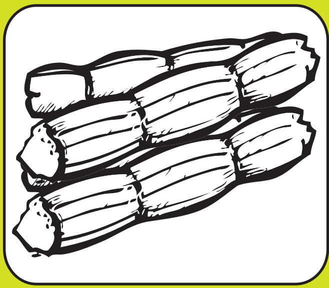

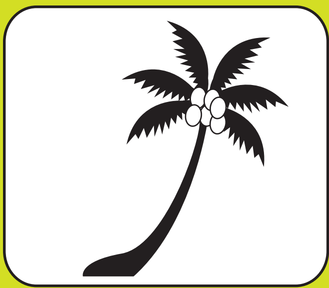

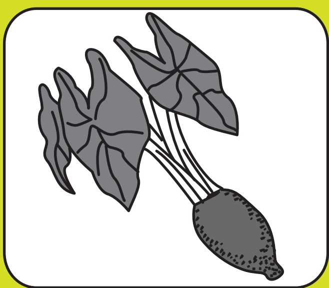
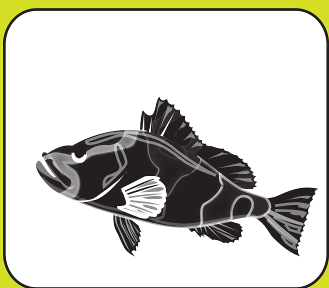


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White and Black list of Fiji's Invasive Alien Species

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ABSTRACT

Universally, there are several common criteria that identify a taxa as an Invasive species. These traits recognize invasive species as a non-native, exotic or alien taxa that has the potential to naturalize or be adventive in its habitat. They also have the tendency to become widespread and thrive in abundance and are essentially problematic with a harmful effect on the environment. Under the GEF taskforce in 2020, a series of meetings coordinated by the Biosecurity Authority of Fiji (BAF) implemented a review and consultation of the existing list of invasive species for Fiji. Presented here is the outcome of the consultation which recognizes a total of 74 invasive taxa comprising 30 plants, 13 fishes, 12 mammals, 10 birds, six land invertebrates and three herpetofauna species. Altogether, a total of 19 taxa are on the black list and 55 taxa are assigned to the white list. The listing designation of all 74 taxa was determined by the technical committee, comprising of specialists and taxonomists familiar with the ecology of respective species, particularly in Fiji.

Keywords: Invasive species, white list, black list, BAF, Fiji

1.0 INTRODUCTION

There is not one general consensus to the definition of an Invasive species, as stated by several literature sources, given that the definition varies according to the institution concerned. For example, the definition of Invasive species by the: i) IUCN[1] states: "Invasive alien species (IAS) are animals, plants or other organisms that are introduced into places outside their natural range, negatively impacting native biodiversity, ecosystem services or human well-being", and ii) FAO[2] states: "Invasive species are any species that are non-native to a particular ecosystem and whose introduction and spread causes, or are likely to cause, socio-cultural, economic or environmental harm or harm to human health". According to Fox and Gordon in 2004, the scientific community has yet to agree on a universally recognized definition of what an invasive alien species is, or on the criteria that are needed to assign a particular species to a list of invasive species in a particular country or region. However, there are some common criteria that are widely used to identify and describe Invasive Alien Species (IAS): i) they are non-native or exotic or alien ii) they have then become naturalized and adventive iii) they spread and are increasing in abundance iv) they are problematic and have harmful effects on the natural environment.

Invasive alien species are one of the biggest threats to global biodiversity, second only to habitat loss. Not all IAS species present in a country will be invasive across all habitats. Whether a habitat is vulnerable to invasion depends on a variety of factors beginning with the abiotic conditions of the habitat, its level of disturbance, and the biotic interactions between the species within that habitat. The management of such species is a key focus of Fiji's National Biodiversity Strategy and Action Plan in 2003, a specific objective of which is to "effectively control invasive and potentially invasive species present in Fiji". As such, under the GEF 6 in 2020 through the Biosecurity Authority of Fiji (BAF), the technical committee of the Fiji Invasive Species Taskforce (FIST), chaired by University of the South Pacific (USP), reviewed and developed Fiji's definition of Invasive Alien Species (IAS). During this process, existing definitions of IAS used by institutions such as the International Union for Conservation of Nature (IUCN) and the Food and Agriculture Organization (FAO) were considered, including several others used in Fiji.

The aim of this paper is to provide an official white and black list of invasive plants and animals across Fiji.

2.0 METHOD

A series of meetings of the Global Environment Facility (GEF) 6 taskforce in 2020 were held to review the definition of IAS for Fiji. This was followed by discussion on a list of IAS for Fiji. With the development of a local definition of IAS, the Technical Committee of Fiji Invasive Species Taskforce (FIST) convened to produce a black and white list of IAS for Fiji. Members of the Technical Committee are highly trained specialists in various taxonomic groups of organisms in the Pacific and in particular Fiji.

3.0 RESULTS AND DISCUSSION

Towards the end of the year 2020, the GEF 6 project taskforce was able to re-define the term Invasive Alien Species (IAS) under the Fiji context. The definition states that "*Invasive Alien Species (IAS) are organisms found outside of their native geographical ranges that have established, spread and become harmful and destructive to the local biodiversity and environment of value to humans"*. With this IAS definition for Fiji, a preliminary annotated checklist of invasive species was produced after a series of meetings of the GEF 6 IAS Project Taskforce. The group listed a total of 105 taxa. The largest group of organisms listed were plants (terrestrial and aquatic) with 44 taxa, followed by the terrestrial invertebrates with 21 taxa. These two groups represented more than 50% of the invasive organisms to be assessed. They were followed by mammals with 12 species, and then birds and fish (freshwater/marine) with 10 taxa each. The remaining eight species were generically listed as marine fishes, fruit fly and other introduced plants. This list of 105 invasive species was then adopted by the Technical Committee of FIST as the basis to develop the white and black list of IAS for Fiji.

In September of 2022, a group of specialists of the various taxonomic groups, most of whom are

1 https://www.iucn.org/resources/issues-brief/invasive-alien-species-and-climate-change

2 https://www.fao.org/forestry/aliens

members of the Technical Committee of FIST, underwent a whole day consultation workshop to review the preliminary annotated invasive species checklist for Fiji. After further consultation and debate, especially, on the questionable groups/ species, the white and black list of IAS was developed for Fiji (Appendix 1). By definition, the 'black listed taxa' are those alien species that are invasive (see definition of IAS) i.e. they occur in almost all types of habitats; they have a large population and they are problematic to the immediate biodiversity of the area and the environment. On the contrary, the 'white listed taxa' are those species that are probable or potential invasive. For this group they are present and may be problematic in certain habitats only and not in others and its population is restricted and not widespread. Some 30+ species were removed from the initial list mostly because these species are restricted in their distribution and are more or less confined to only one or two habitat type(s). Also, the lack of field data to justify the IAS status of some of this species is frustrating and more so if it is personal to an individual.

Consequently, the black and white checklist has a total of 74 species. The largest group being plants with 30 species, out of which 25 species are white listed and five species are black listed. This is followed by the fish group with 13 species of which eight are white listed and five are black listed; mammals with 12 species of which four are in the white list and eight in the black list; and three herpetofauna species of which two are white listed and one black listed. All 10 bird species are white listed. Further, two birds, the Jungle Mynah and the Common Mynah are considered bad pests. They have been in Fiji the past 100+ years and are found in most habited islands. They are white listed here due to their being restricted to where people live (settlements, villages and towns), the fact that they very bad pests and are a real nuisance to humans. The jungle mynahs at times are seen foraging around forest edges and are not observed in primary forest. The six terrestrial invertebrates including a flatworm are white listed, in spite of the current data deficiency of each group.

4.0 CONCLUSION

A total of 74 species are listed in Appendix 1 as the official list of IAS for Fiji. From this list, 19 species are in the black list of IAS with the remaining 55 species being white listed. It should be noted that this is not all the IAS for Fiji. The list is to be regularly updated, preferably after every five years. This is because of the large numbers of white listed IAS, and that there are lots of new introductions into the country of exotic ornamental plants. Thus, the importance of regular monitoring by credible entities in Fijis' network of Protected Area to purposefully capture and mitigate the negative impacts of IAS to the environment. Given the technical capabilities within BAF, it is recommended that they take the lead on this with financial support from Government and other sources outside Fiji. Moreover, awareness education of IAS through both the formal and informal channels of communications should be strengthened, supported financially, and implemented on a regular basis.

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Appendix 1: List of White and Black Invasive Alien Species (IAS) for Fiji

Group	Scientific name	Common/local name	Invasiveness (White or Black list)
Birds	*Acridotheres fuscus*	Jungle mynah	White list
	Acridotheres tristis	Common mynah	White list
	Amandava amandava	Red avadavat	White list
	Columba livia	Feral pigeon	White list
	Egretta novaehollandae	White faced heron	White list
	Gymnorhina tibicen	Australian magpie	White list
	Padda oryzivora	Java sparrow	White list
	Pycnonotus cafer	Bulbul	White list
	Streptopella chinensis	Spotted dove, Kukuru	White list
	Sturnus vulgaris	Starling	White list
Fish	*Aristichthys nobilis*	Big head carp	White list
	Barbonymus gonionotus	Silver barb	White list
	Carassius auratus	Gold fish	White list
	Ctenophyaryngodon idella	Grass carp	White list
	Cyprinus carpio	Grass carp	White list
	Gambusa affinis	Kete leka, Western mosquito fish	Black list
	Gambusa holbrooki	Eastern mosquito fish	Black list

Fish	*Micropterus salmoides*	Bass	White list
	Oreochromis mossambicus	Malea dina, Tilapia	Black list
	Oreochromis niloticus	Malea ni isireli, Nile perch	White list
	Poecilia mexicana	Shortfin molly	Black list
	Poecilia reticulata	Rainbow fish/guppy	Black list
	Xiphophorus maculatus	Platy	White list
Herpetofauna	*Iguana iguana*	Green iguana, Common Green Iguana, Giant Invasive Iguana (Fiji)	White list
	Indotyphlops braminus	Flower pot snake	White list
	Rhinella marina	Cane toad	Black list
Land invertebrates	*Anoplolepis gracilipes*	Yellow crazy ant	White list
	Crossotarsus extemedentatus	Ambrosia beetle	White list
	Pheidole megacephala	Big-headed ant	White list
	Platy manokwari	New Guinea flatworm	White list
	Technomyrmex spp.	White footed ant	White list
	Wasmania auropunctata	Little fire ant	White list
Mammals	*Bos taurus*	Feral cattle	White list
	Canis lupus familiaris	Feral dogs	White list
	Capra hircus	Goat	Black list
	Cervus elaphus	Red deer	White list
Mammals	*Felis catus*	Feral cats	Black list
	Herpestes auropunctatus	Small indian mongoose	Black list
	Herpestes fuscus	Indian brown mongoose	Black list
	Mus musculus	House Mouse	White list
	Rattus exulans	Polynesian rat	Black list
	Rattus norvegicus	Norway rat, Black rat	Black list
	Rattus rattus	Ship rat	Black list
	Sus scrofa	Feral Pig	Black list

Plants	*Acacia farnesiana*	Vaivai vakavotona, Ellington curse	White list
	Acacia mangium	Brown salwood	White list
	Albizia falcataria	Vaivai	White list
	Albizia saman	Vaivai ni vavalagi, rain tree	White list
	Annona glabra	Uto ni bulumakau, bullocks heart	Black list
	Ardisia crispa	Holly, Australian holly	White list
	Clerodendrum quadriloculare	Bronze-leaved cleredendron	White list
	Clidemia hirta	Kauresiga, Korsters curse	White list
	Coffea arabica	Kofe	White list
	Cyperus papyrus	Umbrella plant, Papyrus	White list
	Eichhornia crassipes	Water hyacinth, Dabedabe ni ga	White list
	Gmelina arborea	Yemane	White list
	Hedychium coronarium	Cevuga, white ginger	Black list
	Hydrilla verticillata	Water weed	White list
	Lantana camara	Lantana	White list
	Lemna perpusilla	Kala, Lemna	White list
	Leucaena leucocephala	Vaivai kena me, Balori	White list
	Maesopsis emnii	Umbrella tree	White list
	Mikania micrantha	Wabosucu, Mile-a-minute	White list
	Mimosa pigra	Giant sensitive tree	White list
	Nymphaea capensis f. *capensis*	Water lily, Blue waterlily	White list
	Pinanga coronata	Ivory cane palm	White list
	Piper aduncum	Onalulu, Yaqoyaqona,	White list
	Pistia stratiotes	Water lettuce	Black list
	Psidium cattleianum	Strawberry guava, Cherry quava	White list
	Pueraria lobata	Yaka, Wa yaka, Kudzu	White list
	Schefflera actinophylla	Queensland umbrella tree, Octopus tree	Black list
	Spathodea campanulata	African tulip, Pasiu	Black list
	Sphagneticola trilobata	Wedelia	White list
	Swietenia macrophylla	Mahogany, Large leaved mahogani	White list

An assessment of the invasiveness of the introduced terrestrial vertebrates of Fiji

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ABSTRACT

The terrestrial vertebrates of the Fiji Islands are made of the following groups of animals: mammals (Class Mammalia), birds (class Aves), amphibians (class Anura), and reptiles (class Reptilia). There are 128 (77 aves, 20 mammals, 28 reptiles and 3 amphibians) confirmed number of terrestrial vertebrate species in Fiji. A total of 31 species (13 aves, 14 mammals, 3 reptiles, 1 amphibian) have been introduced into Fiji by humans in the past. A number of these introduced species are considered pests, posing a threat to the economy, human livelihood, and native terrestrial biodiversity. The following questions are therefore pertinent: 1) Are all the introduced terrestrial vertebrates invasive? 2) When do we classify a species as invasive? To answer these questions, information on their distribution in Fiji, from written records and personal observations were recorded. The distribution data was then compared to the status of the areas where they are recorded from. Based on these two datasets (distribution and status of area), species were classified as either white, grey, or black status. White indicating that a species is not a threat, grey that a species has the potential to become an invasive, and black if it is undeniably invasive in Fiji. An invasive species (black status) in this regard is classified as a species that has spread to most terrestrial habitats in the country without human aid. Most of the introduced terrestrial vertebrates in Fiji have the potential to become invasive. However, only a few species discussed herein can be considered real invasive alien species (IAS).

Keywords:
Terrestrial vertebrates, birds, mammals, reptiles, amphibians, white status, grey status, black status.

1.0 INTRODUCTION

In an island ecosystem an introduced species is a species that is surviving on the island but is not indigenous to the island or region and has been deliberately or accidentally introduced by humans whereas a native species is indigenous to that island or region which has managed to arrive and survive there on its own through natural selection or the process of natural evolution (Burns 2015; Blackburn *et al*. 2008; Iannone *et al*. 2020). Introduced species are also often referred to as exotics or alien species. Islands are often viewed as fragile ecosystems and introduced species often can become invasive, establishing populations on different habitats on the island and outcompeting native species (Simberloff 1995). The topic of Invasive Alien Species (IAS) is now of global interest because of its side effects and various definitions have been put together over time to describe it, for example, Iannone (2020) states : "For a species to be invasive it must meet the following criteria – a) be nonnative (alien/exotic), b) be introduced, intentionally or unintentionally and c) cause or be likely to cause environmental and/or economic harm and/or harm to humans".

The effects of IAS are now experienced globally threatening the local or native biodiversity, ecosystem services and functions, economy and human health (Davis 2003; Peyton *et al*. 2019). Invasive alien species have been blamed to be the major cause of decline or even destruction of native species and native habitats is island ecosystems (Vitousek *et al*. 1987; Simberloff 1995; Towns *et al*. 1997; Fritts *et al*. 1998). For instance, feral cats have been blamed for causing up to 14% of birds, mammals and reptile extinctions from islands worldwide (Medina *et al*. 2011). Since the arrival of humans accompanied by exotic plants and animals in the Hawaiian Island group, 10% of the native flora and more than 30 species of birds have gone extinct as a result the lowlands are now dominated by exotic species and the native species are restricted more to the higher elevations (Vitousek *et al*. 1987). In New Zealand, since the arrival of humans about 1000 years ago together with the exotic plants and animals that they introdced, about 40% of the avifauna taxa have gone extinct and introduced mammals species like cats and rats have been blamed for the loss of seabirds, invertebrates, lizards and birds species (Towns *et al*. 1997). In Guam, the accidental introduction of the Brown Tree Snake (*Boiga irregularis* Merrem) has greatly affected the native biodiversity causing the loss of native species like birds, reptiles, and bats from some of the islands (Fritts *et al*. 1998).

Like the islands of Hawaii and other islands ecosystems that have documented the threats of IAS, Fiji is no exception and experiences similar effects. The introduced Small Indian Mongoose (*Herpestes auropunctatus* Hodgson) have been blamed for the extirpation of four bird species from Fijian islands (Hays *et al*. 2007). The endemic Fijian ground frog and endemic Crested Iguana population are now also threatened by the presence of IAS such as cane toads, rats, feral cats and feral dogs (Denny *et al*. 2005). Feral pigs and the Red-vented Bulbul have also been recorded to be a threat to the agriculture sector both on subsistence and commercial scale (Watling 1983; Saunders *et al*. 2007). These are just a few of the documented threats or side effects of IAS in Fiji but most of their negative impacts have not been documented as there is little research focused on this area in Fiji.

