Global socio-economic and environmental impacts of invasive ants

Contact:	Report prepared by Monica Gruber, Pacific Programme Manager, Knowledge Services / Director Pacific Biosecurity Wellington UniVentures | Te Herenga Waka - Victoria University of Wellington | PO Box 1762 | Wellington 6140 | New Zealand (w) +64 4 463 5026 | (m) +64 22 013 7862 | (e) monica.gruber@wellingtonuniventures.nz

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Acknowledgements and contributions

The suggestion for the analyses described in this report originated at the workshop: 'The promises and the pitfalls: sharing lessons from invasive ant management programmes around the Pacific' at the Society for Conservation Biology Oceania Congress in July 2018.

Monica Gruber led the development of the project and wrote the report. Davide Santoro (Pacific Biosecurity) assisted with writing, and all co-authors contributed to a review of the report. Sharon Janssen-May and Ross Wylie (National Red Imported Fire Ant Eradication Program, Biosecurity Queensland, Department of Agriculture and Fisheries) supplied the extrapolation methodology and provided crucial assistance with the analyses. Meghan Cooling (Pacific Biosecurity) and Davide Santoro conducted the literature reviews and the assessments for the SEICAT / EICAT / GISS analyses. Phil Lester (Victoria University of Wellington), Lori Lach (James Cook University), Ben Hoffmann (CSIRO) and Christina Boser (The Nature Conservancy) reviewed the assessments.

Evan Brenton-Rule (formerly Pacific Biosecurity), Shyama Pagad (ISSG) and Sabrina Kumschick (IUCN) made suggestions on methods. David Moverley (SPREP) provided NISSAP / TISSAP documents. Steve Cranwell, Mark O'Brien (Birdlife International) and Ray Pierce (Eco-Oceania) provided advice on sourcing data for threatened species. Souad Boudjelas (PII), Rob Duthie (Kalang), Cas Vanderwoude (HAL), Visoni Timote and Fereti Atumurirava (both SPC), and David Moverley (SPREP) provided additional information on regional activities. Phil Cowan (formerly Manaaki Whenua - Landcare Research New Zealand) suggested a socio-economic analysis and provided support for earlier data gathering in 2016, on which this work builds.

Financial support

Primary data-gathering and analysis was funded by the Australian Department of Agriculture and Water Resources. Other organisations that contributed to financial support included the Nature Conservancy, The New Zealand Ministry of Foreign Affairs and Trade Partnerships in Development Programme, and Victoria University of Wellington Research Trust. Data gathering on the socio-economic costs of invasive ants prior to the initiation of this project was provided through Manaaki Whenua - Landcare Research New Zealand, by the New Zealand-United States Joint Commission on Science and Technology Collaboration Invasive Species Working Group, Pacific Engagement Theme. The views expressed in this report do not necessarily reflect those of the Australian or New Zealand Governments, or of the other contributing funders.

Citing this report: Gruber MAM, Santoro D, Cooling M, Boser C, Hoffmann BD, Janssen-May S, Lach L, Lester PJ, and Wylie FR. 2020. Global socio-economic and environmental impacts of invasive ants. Report prepared for the Australian Department of Agriculture and Water Resources. Version 1.0

Authors disclaimer

Key to ant names

We have usually referred to common names throughout the report, except where common names have not been proposed. The following are the scientific and common names of these ants. Ants previously deemed the most serious threat to the Pacific (and globally) [1-4] are shaded in orange. The species shaded in darker orange are typically referred to as the 'worst five' threat ants, and the 13 species in lighter orange are additional species that are a lesser, but potentially serious, threat to the Pacific region [3]. Although we refer to 'invasive species' often in this report, this term should be interpreted as any ant species that could constitute a threat to any aspect of human interest (i.e. pest native ants would meet this definition).

