present, hence increasing the risk of further invasion[42]. Lastly, the economic valorisation of invasive species can lead to their incorporation into local culture. Once assimilated as a valuable resource either as a raw material or as food, the species can be no longer consider as invasive but rather as a beneficial non-native. If the species becomes labelled with a wrong positive image, the population may be more reluctant to control or eradicate it[43].

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[36] IUCN (2018)
[37] Pasko S., Goldberg J., (2014) ;
See as an example : Weber M.J. *et al* (2016)
[38] Nuñez M.A, *et al* (2012).
[39] See as an example the case of the strawberry guava economic valorisation in the Reunion Island : Minatchy J., Thomas H., *et al* (2017).
[40] IUCN (2018)
[41] See for example : The brushtail possum fur harvest in New Zealnd: Jones C., Barron M., *et al* (2012).
[42] Nuñez M.A, *et al* (2012).
[43] IUCN (2018)

Market-based harvest incentives are therefore a promising but delicate management strategy. With this approach, each implementation case will involve its own economic and ecological risks. Its success implies careful considerations and relies on the quality of the economic and environmental feasibility studies conducted and on the effectiveness of the monitoring and evaluation strategy. In some cases, appropriate policies and legislation may be necessary to facilitate the development of invasive species commercial use[44]. One of the main difficulty is therefore that the development of this kind of invasive control strategy requires strong political, economic and scientific capacities and complementarity. Considering the lack of harmonised, representative data regarding to biological invasions, both at country and global scales, information is not always available to assess the environmental feasibility or the success of programs.

In the Pacific, market-based incentives to control invasive species remain at an early stage with several punctual economic valorisations implemented but to national or regional economic market really developed and promoted[45]. With the exception of the RESCCUE project actions on the commercial valorisation of the Rusa Deer in New Caledonia[46], no regional or country specific programs working on the development of this management approach was found. These observations are however not sufficient to affirm that no other initiatives exist, but due to the lack of regional documentation available in open access, it has not made it possible to identify them.

II. MATERIAL AND METHODS

The present review aims at assessing the commercial markets potential to control exotic invasive species of the PICTs. The initial scope of the work included the establishment of a list identifying all invasive species in the PICTs with commercial potential and, when possible, an assessment of the actual effectiveness of these markets in terms of invasive species management, biodiversity conservation and economic viability.

Considering the limited time and capacity available to carry out this mission, the scope of the review has been narrowed with a focus made exclusively on the four PICTs where RESCCUE is operating: Fiji, French Polynesia, New Caledonia and Vanuatu. In order to ensure a clear and concise presentation of the findings, the choice was made to present the results in a table format. The methodology adopted to design the table can be structured under four main steps: Invasive species listing, table construction, general species data collection and the economic potential assessment.

Invasive species listing

In order to identify invasive species with economic potential, it was necessary to first obtain a list of all the invasive species established in the PICTs surveyed. To do so, among all the consulted databases

[44] Pasko S., Goldberg J., (2014) ;

[45] See as an example :
The conversion of the *Acanthaster planci* into a commercial fertilizer in Vanuatu : https://shefatravel.weebly.com/crown-of-thorns-starfish.html ;
The commercial use of *Falcataria moluccana* wood in French Polynesia : https://www.service-public.pf/sdr/wp-content/uploads/sites/28/2017/06/les_plantations_de_bois_precieux.pdf

[46] Ghysels A., Rageade M., et al. (2018). The RESCCUE project

on invasive species, the IUCN Global Invasive Species Database (GISD)[47] appeared as the most comprehensive, reliable and updated one, notably for the Pacific region.
The species list was then extracted using the advanced search options by checking Fiji, French Polynesia, New Caledonia and Vanuatu in the filter "Location". The research resulted in the identification of 272 species (fauna and flora; terrestrial and aquatic) that are considered as invasive in at least one of the four countries.

The list was then reduced by only considering the 70 invasive alien species ranked as priorities by the Conservatoire d'Espaces Naturels of New Caledonia[48]. The list obtained was easier to work with while ensuring at the same time that the selected invasive species were relevant in terms of priority of action. However, given limited data availability, the priority level of these species in Fiji, French Polynesia and Vanuatu could not be assessed.

Table construction

Once the list established, the selected invasive species were included in a table of 14 columns, which are as follows:

- *Commercial potential level*: indicates the commercial potential level assigned for each species according to the method described below. This column was added at the end of the research work to facilitate the results analysis and classification.
- *Illustration*: allows a better visualization of each species.
- *Common name*: provides at least one of the common names used in the region to designate the species. However, it should however be noted that the name used for a same species differs depending on the region or country.
- *Scientific name*: gives the binomial name of each species to allow its identification in every country.
- *Biological class*: details the biological classification to which the species belongs. In order to simplify the analysis of the document, the paraphyletic group of Fish was considered as a class although it is not biologically correct. The table include eight different biological classes: Mammal, Insect, Fish, Aves, Gastropod, Reptile, Plants and Amphibian.
- *System*: specifies the environment in which the species lives. Here terrestrial or freshwater as no marine species are present in the selected invasive species.
- *Location*: indicates the PICTs where the species is established. For the same species, there is a row for each location where it is present according to the GISD database to allow the classification by alphabetical order per country if needed.
- *ISSG Top 100:* specifies the rank of a species when it is included in the world's 100 worst IAS ranking of the IUCN[49]. Considering that the species list was obtained from New Caledonia's list of priority invasive species, this column is meant to provide more information on the possible level of invasion for the other PICTs.