This paper covers the introduced terrestrial vertebrates in Fiji which includes all land dwelling animals with a vertebral column that have been introduced by man in the past. The list of introduced terrestrial vertebrates of Fiji have been documented in the extensive work by Pernetta and Watling (1978) including their associated habitats (Table 1). The terrestrial vertebrates of the Fiji Islands are made of the following groups of animals: mammals (Class Mammalia), birds (class Aves), amphibians (class Anura), and reptiles (class Reptilia). The birds have been well covered in the work of Watling (2001), the mammals in the work of Falnnery (1995), and the reptiles and amphibians by Morrison (2003). There are 129 (78 aves, 20 mammals, 28 reptiles and 3 amphibians) confirmed number of terrestrial vertebrate species in Fiji. A total of 31 species (13 aves, 14 mammals, 3 reptiles, 1 amphibian) have been introduced into Fiji by humans in the past (Table 1). Eleven of these introduced species are listed in the "100 of the world's worst invasive species" (Lowe *et al*. 2000).

The aim of this paper is to document the invasiveness of the introduced terrestrial vertebrates of Fiji based on their distribution records. The following questions were asked: 1) Are all the introduced terrestrial vertebrates invasive? 2) When do we classify a species as invasive? To answer these questions, the information on their distribution in Fiji, from written records and personal observations were recorded. This distribution data was then compared to the disturbance status of the areas or habitat where they are recorded from. The hypothesis put forward is that all introduced species will be become invasive in island ecosystems. However, we predict that only some of these introduced species have the tendency to become invasive.

2.0 METHODS

This paper is an outcome of the GEF 6 UNDP 'invasive alien species' project, through a one day 'Black and White listing of introduced species workshop' at the Holiday Inn, 22nd August 2022 and a two day 'Fiji invasive alien species symposium' at the University of the University of the South Pacific, 7-9th February 2023.

In this paper the following questions are asked: 1) Are all the introduced terrestrial vertebrates invasive? 2) When do we classify a species as invasive? To answer these questions, to sets of information had to be collected and then combined to give a clearer picture of the invasiveness of terrestrial IAS in Fiji. The two sets of information were the Distribution Status and the Habitat Status.

Distribution Status: information on their distribution in Fiji, from written records and personal observations. This information includes locality data where the IAS have been recorded.

Habitat Status: information on the status of the habitats where the IAS have been recorded from. The classification of habitats was based on the Mueller-Dombois and Forsberg (1998), where they classified Nine (9) principle vegetation types that are found in Fiji (Table 2). Each vegetation type was then classified as either 'intact' (in primary state) or as 'disturbed' (in secondary state). An intact vegetation means that it is still in primary state and has not been subject to human disturbance. A disturbed vegetation means that it has been subject to human disturbance in the past like logging, mining, road construction and other human related activities. We added another vegetation type here as 'Human-modified vegetation' which can be further divided into three habitat types: Plantation Forest (mahogany or pine forest), Agricultural land (gardens, farmlands, coconut, etc) and Human habitation (villages, towns). A total of 21 habitat types were described from the 10 vegetation types (Table 2).

For each IAS, its distribution data was then compared to the status of the habitats where it has been recorded from. Based on these two datasets (distribution and habitat status), the species were classified as either white, grey or black status. Each species was given a score based on the habitats it was recorded in, the highest being 21 and lowest being 1. Any species recorded in >10 habitats was classed as a black-list species. A species that scored between 5-10 was classed as a grey-list species, and a species scoring <5 was classed as a white-list species. The white-list species do not pose a threat to Fiji now as it has a restricted distribution being only present or recorded from a few habitats and they have not been able to spread to other habitats. The grey-list species are recorded in more habitats than white species. They are not really seen as invasive (<50% of habitat types). However, they have the potential to become invasive. The black-list species include all the species that have undeniably become invasive in Fiji. An invasive species (IAS) in this regard is classified as a species that has spread to most terrestrial habitats (>50% of habitat types) in the country with and without human aid. In addition to this a species is classified as a black-list species if it fulfils the IAS definition developed by the Fiji GEF Taskforce (2020) stating: 'Invasive Alien Species (IAS) are organisms found outside of their native geographical ranges, that have established, spread, and become, harmful and destructive to local biodiversity and environment of value'.

3.0 RESULTS

A total of 31 species of terrestrial vertebrates have been introduced into Fiji since the arrival of the first human settlers. However, only 12 of these introduced species have become invasive in Fiji and can be classified as IAS. These 12 species fall under the black-list, four under the grey-list and the remaining 15 species fall under the white-list (Table 3). The results disagree with the initial hypothesis that all the introduced species will become invasive in an island ecosystem like Fiji. The results were also able to answer the two questions set out at the beginning of this paper which are: 1) Not all the introduced terrestrial vertebrate species are invasive and

2) An introduced specie becomes invasive when it is found to be present in most of the habitats present on the island, and in this case when it is recorded in 11 or more habitat types.
Interestingly, some of the species listed in the '100 of the world's worst invasive species' (Lowe *et al*. 2000) did not appear in the black-list (Table 3). This could due to various factors, one for instance is the large body of sea-water separating the islands in the Fiji archipelago. However, this needs further study in the future in order to give us better understanding of the behaviour of some of these introduced species. For example, the European starling was believed to be introduced into Fiji's Southern Lau Group in the 1950s. However, seventy years later, it is present only on the two islands of Ono-i-Lau and Vatoa, which are isolated from the other islands of the Lau group and the rest of Fiji. The Red deer since its introduction in the early 1900s has only been allowed to survive on Wakaya Island and fortunately, it has not been introduced to any other islands. The same could be said for the Australia magpies which is only restricted to parts of Taveuni and Cicia. The Green Iguana which are confirmed to be present only on Qamea, Matagi and Laucala islands. Although these species are not listed as black-list or IAS in this paper, they have the potential to become IAS so their population needs to be controlled or even eradicated soon.

There was no statistical analysis of the data collected to statistically test its significance. This calls for more research in the area of IAS for Fiji where quantitative data can be collected and statistically analysed to test for the invasiveness of the IAS present in Fiji in future surveys.

4.0 DISCUSSION

The 12 species identified as black-list species or IAS in Fiji were all introduced to the main islands and have at least been introduced for 100 years or more (except for the Indian brown mongoose). These two factors could contribute to their invasive status in Fiji as they have had time to establish their population, adopt a niche and expand to other habitats. Introduced species in islands are often seen as better competitors than their native counterparts which have evolved on islands without much competition (Sigiura 2016). They also tend to have devastating effects on islands where their native competitor or predator is missing altogether (Courchamp *et al*. 2003). If no control measures are in place for these species, they will cause changes or even the long term degradation of the island ecosystem as experienced in Guam with the introduction of the Brown Tree Snake (Fritts and Rhidda 1998). In Fiji, especially on Viti Levu Island, this is currently being experienced as well with certain ground dwelling bird species being extirpated from the main island and other bird species being threatened as well because of the presence of feral cats, mongoose and rats (Watling 2001).

The listing of introduced species into black, grey and white should be seen as a tool to assist environmental managers and decision makers. Species listed in the black-list have already spread to most of the habitats and their eradication is probably impossible. However, control measures need to be in place to monitor their population, have eradication or control plans and more importantly to prevent their spread to other islands. A good example in this case is the Cane toad on Viti Levu Island, which is probably impossible now to eradicate. However, certain control measures need to be in place and it should not be introduced to other islands. The grey and white-list species, although are not classified as invasives in this paper, they still have the potential to become invasive if they are introduced to other islands and their populations are not monitored. Since they are only restricted to certain habitats or islands then their eradication is still possible. In this case, effort should be targeted towards total eradication or controlling the spread of these species before it is too late. A good example here is the Green Iguana, which this paper classifies as a grey-list and not an IAS. However, it has potential to become invasive and through the GEF 6 project, the Fiji Government is already trying to eradicate it and control its spread to other islands.

This data presented in this paper is more biased towards Viti Levu Island where most of the distribution data were gathered from. However, it extends the work carried out by Pernetta and Watling (1978) and other researchers who have done work on the terrestrial vertebrate species of Fiji. Through the improvement in the mode of global transportation, IAS will continue to become a threat to Fiji and other island ecosystems globally, so the challenge now will be on how to control the spread of IAS. Fiji needs to have proper legislation in place to achieve this. Furthermore, effort needs to be spent on proper scientific surveys and long-term monitoring protocols first to better understand the behaviour of these IAS.

5.0 CONCLUSION

Newly introduced species into an island ecosystem by humans has the potential to become invasive. However, this is not always the case as observed and presented in this paper where only 39% of the introduced vertebrate species can be classified as IAS. This could be due to various factors that have not been discussed in this paper and could be an avenue for future research to better understand the survival of introduced species and the theory of natural selection in island ecosystems. One such factor that might contribute to the invasiveness of an introduced species is time or how long has a species been introduced. Species introduced over hundreds of years ago have the time to become naturalized, find a niche and establish populations in the new environment whereas species introduced tens of years ago are probably still trying to establish their population or find a niche to enable its long-term survival. IAS is a threat to Fiji's biodiversity, economy and human livelihood. However, scientific research, eradication or control measures and long-term monitoring is still lacking and these issues need to be addressed.

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Table 1: Summary list of the introduced terrestrial vertebrate species that have been introduced to Fiji via human aid in the past.

Scientific name	**Common Names**	**Origin**	**First reported**	**Distribution (local)**
BIRDS				
Acridotheres tristis	Common mynah	Indian subcontinent	1890	Widespread, common. Populated areas (villages, towns, cities) on the larger islands
Acridotheres fuscus *	Jungle mynah	Indian subcontinent	1900	Widespread, common. Populated areas (both rural and urban) including farmlands, wasteland and secondary forest habitat on the main islands.
Pycnonotus cafer *	Bulbul	Indian subcontinent	1903	Wisespread, common, Populated areas (urban and rural), farmland, wasteland, secondary forest and even primary intact forests like Sovi and Wabu reserves, on the larger islands.
Columba livia	Feral pigeon	Eurpoe, SW Asia, N Africa	1840s	Localised. Urban centres and towns on Viti Levu and Vanua Levu island.
Sturnus vulgaris *	European Starling	Europe, Asia and N Africa	1951	Localised. In Fiji, this species is present in the Southern Lau island group in the islands of Vatoa and Ono-i-Lau.
Gymnorhina tibicen	Australian Magpie	Australia and Southern New Guinea	1880s	Localised. In Fiji this species has been recorde from the islands of Taveuni Island and Cicia. In Tavueni it prefers the coconut plantation area.
Padda oryzivora	Java sparrow	Java and indonesia	1925	Localised. This species is restricted to Southern Viti Levu, in the Navua area (rice fields).
Streptopella chinensis	Spotted dove, Malay Turtle-dove, Spotted Turtle dove	SE Asia	1923	Widespread, common. Agriculture land, urban garden and forest, surburban garden and forest, rural inhabited areas, secondary forests, open cleared areas like grassland and shriblands.

Amandava amandava	Red avadavat	Asia, Pakistn to China and Indonesia	1906	Localised. Open areas, grassland, shrubland, agricultural land, forest edges. Viti Levu
Meleagris gallopavo	Wild Turkey	North America	1900s	Rare. Maybe still surviving on estates in Taveuni, Laucala and Naitauba
Gallus gallus	Jungle fowl	Asia	Aboriginal	Jungle fowl, still on some Islands. It is also domesticated and present on inhabitated islands
Anas platyrhynchos	Duck	Asia	1900	Common. Domesticated on larger islands
Coturnix ypsilophora	Brown Quail	Australia	1900	Viti Levu and Vanua Levu
MAMMALS				
Felis catus *	Feral cats	Global. Domesticated.	1900's	Widespread. Uncommon. Even in intact forest habitats and uninhabitated islands but detected individually.
Capra hircus *	Goat	Global. Domesticated.	1900's	Widepread. Domesticated. When feral they can survive in any habitat.
Mus musculus *	House Mouse	Asia.	1800's	Widespread. Larger islands, associated with human habitation. Common. Urban and surbaban areas, villages, agriculture areas.
Sus scrofa *	Feral Pig	Asia.	Aboriginal	Widespread. Common. Feral pigs can be present in any habitat if undostribed, from coastal forest to cloud montance forest
Canis lupus familiaris	Feral dogs	Asia.	Aboriginal	Widespread. Uncommon. Associated with human habitation. Packs observed in isolated forested areas on Viti Levu
Bos taurus L.	Feral cattle	Asia.	1900s	Widespread. Uncommon. Associated with human habitation.
Equus ferus L.	Horse	Asia	late 1800s	Widespread. Uncommon. Associated with human habitation.
*Cervus elaphus L.**	Red deer	Europe-Asia.	1900s	Restricted to Wakaya Island only
Avis aries L.	Sheep	Asia	1900s	Main islands
Rattus rattus *	Ship rat	Asia.	1800s	Widespread. Common. Any terrestrial habitat from the coast to the mountains, both inhabitated and uninhabitated islands.
Rattus exulans	Polynesian rat	Asia.	Aboriginal	Widespread. Common islands where Black rat is not common or absent
Rattus norvegicus	Norway rat	Asia.	1900s	Widespread. Common. Associated with human habitation. Also present in intact forest systems.
Herpestes fuscus	Indian brown mongoose	Asia.	1970	Widespread. Uncommon. On Viti Levu island found more inland in forested areas away from Small Indian Mongoose

Herpestes auropunctatus *	Small Indian mongoose	Asia.	1880s	Widespread. Common. Larger islands - Viti Levu and Vanua Levu. All habitats, associated with human habitation
HERPETOFAUNA (Reptiles and Amphibians)				
*Rhinella marina L.**	Cane toad	South and mainland Central America.	1900s	Widespread. Common. On larger islands. Found in all vegettion types from near sea level to the mountains where there are freshwater bodies - rivers, lakes, ponds.
Indotyphlops braminus	Flower pot snake	Asia.	1900s	Uncommon. Viti Levu island. Associated with human habitation
Iguana iguana L.	Green iguana, Common Green Iguana, Giant Invasive Iguana (Fiji)	Tropical America.	1990's	Resident population on Qamea, Laucala and Matagi where it is widespread and common.
Hemidactylis frenatus Dumeril and Bibron	House Gecko	Asia	Aboriginal	Human inhabited islands
NOTE:				
1. Ref. (Pernetta and Watling 1979, Watling 2001, Watling 2013, Morrison 2003, Veron et al. 2010, A.Naikatini 2023, pers comm., 22 August; S.Vido 2023, pers comm., 22 August; V.Masibalavu 2023, pers comm., 22 August; N.Thomas 2023 pers comm., 22 August)				
2. * - Species listed in the "100 of the world's worst invasive species"(Lowe et al. 2000).				
3. First reports - Aboriginal, refers to species that were introduced by the first settlers. Date in 1800s and 1900s means that there is no clear record of the date of introduction.				

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Table 2: Summary description of the 10 vegetation types (from Mueller-Dombois and Forsberg 1998) and 21 habitat types used to describe the habitat status of the IAS distributions. The code represents the habitat type, for example 1a is the code for Cloud Forest – disturbed and 1b is the code for Cloud Forest – Intact.

	Vegetation		**Satus**		**Code**
#	**Name**	**Description**	**a**	**b**	
1	Cloud Forest	Summits and ridgetops, > 900m in the interior of larger islands (near the coast cloud it can be as low as 300m). Trees are stunted, and have dense bryophyte cover on their trunks. Reduced number of tree species, compared to that of the lowland and upland forests.	Disturbed	Intact	**1a, 1b**
2	Upland Forest	Located between 600m-900m elevation on larger islands. Contains most of the lowland species but with a greater dominance of certain gymnosperms – Agathis and Podocarpus in the wet zones, and Agathis and Dacrydium in the drier zones.	Disturbed	Intact	**2a, 2b**

3	Lowland Forest	Located from sea-level to about 600m elevation on larger islands. Mixed species assemblage of 40-50 canopy species, reaching heights of around 20-30m.	Disturbed	Intact	**3a, 3b**
4	Dry Forest	Found in the leeward lowlands of the high islands, but now almost completely destroyed by grazing and fire. Common tree species includes *Dacrydium, Fagraea*, *Podocarpus neriifolius, Gymnostoma vitiense, Myristica castaneifolia, Disoxylum richii, Parinari insularum, Intsia bijuga*, and *Syzygium* spp.	Disturbed	Intact	**4a, 4b**
5	Freshwater Wetland	Found on poorly drained alluvial sites, in some places with the physiognomy of a *Pandanus* savanna, in others with an open sedge cover and some clumped woody vegetation in thickets.	Disturbed	Intact	**5a, 5b**
6	Coastal Strand	Coastal strand shows a herb-shrub-tree zonation. The herb zone, closest to the beach, contains creepers, sedges and grasses. The shrub zone, contains *Scaevola taccada*, *Wollastonia biflora*, *Sophora tomentosa* and *Clerodendrum inerme*. *Pandanus tectorius* and *Casuarina equisetifolia* then follow, leading into the tree zone of mixed littoral forest.	Disturbed	Intact	**6a,6b**
7	Grassland	A fire-modified vegetation type, characterised by grass species like *Sporobolus* sp., *Miscanthus floridulus*, *Pennisetum polystachyon, patches of Pandanus, Casuarina, introduced shrubs and a* sparse fern cover (*Pteridium* and *Dicranopteris*)	Disturbed	NA	**7a**
8	Mangrove	This is the tidal zone, dominated by *Rhizophora* spp. and *Brugiera gymnorhiza and other mangrove associated plant species.*	Disturbed	Intact	**8a,8b**
9	Small island	Vegetation cover on raised limestone islands, sand cays and atolls (mostly to East in the Lau Group)	Disturbed	Intact	**9a,9b**
10	Man-modified	Constantly being modified by humans. Some are highly disturbed	Disturbed	NA	**10**
10,i	Plantation forest	Plantation forest eg. Mahogany and Pine plantations	Disturbed	NA	**10,i,a**
10,ii	Agricultural land	Land cultivated for crops - gardens, farmland, coconut plantation, fruit tree orchards	Disturbed	NA	**10,ii,a**
10,iii	Human habitation	Villages, towns both in rural and urban settings	Disturbed	NA	**10,iii,a**

Table 3. The distribution status of the introduced terrestrial vertebrate species in the 21 habitat types. The codes in the 'distribution' column stands for the habitat types described in Table 2. The scores under the 'score' column is the tally for the number of habitat types where the IAS has been recorded from. The 'listing' column show the colour-code for each species where black stands for black-list species, grey for grey-list species and white or unshaded represents white-list species.