Common name(s)	Scientific name
African big-headed ant; coastal brown ant	*Pheidole megacephala*
Argentine ant	*Linepithema humile*
Bicoloured pennant ant; Guinea ant; penny ant	*Tetramorium bicarinatum*
Bicoloured trailing ant; flower ant	*Monomorium floricola*
Black crazy ant; longhorn crazy ant	*Paratrechina longicornis*
Browsing ant	*Lepisiota frauenfeldi*
Difficult white-footed ant	*Technomyrmex difficilis*
Fijian white-footed ant	*Technomyrmex vitiensis*
Ghost ant	*Tapinoma melanocephalum*
Little fire ant; electric ant	*Wasmannia auropunctata*
Pharaoh ant	*Monomorium pharaonis*
Red imported fire ant	*Solenopsis invicta*
Similar groove-headed ant	*Tetramorium simillimum*
Singapore ant; destroyer ant; ninja ant	*Trichomyrmex destructor*
Tawny crazy ant; Rasberry crazy ant	*Nylanderia fulva*
Tropical fire ant; ginger ant	*Solenopsis geminata*
White-footed house ant	*Technomyrmex albipes*
Yellow crazy ant; long-legged ant	*Anoplolepis gracilipes*
Carpenter ant	*Camponotus variegatus*
Chinese needle ant	*Brachyponera chinensis*
Bourbon ant	*Nylanderia bourbonica*
Green tree ant; weaver ant	*Oecophylla smaragdina*
Bi-coloured arboreal ant	*Tetraponera rufonigra*
European fire ant	*Myrmica rubra*
Invasive garden ant	*Lasius neglectus*

Acronyms

ACIAR: Australian Centre for International Agricultural Research

BPIAP: Biosecurity Plan for Invasive Ants in the Pacific

CNMI: Commonwealth of Northern Mariana Islands

CROP: Council of Regional Organisations in the Pacific

CSIRO: Commonwealth Scientific and Industrial Research Organisation

EDRR: Early Detection and Rapid Response (e.g. risk assessment, species-specific surveillance, simulation exercises, incursion response)

EDF: European Development Fund

EICAT: Environmental Impact Classification for Alien Taxa

GEF: Global Environment Fund

GISS: Generic Impact Scoring System

HAL: Hawai'i Ant Lab

IHS: Import Health Standards

IUCN: International Union for the Conservation of Nature

LDC: Least Developed Country

MFAT: New Zealand Ministry of Foreign Affairs and Trade

MPI: New Zealand Ministry of Primary Industries

NIABP: National Invasive Ant Biosecurity Plan (Australia)

NISSAP/TISSAP: National / Territory Invasive Species Strategy and Action Plan

PAPP: Pacific Ant Prevention Programme

PIAT: Pacific Invasive Ant Toolkit

PICTs: Pacific Island Countries and Territories

PII: Pacific Invasives Initiative

PPBCBP: Pacific Plant Biosecurity Capacity Building Program

PRISMSS: Pacific Regional Invasive Species Management Support Service

PPPO: Pacific Plant Protection Organisation

PSF: Pacific Security Fund

SCHS: Sea Container Hygiene System

SEICAT: Socio-economic Impact Classification for Alien Taxa

SPC: (Secretariat of) the Pacific Community

SPREP: Secretariat of the Pacific Regional Environment Programme

Executive Summary

Introduction

Effective biosecurity and invasive species / pest management are fundamental to sustainable development. Invasive ants, particularly those prone to outbreaks of high abundance, pose significant threats to the environment, agriculture, economy, lifestyle, and health. These risks are recognised and well-managed by biosecurity agencies in developed countries such as New Zealand and Australia, which spend millions of dollars annually on preventing and managing incursions of invasive ants. However, repeated unmanaged outbreaks and unexpected incursions of invasive ants in developing Pacific Island Countries and Territories (PICTs) highlight the need for continuing improvements to preventive capacity in the region. Unmanaged incursions and outbreaks threaten domestic food security and relationships with trading partners. However, we do not have a comprehensive view on the potential impacts of invasive ants in the Pacific region, particularly in developing PICTs. Such knowledge is required to engage the support of in-country stakeholders for enhanced biosecurity.

Objectives

Our primary objective was to develop a global view of the potential and realised socio-economic and environmental impacts of invasive ants, and predict how this might translate to impacts on PICTs. We quantified the potential socio-economic costs of one the most-studied invasive ant species, red imported fire ants, across multiple sectors using an extrapolation analysis. We used the formalised Socio-Economic Impact Classification for Alien Taxa (SEICAT), Environmental Impact Classification for Alien Taxa (EICAT), and the Generic Impact Scoring System (GISS) to qualitatively assess the global impacts of more than 70 species of invasive ants. We also reviewed the relationship between climate change and invasive ants and conducted a non-comprehensive review of current PICT and regional agency priorities and initiatives, and ant prevention activities.