[47] http://www.iucngisd.org/gisd/
[48] CEN (2017). Liste illustrée des 70 EEE classes prioritaires en Nouvelle-Calédonie.
[49] http://www.iucngisd.org/gisd/100_worst.php

- *Description*: brings a general description of the species, the objective here is not to bring an exhaustive description of the species but rather to highlight the main characteristics of the species, notably on its habitat, its diet and its reproduction mode.
- *Mechanisms and Damages*: indicates succinctly the physical or chemical mechanisms that make the species negatively impact its environment.
- *Potential of physical control:* aims to specify if physical harvest could be efficient in terms of invasive species management and population control. This notion is important since many commercial uses require a physical harvest.
- *Potential commercial use:* presents uses or relevant characteristics of the species that could lead to a possible commercial use although no information was found on an already existing market.
- *Proven commercial use*: indicates if an already operating commercial use has been found. This only specifies whether economic benefits have already been generated from the harvest of the species but does not consider if the business led to any environmental benefits.
- *References*: includes only documents that are particularly relevant to have a direct case study or potential assessment of the species economical valorisation.

General data collection

The initial completion of the table, from the column F "Biological class" to the column L "Mechanisms and damages", was made using the invasive species factsheets in the IUCN GISD database. Information were then completed with the CABI Invasive Species Compendium[50], the IUCN Redlist[51] and Google[52].

Economic potentials research and assessment

In addition to the previously mentioned sources of information, the identification of possible commercial potentials has required extensive research for each species. Google scholar[53] and Sciencedirect[54] were searched using combinations of the following keywords: *alien species name* (common name or scientific name), use, products, management, commercial, properties, opportunities, *possible commercial products keywords* (timber, meat, cosmetics, properties etc.). The vast majority of the documents obtained were scientific publications while the few grey literatures consulted was obtained from Google searches.

All abstracts and documents were screened to determine if they provided relevant information on invasive species commercial uses. The assessment of the quality of the findings was that the source appeared reliable and traceable. When no relevant information was found, the symbol "/" was entered in the corresponding cell.

Once all the information was gathered, a classification of the species according to their commercial potential was done. The classification is visible by the row colour and the number assigned to the species in the column "Commercial potential level" and is detailed in the sheet "Legend". This classification was made upon two criteria, the actual feasibility of the identified commercial potential

[50] https://www.cabi.org/isc/
[51] http://www.iucnredlist.org/
[52] https://www.google.com/webhp?source=search_app
[53] https://scholar.google.fr/
[54] https://www.sciencedirect.com/

and its possible effectiveness in terms of invasiveness management. The different levels of commercial potential obtained are as follows:

Level 1	Proven commercial use or high potential for population control
Level 2	Potential commercial use for population control but more knowledge required
Level 3	Existing commercial use but inefficient for invasiveness management or too important lack of data
Level 4	No potential or not relevant enough considering existing knowledge

Once this classification established, country-specificities were attempted to be brought for species belonging to the level 1. However, due to the difficulty to find precise information on on-native species, notably in the Pacific, very few details were added.

Finally, to facilitate the analysis of the results, three sheets were added to the table.
The second sheet "List NC" contains the results obtained for each species but without specifying the location of each species. This table has therefore only one row for each species enabling a more rapid screening of the findings. The fourth sheet "General data" and the fifth sheet "Specific data" contain the pivot tables and related figures produced for the data analysis and results presentation.

III. RESULTS

General data description

The final product of this study is a table of 14 columns and 162 rows reviewing the economic potentials of 70 invasive species present in the Pacific region. As a line was created for each species in each location, a single species can occur up to four times in the main table. For instance, the African Tulip Tree (*Spathodea campanulata*) has four lines, as it is present in the four PICTs considered in this study: New Caledonia, Fiji, Vanuatu, French Polynesia. With the exception of some species with a commercial potential level 1, where location-specific details are usually provided, all lines for a given species are identical.

Out of the 70 species studied, 42 species belong to level 4 where no relevant economic use has been found while 28 species have a commercial potential ranging from level 1 to 3 (Figure 1 below). Among those, 8 species are categorised with an economic potential of level 1 and 11 with and economic potential of level 2. As they appear as the most promising species for market-based harvest incentives, they have been summarized in annexes 1 and 2 at the end of this note. In all, the list includes 22 Plants, 12 Mammals, 18 Insects, 4 Gastropods, 8 Fishes, 4 Aves, 1 Amphibian and 1 Reptile (table 2, annex 3).

In terms of geographical dispersion, among the 70 invasive alien species established as priority in New Caledonia, 42 species are also reported invasive in French Polynesia, 29 in Fiji and 21 in Vanuatu. A further description of the number of species by commercial level for each country is available on the figure 2 here below.