Scientific name	**Common Names**	**Distribution**	**Score**	**Listing**
BIRDS				
Pycnonotus cafer [B]	Bulbul	1a,1b,2a,2b,3a,3b,4a,4b,5a,5b,6a,6b,7a,8a,10ia,10iia,10iiia	17	
Acridotheres fuscus [B]	Jungle mynah	1a,2a,3a,4a,5a,6a,6b,7a,8a,8b,10ia, 10iia, 19iiia	14	
Acridotheres tristis [B]	Common mynah	2a, 3a,4a,5a,6a,7a,8a,10ia,10iia, 10iiic	11	

Streptopella chinensis	Spotted dove	3a,4a,5a,6a,7a,10ia,10iia,10iiia	8	
Gallus gallus	Jungle fowl	3a,3b,6a,6b (domesticated 10iia,10iiia)	4	
Columba livia	Feral pigeon	7a,10ia,10iia,10iiia	4	
Amandava amandava	Red avadavat	7a,10iia,10iiia	3	
Coturnix ypsilophora	Brown Quail	4a,4b,7a	3	
Sturnus vulgaris ^	European Starling	Southern Lau - Vatoa,Ono I Lau	2	
Gymnorhina tibicen^	Australian Magpie	10iia on Taveuni and Cicia	2	
Padda oryzivora^	Java sparrow	10iia, 10iiia on Southern Viti Levu - Navua area	2	
Meleagris gallopavo^	Wild Turkey	10iiia - Taveuni or Naitauba?	1	
Anas platyrhynchos	Duck	Domesticated -10iiia	1	
MAMMALS				
Rattus rattus[B]	Ship rat	All habitats	21	
Felis catus [B]	Feral cats	2a,2b,3a,3b,4a,4b,5a,5b,6a,6b,7a,8a,8b,9a,9b,10ia,10iia,10iiia	18	
Herpestes auropunctatus [B]	Small Indian mongoose	1a,1b,2a,2b,3a,3b,4a,4b,5a,5b,6a,6b,7a,8a,8b,10ia,10iia,10iiia	18	
Sus scrofa [B]	Feral Pig	1a,1b,2a,2b,3a,3b,4a,4b,5a,5b,6a,6b,7a,10ia,10iia	15	
Rattus norvegicus [B]	Norway rat	1a,1b,2a,2b,3a,3b,4a,4b,6a,6b,7a,8b,19ia,10iia,10iiia	15	
Rattus exulans [B]	Polynesian rat	3a,3b,6a,6b,9a,9b,3a,3b,4a,4b,10iia,10iiia	12	
Capra hircus [B]	Goat	2b,3a,3b,4a,4b,7a,9b,9a,10ia,10iia,10iiia	11	
Herpestes fuscus [B]	Indian brown mongoose	1a,2a,2b,3a,3b,4a,6a,7a,10ia,10iia,10iiia	11	
Canis lupus familiaris	Feral dogs	3a,3b,4a,6a,6b,10iia,10iiia	7	
Bos taurus L.	Feral cattle	3a,4a,7a,10ia, 10iia, 10iiia	6	
Equus ferus L.	Horse	7a, 10ia, 10iia, 10iiia	4	
Mus musculus	House Mouse	10iia, 10iiia	2	
Cervus elaphus L.^	Red deer	Wakaya Island	1	
Avis aries L.	Sheep	10iia	1	

HERPETOFAUNA (Reptiles and Amphibians)				
Rhinella marina L.[B]	Cane toad	1a,1b,2a,2b,3a,3b,4a,4b,5a,5b,6a,6b,7a,10ia,10iia,10iiia	16	
Iguana iguana L.^	Green iguana	3a,3b,4b,6a,6b,8a,8b,10iia,10iiia - Qamea, Laucala, Matagi	9	
Indotyphlops braminus	Flower pot snake	Southern Viti Levu -10iia,10iiia	3	
Hemidactylis frenatus Dumeril and Bibron	House Gecko	10iia, 10iiia	2	
NOTE:				
1. Ref. (Pernetta and Watling 1979; Watling 2001; Wating 2009; Morrison 2003a; Morrison 2003b; Morrison 2003c; Morrison 2004; Morrison 2006; Morrison et al. 2009; Veron et al. 2010; Naikatini 2008; Naikatini 2009; Naikatini 2011; Andersen et al. 2009; Thomas 2009; Niukula 2009; Tuiwawa et al. 2013: Tuiwawa et al. 2014; Tuiwawa and Pene 2014; Tuiwawa and Pene 2015; Tuiwawa and Pene 2017; Tuiwawa and Pene 2018a; Tuiwawa and Pene 2018b; A.Naikatini 2023, pers comm., 22 August; S.Vido 2023, pers comm., 22 August; V.Masibalavu 2023, pers comm., 22 August; N.Thomas 2023 pers comm., 22 August)				
2. ^ - Restricted distribution, only on certain islands. **3.** [B] – Black list species or IAS species for Fiji.				

Current Status, Distribution and Assessment of Invasive Alien Plant Species (IAPS) across Forests of Conservation Significance in Fiji

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ABSTRACT

Invasive Alien Plant Species (IAPS) are defined as those species that are intrusive in a naturally sound environment by means of intentional and or accidental introduction that poses a threat to the well-being of native species. Here in Fiji, the presented list of IAPS are those plants that are present in a forest without any established source of introduction except that which is generically assumed and expected to be the causal sources and pathways. Through a series of terrestrial Rapid Biodiversity Assessment in at least the last 15 years, a total of some 20 plus species of plants that are known to have an invasive behavior, locally and in other parts of the world, are listed with their status and local distribution documented across forests of conservation significance. Recorded opportunistically and methodologically upon site surveys, the presence and absence of these species show that some of the very common, widespread and serious invasive species are: *Clidemia hirta* (L.) D. Don (Koster's curse), *Mikania macrantha* Knuth. (Mile-a-minute), *Spathodea campanulata* P. Beauv. (African tulip tree) and *Merremia peltata* (L.) Merr. (Merremia). These species of plants have been documented to be present in almost all types of forest across Fiji's terrestrial landscape. The other more uncommon species include *Arundo donax* L. (Giant reed) and *Lantana camara* L. (Lantana). A few others that are known to show an invasive behavior are *Swietenia macrophylla* King (Mahogany) and *Piper aduncum* L. (Spiked pepper). This paper presents the collective knowledge of what is locally and currently known about the status, distribution and assessment of IAPS across several terrestrial forests of conservation significance in Fiji.

Key words: Invasive Alien Plants, Forest, Conservation, Fiji

1.0 INTRODUCTION

Background: Under the general framework of conservation, the security and well-being of ecosystems, climate and biodiversity has always been the objective of work in the collective undertakings streamed towards improving the protection and management of our forests. Here in Fiji, Forest areas of high biodiversity is one of the primary criterions for identifying areas of conservation significance in the terrestrial space of work. It must be noted that these areas are not exclusive to one type of system and instead, includes all types of forest and terrestrial ecosystems ranging from the mangrove and coastal systems up into the lowland rainforest and the interior highlands.

In at least, the last 10 years, several key rapid biodiversity assessments (BioRAPs), comprising teams of local and overseas experts and scientists, have been the focal points of generating information that often are the gap areas in the overall management of our national resources. Generation of information resources, from these surveys, are in the forms of baseline information of areas that, frankly, are inaccessible to reach however important, at the project, national and even regional level of assessments, for the overall purposes of livelihood and sustainability. It is through the institutional collaboration and technical mobilization, upon government requests and or independent research initiatives, that these technical groups of expertise are able to access and assess areas of potential significance and national interest. The criteria that is generally considered for an area to be considered a priority area for conservation is based on the taxonomic groups that is present that includes assessing the diversity parameters of the area: species richness, species endemism, rarity and or threatened, including an assessment of the conditions of these area i.e., whether the area is intact, disturbed or compromised (Morrison and Nawadra 2009).

To date, the RAP surveys has been the tool to assess the conservation value of many terrestrial forest, as potential sites of conservation significance, across the principal islands in Fiji - Viti Levu, Vanua Levu, Taveuni, Kadavu, Ovalau and Lau (Tuiwawa and Morrison 2008; Tuiwawa and Whistler 2009 a, b; Morrison and Nawadra 2009; Tuiwawa *et al.* 2011; Tuiwawa *et al.* 2013 a, b; Tuiwawa and Pene 2015, 2018 a, b; Tuiwawa *et al.* 2018c). As such, these surveys have served as a baseline platform to providing information about invasive alien plant species throughout Fiji, across some of the most inaccessible site areas. Examples of these extensive BioRAPs surveys are provided to ascertain local occurrences and distribution of IAPS as well as patterns of possible recurrences in other similar locations across Fiji.

Introduction: Invasive Alien Plant Species (IAPS) are defined as those species that are intrusive in a naturally sound environment by means of intentional and or accidental introduction that poses a threat to the well-being of native species. In other words, they are non-native or non-indigenous also known as exotic plant species that are introduced into an area, where they have never occurred before, by either intentional or accidental introduction. They occur in areas that are natural (native or primary or undisturbed) or semi-natural forests (restored habitats, secondary habitats, or partially disturbed areas such as forest trails, gaps and edges) and the effect of their presence is observed to be an ecological impact that is irreversible (Meyer 2000). Accordingly, the effect of IAPS on the native environment is that they target the composition and structure, and possibly the processes of the local environment. The effects are observed through anyone of the following results (Meyer 2000):
Decrease in the local diversity, overall species richness;
Formation monotypic stands instead of a heterogenous forest composition;
Loss and even the replacement of native plant species.
Hence, the knowledge of invasive alien plants is scarce if not in non-existence in most local sites, however their potential impact from the region or from other parts of the world, are extrapolated, insinuated and assumed will be the same on the local environment (Meyer 2000). Here, we take a look at the presence and absence of plants that are considered to have an invasive alien behavior across priority terrestrial forest areas for conservation in Fiji. The paper aims to: 1) Provide an overview of Invasive Alien Plant Species 2) State the assessment approaches of identifying the occurrence IAPS 3) Provide some information about the current status and distribution of IAPS across forest areas of conservation significance.

2.0 METHOD

The information presented is derived from: Existing literatures, Personal communications, Field observations and Rapid Assessment surveys (RAPs) reports conducted in at least the last 10 years. A literature review specifically on the technical series of BioRAP reports from the years 2000-2020 were evaluated. Sections of the report that described the nature of invasive plants at unique forest sites are highlighted and discussed throughout. The literature is restricted to the works of Meyer, J.Y., Tuiwawa, M., Whistler, A. and Watling, D. over their course of research in the last 10-20+ years across Fiji and the region.

3.0 RESULTS AND DISCUSION

3.1 *Overview of Invasive Alien Plant Species (IAPS)*

In some literature, authors have identified and associated the term and context of Invasive Alien Plant Species (IAPS), under the generic term Invasive Species (IS) and assumes the nature of the taxa as an alien species, is implied under the term IS. While it maybe, that these species are occurring within areas outside their native range of distribution, the term 'alien' is important to emphasize and include in their description and ecological designation, as collectively the term clearly verifies the status of their ecological nature and possible problematic behavior it may or may not pose at any given location. The inclusion of the term 'alien' clearly demarcates the taxa's point of origin and more importantly, denotes, the species as one that is not native to the area of concern. This is important to keep in mind, when listing and identifying a taxa, an Invasive Alien Species (IAS), to a specific location and particularly the implications in the broader context of geographic distribution.

Hence, in the simplest of definitions, IAPS is an ecological term that is being used to describe the correlative association between a group of plants and their immediate environment. The term, IAPS, is also understood to refer to those species whose introduction and/or spread outside their natural distribution range threatens the biological diversity of that area. According to many invasive species literature sources, the common understanding of the term is they are a groups of plants that are non-native to an ecosystem and that may cause economic or environmental harm to the local environment. Their occurrence alone, has a negative impact on the local biodiversity when left unmonitored and poorly managed. In some instances, their abundance alone has resulted to the decline and or elimination of indigenous species. Thus, under the Convention of Biological Diversity (CBD), the detrimental effects of IAPS on the environment identifies them as one of the biggest threats to biodiversity, to date[3].

3.2 *Assessment approaches for detecting IAPS in a terrestrial forest here in Fiji*

Conservation International (CI) through its Rapid Assessment Program (RAP) have been able to successfully make assessments across the terrestrial landscapes of conservation work, and this program of work started back in the early 1990s (Morrison and Nawadra 2009). The program uses the availability of local capacity and resources to carry out the rapid assessments across areas of national interests and this has been particularly useful and effective across forest areas that are near almost inaccessible to reach and typically difficult to access for many technical reasons. In most cases, the information generated off these surveys are most important and quite effective in the management and decision-making process of deciding, whether or not, an area has any value of conservation significance and other national priority (Morrison and Nawadra 2009).

3.2.1 *Technical Surveys in at least the last 10 years*

Under the Biodiversity Rapid Assessments (BioRAPs), both the quantitative and qualitative methods of assessment have been used to capture the occurrence of taxa in the field. Whether taxon occurs as individuals, communities and or populations, these respective methods of assessment are fairly robust in measuring the presence, absence and incursion tenacity within the area surveyed. In at least the last 15-20 years of research, almost all the BioRAPs conducted within the terrestrial terrains and forests across Fiji, have recorded the presence and absence, local occurrences, of IAPS across various sites of natural or human-induced disturbances that more or less lies within the physical boundaries of potential and or existing conservation areas of significance (Tuiwawa and Morrison 2008; Tuiwawa and Whistler 2009 a, b; Morrison and Nawadra 2009; Tuiwawa *et al.* 2011; Tuiwawa *et al.* 2013 a, b; Tuiwawa and Pene 2015, 2018 a, b; Tuiwawa *et al.* 2018c).

Assessments are conducted using both opportunistic surveys, and systematics approaches via means of sampling plots and transects as quantitative measurements. This has been a recommended standard practice and outcome, especially when teams are swiftly tracking between localities. Line transects, if not opportunistic count methods, are the norms of documenting occurrences, hence the number of these transects and time spent on a particular location is largely dependent on the availability of time for the survey conducted. Hence, some if not most of the time, there is the occasional occurrences of these species along the way. While in other instances, assessing representative and selected sites of interest, we find that IAPS being part of the actual forest cover (Tuiwawa and Whistler, 2009 a, b; Morrison and Nawadra 2009; Tuiwawa *et al.* 2011; Tuiwawa *et al.* 2013 a, b; Tuiwawa and Pene 2015, 2018 a, b; Pene and Rounds 2013; Tuiwawa *et al.* 2018c).

Consequently, in listing and documenting the natural vegetation, we also include references of occurrences of IAPS within the sampling plots and transects that are being laid out for the assessment. Part of the field data being collected include: GPS readings, field photos, botanical specimens, mapping illustrations (Tuiwawa and Morrison 2008; Tuiwawa and Whistler 2009 a, b; Morrison and Nawadra 2009; Tuiwawa *et al.* 2011; Tuiwawa *et al.* 2013 a, b; Tuiwawa and Pene 2015, 2018 a, b; Tuiwawa *et al.* 2018c). The results to almost all of these surveys are published in a series of technical reports, some of which are available online.

3.2.1.1 *Opportunistic surveys*

This is with reference to making observations of species that is not necessarily the specific target of the survey techniques being implemented. Observations may include incidental occurrences of the IAPS while conducting specific survey techniques or whilst trekking between locations.

Opportunistic surveys is one of the most effective approaches of assessing occurrences whilst rapidly moving from points A to point B within a limited timeframe of work. It is applicable within any types of terrains – on land and semi-aquatic terrains that is visually within the physical reaches of an assessor. The objective of this approach is to establish with high level of confidence the occurrences of IAPS along the tracked area and the possible presence of threat. More so, it also meant to expand our knowledge about the distribution of IAPS, especially, at the local level. It is important to know where these IAPS list of species are as well as where they are absent as such information will help establish the level of risk on the forest areas of concern and or interest. When undertaken by appropriate skilled assessor(s), one can safely assume a high level of confidence in the survey results.