Socio-economic and environmental impacts of ants

We found that invasive ants have extensive adverse socio-economic and environmental impacts globally, in diverse sectors such as plant and animal industries, development, infrastructure, health, and lifestyle. Not unexpectedly, red imported fire ants, together with a few other well-studied species, are responsible for the majority of impacts, both environmental and socio-economic. However, we also identified several potential horizon species for the Pacific.

Our extrapolation analysis of the potential annual socio-economic impacts of red imported fire ant estimated that if it were distributed throughout the Pacific, impacts on our focal PICTs could amount to over USD 320 million annually. This would correspond to approximately 0.7% of the combined annual GDP of these PICTS, and for individual PICTs, this cost could represent more than 2% of GDP. As an indication of the relative impact a potential cost of 1-2% of GDP for a single invasive species might have, spending on healthcare in some PICTS can be as low as 2.8% of GDP. In addition, more than 7 million people could be stung annually by red imported fire ants, adding a further burden and cost to healthcare systems. Over half of the costs of red imported fire ants (61%) were predicted to result from impacts on crops and livestock. The agriculture sector is a major source of employment and subsistence in most PICTs. As a consequence, the impacts of red imported fire ants on PICTs are likely to be felt community-wide and by societies as a whole. The PICTs predicted to be most severely affected financially by red imported fire ants were Niue, Kiribati, and Vanuatu. Kiribati and Vanuatu both have Least Developed Country (LDC) status, and their GDPs are ranked among the lowest five of our focal PICTs. We would expect countries with LDC status and relatively low GDP rankings to be least able to respond to an incursion of any invasive ant. Red imported fire ant could therefore potentially have considerable financial impact on the health of people and the on-going development of the region.

We intended to extend our extrapolation to other invasive ant species. However, much less comprehensive information was available for species other than red imported fire ant. It should be noted, however, that as some of these other species are present within the region (e.g. little fire ant and yellow crazy ant) their likelihood of establishing more broadly within the region is potentially higher than that of red imported fire ant. These already present species also represent a significant threat, but we have not been able to quantify their impacts due to insufficient data.

Our SEICAT analysis designated the little fire ant as the most serious socio-economic threat, with potentially 'massive' impacts. Red imported fire ant and yellow crazy ant were ranked second equal in the analysis. All other ant species were ranked as having moderate or minor impacts. According to Maslow's hierarchy of needs, the impacts are classified as affecting people's most fundamental requirements: biological and physiological needs and safety. These requirements represent the category of deficiency needs, meaning they would potentially limit or interfere with people's desires for fulfilment at higher levels of the hierarchy (i.e. well-being and self-development), findings which echo the results of our extrapolation analysis.

The EICAT analysis identified red imported fire ant, yellow crazy ant and African big-headed ant as having massive impacts, having already caused extinctions or extirpations of endemic species. We recorded major to massive environmental impacts for 14 of the 19 Global Invasive Species Database (GISD) species of concern. Two species on the GISD did not appear in our EICAT rankings, due to a lack of supporting data on impacts. The information on which the GISD list is based is as much as 15 years old, and should be revised in light our findings and that of other studies.

Our SEICAT/EICAT analyses varied in their agreement with previous trait-based predictive modelling of potential future invasive ants Our three highest ranking species were categorised as 'superinvasive' by trait-based models, but we did not find evidence of impacts for nine of the other species ranked as invasive or 'superinvasive' by trait-based modelling. However, trait-based predictive modelling and impact assessment are different approaches. Perhaps these nine could be considered potential horizon species for the Pacific, although their specific risk profiles will be dependent on trading links within their current distributions and climate and habitat suitability, which we have not explored.

Using the IUCN red list as a reference, we identified a total of 377 species of birds, reptiles, amphibians, mammals, land snails and crabs, and insects that are threatened and could be vulnerable to invasive ant impacts in our focal PICTs. The effects of ants on animals such as seabirds, and cryptic species like land snails may be undetected. For those ant species that are distributed widely throughout the Pacific (e.g. little fire ant and yellow crazy ants), these potential undetected conservation impacts may be widespread and significant. Critically endangered birds in the Pacific are already threatened by ants, and yellow crazy ant has been implicated as contributing to the extinction of the Christmas Island pipistrelle bat. All of our focal PICTs are at risk of outbreaks or arrival of ants that could contribute to extinctions.