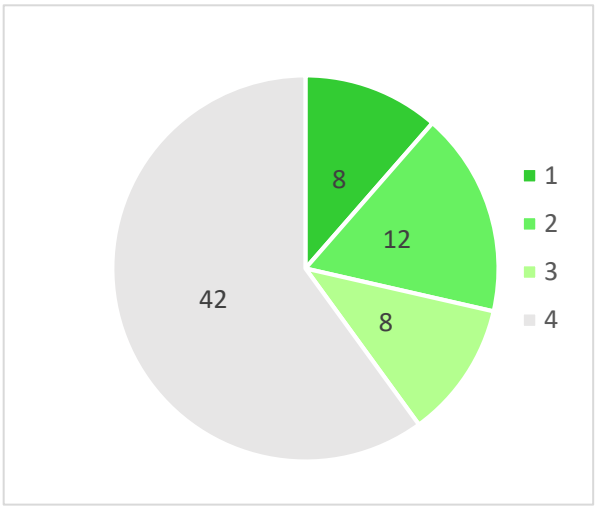

Figure 1: Number of IAS for each commercial potential level (out of the 70 considered IAS)

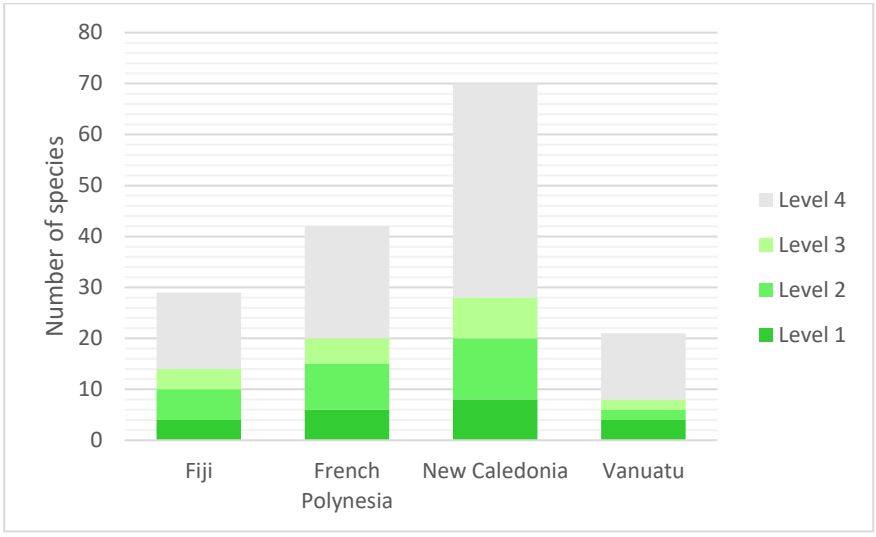

Figure 2: Commercial potential levels for each country

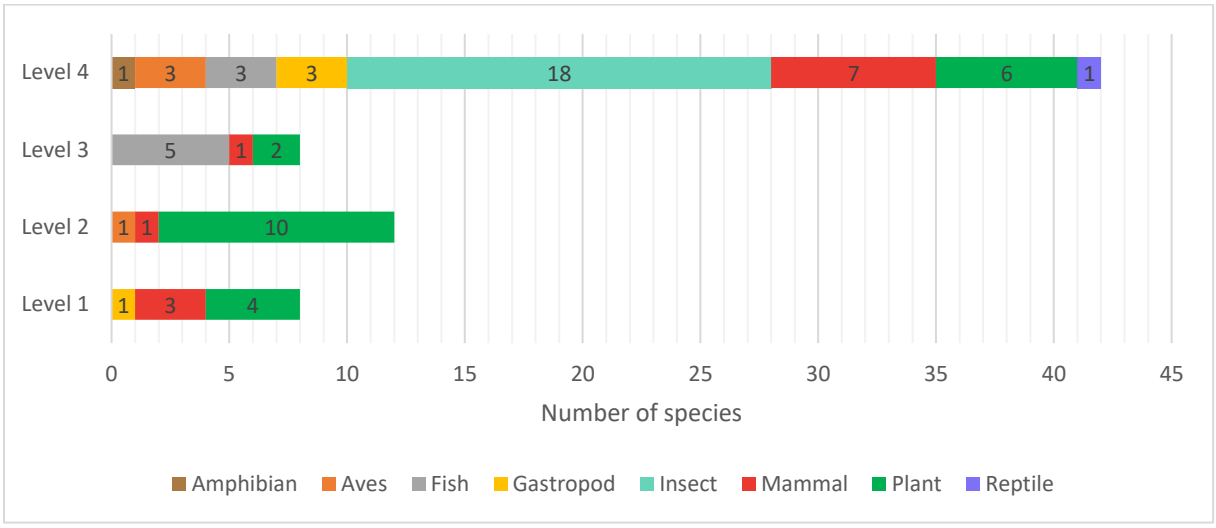

Figure 3: Biological class details for each commercial potential level (out of 70 species)

Commercial potential level 1 and 2 (cf. Annex 1 and 2)

In total, out of the 70 invasive species studied, 20 species are labelled with a commercial potential of level 1 or 2. Among the 8 invasive alien species labelled with and economic level 1, 4 are Plants, 3 are Mammals and 1 is a Gastropod. Among the 12 species labelled with a commercial potential level 2, 10 are Plants, 1 is a Mammal and 1 is an Aves (see Figure 3 above).