3.2.1.2 *Quantitative method*

Quantitative methods is with reference to the collection and analysis of numerical datasets to describe situations and correlations with some level of certainty and confidence. In a lot of the RAP surveys, it is the diversity and abundance of invasive plants that are assessed at several key points throughout the study sites. Often, certain sized sampling plots along several transect lines traversing through several habitat types are set in place for quantitative measurements. The design to the approach of assessment is largely dependent on the assessors and the objective of the survey. In most instances, it is through team consultation and references of past literatures that the appropriate designs are produced and established to carry out the assessment.

3.3 *Current Status and Distribution of recorded IAPS from Priority Areas of Conservation*

Information about Invasive plants, let alone Invasive Alien Plant Species, are not always forthcoming and expectantly so, because of the limited number of surveys and research that has been carried out, to date, particularly across remote locations. The series of BioRAPs referenced, provides a platform where data and information across inaccessible areas, can be shared amongst peers, and further discussed to determine the actual status and distribution of most, if not all the taxa, currently identified as an invasive species. In most instances, the information derived from these BioRAP surveys are likely to be the first and only source of information about these groups, from these locations, after a very long time. This makes their reportings and annotations quite valuable when assessing current status in Fiji.

Accordingly, from the series of BioRAPs conducted, we are also able to assess the commonalities in the list of species provided from each of the locations surveyed. At this point, it seems that there are at least a few species that are found along the coast that have also been reported to occur in the interior highlands e.g. *Clidemia hirta*, *Spathodea campanulata*, *Lantana camara*. Such gives us a fair idea of how vigorous typical species are in thriving across all types of forest/habitat area. These reportings serves to justify the reasons for listing these taxa as invasive alien plant species for Fiji.

Below are three examples of forest areas that are of conservation importance together with some information about the distribution sites at which IAPS were recorded from the BioRAP surveys:

1) *Nakauvadra Range***:** Under the Fiji Water Foundation and Conservation International in 2008, the areas of the Nakauvadra range was surveyed in search for conservation corridor on Viti Levu. The undertaking included collection of baseline data on the diversity and conservation significance of the major terrestrial flora and fauna groups within the Nakauvadra range, as well as the threats to the local biodiversity of the area. The Nakauvadra range is located on the drier side of the island of Viti Levu. It is an important source of water to many communities that lie within its lower reaches.

The BioRAP survey in 2008 of the Nakauvadra range saw to the occurrence of 80 plant species that were alien in nature, of which five were identified as IAPS (Fig. 1): *Spathodea campanulata* P. Beauv. (African tulip), *Lantana camara* L. (lantana), *Arundo donax* (giant reeds), *Mikania micrantha* (mile-a-minute) and *Clidemia hirta* (Koster's curse). In areas of 400m above sea-level saw to the occurrences of invasive species, such as *Spathodea campanulata* (african tulip), *Lantana camara* (lantana), *Arundo donax* L. (giant reeds), *Mikania micrantha* Knuth. (mile-a-minute) and *Clidemia hirta* (L.) D. Don (Koster's curse), occurring along the creek embankments and traditional tracks (Tuiwawa and Whistler 2009a). Given the nature of these listed species, and the negative behavior they have been reported to have on the native flora, there were concerns to the incidental observations of occurrences at elevations well above 400 m a.s.l. The listed species of IAPS are internationally recognized and established IAPS, and even without further local studies, we have an idea of the damages that they can incur, if they are left unmonitored and not properly managed.

As the areas of occurrences are particularly along the waterways and traditional tracks, within these forest areas, it was thought that additional pathways included the open canopy of the grassland area located adjacent to range. The vast vegetation of open grassland is also thought to have come into existence by natural means or the result of many centuries of anthropogenic activities. Subjected, primarily, to the slash and burning activities, human habitation and movement within the area, including the natural course of reproduction, these are additional and other plausible means of introduction, access and establishment of IAPS into the Nakauvadra range. Because of the close proximity of these forest systems, it is quite possible to assume that the discontinuity in forest cover has created an open pathway or passage for incursions of IAPS into the surrounding closed forest systems.

Plate 1: *Clidemia hirta.* Copyright.tropical.theferns.info

Plate 2: *Lantana camara.* Copyright. www.inaturalist.org

Plate 3: *Spathodea campanulata.* Copyright: keyserver.lucidcentral.org

Plate 4: *Merremia peltata.* Copyright: apps.lucidcentral.org

Figure 1: A few examples of Invasive Alien Plant Species (IAPS) documented from the Nakauvadra Range, Viti Levu, Fiji.

2) *Rewa Delta*: Under the Mangrove Ecosystems for Climate change Adaptation and Livelihoods (MESCAL) project in 2012, a BioRAP was carried out across the Rewa delta to document and assess the mangrove resources across the shorelines of the area (Tuiwawa *et al.* 2013). Apart from the diversity of the area and prior to the BioRAP survey and findings, the delta was ascertained an important site to conserve for many valid reasons. First and foremost, the delta is the primary source of livelihood for the many coastal and mangrove residents and communities in the area (Watling 1985). Secondly, the delta has the largest mangrove stands in Fiji with an area coverage of more than 40,000 ha spread across two provincial boundaries, i.e. the provinces of Tailevu and Rewa (Watling 1985; Tuiwawa *et al.* 2009). Thirdly, it also has the largest water catchments along the south-eastern parts of

Fiji's largest island, Viti Levu, that is the primary source of water to almost a third of Fiji's population, particularly the coastal and mangrove communities in the area (Watling and Chape 1992; Fong 2013). The RAP findings only confirmed and validated these reasons, as an important area to protect and conserve.

The BioRAP surveys in 2012, showed that there were multiple forest types and habitat types that were part of or associated with the existing mangrove delta (Tuiwawa *et al*. 2013). These were defined by six principal vegetation types and at least ten forest/habitat types that collectively make up the entire Rewa delta system (Tuiwawa *et al*. 2013). Of the 181 plant taxa documented, close to 29% were identified as introduced plants, to which 52 species were recorded and identified as invasive species (Meyer 2000; Pene and Rounds 2013; Tuiwawa *et al*. 2013).

The *Rhizophora* and *Bruguiera* forests were the areas with the least number of invasive species recorded. Within the sampled plots stationed inside the mangrove habitats, there were three main invasive plants recorded: *Annona glabra* L. (Bullock's heart, Uto ni bulumakau), *Eichhornia crassipes* (Mart.) Solms (Water hyacinth), *C. hirta* (Pene and Rounds 2013). In the sampling plots at which they were seen and counted; the average individual counted ranged from 1-9 standing plants per $100m^2$ with the average percentage ground cover of about 25% per 10m x 10m plot.

By contrast, the mangrove forest/habitat peripheries recorded the highest numbers of invasive species. These latter areas were mostly disturbed regions that were located in the drier end, including the back of the mangrove zone, that were identified as agricultural areas, secondary forests, roadsides and disturbed coastal forests (Pene and Rounds 2013; Tuiwawa *et al*. 2013). Within these areas, there were eight invasive plants recorded that occurred in fair abundance across all types of forest/habitats: *S. campanulata*, *M. peltata*, *Mikania micrantha* Kunth (Mile-a-minute, wa bo sucu), *Sphagneticola trilobata* (L.) Pruski (Wedelia, Singapore daisy), *P. aduncum*, *Samanea saman* (Jacq.) Merr. (Raintree, Vaivai), *L. camara*, *Stachytarpheta urticifolia* Sims (Blue rat's tail). Creepers were seen in abundance where there was open space with available light while monotypic stands of invasive trees could be observed in medium to large pockets of tree stands throughout farming areas, roadsides and margins of the coastal forest (Pene and Rounds 2013).

The profiling of the list of invasive species, across the delta, is new information and the data generated from the BioRAP was the first comprehensive records for the country. To date, the local study to assess the impact of these association is limited and restricted to a lot of the agricultural surveys by the Ministry of Agriculture (MoA) and Pacific Commission (SPC) program and initiative.

3) *Nakorotubu Range*: Similar to previous BioRAPs, a RAP survey was undertaken across the Nakorotubu range in 2010, to assess the biodiversity resources of the area. The Nakorotubu range located on the western side of the island of Viti Levu,

and it is an important forest area of conservation significance. Tabulated in table 1, is a list of IAPS that were recorded from the survey.

Table 1: List of IAPS recorded from the BioRAP survey from the Nakorotubu Range, Viti Levu, Fiji.

Species Name	Common name	Locality	Abundance
Clidemia hirta	Korster's curse	All types of forest	Widespread and very common
Mikania macrantha	Mile-a-minute	All types of forest	Widespread and common
Arundo donax	Giant reed, Gasau ni veikau	Along the roadside, villages, river flats	Uncommon
Lantana camara	Lantana	Roadsides, paddocks	Uncommon
Spathodea campanulata	African tulip tree, Pasiu	Fallow land, gardens and settlements	Widespread and very common
Merremia peltata	Merremia, Wa bula	Forest openings and degraded areas	Widespread and common

While the survey showed high conservation value of the area, there also from the findings were the presence of Invasive plants in the areas that were trekked and surveyed. Of the 64 exotic plant species that were reported, six were listed as invasive plants. All six species are internationally recognized as invasive species: *C. hirta* was found in almost all the forest types that were identified, and they were seen to be very widespread and common in abundance; *M. macrantha* displayed similar situation; *A. donax* was mostly observed along the roadsides and river-flats of villages and it was uncommon but present in the area; *L. camara* showed similar behavior; *S. campanulata*, a resilient invasive was found in almost all the disturbed area where there was some form of human interactions. It was seen to be very common and widespread; *M. peltata* showed similar patterns and was locally common around human settlements (Tuiwawa and Whistler 2009b).

Further to the findings, there also were 13 other species that were present and have been known to show an invasive behavior. Tabulated in table 2 is the list of potential invasive species that were recorded to occur at the surveyed sites. They too have the tendency of encroaching into the surrounding forests from where they were initially introduced (Tuiwawa and Whistler 2009b).

Table 2: List of potential invasive species recorded from the BioRAP survey of the Nakorotubu range, Viti Levu, Fiji.

Species Name	Common Name	Locality	Abundance
Sphagneticola trilobata	Wedelia	Villages, settlements and roadsides	Locally common
Hedychium coronarium	Cevuga vula	Disturbed streams, river flats and village outskirts	Locally common
Passiflora foetida	Loli mei rakalavo	Forest openings	Locally common

Piper aduncum	Yaqoyaqona	River and creeks embankments	Locally common
Zingiber zerumbet	Cagolaya	Secondary forest	Common
Ageratum conyzoides	Botebotekoro	Secondary forest, village outskirts, river flats	Very common and widespread
Musa velutina	Ornamental banana	Outskirts of village and roadsides	Common
Derris malaccensis	Duva ni niuqini	River and creek embarkment	Locally common
Gmelina aborea	-	Pastures and village outskirts	Uncommon
Solanum torvum	Prickly solanum	Secondary forest, creek, river flats	Common
Costus speciosus	-	Roadsides, along tracks to gardens	Common
Swietenia macro-phylla	Mahogany	Near villages and plantation	Locally common
Alpinia purpurata	-	Roadsides, outskirts of villages and settlements	Common

4.0 CONCLUSION

Based on the reports and findings from the series of BioRAPs, it is only fair to affirm at this point that: 1) Fiji has an evolving list of Invasive Alien Plant Species (IAPS); 2) the status to a lot of the IAPS species is only as good as the study that have been conducted and published. The information provided is the first for many species in these remote locations and; 3) more surveys means more learning information as we move ahead.

In addition, the surveys conducted are able to detect and verify the occurrences of established invasive alien plants across all types of forest and habitat types here in Fiji. These locations are some of the most remote and difficult places to access. The fact that these locations seem to demonstrate a common list of invasive plants is to some extent concerning. Locally, impact studies of IAPS on the native forest are limited. However, international case studies that have been published, do provide practioners a fair idea of the potential impact that are associated with unmonitored and poorly managed areas with established IAPS. These concerns inevitably re-directd our attention to the mitigation measures that may or may not be currently in place to safeguard these forests of conservation significance. Further, the control and mitigation measures are drawn to the limelight of how and where they are effective in monitoring the spread of the IAPS into priority forest areas of conservation. While this is perhaps beyond the scope of the paper, it nonetheless, gravitates an important management aspect to consider when developing the next steps and the way forward for IAPS in Fiji.

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Effect of African tulip tree (*Spathodea campanulata* P. Beauv) wood chips on weed density and yields of taro (*Colocasia esculenta* (L.) Schott) in Fiji

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ABSTRACT

Spathodea campanulata P. Beauv, commonly known as African tulip tree is regarded as an invasive plant in most countries. It was introduced into Fiji in 1936 and has rapidly spread throughout the country. It has invaded agricultural farming area and native forest. Its negative impact to the environment outweighs its potential uses. African tulip tree wood has been reported useful for light timber work due to its very low density. However, using African tulip tree wood chips as mulching material for crop production is relatively unknown. Therefore, a study was conducted at Koronivia Research Station, to examine the effects of African tulip tree wood chips on weed growth and yields of taro (*Colocasia esculenta* (L.) Schott). The field experiment tested three different thickness of African tulip tree wood chip mulch [2.5cm (1in.), 7.6cm (2in.), and 12.7cm (3in.)] and no wood chip mulch as control plot. The results showed that 12.7cm wood chip mulch suppressed about 1,700 more individual weed plants per m^2 than 2.5cm wood chip mulch. The weight and diameter of taro corms were higher in 7.6cm mulch than other three treatments (2.5cm, 12.7cm and no mulch). There was no significant difference between 7.6cm and 12.7cm wood chip mulch in the number of weeds controlled and yield of taro. The 7.6cm mulch thickness would require less volume of African tulip tree wood chips than 12.7cm thickness to cover a given area of land and is therefore recommended.

Key words: African tulip tree, *Spathodea campanulata*, Fiji, mulch, weed suppression, wood chips.

INTRODUCTION

Spathodea campanulata P. Beauv, belonging to the family Bignoniaceae (here after, African tulip tree) is native to tropical Africa. It is distributed mostly to tropical and sub-tropical regions of the world (PIER 2018). In the Pacific region, it is present in Australia, American Samoa, Cook Is., Papua New Guinea, Samoa, French Polynesia, Tonga, FSM, Fiji, Guam, Kiribati, Marshall Is, Nauru, New Caledonia, Niue, Palau, Walis & Futuna, Vanuatu, Solomon Islands, Niue (PIER 2018).

African tulip tree was first reported in Fiji in 1936 (Parham 1972). It is widespread in Viti Levu especially in the wet eastern region of the main island. It is present in Vanua Levu, Taveuni and Ovalau. African tulip tree is easily recognized by its large orange-red flowers, with pale grey bark, upright trunk growing more than 25 meters in height (PIER 2018). It is propagated by seeds which are wind dispersed and root suckers (PIER 2018). African tulip tree can produce an average of 1,000 seeds per pod with a germination rate of about 95% (Deesh *et al*. 2023 unpublished). African tulip tree can produce new plant from cut green stem or branches on the ground and able to resprout quickly from cut stump (PIER 2018; pers. obs).

African tulip tree is among the top 100 worst invasive species globally (Global Invasive Species Database 2023). It is a threat to natural biodiversity by out-growing native plant species (PIER 2018). African tulip has invaded both abandoned agricultural land and natural forests in the Pacific Island countries, such as the Cook Islands, Fiji, Guam, Hawai ‘i, Samoa and Vanuatu (PIER 2018). African tulip tree seedlings can tolerate low light intensity and saplings thrive well in rainforest areas without recent disturbance (Larrue *et al*. 2014). African tulip tree has impacted the economy, cultural, and social welfare of people in the Pacific (Brown and Daigneault 2014)

African tulip tree has many uses. In its native range, African tulip tree is used for ecological, living fence and ornamental purposes by the indigenous communities in Cameroon (Fongod *et al*. 2014). In addition, the plant species is also used to treat malaria by indigenous people of Ghana (Osei-Djarbeng 2015), diabetes by the indigenous people of Cameroon (Tsabang *et al*. 2017), allergy, dysentery, diarrhea, and asthma by the indigenous people of Uganda (Tugume and Nyakoojo 2019).

African tulip tree is used for soil improvement, reafforestation, erosion control and land rehabilitation, and as a live fence (Bosch 2002). In countries where African tulip tree has been introduced into, the species is cultivated as plantation crop for plywood in the Philippines (Bosch 2002), live fence and timber for lightwood construction in Fiji (Kumar *et al*. 2020). Its leaves are used as mulch material (Bosch 2002). Mulching has been widely used in landscaping, gardening, horticultural crops and tree crops production with aim as to control weeds biologically, reduce usage of herbicides and provide adequate moisture in soil (Granatstein and Mullinix 2008).
However, the use of African tulip tree’s woodchips for mulching material is relatively unknown. Therefore, the purpose of this study was to investigate the effect of African tulip tree woodchips’ different thickness on weed density and marketable yields of taro (*Colocasia esculenta* (L.) Schott).