Implications of climate change

Change in ecological and environmental systems is influenced by multiple factors such as climate variation, biological invasions, and anthropogenic influences. The interplay of threats, system complexity, and scientific and societal unknowns, make it difficult to accurately predict specific environmental outcomes of climate change. Recent weather trends and the predicted increase in the frequency of extreme weather events are predicted to favour invasive species and pests, enhancing their dispersal and impacts.

Evidence of these predictions is beginning to emerge for ants, with outbreaks of species that were previously in low abundance and relatively innocuous. Impacts will potentially be amplified by development-related activities such as forest clearance. A global assessment predicting future distributions of the worst invasive ant species suggests that the potential distribution of only five ant species will increase. Of the species typically cited as the 'worst' invasive ants, climatically suitable areas are only predicted to increase for red imported fire ant.

Apart from changing climate and habitat suitability, other factors will naturally influence the realised distributions and severity of invasive ant impacts. One message is clear: red imported fire ants will not be a diminishing risk to the Pacific under future climate scenarios.

PICT and regional agency priorities

We reviewed invasive species priorities publicly accessible for 13 of our 22 focal PICTs. All sources except one listed invasive ants as a priority for prevention or management. The exception, Palau, did not mention any priority species. Some plans also mentioned co-ordination of international and domestic biosecurity. In general, most PICTs identify ants already present as an environmental problem, however, in many cases preventive actions are not specified. However, we know that more developed countries such as Fiji and Samoa have dedicated biosecurity teams, whose priorities include ant prevention.

The work programmes of Secretariat of the Pacific Regional Environment Programme (SPREP) and the Pacific Community (SPC) are based on priorities set by their member countries and territories. Both SPC and SPREP have priorities for enhanced biosecurity in the Pacific over the coming years, which are being supported through a number of activities. SPREP has recently implemented a Pacific Regional Invasive Species Management Support Service (PRISMSS) as a coordinating regional mechanism to more effectively address invasive species issues in the Pacific region.

The Pacific Ant Prevention Programme

A comprehensive invasive ant prevention programme for the Pacific has been proposed as a mechanism for ongoing support to PICTs. A Pacific Ant Prevention Plan (PAPP) was initiated in 2003, which supported collections of ants from all nine participating PICTs for reference collections, identification workshops and surveillance. However, the efforts of that project have not always been sustained. Since that time several parties who recognise the on-going threat of invasive ants have attempted to reinvigorate the PAPP, an action the Pacific Plant Protection Organisation (PPPO) members endorsed in 2014. Many past and on-going activities by groups in Australia, New Zealand and elsewhere have contributed to capability-building in the Pacific. Taken together, these various activities suggest that there continues to be regional support for a dedicated invasive ant programme for the Pacific, and many of the objectives of the PAPP are progressing. However, co-ordination of all these activities is lacking.

Conclusions and recommendations

We estimate that invasive ants could cost PICTs as much as 2% of their annual GDP, with substantial impacts on environment, agriculture, lifestyle, and health. Our analyses highlight the importance of preventing their spread and eradication where possible.

Australia is expending considerable effort to eradicate invasive ants such as red imported fire ants, little fire ants, browsing ants and yellow crazy ants. Enhanced biosecurity in PICTs will assist in preventing re-invasions of these species, and provide an additional risk management mechanism for Australia (and other countries, including New Zealand). Prevention of red imported fire ant incursions will also protect future market access opportunities for PICTs.

Based on our findings, we suggest that the highest priority actions should be to prevent red imported fire ants from establishing within PICTs, while ensuring containment of invasive ant species already present. PICTs must be fully prepared for all ant incursions. Specific initial actions suggested are:

1. *Improved co-ordination of ant prevention activities* across the region to capitalise on existing and future capability-building activities. While numerous activities are undertaken with the support of several donors, these efforts are not comprehensively coordinated. Greater coordination with increase the effectiveness of capability-building and reduce potential gaps and overlaps;
2. *Targeted support for Early Detection and Rapid Response (EDRR).* The ability to detect invasive ant incursions as early as possible is the key to success of eradication efforts;

3. *Simplified import permitting processes* to support pre-border risk reduction. Import Health Standards (IHS), as used by New Zealand and Australia, are not the norm in PICTs. Instead, they typically rely on import permits. Streamlining of these importing processes through IHS will reduce the effort required, promote compliance and enhance the effectiveness of importing processes;
4. *Promotion of Sea Container Hygiene System (SCHS) throughout the Pacific*. Australia and New Zealand effectively use SCHS for reducing the risk of ant incursions. Extending the SCHS so that Pacific countries are also protected will reduce this risk for both PICTs and their trading partners.