With the exception of the Giant African Snail (*Lissachatina fulica*), all the Animals present in these two commercial potential categories are those with hunting meat sale potential. The differentiation between the Animals of level 1 and 2 was mainly based on the effectiveness of hunting to control the population according to existing documentation or to the unusual aspect of the practice. Hence, no documentation was found on the management of Mallard (*Anas platyrhynchos*) through hunting and, although existing and sometimes highly appreciated, Feral cattle (*Bos Taurus*) hunting remains uncommon. The various existing hunting practices to control these species can be private hunting, trophy hunting (for instance for feral cattle or feral goats), game hunting or hunting competition. One of the major challenge for this economic opportunity is that bushmeat commercialisation is usually illegal for sanitary reasons, all transactions thus taking place on the informal market. Considering this missed opportunity, some countries are gradually allowing the sale of wild meat through formal trading networks. It is for instance the case in New Zealand and Australia for certified hunters [55] and in French Polynesia for the sale of the feral goats (*capra hircus*) and wild pigs (*sus scrofa*)[56] bushmeat. Nevertheless, in many cases, these markets are however either at an early stage and not sufficiently developed to be effectively functional.

Besides meat sales, the production of leather from hunted animals could also represent an interesting market-based incentive. Although this potential is mentioned in the table, no further research has been made about it.

The Giant African Snail (*Lissachatina fulica*), is the only gastropod reviewed that has already numerous existing commercial applications. *L.fulica* products are very diverse, it is used for both human and animal consumption as well as for energy production and cosmetics. GAS market already exist in the world, notably in West Africa and Asia, but isn't really developed in the Pacific with the exception of food products[57].

Among the 14 Plants labelled with an economic potential of levels 1 or 2, the most frequent and promising commercial use is bioenergy production. In this field, aquatic plants (*Salvinia molesta, Eichhornia crassipes, Pistia stratiotes, Hydrilla verticillata*) have the greatest potential due to their high energy yields, the quality of their compost and the effectiveness of mechanical removal to control populations (although very labour-intensive). Many experiments and short-term case studies on bioenergy production from these aquatic plants were made and documentation on this matter can be easily found[58]. No environmental impact assessment and long term economic feasibility on a potential market development have been encountered. *Merremia Peltata* also presents interesting bioenergy potential. The vine is currently used in Samoa to produce biogas, for both households' consumption and to sell additional electricity onto the grid[59]. As the pilot project is now being scaled up, the process seems to be efficient in terms of energy generation. Yet, financial profitability remains uncertain at this point and no feedback on the environmental impact of the project seems to have been made.

[55] Australia : https://ablis.business.gov.au/service/wa/australian-standard-as-4464-hygienic-production-of-wild-game-meat-for-human-consumption/17585
New Zealand : https://www.mpi.govt.nz/processing/meat-and-game/homekill-hunting-game-and-wild-foods/commercial-hunters-and-certified-wildgame-suppliers/

[56] Tahiti Infos (03/14/2018). https://www.tahiti-infos.com/Les-chasseurs-pourront-officiellement-vendre-le-gibier_a169942.html. Article referring to the deliberation n°2018-4 APF of March 13th 2018 of the French Polynesia Assembly available here: www.assemblee.pf/travaux/downloadTexte/1272145

[57] More information on Giant African Snail commercial potential : Santini C (2017), The RESCCUE Project

[58] See as an example : Syaichurrozi I. (2018) ; Njogu P., Kinuya R., *et al* (2015)

[59] Hourçourigaray J., Wary D., Bitot S. (2014)

Finally, although less explored, the Donax Cane (*Arundo Donax*) also has good potential in bioenergy production, particularly in bioethanol production. However, aside from potential assessments, no actual case studies were found[60].

Salvinia, Water Hyacinth and Donax Cane also have phytoremediation properties that could allow their commercial exploitation for wastewater treatment purposes[61]. The transformation of water hyacinth into phytoremediation products is already done by Green Keeper Africa[62] in Benin and Niger, whose products appear to be more effective than sand at absorbing oil pollution. Although the activity has led to jobs creation and economic benefits, the environmental benefits, notably in terms of biodiversity conservation, have yet to be evaluated. Also, as the water hyacinth is among the most invasive species of the world (32/100 on IUCN ranking), more documentation is available on its management and many other commercial uses can be found for this species such as weaving and biofibers production[63]. Some of these uses could be considered for less studied aquatic plants with similar properties.

In addition to bioenergy and phytoremediation uses, *A.donax* has valuable properties for the production of biochar and medium quality kraft paper[64]. *Fucraea Foetida* is also used in some countries to produce biofibers for bags production, its properties make them good substitutes for conventional man-made fibers[65].

The indian fleabane (*Pluchea indica*), is a shrub whose leave are very popular in Asia for its nutritive and pharmaceutical properties (Khlu leave). Many products made from Khlu leaves can be found in the Asian market, notably beauty products[66] and tea[67]. In Thailand for instance, the Khlu leaves tea is sold around 2 to 6$/100gr[68]. Nevertheless, as no information was found regarding to the effectiveness and modalities of physical control on *P.indica* population, more information are necessary to ensure an effective harvest with a perspective of invasiveness management.