2.0 MATERIALS AND METHODS

2.1 *Study site*

The study was conducted at the Koronivia Research Station crop farm from July 2017 to April 2018. The soil was clay loam and classified as Ultisol (Humoxic Tropohumult, Koronivia series) by Leslie (1984). The study site coordinates were 18.0465° S, 178.5339° E. The average monthly rainfall and temperature recorded at Koronivia Research Station during the study period was 303mm and 25.85 °C, respectively.

2.2 *Preparation of African tulip tree wood chips*

Similar size green African tulip tree stems were harvested from a nearby field and transported to Koronivia Research Station. At the station, the stems were cut into about 30cm length so that they could fit easily into the wood chipping machine. The wood chipper broke down the African tulip tree stem into wood chips with the average dimension of about 40mm.

2.2 *Planting of dalo*

The field was ploughed and harrowed. About 30cm deep and 10cm wide planting holes, 1m x 1m apart were prepared using post-hole spade. Tausala taro variety suckers of similar size were selected and planted, with one per hole and the base was lightly covered with soil. A total of 18 dalo suckers were planted in each plot.

2.3 *Application of African tulip tree wood chips*

The African tulip tree wood chips were spread over the surface of the soil and levelled according to the African tulip tree chip thickness required for each plot. The four treatments were 2.5cm (1in.), 7.6cm (3in.), 12.7cm (5in.) and Farmers practice (no wood chips). The size of each plot was 6m x 3m, with 4 treatments replicated 3 times.

2.4 *Weed assessment*

At 30 days after planting, weed identification and weed count were conducted. Weed assessment was carried out fortnightly on weeds uprooted by hand from three 1m x 1m quadrats randomly laid in each plot. Weed density was recorded and analyzed. A weed specie density is a value that shows the number of individuals of this particular specie in a square meter (m^2) area. The mean field density which shows the magnitude of the infestation of a particular specie in each treatment was calculated (Mehdi *et al*. 2008). Weeds were identified to species level using several weed reference books which includes Smith, A. C. (1985) Flora Vitiensis Nova: A New Flora of Fiji; Parham J. W. (1972) Plants of the Fiji Islands; Whistler A.W. (1983) Wayside Plants of the Islands (A Guide to the Lowland Flora of the Pacific Islands – Hawai'i, Samoa, Tonga, Tahiti, Fiji, Guam, and Belau; and Thaman *et al*. (2012) Plants of Tuvalu.

2.5 *Taro growth and harvesting*

Taro growth data such as plant height and number of dalo suckers produced by each mother plant were collated on a monthly basis. Taro was harvested at 9 months after planting. Number of suckers produced by each mother plant in each plot were counted and recorded. Immediately after harvesting, taro corms harvested from each plot were placed in separate bags and labelled. The bags were taken to the Plant Protection Section laboratory at Koronivia Research Station where each corm was sliced off the petiole and dry cleaned by removing soil and dirt using small knife prior to taking the measurement.

2.6 *Corm measurement*

The length of corm was measured from the bottom end to the top end of the corm using measuring tape. The circumference of the corm was measured at the middle section of the corm using measuring tape. The diameter) of the corm was calculated using the formular:

where C is circumference & is 3.1415.

The number of corms were counted, and corm weight was measured using a digital scale.

2.7 *Data analysis*

To test the effects of African tulip tree wood chips as mulch and no wood chips on taro corm length, diameter, weight, and suckers produced, a single factor ANOVA was conducted. Data was analysed using Microsoft® Excel® for Microsoft 365 MSO (Version 2302). The mean values were separated by using the Fisher's Least Significant Difference (LSD) test at $P = 0.05$.

3.0 RESULTS AND DISCUSSION

3.1 Effect of African tulip tree woodchips on weed density in taro plots

There was a significant difference between the African tulip tree chips mulching depth and no mulch in the density of weeds recorded in taro plots ($F_{3,8} = 16.76$ $P < 0.05$) (Fig. 1).

The largest weed density (2,080 m^{-2}) was recorded from 2.5cm, followed by Farmers practice (no wood chip) with 2,014 m^{-2} then 7.6cm. with 608 m^{-2} and 12.7cm of African tulip tree wood chip mulch got the lowest weed density of 371 m^{-2} (Fig. 1).

There was no significant difference between 2.5cm wood chip mulching depth and no wood chip in the density of weeds recorded. However, there was a significant difference between the two thickest mulching depth and both 2.5cm and no wood chip in the density of weeds recorded (Fig. 1). Furthermore, there was no significant difference between 12.7cm and 7.6cm. wood chip mulching depth in the density of weeds controlled (Fig. 1).

Figure 1: Mean weed density (m^{-2}) recorded from dalo plots mulched with 2.5cm, 7.6cm, 12.7cm of African tulip tree wood chips and Farmers practice (no woodchip). Interval bars with the same letters are not significantly different at $P = 0.05$ using LSD.

Plates 1 & 2: Weed density in Treatment 1 (2.5cm) and Treatment 2 (7.6cm) in dalo plots at 2 months after planting.

Plates 3 & 4: Weed density in Treatment 3 (12.7cm) and Treatment 4 (no wood chip) in taro plots at 2 months after planting.

Cyperus rotundus L. (purple nutsedge) was the most common weed in all three African tulip tree wood chip treatments (Table 1). *Echinochloa colona* (L.) Link (jungle rice) was the most common weed in no wood chip plots. Weed species belonging to the Poaceae family was the most dominant plant family in all treatments (Table 1). Only nine species occupied the top five most common weed species in all four treatments (Table 1). Out of which, all were monocotyledons except two dicotyledons, *Ageratum conyzoides* L. and *Oldenlandia corymbose* L. recorded in a plot with 12.7cm wood chip mulch (Table 1).

Table 1: The top five most common weeds in each treatment.

#	African tulip tree wood chip mulch thickness			No wood chip
	2.5cm	**7.6cm**	**12.7cm**	
1	*Cyperus rotundus* L. Family: Cyperaceae	*Cyperus rotundus* L. Family: Cyperaceae	*Cyperus rotundus* L. Family: Cyperaceae	*Echinochloa colona* (L.) Link) Family: Poaceae
2	*Digiteria* sp. Family: Poaceae	*Cynodon dactylon* (L.) Pers. Family: Poaceae	*Cynodon dactylon* (L.) Pers. Family: Poaceae	*Digiteria* sp. Family: Poaceae
3	*Echinochloa colona* (L.) Link) Family: Poaceae	*Commelina diffusa* Burm. F Family: Commelinaceae	*Commelina diffusa* Burm. F Family: Commelinaceae	*Cyperus rotundus* L. Family: Cyperaceae
4	*Cynodon dactylon* (L.) Pers. Family: Poaceae	*Digiteria* sp. Family; Poaceae	*Echinochloa colona* (L.) Link) Family: Poaceae	*Setaria parviflora* (Poir.) Kerguélen Family: Poaceae
5	*Commelina diffusa* Burm. F Family: Commelinaceae	*Echinochloa colona* (L.) Link) Family: Poaceae	**Ageratum conyzoides* L. Family: Asteraceae	*Paspulum conjugatum* P. J. Bergius Family: Poaceae
			**Oldenlandia corymbose* L. Family: Rubiceae	

Note: * Equal in mean density.

The present study demonstrated that the thicker the depth of African tulip tree wood chip mulch, the higher the density of weeds is controlled (Fig. 1). For example, 12.7cm wood chip mulch controlled an average of about 1,700 more individual weed plants per m^2 than 2.5cm mulch (Fig. 1). Similarly, the lower the thickness of African tulip tree wood chips (2.5cm or less) or even no mulching the greater the density of weeds infesting the crop field. Hence, more time and resources are required to control weeds. Similar results with wood chips have been reported by Broschat (2007), Gruber *et al*. (2008) and van Donk *et al*. (2011). In addition, Granatstein and Mullinix (2008) demonstrated that fruit tree orchard plots mulched with wood chips obtained 3% weed cover as compared to 40% for unmulched plots.

3.2 Effect of African tulip tree wood chips on taro sucker production

Taro plots mulched with 7.6cm and 12.7cm of African tulip tree wood chips produced an average of 110 and 111 dalo suckers per plot at 9 months after planting, respectively (Table 2). Both treatments produced an average of 6 suckers per mother plant at 9 months after planting (Table 1). No wood chip treatment produced the lowest number of suckers with 48 and at an average of 3 suckers per plant (Table 2).

The present study showed that taro plots mulched with thicker depth African tulip tree wood chip mulches (7.6cm and 12.7cm) produced 100% more taro suckers per mother plant than no wood chip (Table 2). The result concurs with the study reported by Baiyeri *et al*. (2004) that *Musa* spp. grown under alley cropping with regular input of pruned hedgerow material as mulch produced taller suckers and had faster cycling index as compared to sole crop. van Donk *et al*. (2011) demonstrated that number of *Penstemon digitalis* Nutt (a herbaceous perennial plant) flower stalks were greater in 10cm thick wood chip mulch as compared to no mulch. In addition, Scott (2007) stated that wood chip is a superior mulch for enhanced plant productivity.

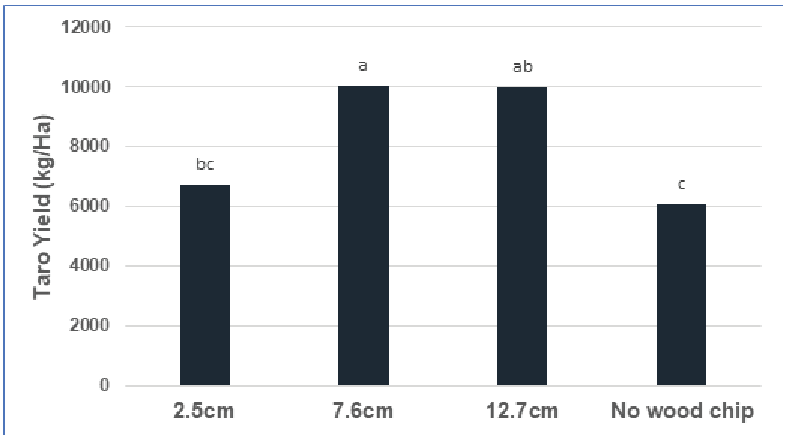
Table 2: Number of taro suckers produced at 9 months after planting with 2.5cm, 7.6cm and 12.7cm of African tulip tree wood chip mulch and no wood chip mulch.

Taro suckers	African tulip tree wood chip mulch thickness			
	2.5cm	7.6cm	12.7cm	No wood chip
Total no. of mother plants	45	54	54	54
Mean number of dalo suckers per plot	58	110	111	48
Total no. of suckers produced (3 plots)	174	331	332	145
Mean no. of suckers produced per plant	4	6	6	3

3.3 Effect of African tulip tree wood chips on taro corm yield

There was a significant difference between the African tulip tree chips mulching depth and no mulch in the weight of corms produced ($F_{3,8}$ = 4.50, P < 0.05) (Fig. 2). Taro plots mulched with 7.6cm and 12.7cm of African tulip tree wood chips produced an average yield of 10,045 and 9,999 kg/ha, respectively (Fig. 2). No wood chip treatment produced the lowest yield of 6,189 kg/ha.

Figure 2. Effect of different thickness of African tulip tree wood chips mulch on taro yield (kg/Ha). Interval bars with the same letters are not significantly different at P = 0.05 using LSD.



The current study demonstrated that taro plots mulched with thicker African tulip tree wood chip mulches (7.6cm and 12.7cm) produced the highest yields and about 38% more taro yields than no wood chip mulch (Fig. 2). In another similar study on plantain (*Musa* sp.) in Nigeria, plots that received mulching with saw dust + glyphosate treatment produced the highest number of hands per bunch, highest number of marketable fingers per bunch, the longest finger, the largest finger girth and highest bunch yield as compared to other treatments which includes weed-free by hoeing (Echezona *et al.* 2011).

3.4 Effect of African tulip tree wood chips on taro corm length and diameter

There was a significant difference between the African tulip tree wood chip mulch and no wood chip mulch in the length of corms produced ($F_{3,8}$ = 5.44, P < 0.05) (Table 3). Plots with 12.7cm wood chips produced the longest corm length with 18.72cm, followed by 7.6cm with 18.57cm, then 2.5cm with 15.20cm and no wood chip with 15.01cm (Table 3). There was no significant difference between 12.7cm and 7.6cm wood chip in the length of taro corm produced. However, there was a significant difference between the two thickest mulch and both 2.5cm and no wood chip in the length of taro corm produced (Table 3).

Table 3: Length and diameter of taro corm produced at 9 months after planting with 2.5cm, 7.6cm and 12.7cm of African tulip tree wood chips mulch and no wood chip mulch.

Mean values with the same letters in each row are not significantly different at *P* = 0.05 using LSD.

Treatments	2.5cm	7.6cm	12.7cm	No wood chip
Mean Length of taro corm (cm)	15.20 [b]	18.57 [a]	18.72 [a]	15.01 [b]
Mean diameter of taro corm (cm)	9.81 [b]	12.12 [a]	11.86 [a]	9.66 [b]

There was a significant difference between the African tulip tree wood chip mulch and no mulch in the diameter of taro corms produced ($F_{3,8} = 12.77$, $P < 0.05$) (Table 3). Plots with 7.6cm woodchip produced the highest corm diameter with 12.12cm, followed by 12.7cm with 11.86cm, then 2.5cm with 9.81cm and no woodchip with 9.66cm (Table 3). There was no significant difference between 12.7cm and 7.6cm wood chip mulch in the diameter of taro corm produced. However, there was a significant difference between the two thickest mulching depth and both 2.5cm and no wood chip in the diameter of taro corm produced (Table 3).

The present study showed that taro grown with 12.7cm wood chip mulch produced about 20% longer taro corm as compared to taro grown with no wood chip mulch (Table 3). In addition, taro grown with 7.6cm wood chip mulch produced about 20% more broader taro corm than taro grown with no wood chip mulch (Table 3). Similar results with wood chip mulch demonstrated, that plants grown with Cyperus (*Taxodium distichum* (L.) L. Rich) mulch grew much taller and have greater stem width than those grown in bare soil (Brown 1996). In another study, *Musa* spp. grown under alley cropping with regular input of mulching materials produced significantly higher number of fruits per bunch and fruit size than the sole crop without mulching (Baiyeri *et al*. 2004).

4.0 CONCLUSION

It was evident that 7.6cm and 12.7cm African tulip tree wood chip mulch controlled the highest number of weeds on taro plots, produced the highest number of suckers per plot and per mother plant, produced the highest taro corm yield, the highest taro corm length and diameter. The variation in yield and yield components may be due to high concentration of soil organic matter in wood chip mulched taro plots. According to Gruber *et al*. (2008), wood chips application can increase soil organic matter.

As there was no significant difference between the two African tulip tree wood chip mulch thickness, therefore, 7.6cm is recommended over 12.7cm because it requires less mulching material.

Further studies to obtain the benefit cost ratio and gross margin of the application of African tulip tree wood chips is recommended to determine the profitability of the weed management strategy.

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An Assessment of the invasiveness of introduced Herpetofauna on Qamea and Matagi Islands, Cakaudrove Province, Fiji

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ABSTRACT

The herpetofauna of an area refers to the reptiles (class Reptilia) and amphibians (class Anura) that inhabit that area. The herpetofauna of the Fiji Islands consists of around thirty-one species (28 reptiles and three amphibians). The introduced herpetofauna of Fiji consists of four species (3 reptiles and one amphibian). Three of these introduced species now occur on the islands of Qamea and Matagi in the Cakaudrove Province. In this paper two questions are addressed: What is the distribution status of these introduced species on these two islands and based on their distribution status, would they be considered as invasive species? To answer these questions nocturnal surveys were conducted in the wet and dry season of 2019-2020. The results showed that only one species the Cane toad (*Rhinella marina* L.) showed characteristics of an invasive species as it was recorded in all the nocturnal surveys and was present in all the terrestrial habitats surveyed on the two islands. One of the species, the House gecko (*Hemidactylis frenatus* Dumeril and Bibron) was only recorded in the human habitation area (houses). The third species, the Green iguana (*Iguana iguana* L.) was hardly detected during the nocturnal surveys which might suggest that it is not as common as it was thought to be or that the survey methodology was ineffective. This needs to be verified in future surveys.

Key words: Herpetofauna, reptiles, amphibians, invasive alien species (IAS)

1.0 INTRODUCTION

An introduced species is a species that has been deliberately or accidentally introduced by humans into an area outside its known native range. However, when this introduced species begins to spread affecting the native biodiversity, environment, economy, and human livelihood it becomes an invasive species (Mooney and Cleland 2001; Payton *et al.* 2019; Canadian Council on Invasive Species 2023). Introduced species are often referred to as alien species, or exotic species. Invasive species are now commonly referred to as Invasive Alien species or IAS. There are many definitions that have developed to define IAS worldwide. However, in this paper the definition developed by the GEF 6 Taskforce (2020) is used: 'Invasive Alien Species (IAS) are organisms found outside of their native geographical ranges, which have established, spread, and become, harmful and destructive to local biodiversity and environment of value'.