The actions we propose appear to align well with current policies in Australia and New Zealand, including Australia's National Invasive Ant Biosecurity Plan (NIABP). Given recent re-emphasis on security in the Pacific, signalled by New Zealand's *Pacific Reset*, and Australia's *Step Up* policies, this could be an optimum time to promote or seek joint multilateral support for such actions.

Introduction

This report summarises an investigation commissioned to assess the potential socio-economic costs of invasive ants in the Pacific. The information gathered is intended to contribute to developing a case to enhance resilience to the biosecurity risk posed by invasive ants throughout the Pacific. The report outlines the findings as at December 2019. The expected outcomes were that our analysis would enable:

1. Greater, and more predictive, understanding of social impacts including human health, employment or ability to grow crops;
2. Greater understanding of impacts on biodiversity and ecosystem services;
3. Justification for a sustained programme for invasive ants in the Pacific that will benefit both PICTs and also donor countries.

Longer term outcomes of projects that this activity is intended to support are:

1. Strengthened regional biosecurity: justification for financial commitment to surveillance and rapid response;
2. Better management of invasive ants by PICTs to reduce the risk of introduction between Pacific Island Nations as well as to Australia and New Zealand. This will also indirectly benefit a number of trade agreements by reducing biosecurity risk of traded goods, including:
    a. The Pacific Island Countries Trade Agreement (PICTA). The free trade agreement currently including Cook Islands, Fiji, Kiribati, Nauru, Niue, Papua New Guinea, Samoa, Solomon Islands, Tonga, Tuvalu and Vanuatu;
    b. The Pacific Agreement on Closer Economic Relations-Plus (PACER-Plus), a Free Trade Agreement covering goods, services and investment, including Australia, New Zealand and eight Pacific island countries – Cook Islands, Kiribati, Nauru, Niue, Samoa, Solomon Islands, Tonga, Tuvalu and Vanuatu;
3. Greater access to effective tools and resources for PICTs to manage invasive ants into the future so that impact is minimised, and the inertia in response to these invasions is relieved.

Invasive ants can have devastating and widespread negative ecological and environmental effects [e.g., 1, 5, 6], and are known to adversely affect many other aspects of human interest including infrastructure, agriculture and economy, biodiversity and human health [e.g., 1, 7-9]. Ants have been introduced outside their native ranges to all continents except Antarctica. Nineteen ant species (as at December 2019) are listed in the Global Invasive Species Database of the Invasive Species Specialist Group (ISSG) of the International Union for the Conservation of Nature (IUCN). However, only a handful of introduced ant species are routinely cited as responsible for the most widespread impacts [e.g. 1, 2]. Ever-increasing global trade contributes to growing rates of species introductions in new areas [10, 11]. As a consequence, previously unexpected invasive ant threats are also beginning to have significant impacts [e.g., 12, 13], some of which are also predicted to increase [14]. Predicting which species are responsible for the greatest impacts, and which might be in the future, will assist with risk analysis and targeted surveillance actions for priority species. Targeted actions are particularly important in developing countries, which can be challenged by many factors.

Biosecurity is the only proven effective way to prevent the significant socio-economic and environmental costs of invasive species and pests. Arguably, New Zealand and Australia have the most effective biosecurity systems in the world, including end-to-end systems specifically designed to mitigate the threat of invasive ants and other invertebrates [e.g. the Sea Container Hygiene System; 15, 16]. However, these systems are associated with significant costs and can be a relative luxury in developing countries, where basic needs such as education, health and sanitation are naturally higher priorities. Thus, the benefits of enhanced biosecurity need to justify their cost. To date, no qualitative or quantitative predictive analysis has cohesively assessed the impacts of invasive ants outside of single countries or states. Typically, studies focus on specific species in specific locales [7, 17, 18].