For trees included in commercial levels 1 and 2, timber production and wooden constructions are the most common existing market potentials. As for other plants, the feasibility of using timber production to control invasive trees will notably depends on the costs associated with the harvest (e.g. forest density, distance from a road etc.) and the possible environmental impacts of the logging. With the exception of the Strawberry Guava (*Psidium cattleianum*)[69], no documentation was available on the management of invasive trees through timber production. In addition to the wooden market, Caribbean pine (*Pinus Caribaea*) also has interesting properties for the production of activated carbon for wastewater treatment. This, however, remains at an experimental stage as no commercial market have been reported.

[60] William C., Biswas T. (2010).
[61] Singh Maharjan R.B., Ming C.L. (2012). ; William C., Biswas T. (2010).
[62] Green Keeper Africa. http://greenkeeperafrica.com/
[63] GTIBMA. La jacinthe d'eau : nuisance et/ou ressource ? http://www.gt-ibma.eu/la-jacinthe-deau-eichhornia-crassipes-nuisance-et-ou-ressource/
[64] William C., Biswas T. (2010).
[65] Manimaran P., Senthamaraikannan P., *et al* (2018).
[66] https://www.rueanmaihom.net/en/category/8059/ผลิตภัณฑ์ความงามจากใบขลู่
[67] Suriyaphan O. (2014).
[68] Suriyaphan O. (2014).
[69] Minatchy J., Thomas H., *et al* (2017).

The Strawberry guava (*Psidium cattleianum*) is labelled with a commercial potential of level 2 although relevant economic potentials have been found such as light timber construction and food products (jams, ice cream etc). This species is indeed one of the only species surveyed with an actual reported case studies about economic valorisation and invasiveness management. Timber valorisation was intended in the Réunion to control the weed which is among the most invasive alien plant on the island. Three years after stems cutting, the environmental consequences are negative with the facilitated spreading of other invasive plants in the studied plots[70].

Commercial potential level 3

Among the 8 invasive species labelled with an economic potential of level 3, 5 are Fishes, 2 are Plants and 1 is Mammal (see Figure 3 above). Most of the species in this category are the one with existing commercial valorisations but with a data shortage too important to be able to estimate their potential for marker-based invasive species management.

Hence, even if all the listed fishes of this category are edible and have an existing commercial valorisation through fishery and fish sale, no documentation was available on the potential of fishery to control invasiveness. For example, the Mozambique Tilapia is one of the most common aquaculture fish but this practice is also the origin of its invasion. The only case study found was on Carp (*Cyprinus carpio*) regulation through overfishing in South Dakota, USA, where the species is widespread. Instead of leading to a population decrease, the rising mortality rate has resulted in a phenomenon of biological compensation with an increase in the number of individuals[71]. Due to the lack of information on the potential of fishing for invasive species management, it was not possible to assess the viability of fishery on that purpose.

Finally, although various commercial uses can already be identified, the potential of the European rabbit (*Oryctolagus cuniculus*) for market-based invasiveness management is difficult to assess. The two main possible uses identified in this review are the sale of bushmeat through hunting and fur production, both seem unlikely from a commercial management perspective. First of all, no example of wild rabbit eradication only through hunting was found in the literature. Considering the proliferation rate of this species, this technique does not seem to be sufficient in itself to control the population. Second, although cases of invasive species management attempts with fur production can be found[72], developing this market for European rabbit seems unlikely to succeed in the Pacific.

[70] Minatchy J., Thomas H., *et al* (2017).
[71] Weber M.J., Hennen M.J., et al (2016
[72] See as an example : Brushtail Possum fur harvest in New Zealand, Jones C., Barron M., *et al* (2012).
And also: the New Zealand Fur Council, https://nzfurcouncil.org.nz/ dedicated to promoting the Brushtail Possum fur hunting for conservation,

Commercial potential level 4

This category gathered the 42 remaining species with no relevant economic valorisation identified. These include 6 Plants, all the 18 listed insects, 3 Gastropods, 7 Mammals, 3 Aves, 3 Fishes, 1 Reptile and 1 Amphibian.

The majority of the Animals in this category are species that are usually domestic but of which some individuals have become wild and invasive. It is for instance the case for the various bee species surveyed, the feral dog (*Canis lupus familaris*), the feral cat (*Felis catus*) etc. Considering their cultural status, a realistic commercial valorisation ensuring economic and environmental benefit without raising any ethical issues was difficult to find. Animals in this category also includes common pest (mice, ants etc.) whose population control are usually done through chemical treatments and for which commercial valorisation does not appear as promising.

As for Insects, the possibility of processing them into food products has been considered. Insect consumption is already a well-established market in Asia and is gradually developing in the rest of the world, with many initiatives and innovative products developed[73]. Many products made from ants, beetles, termites or bee larvae can be found, however, as no information was found regarding to the edibility of the species listed, this uses was not considered for the commercial potential level assessment.

Finally, during the survey, it has been possible to identify some environmental interactions between some of the invasive species considered. Among these interactions can be mentioned that *sus scrofa* consume the strawberry guava and hence act as an important seed dispersal for this species. Similarly, the New Guinea flatworm (*Platydemus manokwari*) turned out to be a common biological agent for the Giant African Snail while the GAS is itself a biological agent for the Rosywolf snail (*Euglandina rosea)*. Hence, it should be considered that the management of one of those species could have positive or negative impacts on one of the other, depending on the importance of this interaction in the ecosystem studied.