In comparison to continents or larger land masses, islands are more fragile ecosystems where the native biodiversity can be severely affected due to the presence of IAS (Simberloff 1995, Fritts and Rhodda 1998). This has been observed and documented worldwide, including the Pacific region. In Guam, the accidental introduction of the Brown tree snake (*Boiga irregularis* Merrem) has severely the affected macrofaunal biodiversity causing the loss of birds and reptiles from several islands (Fritts and Rhodda 1995). In Hawaii, 10% of its native flora and 30 species of birds have become extinct because of introduced species (Vitousek *et al*. 1987). Similarly, in New Zealand the introduction of mammals like cats and rats have been blamed for the loss of invertebrates, reptile species and about 40% of the avifauna taxa (Towns *et al*. 1997). In Fiji, the introduction of the Small Indian mongoose (*Herpestes auropunctatus* Hodgson) is thought to have caused the extirpation of four bird species from the larger islands (Hays *et al*. 2007). The presence of rats, feral cats, mongoose, and cane toads in Fiji is a threat to iconic endemic species like the Fiji tree frog (*Platymantis vitiensis* Girard), Fiji ground frog (*Cornufer vitianus* A.H.A. Duméril), and the Crested iguana (*Brachylophus vitiensis* Gibbons) (Denny *et al*. 2005).

The Global Environment Fund (GEF) 6 Fiji IAS Project titled 'Building capacities to address Invasive Alien Species to Enhance the Chances of Long - term Survival of Terrestrial Endemic and Threatened Species on Taveuni Island, Surrounding Islets and Throughout Fiji Project' was approved in 2017 to run from 2018 to 2023 with a funding pot of $3.5 million USD (Rijpma and Fong 2021). The Biosecurity Authority of Fiji (BAF) is one of the main implementing agencies of this project in Fiji. This project specifically targeted IAS in Fiji but with a more focussed approach on the island of Taveuni, and the surrounding islets of Qamea, Matagi, and Laucala because of the unique biodiversity of Taveuni and the imposing threat from the introduced Green iguana (*Iguana iguana* L.) (*ibid*). The Green iguana was illegally and deliberately introduced as a household pet on Yaroi Estate, Qamea Island by the estate owners in the year 2000 and has since managed to escape and survive in the wild (Naikatini *et al.* 2009). Since 2000, this introduced reptile has become naturalised on Qamea Island and spread to the nearby islands of Matagi and Laucala (*ibid*). Taveuni Island is a biodiversity hotspot and an economic hub in Fiji (Tuiwawa and Pene 2017; SPREP 2020), and the presence of the Green iguana in the three surrounding islands poses an unknown threat to both the island's unique biodiversity and eco-tourism.

The herpetofauna of an area refers to the reptiles (class Reptilia) and amphibians (class Anura) that inhabit that area. The herpetofauna of the Fiji Islands consists of around thirty-one species made up of twenty-eight reptiles and three amphibians with seven of them currently listed as threatened by extinction on the IUCN Red List (Morrison 2003; IUCN 2022). The introduced herpetofauna of Fiji consists of four species made up of three reptiles and one amphibian (Morrison 2003). One of the three introduced herpetofauna, the Cane toad (*Rhinella marina* L) is listed on the '100 of the world's worst invasive alien species: a selection from the global invasive species database' (Lowe *et al*. 2000). There has been no herpetofauna survey or a proper biodiversity survey conducted on Qamea Island and the records of reptile and amphibian species present on the island are based on anecdotal reports.

The aim of this study was to explore the invasiveness of the introduced herpetofauna on the two islands. Two questions were addressed: 1) What is the distribution status of the introduced herpetofauna on the two islands; and 2) Based on their distribution status, would the introduced fauna be classified as invasive species? Working on the hypothesis that any introduced species will become invasive in an island ecosystem. We predict that the three species will be widespread on the two islands and are detected in different habitat types present on the two islands.

2.0 MATERIALS AND METHODS

The field survey was conducted on the islands of Qamea and Matagi in the Cakaudrove Province. Matagi Island is what remains of a drowned caldera with a horse-shoe shape, covering an area 1 km^2 and is privately owned (Cronin and Neall 2001). Qamea Island is larger in size measuring about 10 km in length, 5 km in width and covers an area of about 34 km^2. It is a volcanic island believed to be formed around the same time as Taveuni Island, with a rugged terrain and a highest peak reaching over 300 m in elevation (Woodhall 1994). The survey was conducted in November 2019 and July 2020. These two surveys were conducted to account for the two main seasons in Fiji, the wet-warm season from October to March and the dry-cool season from April to September.

The herpetofauna survey of the two islands were conducted at night (nocturnal surveys). The sampling approach was a modified, stratified sampling procedure to ensure a consistent and comprehensive sampling effort. Each island was divided into 1 km² grid cells based on the Fiji Lands Department 1:50 000 topographical map (Fiji Lands 2004). A unidirectional (non-linear) 1 km x 10 m belt transect was surveyed within each grid cell wherever possible depending on accessibility. This technique has been used for herpetofauna surveys in Fiji in the past, such as for frogs (Osborne *et al.* 2008) and iguanas (Morrison *et al.* 2008, 2009). Each transect was marked early in the afternoon after 3pm, using a hip-chain with the roll of thin cotton line, which marked the centre line of the transect and served as a guide during the night. While setting up the transect, habitat types along the transect were marked using flagging tapes, mapped, and recorded. The habitats were recorded at 100 m intervals along the transect. In addition, opportunistic diurnal Green iguana surveys were performed while setting up the transect. Any iguana or evidence of iguana presence (such as feeding marks) observed during this time was also recorded. A Garmin SX GPS was used to mark and record the geographical coordinates at the start and the direction of each transect.

Nocturnal surveys were conducted at least 30 minutes after sunset when it was dark. The survey was conducted by a team of four searchers actively searching along either side of the transect line (within 5m from the transect line), using spotlight head torches and handheld dive torch. Vegetation along the transect were actively searched using spotlighting as the iguanas are typically found using the reflection from their lighter-coloured underbellies, at night while they are sleeping. One of the team members actively recorded Cane toads recorded along the transect line while the other member searched in the trunks, branches, and canopy for Iguana presence. The survey effort for each transect was also recorded to be consistent in terms of manpower (number of surveyors) and time (period spent surveying along the 1 km transect), with minimal flex to allow for difficulties in traversing rough terrain. This was to ensure that the total counts along the transects yield comparable estimates of density per grid cell.

The number of Green iguanas and Cane toads observed along the transect were recorded onto a record data sheet. In addition to the presence data, the time at start and end of surveys were recorded, the number and names of survey team and the weather conditions. Once spotlighted, an attempt to capture the iguana was made and once captured, its identification was confirmed whether it was a native or introduced iguana using the iguana identification guide from Morrison (2003) and Thomas *et al.* (2013). Additional information such as the sex and life stage (hatchling, juvenile, adult, or gravid female) were also recorded for each captured iguana.

3.0 RESULTS

The field survey was conducted for 20 days in November 2019 (wet season) and for another 20 days in July 2020 (dry season). During the wet season, a total of 22 transects were surveyed, with 20 transects on Qamea Island and two transects on Matagi Island (Figure 1). An estimated area of 20 ha was covered while surveying for the Green iguana and 2 ha for Cane toads during the wet season. In the dry season, 23 transects were surveyed with 22 transects on Qamea Island and one transect on Matagi Island (Figure 2). As estimated area of 23 ha was covered while surveying for Green iguana and over 2 ha for Cane toads during the dry season.

Figure 1. Location of the 23 transects surveyed in November 2019 during the wet-warm season, on Qamea and Matagi Island.

During the two surveys a total of eight herpetofauna species were recorded which consisted of two endemic species, three native species and three introduced species (Table 1). The two endemic species are threatened species listed in the IUCN Red List, the Lauan Banded Iguana (*Brachylophus fasciatus* Brongniart) listed as Endangered (EN), and the Fiji ground frog listed as Near Threatened (NT; IUCN 2022).

The three introduced herpetofauna were the Cane toad, the Green iguana and the common House gecko. The House gecko was only encountered in the villages and other human-inhabited areas and was not recorded on any of the transects that were surveyed.

Figure 2. Location of the 23 transects surveyed in July 2020 during the dry-cool season, on Qamea and Matagi Island.

Table 1. Checklist of the herpetofauna (reptiles and amphibians) of Qamea and Matagi islands recorded during the 2019 and 2020 surveys.

Local Name	Species	Distribution	Red List
Lau Banded Iguana	*Brachylophus fasciatus*	Endemic	EN
Green Iguana	*Iguana iguana*	Introduced	LC
Fiji Ground Frog	*Cornufer vitianus*	Endemic	NT
Cane Toad	*Rhinella marina*	Introduced	LC
Pacific Boa	*Candoia bibroni*	Native	LC
Oceanic Gecko	*Gehyra oceanica*	Native	LC
Skink Toad Gecko	*Nactus pelagicus*	Native	LC
House Gecko	*Hemidactylus frenatus*	Introduced	LC

A total of 47 transects were surveyed during the wet and dry season covering eight major habitats present on Qamea and Matagi Island. The major habitats present on these two islands include the: primary lowland rainforest, secondary lowland rainforest, primary littoral forest, secondary littoral forest, mangrove forest, back of the mangrove-littoral forest, dry forest, and the secondary mixed habitat (Tuiwawa and Maiwaqa 2020). Only one Green iguana was recorded during both the surveys (recorded in the dry season on Matagi Island) where more than 400 Cane toads were recorded during both the surveys but were more abundant in the rainy season (148 toads in the dry compared to 311 toads recorded in the dry season) (Figure 3). The Green iguana was recorded only in a secondary lowland forest habitat whereas the Cane toad was recorded in almost all the habitats with the highest counts observed in the secondary or disturbed habitats (Figure 3).

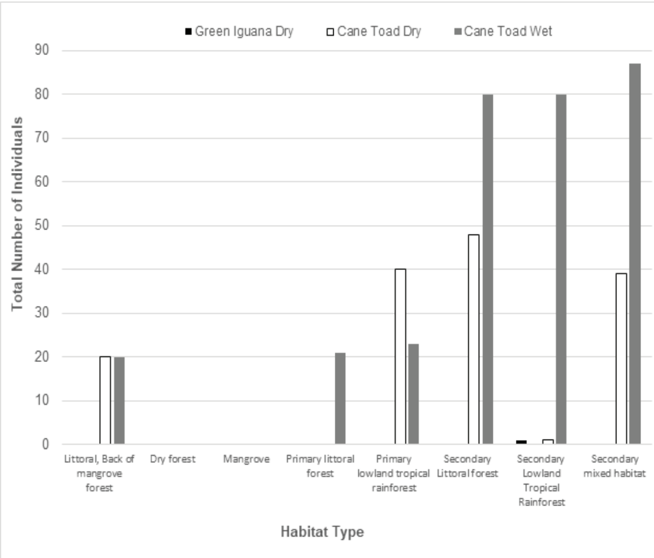

Figure 3. Cane toad (grey bars) and Green iguana (black bar) counts recorded during the 2019 (wet season; dark grey) and the 2020 (dry season; white) surveys.

The only Green iguana recorded during the two surveys was observed perching on a *Hibiscus tiliaceus* L. tree branch about 3m above the ground in a secondary or disturbed lowland rainforest habitat. This forested habitats on Matagi Island are protected by the owners and both the workers and visitors hardly access this habitat, so the Iguana and other wildlife are left undisturbed. On Qamea Island, most of the recent records according to the BAF officers are from the northwestern coastline which is covered by coastal dry forest. However, this area was not surveyed as it is almost inaccessible due to the rugged rocky topography. The Cane toads were present on almost all the habitats on the two islands. However, it was most abundant in the three most disturbed or secondary habitats: the secondary littoral forest, secondary lowland forest and the secondary mixed habitat.

4.0 DISCUSSION

The Green iguana is a recent newcomer to Fiji, having arrived on the islands of Qamea and Matagi about twenty years ago (Naikatini *et al*. 2009). In comparison, the Cane toad has been in Fiji for more than 100 years (Pernetta and Watling 1978; Morrison 2003) and is now widespread on the main islands. The species has been able to establish sub-populations in different habitats on the larger islands in the archipelago, over this longer timeframe. Unlike the Cane toad, the Green iguana has not been as successful. House geckoes, an Aboriginal introduction, have been in Fiji longer than the Cane toad or the Green iguana, but remain restricted to human infrastructure and coastal littoral habitat and do not behave like an IAS.

The results of the two surveys clearly illustrate the invasive nature of the Cane toad. However, the Green iguana was considerably more rare or cryptic in its refugia on Qamea and Matagi Island, as it was not as common as initially hypothesized. It must be stated in full disclosure that anecdotal reports of the Green iguana from the local people of Qamea do not agree with the results presented here. The Green iguana is now being actively searched on Qamea by the Biosecurity of Fiji (BAF) and locals in the last 20 years with the main objective of trying to eradicate it from the island of Qamea. Repeat surveys for the Green iguana by BAF indicate potentially higher densities of iguanas at specific sites along the northwestern coast of Qamea Island (Tuamoto T. *pers. comm*, 2022).

This raises pertinent questions which need further investigation via long term monitoring. Future surveys firstly need to evaluate other sampling methods for efficacy and utility. Another question that could be explored is whether the Green iguana has become fully naturalised on Qamea Island in the last 20 years or if the species is still trying to establish natural sub-populations. It is probable that the Green iguana's main defensive behaviour is to hide when it detects a human presence, thereby rendering it difficult to spot these iguanas during the day or night. More effective sampling techniques, once determined, could be employed in forthcoming surveys comparing proportional abundance and distribution of the Cane toad and Green iguana to review the IAS status of either species. Eradication measures, once thought to be costly due to the perceived spread of Green iguana, may benefit from localization and focus on targeting gravid females to reduce juvenile recruitment into these cryptic populations.

5.0 CONCLUSION

The two surveys recorded eight species of herpetofauna on the islands of Qamea and Matagi, three of which are introduced species. Only one species from the three introduced species shows the behaviour of an IAS – the Cane toad. The Green iguana arguably does not behave as a typical IAS from the results presented in this paper. However, it has the potential to become one if there are no control measures in place to help control its spread. Current efforts by the relevant authorities to prevent further dispersal of the Green iguana in the Fiji Islands are commended and relevant stakeholders need to continue with the long-term commitment.

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Growth performance of selected exotic timber tree species for grassland restoration in Fiji

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ABSTRACT

Plant growth by height assessments were undertaken on four selected 5 year-old exotic timber species; *Tectona grandis* L.f., *Dalbergia cochinchinensis* Pierre ex Laness., *Swietenia macrophylla* King and *Acacia auriculiformis* A. Cunn. ex Benth at Yavuna and Vaqia in western Viti Levu, Fiji. The average annual height growth rate for *D. cochinchinensis* was 2.67±1.48cm; *S. macrophylla* was 2.32±1.05cm; *T. grandis* was 1.22±0.51m and *A. auriculiformis* was 1.08±0.56m. *Dalbergia cochinchinensis* exhibited the best growth after five years. All four species are highly valuable timber species that can be planted with native species for grassland restoration program. The exotic species can act as pioneer species, providing the microclimate in which native species can thrive in or be integrated into crop lands to diversify produce in addition to other ecological functions. Due to their growth performance and valuable timber species, this study has demonstrated that the four tree species can be actively promoted in the Ministry of Forestry's initiatives to achieve 30 million trees in 15 years. In addition, the existing plots can be explored for further research opportunities in the future.

Key words: Exotic species, grassland restoration, highly valuable timber, Fiji.

1.0 INTRODUCTION

The global forest cover is estimated to be 4.06 billion hectares (Sofo *et al*. 2020), and this is equivalent to 31% of the global land area, which is translated to 0.6ha for every person on earth. Between 1990-2015, there was an overall decrease in global forest area of 3% from 4,128M ha to 3,999M ha which has been attributed to natural and human induced deforestation. The Food and Agriculture Organization in 2015 reported that forty four percent (44%) of the global forest areas are found in tropical countries and a further 1,204 M ha are covered by other woodlands.

Initiatives to restore forest cover and slow down the pace of forest destruction in tropical countries have attracted international research and development communities (DeFries *et al*. 2002). Thus, over the years, methods of reforestation have been explored and successfully applied, especially in these tropical countries, bringing about multiple benefits (Chazdon, 2008). The motivation behind investing in reforestation has recently been its benefits globally, an example of which is carbon sequestration as climate change mitigation (Canadell *et al*. 2008) The proposed benefits have prompted the development of ambitious reforestation plans at a national, regional and global scale (Greve *et al*. 2013).

The Fiji Islands is a group of archipelagoes located between 177° West to 117° East and 15° to 22° South in the Pacific Ocean. The two large islands, Viti Levu and Vanua Levu have a combined land area of 18,274 km^2, which is 87% of the total land area of Fiji with the tallest mountain of 1,232 m.a.s.l being in Viti Levu. The high mountain range intercepts the prevailing south – east trade winds, creating rain shadow on the leeward side of the main island that causes an inordinate rainfall pattern that exists in Fiji, ranging from 1,800 mm in the coastal region of the western sides to 3,000 mm and more on the south-eastern side (Mataki *et al.* 2006). The wet or the windward side of the islands is covered in rainforests, while most of the dry, leeward side is presently covered in small forest remnants and grassland locally called as "Talasiga" ("sunburnt land") in the native vernacular (Parham 1972; Muller- Dombois and Fosberg 1998). Palynological evidence suggests that, before the arrival of people c. 3,500 plus years ago, much of the present day talasiga grassland in Viti levu was covered in forests (Keppel 2002). Herbaceous vegetation composed of grasses, sedges, and ferns may, however, have emerged in some of the driest places, especially during glacial period (Southern 1986).