Our primary objective was to develop a global view of the socio-economic and environmental impacts of invasive ants, through a review of peer-reviewed articles and grey literature (i.e. websites, government and other reports). From this analysis, we extrapolated the potential socio-economic costs across applicable sectors in selected PICTs (Table 1). As well as the parties to the Pacific Island Countries Trade Agreement, and the Pacific Agreement on Closer Economic Relations – Plus (PACER-Plus), we focused on other developing PICTs in the region as these are most vulnerable to the severe effects of climate change [e.g., 19, 20, 21], with some already reporting impacts [e.g., 22].

Our initial primary species of interest for the extrapolation analysis was red imported fire ant. We primarily focussed on red imported fire ant for several reasons: 1) the ant is not present in our focal PICTs (and therefore a key focus for prevention across the region); 2) it has well-documented impacts on key trading partners [e.g. 7]; 3) in practical terms it may be more effective for PICTs to focus on one species well, rather than fragment already limited resources; and 4) species already present may be viewed by PICTs as a lower priority, particularly in the case of outbreaking species whose impacts are not always evident. Our recommendations are equally applicable to the invasive ants already in parts of the region, and tools such as the SCHS are effective for all ant species.

In addition to quantitative socioeconomic analyses, we used the Socio-Economic Impact Classification for Alien Taxa [SEICAT; 23], the Environmental Impact Classification for Alien Taxa [EICAT; 24], and the Generic Impact Scoring System [GISS; 25] methodologies. These methodologies qualitatively assess the impacts of invasive species. SEICAT and EICAT were designed to align with the IUCN Red List, are endorsed by the IUCN, and are intended to be easily incorporated into international invasive species risk assessment and prioritization practices and policies [61].

Our report is intended to:

- Summarise the findings of the research (i.e. the short-term outcomes);
- Highlight gaps in the ability to achieve the longer-term outcomes;
- Provide a roadmap to achieve a cohesive programme for invasive ants in the Pacific.

The methods and additional information for our analyses is presented in the appendices.

Findings and discussion

Our extensive quantitative and qualitative reviews affirmed that invasive ants identified as significant threats to the Pacific [3] have extensive adverse socio-economic and environmental impacts globally, in diverse sectors such as plant and animal industries, infrastructure, health, and lifestyle. We also identified several new horizon species for the Pacific. Not unexpectedly, red imported fire ant, little fire ant and yellow crazy ant, together with a few other well-studied species are responsible for the majority of impacts, both environmental and socio-economic.

Quantitative socio-economic analysis

We conducted an extrapolation analysis for the potential socio-economic impacts of red imported fire ant to selected developing PICTs (Table 1). These costs exclude the costs of control or eradication of the ant. Overall, our analysis estimated that the potential annual socio-economic costs for impacts in areas infested by red imported fire ant could amount to USD 324,378,185 across our focal PICTs (Table 2). This figure would correspond to approximately 0.7% of the combined annual GDP of these PICTS (USD 47,785,000,000; Table 2). However, for some PICTs, the cost could represent more than 2% of GDP (Table 2). Almost half of the costs of red imported fire ants (44%) were predicted to result from impacts on crops. The financial impact on infrastructure (including schools and electrical damage) accounted for 28% of the total. The livestock sector was assigned 15% of impact costs (Table 2), with 64% of those costs attributed to pigs, 19% to cattle, 9% to goats, and the remainder to horses, sheep, buffaloes, and asses.

Table 1: Demographic and development-related characteristics of the Pacific Island Countries and Territories (PICTs) included in our extrapolation-based socio-economic analyses, including: Human Development Index (HDI) ranking and category; population size; Gross Domestic Product (GDP); per capita GDP; and GDP ranking (of PICT relative to the rest of the group reported here; 1 indicates highest ranked, 22 indicates lowest ranked). The 2019 Human Development Index (HDI) (http://hdr.undp.org/), ranks countries (not territories) from 1-189, and further categorizes each as very high, high, medium or low human development. For comparison Norway is ranked at 1, Australia at 6, New Zealand at 14, and the United States and United Kingdom equal at 15 (all very high). Least Developed Country (LDC) status is based on the United Nations Economic and Social Council (ECOSOC) classifications. LDC PICTs are highlighted in grey shading. GDP was obtained from World Bank statistics (https://data.worldbank.org/indicator/) unless otherwise indicated: [1] from the Cook Islands government statistics website (http://www.mfem.gov.ck/statistics/economic-statistics), converted from NZD. [2] 2000 – most recent figure from World Bank statistics. [3] 2009 – from the SPC Niue Statistics website (https://niue.prism.spc.int/), converted from NZD. [4] 2015/2016 - converted from NZD. From the Tokelau government website (https://www.tokelau.org.nz/Bulletin/April+2017/GDP+first.html),. [5] 2004 – from the CIA World Factbook (https://www.cia.gov/library/publications/the-world-factbook/). All dollar figures are for 2017 and are expressed in USD.