IV. DISCUSSION

The present survey helped to identify possible commercial markets that may be relevant for invasive species management in the four PICTs studied and beyond. The most promising commercial uses opportunities identified are the sale of bush meat for Mammals and bioenergy and timber production for Plants. Such commercial uses are already practiced worldwide, including for the management of invasive species, so information and lessons learnt from these concrete examples can be used to build a viable market.

In particular, bush meat markets from invasive species seem to be especially relevant to PICTs as hunting is already a frequent practice. While promoting the hunting of invasive species, further work would be needed to identify the legal barriers and technical feasibility for developing such markets in

[73] See as an example : https://www.insectescomestibles.fr/ ; https://4ento.com/2015/02/23/insect-food-products-currently-available/

selected PICTs. An interesting example is the work done in New Caledonia by the RESCCUE project to examine the feasibility of developing a bush meat market (short supply chain) from deer hunting[74].

Similarly, although experiences in the PICTs have been mixed[75], bioenergy could represent a potential invasive plants market opportunity in the Pacific. The challenging point of biomass and biogas systems remains the financial profitability that varies greatly depending on the reliability of the organic source[76], the technology efficiency and how the outputs are then enhanced[77]. Developing a value-added industry from invasive plants harvesting may require a well-designed financial scheme based on a cost-sharing model such as public-private partnerships[78]. However, if suitably implemented, producing energy from weeds represent a simple, replicable and effective solution for a clean energy production at the household level[79].

In any case, exploiting some species may necessitate a switch in population's consideration, either because they are part of the local culture and are not perceived as harmful or because they have a bad connotation (eg. The Giant African Snail).

More innovative uses for invasive species management have also been found, and include the production of biofibers, biochar, unusual food products, fertilizers, etc. Although less studied and therefore more risky to implement, such innovative uses remain potentially promising and worth considering. However, the research conducted did not allow the identification of a market on an invasive species already well established in the Pacific.

The applied methodology has allowed the identification of 28 invasive species with a relevant commercial potential for population management. Among them, 8 are classified with a commercial potential of level 1, 12 with a commercial potential of level 2 and 8 with a commercial potential of level 3. This classification enables a first analysis of the findings; it must however be put into perspective. Determining the real potential of an economic activity to control a species requires a specific environmental and economic assessment that would consider the exact context in which it would be implemented. If such studies were conducted they could potentially change this initial classification (see for example the previously discussed case of the commercial potential of the strawberry guava for Réunion).

Considering the small size of the sample analysed (70 invasive species) compared to the 272 species initially reported as invasive by the IUCN database, it can be expected that the potential for commercialization of invasive species in the Pacific is important. This study was also based on a list of 70 species considered as top management priorities in New Caledonia. This ensures that the implementation of a well-designed market-based management strategy should have significant environmental and economic benefits, at least in New Caledonia. For the other PICTs involved in the RESCCUE project (Fiji, French Polynesia, Vanuatu), information pertaining to the degree of the

[74] Ghysels A., Rageade M., *et al.* (2018).
[75] IRENA (2013)
[76] Hourçourigaray J., Wary D., Bitot S. (2014)
[77] See for more information : Review of biogas digester technology in rural Bangladesh. Khan, M E., Martin, A R. (2016)
[78] Stafford W., Blignaut J. (2017).
[79] See as examples : Biogas production using water hyacinths to meet collective energy needs in a sahelian country , Almoustapha O., Kenfack S., *et al* (2008)
Piu village Merremia biogas project in Samoa, Hourçourigaray J., Wary D., Bitot S. (2014), p.28

biological invasion is not available, therefore, the importance of the species management could differ. At the moment, no harmonised data available to specify the level of biological invasion for the Pacific countries and territories. Platforms such as GBIF[80] and GRIIS[81] are being completed in order to be able to provide this missing data for the Pacific PICTs.

Overall, the main difficulty encountered is the shortage of reported case study available on open access. The lack of sharing of lessons learned and feasibility studies when they were carried out makes it difficult to assess the potential of an identified commercial use. For instance, extensive literature exists on cases of invasive species management through hunting but no specification is usually made on the use of the meat obtained. Likewise, various pilot experiments are made to assess the bioenergy potential of chosen species, but details regarding the economic and environmental benefits of pilot programs are harder to find. More experience sharing is definitely needed to facilitate the development of invasive species commercial valorisation initiatives in the various PICTs.

This study is intended to serve as a basis for more in-depth studies on market-based incentives for invasive species management in the PICTs. While reasonable care has been taken for this review to ensure that the results provided are correct and comprehensive, they should still be used with caution given the difficulty sometimes encountered in finding consistent data.