Burning during the dry season on the drier/leeward sides of the main island has contributed to a large area of increasingly flammable grasslands. Restoration of grassland and degraded forests in developing countries requires careful selection of tree species that can rapidly suppress or shade out flammable grasses and improve the soil productivity (Gindel 2013; Evanari *et al*. 1982; Minhas *et al*. 1996).

Therefore, the aim of this study was to investigate the performance of four exotic species that were planted through two reforestation trials in western Viti Levu in 2015. Knowledge gained from this study would provide baseline data for future reforestation projects and supporting the Ministry of Forestry's 30 million trees in 15 years initiatives.

2.0 MATERIALS AND METHODS

2.1 *Study Site*

Two research trial plots were established in 2015 on the western side of Viti Levu Island by the Silviculture Research Division (SRD) of the Ministry of Forestry. A total of 617 seedlings from 16 tree species were planted in the trial plots. However, only the four best performing exotic species from both sites were assessed and discussed. Annual performance assessment was conducted over the course of 5 years and the annual performance assessment results that is, average height growth rate and the average girth growth rate.

Yavuna (Nausori Highlands)

The Yavuna trial plot was established as a grassland restoration research plot on a communal land owned by the village of Yavuna in the Province of Ba. Prior to the establishment of the research plot, consultation was conducted and consent and approval were sought from land owners on the use of their land for research purposes. A total of 1.55 acres of land were allocated. During its establishment, the land use was mainly grassland used as grazing area for horses and cows from neighboring villages. A total of 420 seedlings were planted, comprising 210 sandalwood seedlings and 210 seedlings of native and exotic species. A 6 x 4m spacing was used, with 10 rows of 14 sandalwood and mixed species seedlings in each line. The trial was replicated 3 times.

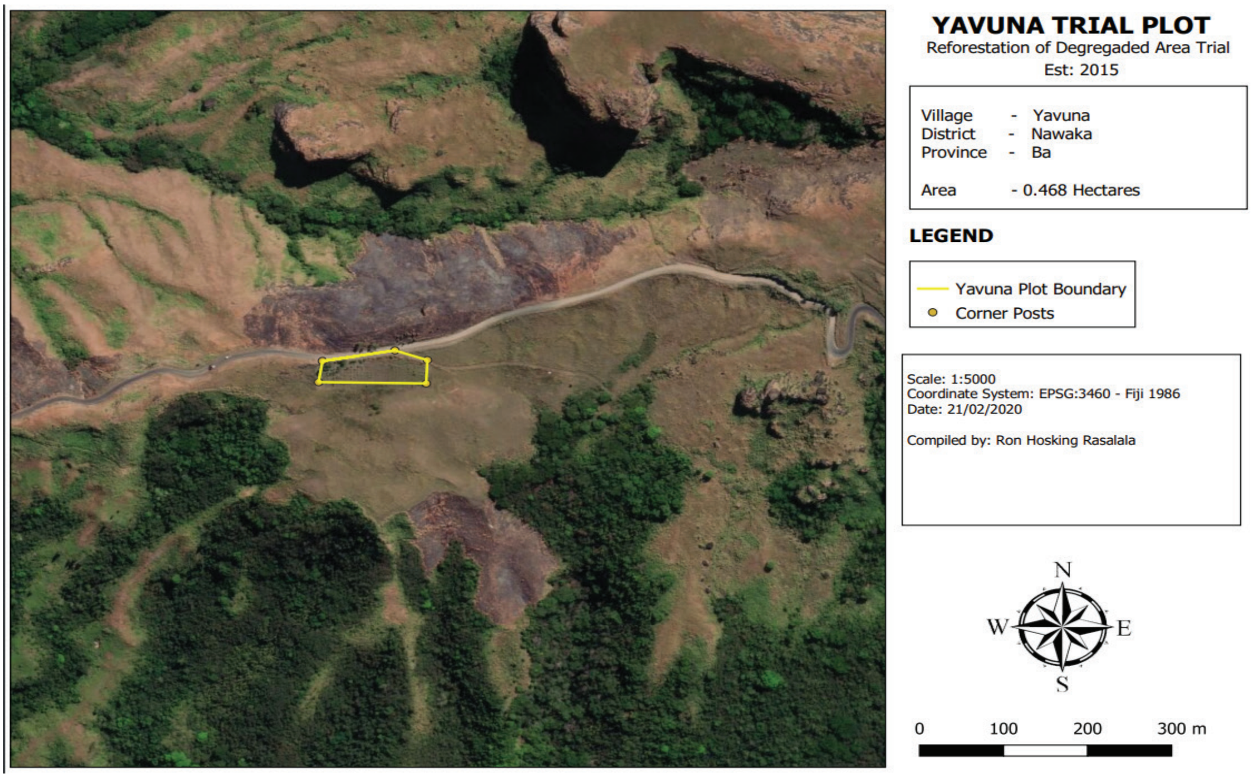

Figure 1. Locality Map for the Yavuna Research Trial Plot

1.1.1 *Vaqia, Ba*

Vaqia Research trial plot was created as part of a mixed species spacing trial plot. The land was leased by Mrs Salochna Wati, a farmer, who had shown interest in the Ministy's reforestation programs. After a series of consultation, Mrs Wati allocated 0.77 acre of her land for the research trial. Maintenance and monitoring were done jointly by the Ministry of Forestry Research Division and Mrs Wati's family. Prior to establishment of trial plot, the area was primarily grassland and was used as grazing area for goats. A total of 197 seedlings from 6 species were planted using 6 x 6 m spacing.

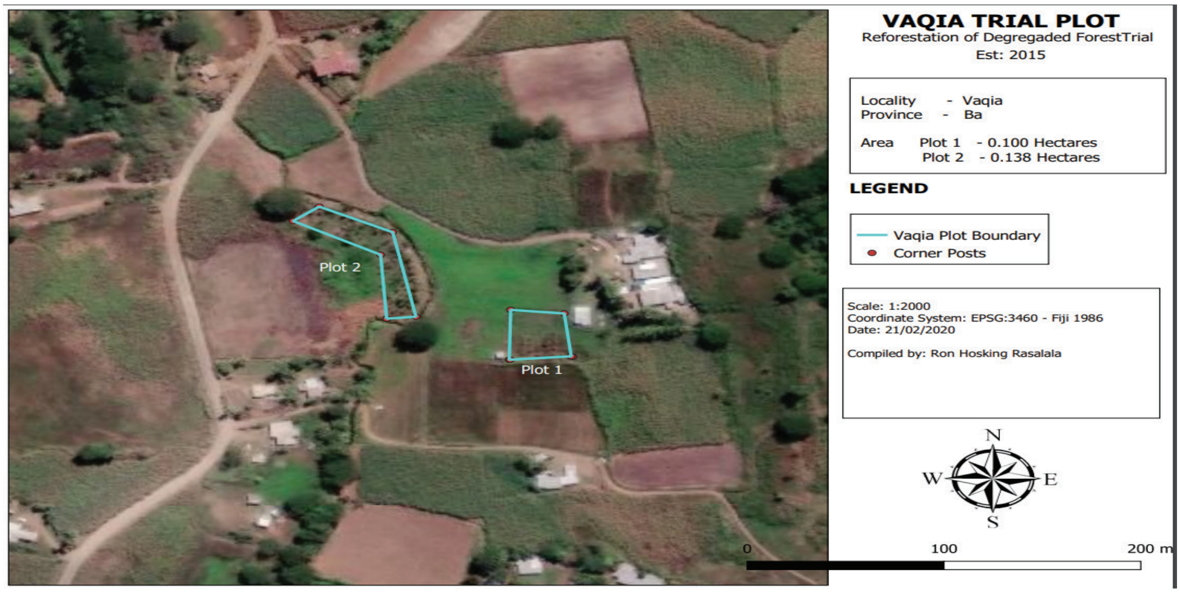

Figure 2: The Vaqia research plots in Ba.

2.2 *Species Selected*

Tectona grandis Linn f. (Teak) is a member of the Verbenaceae family, order Laminales (Trope 1921). According to Longman and Jenik (1974), it is phonologically classified as deciduous in nature, it is native to South-East Asia and occurs naturally only in the Indian Peninsula, Myanmar, Northern Thailand and Northwestern Laos along the northern Thai border (Kaosa-ard 1981). It is one of the most extensively planted timber tree species in the tropics due to its unique wood properties and wood value (Tangmitcharoen and Owens 1997). *Tectona grandis* was introduced to Fiji as an ornamental in gardens and schoolyards by the commonwealth expatriates in the 1800's, with records of teak growing in Naitasiri, Davuilevu, Rewa and Ovalau (Param 1972). Further research on teak was conducted in the 1960's by the Fijian Department of Forestry, in conjunction with mahogany trials. Based on these trials and the market force at that time, the Fijian Department of Forestry decided to concentrate on the development of mahogany. Further development of teak plantation is currently being undertaken by Future Forests (Fiji) Ltd., a Fiji-incorporated company. The company was established in 2005 and is focused on sustainable, large-scale planting and harvesting of teak and have since planted over 140,000 teak trees on freehold and lease land in the Province of Ra, Viti Levu, Fiji (Future Forest (Fiji) Prospectus 2011). Other replanting programs are currently being implemented by the Ministry of Forestry and other organisations based on community interests.

Dalbergia cochinchinensis Pierre ex Laness. (Thai rosewood) is a member of the genus *Dalbergia* which consist of trees, shrubs and woody climbers that is widely distributed in the tropic and subtropical regions (Vasudeva *et al*. 2009). It is a medium to large sized tree with a dome shaped crown of lush green foliage mainly found in monsoon forests that experience seasons of heavy rainfall. Usually in association with species such as *Tectona grandis*, the Thai rosewood can grow up to 25 m tall and is one of the most valuable timbers globally. *Dalbergia cochinchinensis* was introduced into Fiji in the 1950's as part of the Department of Forestry Research Program to identify alternative timber species that can help alleviate pressure in the dwindling natural forests (Ministry of Forestry Annual Report 1952), with superior seed sources introduced from Thailand by Pacific Reforestation (Fiji) Ltd during the early 1990s.

Acacia auriculiformis A. Cunn. ex Benth is a tropical arbore scent species native to areas of northern Australia and southern New Guinea (Maslin and Pedley 1982). It has attracted a lot of attention in the forestry sector due to its potential for plantation forestry and is widely planted as an ornamental plant in the tropical environment (Turnbull 1987). *Acacia auriculiformis* was introduced into Fiji in the 1950's as part of the Department of Forestry Research Program in the identification of alternative timber species that can help alleviate pressure in the dwindling natural forests (Ministry of Forestry Annual Report 1952) with superior seed sources introduced from Papua New Guinea and north Queensland by Pacific Reforestation (Fiji) Ltd. during the early 1990s.

Swietenia macrophylla King (Big-leaf Mahogany) belongs to the *Meliaceae* family. It is evergreen and deciduous in nature that could reach heights between 30 and 40 metres. It is intensively exploited in the neo-tropical region of the Americas due to its high timber value (Lemes *et al*.2003). *Swietenia macrophylla* was introduced into Fiji from Central America in 1911 as an ornamental and showed promising results based on small trial plantations established in various parts of Fiji. Mahogany was further developed to large scale plantation from 1952 (Cown *et al*. 1989).

2.3 Data analysis

Mean annual increment for height and girth measurements were calculated for the four species by dividing the height value in 2020 by the age of the plantation. One-way analysis of variance (ANOVA) was performed on mean annual increment of height for individual trees to test the significance of the location and environment across the four species. A Tukey test was run on the mean annual increment values of the four species using Excel to determine which mean growth increment were statistically different from each other.

3.0 RESULTS AND DISCUSSION

3.1 *Yavuna Research Plot*

The Yavuna research plot was assessed over the 5-year period and had only a 42% survival rate. The low survival rate was due to animal grazing, trampling and the trimming of tree canopy by Energy Fiji Ltd. to prevent contact with power lines. With the low survival rate, this study will only analyze the performance of 20 *T. grandis*, 18 *D. cochinchinensis* and 19 *A. auriculiformis* individuals as the best performing species in this research plot.

Table 1: Annual growth performance of tree species at Yavuna research plot over a period of 5 years.

Tree species	**Annual growth rate (height)**		**Annual growth rate (girth)**	
	Min. – Max. (m)	**Mean ± SD (m)**	**Min. – Max. (cm)**	**Mean ± SD (cm)**
Tectona grandis (Teak)	0.05 – 1.38	0.51 ± 0.10	0.67 – 2.68	1.40 ± 0.76
Dalbergia cochinchinensis (Rosewood)	0.08 – 0.50	0.23 ± 0.12	0.36 – 0.93	0.63 ± 0.14
Acacia auriculiformis (Acacia)	0.08 – 1.05	0.32 ± 0.26	0.06 – 0.47	0.35 ± 0.10

There was a significant difference ($F_{2,56} = 3.17$; $P = 0.038$) between the three selected tree species in their annual growth rate at Yavuna research plot. For the three species selected at Yavuna, the species with the highest annual height growth rate were *T. grandis* with an average of 0.51 ± 0.10m, followed by *A. auriculiformis* with an average of 0.32±0.26m, and lastly, *D. cochinchinensis* with 0.23 ± 0.12m (Table 1). For girth or diameter development, *T. grandis* had the highest girth annual growth rate of 1.40 ± 0.76cm, followed by *D. cochinchinensis* with 0.63 ± 0.14cm and finally, *A. auriculiformis* with 0.35 ± 0.10 (Table 1).

3.2 *Vaqia Ba Research Plot*

The Vaqia research plot was assessed over the 5-year period and had an 80.20% survival rate. The three best performing species which were 39 *T. grandis* (teak), 34 ***D.*** *cochinchinensis* (rosewood), and 43 *S. macrophylla* (mahogany) were analysed for the purpose of this paper.

Table 2: Annual growth performance of tree species at Vaqia Ba research plot over a period of 5 years.

Tree species	Annual growth rate (height)		Annual growth rate (girth)	
	Min. – Max. (m)	Mean ± SD (m)	Min. – Max. (cm)	Mean ± SD (cm)
Tectona grandis (Teak)	0.49 – 2.48	1.22 ± 0.51	0.48 – 3.85	1.45 ± 0.69
Dalbergia cochinchinensis (Rosewood)	0.21 – 1.81	0.89 ± 0.36	0.22 – 4.38	2.67 ± 1.48
Swietenia macrophylla (Mahogany)	0.12 – 2.10	1.08 ± 0.56	0.42 – 4.06	2.32 ± 1.05

There was a significant difference ($F_{2,115} = 3.08$; $P = 0.020$) between the three selected tree species in their annual growth rate at Vaqia research plot. For the three species selected at Vaqia, the species with the highest annual height growth rate were *T. grandis* with an average of 1.22 ± 0.51m, followed by *S. macrophylla* with an average of 1.08 ± 0.56m, and *D. cochinchinensis* with 0.89 ± 0.36m (Table 2). For girth or diameter development, *D. cochinchinensis* had the highest average girth annual growth rate of 2.67 ± 1.48cm, followed by *S. macrophylla* with 2.32 ± 0.14cm, and *T. grandis* with 1.45 ± 0.69cm (Table 2).

The average annual height growth rate and the average girth development or diameter growth rate for *T. grandis* planted in Vaqia was 0.71m and 0.66cm more than the *T. grandis* planted in Yavuna, respectively (Tables 1 and 2). Similarly, the average annual height growth rate and the average girth development or diameter growth rate for *D. cochinchinensis* planted in Vaqia was 0.05cm and 2.04cm more than the *D. cochinchinensis* planted in Yavuna, respectively (Tables 1 and 2).

The lower average annual growth rate and girth development of both tree species at Yavuna could be the result of the land tenure system and anthropogenic activities. Since the establishment of the Yavuna research plot, there had been incidences of anthropogenic and animal activities on the research plot, including the trimming of tree canopies to avoid contact with Energy Fiji Limited's power lines. In contrast, the Vaqia research plot was situated on private owned property and the owner had taken ownership, conducting regular and thorough maintenance at the research plot.

In the fifth year, *T. grandis* had grown to an average height of 3.21 m and 7.70 m in Yavuna and Vaqia research plots, respectively. Similar research work had been reported in Nepal where a 6.5-year-old *T. grandis* plantation had grown to an average height of 9.2 m (Thapa and Gautam 2005). In a separate location in Nepal, 10-year old *T. grandis* trees recorded an average plant height of 15.3 m with a periodic height increment of 1.5 m per annum (Joshi 1982).

The present study concurs with similar studies in Nepal that growth rate of *T. grandis* vary from place to place. The present study has demonstrated that *T. grandis* grows much faster than *D. cochinchinensis* and both sites, Yavuna and Vaqia are suitable areas to grow T. *grandis* for future timber needs.

In the fifth year, *D. cochinchinensis* had grown to an average height of 2.32m and 6.38m in Yavuna and Vaqia, respectively. Similar study was reported in Nepal where a 6.5-year-old *D. cochinchinensis* plantation had grown to an average height of 5.9m (Thapa 1998).

Therefore, it is recommended that the four species identified from the present study; *D. cochinchinensis*, *S. macrophylla*, *T. grandis* and *A. auriculiformis* to be promoted for grassland restoration as part of the Ministry of Forestry's 30 million tree in 15 years plantation initiative. It is also clear from the experience gained from this study that close collaboration with communities is imperative to ensure their engagement and involvement in establishing, maintaining and monitoring research plots for security purposes. Moreover, existing plots can be explored for further research opportunities in the future.

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Investigating the utility of *Abrus precatorius* L. to control the highly invasive White-Footed Ant, *Technomyrmex* spp., in Fiji: A Preliminary Study

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ABSTRACT

The *Technomyrmex* white-footed ant, commonly known as the white-footed ant, is recognized as an invasive alien species in the Pacific Islands. The biological invasion of white-footed ant into homes, gardens and cities throughout Fiji has become problematic, particularly where mutualistic associations exist with honeydew producing insects such as mealybugs, aphids, and scales. The white-footed ant displays a particular proclivity towards sugar-rich baits and their association with honeydew producing insects have had a notable impact on many horticultural crops. Despite anecdotal evidence, quantitative studies investigating negative impacts caused by WFA on cropping systems in Fiji, remain under prioritized. The proposed study seeks to address the management of *Technomyrmex* white-footed ant using extracts from the invasive herbaceous plant *Abrus precatorius* L., as a potential organic pesticide for managing the invasive white-footed ant in Fiji. Management of the white-footed ant is vital at a time when home gardens have become incredibly important to address food security in developing and under-developed countries. The implications of this study provide an innovative and sustainable solution to the utilization of an invasive weed to control a problematic invasive ant species. Furthermore, the development of *A. precatorius* as an effective environmentally friendly pesticide should help reduce the use of harmful synthetic pesticides to control the white-footed ant.

Keywords: Invasive Alien Species (IAS), *Technomyrmex* white-footed ant, *Abrus precatorius*, organic pesticide, food security

1.0 INTRODUCTION

Pacific Island Countries, whose land masses range from high volcanic islands to low-lying atolls, are spread across the vast Pacific Ocean and are typically vulnerable to environmental disasters such as tropical cyclones, earthquakes, droughts, volcanic activity, tsunamis, and the spread of invasive alien species (IAS), to name a few (Gallardo *et al*. 2019). Islands are markedly susceptible to invasive alien species, both plant and animal, which cause the loss of biodiversity, the disruption of ecosystems and a reduction in crop yields (Masters and Norgrove 2010). Furthermore, climate change promotes IAS as new species that alter the species hierarchy in an ecosystem and create invasive pathways because of climate induced stress (Masters and Norgrove 2010). Island nations have already begun to suffer from the effects of environmental disasters due to climate change, which has exacerbated the invasion of alien species that further threaten ecosystems and biodiversity. Ants have been identified as an exceptionally difficult and invasive animal to control, with annual damage costs estimated to reach billions of dollars. While early prevention is the key to minimizing the economic, ecological, and social costs of IAS, eradication of IAS can be highly expensive and may require multiple efforts. Sharaf *et al*. (2011) identified one such invasive ant species as belonging to the Dolichoderinae subfamily and the genus Technomyrmex.

Ant members of the *Technomyrmex* genus are found in tropical and subtropical regions, with most species occurring in Afrotropical and Oriental-Malesian areas (Sharaf *et al*. 2011). Several species are arboreal or sub-arboreal, with some living directly on the ground. *Technomyrmex* was assigned its genus in 1872 by Mayr, after the identification of "a small, black ant with a whitish tibia" by Frederick in 1861 (Warner 2003). As one of the most diverse and largest ant genera, *Technomyrmex* consists of a total of 94 official species and 4 fossil species globally (Sharaf *et al*. 2018). The occurrence of the *Technomyrmex* genus has been documented in major geographic regions such as Africa, the Americas, Asia, Europe, and Oceania (AntWeb 2021).

Despite its remoteness and small size, Fiji has a distinct and diverse ant fauna, having recorded at least 187 known species that belong to 43 genera and an endemism rate greater than 70%, according to (Sarnat and Economo 2012). The genus *Technomyrmex* is still poorly understood; for example, *Technomyrmex difficilis* Forel was initially (mis)identified as *Technomyrmex albipes* (Fr. Smith) (Delabie *et al*. 2011). Following the logic of Sarnat and Economo (2012), *Technomyrmex vitiensis* Mann. was the only species documented from Fiji, although many were initially identified as *T. albipes*. However, Thaman (2018) suggests that the recent spread of *T. difficilis* from Papua New Guinea, Micronesia, Australia, or Hawai'i has facilitated its expansion in Fiji. According to Fournier *et al*. (2019) ants are one of the worst IAS not only ecologically but also agriculturally, infrastructurally and in terms of human health. A critical element in understanding and managing invasive species, is to ascertain their current and potential distribution. Hence, it is necessary to monitor and assess the spread of the *Technomyrmex* white-footed ant in Fiji, to gain a better understanding of its invasive potential.

Regarded as a nuisance pest by homeowners, ants of the *Technomyrmex* genus, commonly referred to as white-footed ants, can be seen commonly foraging in the exterior of buildings, kitchens, bathrooms, along branches, shrubs, and tree trunks. Furthermore, they are described to display a certain dietary proclivity towards plant nectars and honeydew, which is produced by hemipterans that include mealybugs, scale insects and aphids. Despite the preference towards sweet liquids, species such as *T. albipes* also feed on dead insects and other sources of protein (Warner *et al*. 2004). Interestingly, other species of *Technomyrmex* are considered as general foragers by way of their feeding habits (Sharaf *et al*. 2018).

To date, baiting, an integrated pest management strategy, has been identified as the most effective method to manage the white-footed ant. Building on the work of Prasad (2013), which investigated the potential use of *Abrus precatorius* L. against the invasive Asian subterranean termite (*Coptotermes gestroi* Wasmann) in Fiji.

Abrus precatorius (here after, Abrus) belongs to the family Fabaceae and is native to India. Abrus is a herbaceous twining plant that has distinctive red coloured seeds with a black spot at its base. The seeds are sometimes used to make necklaces and hence given one of its common names, 'rosary pea' (Chhabi *et al*. 2019). Abrus is recognized as an invasive or nuisance weed in many tropical countries, including Fiji, because of its propensity to smother or outgrow other native vegetation (Prasad *et al*. 2015). However, Abrus has shown insecticidal activity against honeybee, ticks, mealy bug, malaria mosquito and rice weevils (Prasad 2013). The plant contains a poisonous protein, abrin, which is toxic to mammals and insects (Raga *et al*. 2013; Prasad *et al*. 2015). Therefore, it can only be used with caution as attractant baits in pest management, but not applied to crops or food. The proposed study seeks to investigate the utility of Abrus baits for white-footed ant management in Fiji.

2.0 MATERIALS AND METHODS

2.1 *Study locality and sampling*

The herbaceous plant, Abrus was collected from Malomalo village, Natadola, Nadi (located along the southwestern coast of Viti Levu), based on information gathered from Prasad (2013) (Fig. 1). The *Technomyrmex* White-footed ant (here after, TWFA) samples were collected from trees, shrubs, flower beds and infrastructure within the University of the South Pacific's (USP) Laucala campus. Identification of the white-footed ant samples collected were conducted in consultation with Dr. Hilda Waqa-Sakiti (PACE-SD) and Eli Sarnat.

Parts of the plant upon which the TWFA were found were carefully detached and placed into plastic containers, using a soft paint brush where necessary, except for the white-footed ants trailing along infrastructure where sterile forceps was used. A separate glass tank (*vivarium*) filled with moist cotton wool with aerated spaces (to maintain the required humid conditions) and soil was prepared to house the TWFA and plant materials. The *vivarium* were stored in a secured room regulated with 70 ± 10% relative humidity (RH), room temperature of 28°C, and ambient light.

2.2. *Study methods*

2.2.1 Choice (repellency) test

The repellency experimental set-up was adapted with modifications from Warner (2003) (Fig. 2). Five serially diluted treatment groups were trialled as the extract solutions, one of which was distilled water as an experimental control. These treatment groups were leaf and seed extract concentrations of 100% (crude) w/v, 50% w/v, 10% w/v and 1% w/v (Prasad, 2013). A 5 x 5 Latin Square Design were employed for separate repellency tests of the leaf and seed extracts. A volume of 4.5ml of the respective extract solutions were added to 6 ml glass vials with plastic caps that have 2 mm wide holes drilled through. Dental wicks were inserted through the drilled holes to absorb extract solutions and slowly release the aromatic compounds, attracting the TWFA.

The 6 ml glass vials were randomly assigned to positions in the repellency test arena, which consisted of a wall made by gluing two thick sheets of corrugated cardboard boxes. Putty-like adhesive e.g., Blu Tack® were used to hold the glass vials onto the cardboard wall. One side of the wall held vials with the seed extract solution trials while the other comprised the leaf extract solution. Plant tissue infested with the TWFA were placed at the base of the repellency test arena. The TWFA were allowed to move freely throughout the repellency test arena during the test period.

The TWFA movements were recorded at intervals of 15, 30, 45, 60, 90, 120, 180, and 240 minutes. Each extract solution were classified as an attractant or a deterrent, based on the number of TWFA that remain on the extract-treated wicks/vials. Extract attractancy were demonstrated by more than 50% of TWFA remaining. Extract repellency were demonstrated by less than 50% of TWFA remaining, as described in Prasad (2013).

The choice test was carried out over a period of six days. Two separate sets of treatments were applied for the choice test. The first set of treatments, applied over a period of 2 days, included: 1% Abrus seed solution, 1% Abrus leaf solution, 10% Abrus seed solution and 10% Abrus leaf solution. The second set of treatments, applied over a period of four days, included: 0.1% Abrus seed solution, 1% Abrus leaf solution, 10% Abrus leaf solution and sterile water as the control.

Treatments that yield significant results from the choice (repellency) tests were utilized in the no-choice (toxicity) tests.

2.2.2 No-choice (toxicity) and efficacy test

No-choice (toxicity) experiments were utilised to establish the toxicity and rate of kill of Abrus plants against TWFA, with modifications from the set up used by Warner (2003). The treatments adapted from Prasad (2013), of 100% w/v, 50% w/v, 10% w/v, 1% w/v concentration and the control (distilled water) were applied to the TWFA. The TWFA colonies were held in Lion Star Plastics® PRAXIS keeper boxes with lids (240 x 170 x 145 mm). Each box had a nesting tube containing ~200 ants and a dozen brood (larvae). A small amount of reusable putty-like adhesive e.g., Blu Tack®, were used to keep the nesting tube in place.

Each box also received a 6 ml glass vial with plastic cap, containing an aqueous sucrose solution (25% sucrose w/v), that were positioned on the right rear wall and a 6 ml glass vial carrying 4.5 ml of the extract solution(s) (treatments) on the left rear wall. The TWFA were also provisioned with water, by way of soaking a small cotton ball in roughly 2 ml of distilled water in a standard petri dish. The caps were drilled with five holes (0.86 mm diameter), inverted, and positioned to the rear side of the boxes with Blu Tack®. Each vial had felt pads secured below the cap to catch droplets and ensure TWFA are not caught in the sticky residue (Fig. 3).

The no-choice pilot test was conducted over a period of eight days. Two treatments were applied in the no-choice pilot test: 1% Abrus leaf solution and 1% seed solution. *Technomyrmex* WFA were also provisioned with water, a source of protein (tinned tuna) and a sucrose solution. The 25% sucrose solution vial was included in the no-choice to further eliminate bias and maximize the TWFA preferential choice of the solutions provided.

2.3 *Regulation of moisture, light, and temperature*

The experimental setup was maintained at 70 ± 10% relative humidity and 28°C room temperature at the tissue culture lab of the Biological and Chemical Sciences Division under the School of Agriculture, Geography, Environment, Oceans and Natural Sciences (SAGEONS) of the University of the South Pacific (USP). Furthermore, the TWFA were regulated at 12:12 h (light:dark) photoperiod of in the laboratory.

Figure 1. Location of *Abrus precatorius* L. population at Malomalo village near to Natadola Beach, Viti Levu Island, Fiji.

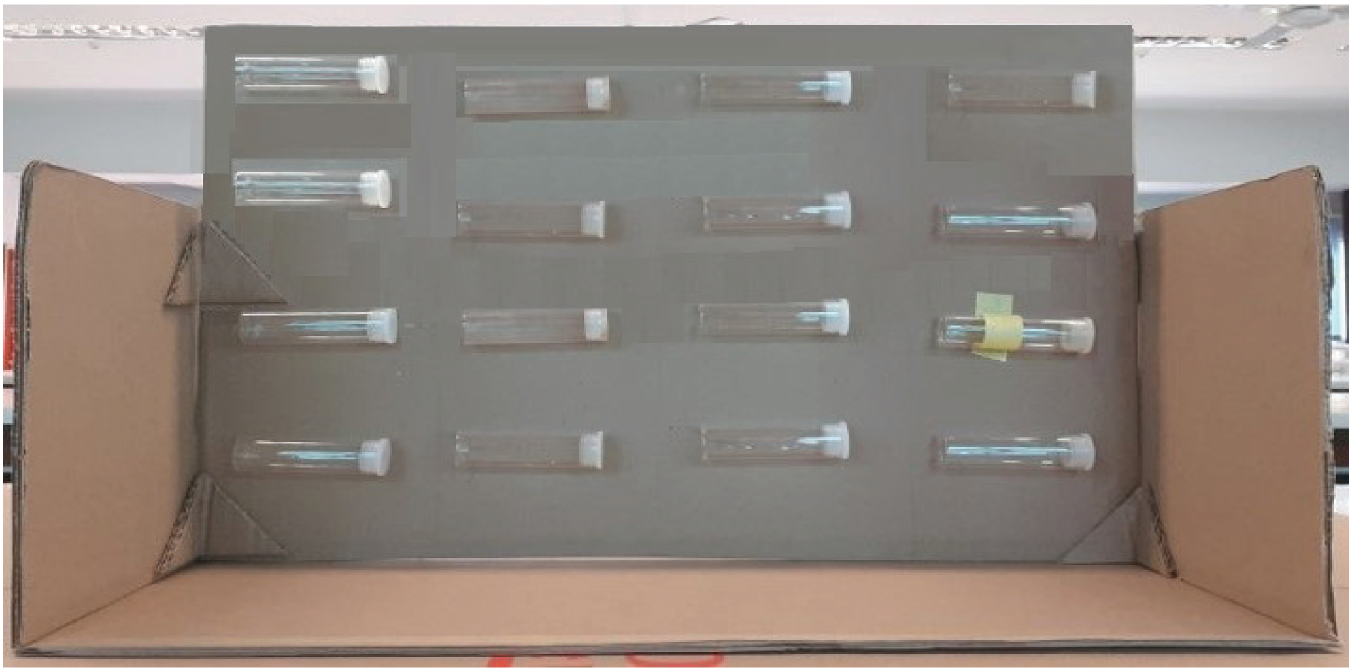

Figure 2. Pilot study Choice test set up: latin square experimental design layout of test vials.

Figure 3. No-choice test experimental setup (Adapted from Warner (2003)).

3.0 RESULTS

3.1 *Choice (repellency) test*

In the choice test's treatment one, there was no obvious proclivity displayed by the TWFA to the 1% Abrus seed solution, 1% Abrus leaf solution, 10% Abrus seed solution and 10% Abrus leaf solution applied over a period of two days. Similarly, in the choice test's treatment two, there was no obvious proclivity displayed by the TWFA to the 1% Abrus seed solution, 1% Abrus leaf solution, 10% Abrus seed solution and 10% Abrus leaf solution applied over a period of four days.

3.2 *No-choice (toxicity) and efficacy test*

In the no-choice pilot test's two treatments, the 1% Abrus seed solution recorded greater mortality (by count; $t_{df\ 5.9495} = 2.7254$, $P = 0.035$) than the 1% Abrus leaf solution (Fig. 4).

Figure 4. Mortality rate of White footed ants induced by: A) 1% solution of seed extract, and B) 1% solution of leaf extract; extracts are water based from oven dried Abrus tissue. No-choice tests were run over a period of eight days

4.0 DISCUSSION

Whilst the early results indicate potential varying toxicity levels in the Abrus seed and leaf, this requires a more robust dataset from the true experiments to clarify and validate the results. It is worth noting that studies by Prasad (2013) and Thulasi (2021) suggest mortality is directly proportional to treatment concentration. This study indicated that more concentrated Abrus solutions lack attractancy and are possibly repellent to the TWFA. Similarly, in the termite study, Prasad (2013) discovered that while 1% Abrus leaf solution and 1% Abrus seed solution potentially acted as an attractant to the Asian subterranean termites, 10% Abrus leaf solution and 10% Abrus seed solution acted as a repellent to the termites.

The implications of this study suggest that Abrus could be developed into an effective and environmentally friendly bait toxicant that can reduce the use of harmful synthetic pesticides to control the TWFA. In addition, through this study, it is hoped that an innovative and sustainable solution to control a problematic invasive ant species can be achieved through the utilization of an invasive weed.

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