[80] https://www.gbif.org/
[81] http://www.griis.org/

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ANNEXES

Annex 1: Summary of Invasive Alien Species with a commercial potential of level 1

Common Name	Scientific Name	Class	System	Location	Potential of Physical Control	Potential Commercial Use	Proven Commercial Use
Feral Goat	*Capra hircus*	Mammal	Terrestrial	Fiji French Polynesia New Caledonia	Eradication was made possible in at least 120 islands. Hunting is the most common method for eradication. Include the use of hunting dogs, judas goat and shooting from an helicopter. Multiple methods and specialized eradication methods were used for eradication on larger islands. These techniques rely heavily on technology and skilled staff. Judas goats are used at the end for low densities.	Meat sale but legal and technical barriers for wild meat commercialisation. As it is a species difficult to hunt, feral goat hunt is appreciated for recreational and trophy hunting.	Some organisations are offering worldwide hunting trips to hunt feral goats.
Feral Pig	*Sus scrofa*	Mammal	Terrestrial	Fiji French Polynesia New Caledonia	Hunting: the Santiago Island is a successful case study of controlling wild pigs population by hunting. Harvesting 66% of the total population per year is required to keep the Texas feral pig populations stable (estimated population of 2.5 million).	Meat sale but legal and technical barriers for wild meat commercialisation	In New Caledonia, there is a market for farm pig meat. Wild pig meat sale remains informal and still needs to be developed.
Giant African snail	*Achatina fulica*	Gastropod	Terrestrial	French Polynesia New Caledonia Vanuatu	Physical control can often be as effective as any other means where they congregate in large numbers.	Edible snail, it has interesting nutritive properties both for human and animal consumption (especially pigs). Significant decrease of the population in Africa due to consumption, breeding of GAS in West Africa. Can also be used as a fertilizer and have pharmaceutical properties relevant for medicinal and cosmetic uses.	Breeding and exportation in West Africa and Asia.
Indian fleabane	*Pluchea indica*	Plant	Terrestrial	New Caledonia	There is no rhizome system, so it may presumably be readily controlled by suitable cultivation where soil conditions allow. Lack of information for control methods.	/	Very popular in South East Asia where it is native, for its taste, nutritive values, medicinal properties and pharmaceutical properties. Proven commercial value in beauty product and tea production. In Thailand, the tea is sold around 2-6USD/100gr (Khlu tea).
Javan deer, Rusa deer, Timor deer	*Cervus timorensis rusa*	Mammal	Terrestrial	New Caledonia	Hunting is the most commonly used practice to control deer population. Recreational hunting appears to be insufficient to significantly affect the population size so regular hunting sessions have to be organised (ground hunting and by helicopter).	Meat sale but legal and technical barriers for wild meat commercialisation	In New Caledonia, there is a market for farm deer meat. Bush meat market remains informal and still needs to be developed.

Salvinia	*Salvinia molesta*	Plant	Freshwater	Fiji French Polynesia New Caledonia Vanuatu	Manual removal is effective but very labour intensive. It is important to determine the good removal rate to prevent significant regrowth.	Have been used for mulch, compost, fodder, paper making, handcrafts and bio-gas generation. The main impediment is that it that 90% of the harvest is wet weight so a large proportion of the harvest is water but have an high growth rate. Can be used for phytoremediation in water polluted by heavy metal (mining)	/
Water hyacinth	*Eichhornia crassipes*	Plant	Freshwater	Fiji French Polynesia New Caledonia Vanuatu	Control strategies must address both watershed management (to reduce nutrient supply) and direct weed control (eg: by introduction of biological control agents). Chemical control is discouraged and physical eradication is largely used.	Bioenergy: high potential in biogas production. Even more effective when co-digestion with animal residues. Pilot experiment in Niger in 2008 to produce biogas and biofertilizer from the digestion of water hyacinth. Was a success. Experiments also made in Kenya. Compost: Very good fertilizer Water treatment : good potential even for industry waste water, inexpensive. Experiment made in Nepal	Water treatment: In Benin and Niger, Green Keeper Africa is producing natural absorbents made of water hyacinth which are sold to professionals for the control of leaks of polluting products. These products appear as more efficient than sand to absorbs. The company also recycles its products as water hyacinth engorged with hydrocarbons is an excellent fuel. The fiber obtained from water hyacinth is used for weaving and object manufacturing as it is the case of the company MitiMeth in Niger.
Water lettuce	*Pistia stratiotes*	Plant	Freshwater	French Polynesia New Caledonia Vanuatu	Physical removal of the plants can be done manually or by means of machines. In general, re-colonization of Pistia will occur so control measures should be part of a long-term maintenance programme.	Recognize potential for bioenergy production Significant antioxydative and wound healing activities Significant bioenergy potential Use as animal fodder Successful to synthetize gold nanoparticles from it. Possibility to synthetize GNP in a rapid, non expensive and energy efficient manner	/

Annex 2: Summary of Invasive Alien Species with a commercial potential of level 2

Common Name	Scientific Name	Class	System	Location	Potential of Physical Control	Potential Commercial Use	Proven Commercial Use
Barbados cedar	*Cedrela odorata*	Plant	Terrestrial	Fiji New Caledonia	Seedlings can be manually removed, as is practiced in the Galapagos Islands, though larger plants need some form of chemical treatment.	Timber, one of the world's most important timber species. The bark is also used for traditional medicine (fever, malaria, diabetes). High genetic variation so need to be sure the ones in the Pacific present the same timber characteristics. Have an insect repelling resin, works for furnitures and external construction as it is resistant to fungal decay and termites. As it is CITES in South America, commercial use needs careful control of the chain of custody.	/
Carribean pine	*Pinus caribaea*	Plant	Terrestrial	French Polynesia New Caledonia	Mechanical control not really used, usually stem injection and basal bark treatment	Good quality construction timber with high durability. Used for engineering purposes and softwood constructions (playground, flooring, carpentry) Can produce activated carbon from sawdust that presents good potential for water and wastewater treatment, seems as efficient as commercial activated carbon.	/
Chinese guava, Strawberry guava	*Psidium cattleianum*	Plant	Terrestrial	Fiji French Polynesia New Caledonia	Except for young seedlings, hand pulling is not feasible due to the strong root system and the presence of suckers. Mechanical cutting of the stem leads to the development of abundant suckers from the stump and any mechanical control must be associated with chemical control to avoid resprouting.	The fruit is edible and can also be processed into jams. The wood can be used for construction. Nevertheless, these uses cannot really compensate the invasiveness of the species if they are not at an important scale. Heavy presence of fruit flies.	Development of a wood industry in Reunion Island. In terms of environmental impacts, the cutting of the Strawberry Guava has contributed to the development of other invasive plants on the plots.
Donax cane	*Arundo donax*	Plant	Terrestrial	Fiji French Polynesia New Caledonia	Smaller infestations can be eradicated by manual methods, especially where there is a risk of damage to sensitive native plants and wildlife by other methods. Successful with young plants less than 2 m in height, but care must be taken to remove all the rhizome material. Stems and roots should be removed or burned on site to avoid re-rooting and a chipper can be used to reduce the volume of cut material.	Suitable for commercial pyrolysis and biochar production. Wastewater treatment properties, A.donax is resistant to salt water and can remove certain pollutants such as nitrogen and potassium. Has similar properties than eucalyptus to produce Kraft paper, can make generic photocopier paper of lower brightness and lower quality. Significant potential in bioethanol production.	/
Feral cattle	*Bos taurus*	Mammal	Terrestrial	Fiji French Polynesia	Dogs and shooting are a standard method of control. Wild cow can be very dangerous hence	Meat production but legal barriers for wild meat commercialisation	/

				New Caledonia	it can represent a potential trophy hunting or sport game. No examples of wild cattle eradication through hunting were found in the literature. Ahiu Hawaii operates about 40 cattle hunts per year, and each hunt requires a team of several people.		
Giant cubaya	*Furcraea foetida*	Plant	Terrestrial	French Polynesia New Caledonia	A related species was removed manually by uprooting in Galapagos so could be possible for F.Foetida. Bulbils should also be removed to prevent regrowth.	/	Used for fiber production, notably in Brasil and Mauritius for sugar bags production. F. Foetida possess required tensile properties that make them a perfect substitute for the conventional man-made fibers.
Grevilla	*Grevillea robusta*	Plant	Terrestrial	French Polynesia New Caledonia	Vulnerable to fire and goat grazing. Very strong root system.	/	Timber that can be used for medium strength pieces (flooring, panelling, furnitures etc), tonal qualities for instruments.
Leucaena, White leadtree	*Leucaena leucocephala*	Plant	Terrestrial	Fiji French Polynesia New Caledonia Vanuatu	Like most agroforestry trees it will resprout vigorously after cutting and some or all of the root mass must thus be removed. A combination of cutting followed by herbicide is effective for older trees.	/	Used for light wood production and for pulp and paper production but not significantly.
Mallard	*Anas platyrhynchos*	Aves	Freshwater/Terrestrial	New Caledonia Vanuatu	Hunting. Decline of the Mallard population has been observed multiple times due to overhunting.	/	The recreational hunt of mallard is very famous in the US and is a source of economic benefits. In 2001, waterfowl hunting generated over USD2.3 billion in total economic output in the US.
Rubber vine	*Cryptostegia grandiflora*	Plant	Terrestrial	Fiji French Polynesia New Caledonia	Physical control possible but can be very labour intensive and expensive in large and dense areas. Need to combine it with other control to prevent regrowth.	/	Rubber production but not as competitive as other existing rubber plants

Water weed, Florida elodea	*Hydrilla verticillata*	Plant	Freshwater	New Caledonia	Manual or mechanical removal efficient but relatively expensive. Once cut, if not removes from water, the spreading can be even more important.	Potential use for bioenergy bur further studies are needed. Produce a very good compost with essential nutrients in enormous quantities.	/
Merremia	*Merremia Peltata*	Plant	Terrestrial	New Caledonia French Polynesia	The usual physical control practice is to cut the emerging Merremia using long-bladed knives but its is labour-intensive and can easily damage establishing plants	Pilot project of biogas production from merremia peltata in SAMOA , financed by the UNDP. The system appeared as financially feasible in countries where the cost of labor is low.	Biogas production

Annex 3: Tables

Table 1: Number of IAS per commercial potential level for each PICT

Level occurrences per location	Commercial potential level				
Location	**Level 1**	**Level 2**	**Level 3**	**Level 4**	**Total**
Fiji	4	6	4	15	29
French Polynesia	6	9	5	22	42
New Caledonia	8	12	8	42	70
Vanuatu	4	2	2	13	21
Total	**22**	**29**	**19**	**92**	**162**

Table 2: Commercial potential levels for each biological class

Level occurrences per class	Commercial potential level				
Biological class	**Level 1**	**Level 2**	**Level 3**	**Level 4**	**Total**
Amphibian				1	1
Aves		1		3	4
Fish			5	3	8
Gastropod	1			3	4
Insect				18	18
Mammal	3	1	1	7	12
Plant	4	10	2	6	22
Reptile				1	1
Total	**8**	**12**	**8**	**42**	**70**