PICT	HDI Ranking	HDI Category	Population	GDP (000,000's)	Per capita GDP	GDP ranking	Land area (00 hectares)	Population density
American Samoa	-	-	55,640	634	11,394	6	197	282
Cook Islands	-	-	17,380	335 [1]	19,275	3	237	73
Federated States of Micronesia (FSM)	135	Medium	105,540	336	3,184	17	701	151
Fiji	98	High	905,500	5,061	5,589	11	18,333	49
French Polynesia	-	-	283,010	3,447 [2]	12,180	5	3,521	80
Guam	-	-	164,230	5,859	35,676	1	541	304
Kiribati	132	Medium	116,400	185	1,589	21	811	144
Nauru	Data deficient	Data deficient	11,360	113	9,948	8	21	541
New Caledonia	-	-	276,260	2,682 [2]	9,708	9	18,575	15
Niue	-	-	1,620	17 [3]	10,507	7	261	6
Commonwealth of the Northern Marianas Islands (CNMI)	-	-	55,140	1,593	28,888	2	457	121
Palau	55	Very high	21,730	289	13,300	4	444	49
Papua New Guinea (PNG)	155	Low	8,251,160	20,536	249	22	462,840	18
Republic of Marshall Islands (RMI)	117	Medium	53,130	204	3,840	15	181	294
Samoa	111	High	196,440	840	4,276	13	2,831	69
Solomon Islands	153	Medium	611,340	1,303	2,131	20	28,370	22
Timor-Leste	131	Medium	1,296,000	2,954	2,279	19	14,919	87
Tokelau	-	-	1,300	9 [4]	6,923	10	10	130
Tonga	105	High	108,020	427	3,953	14	720	150
Tuvalu	Data deficient	Data deficient	11,200	39	3,485	16	26	430
Vanuatu	141	Medium	276,240	862	3,120	18	12,281	22
Wallis & Futuna	-	-	11,780	60 [5]	5,096	12	142	83

The highest red imported fire ant impacts were predicted to be on the agriculture sector (59%, including crops and livestock). In the past two decades PICT economies have seen a decrease the proportion of GDP attributed to the agricultural and industrial sectors, and an increase in the proportion of GDP attributed to the services sector. For example, Fiji's agricultural sector declined from 18.8% of GDP in 1995 to 12.1% in 2011, while the agricultural sector in Samoa decreased from 18.4% of GDP in 1995 to 9.8% in 2012 [26]. Although the declining trend for agriculture may have slowed due to the re-emergence of coconut as an export commodity [27], the agriculture sector remains a major source of employment and subsistence in most PICTs [26]. As a consequence, the impacts of red imported fire ants on PICTs are likely to be felt more broadly community-wide and by societies as a whole.

The PICTs predicted to be most severely affected economically by red imported fire ants were Niue, Kiribati, and Vanuatu (over 2% of GDP; Table 2). Kiribati and Vanuatu both have LDC status, and are within the lowest 5 GDP rankings of our focal PICTs. The predicted impact for the other least developed countries in our focal group was 1.2% for Timor Leste and 1.6% for Tuvalu. We would expect those countries with LDC status and those with relatively low GDP rankings to be least able to respond to an incursion of red imported fire ants, or indeed, any invasive ant species. The results of our extrapolation analysis suggest that these LDC PICTs will likely also be those most affected.

By contrast, Papua New Guinea was predicted to expect losses of less than 0.7% of GDP (which is less than the average for all PICTs we assessed). Although these impacts appear low relative to other PICTs, several intrinsic factors that we have not assessed will potentially amplify impacts: 1) the country is large, with many difficult to access settlements; 2) potential new habitat for red imported fire ants due to deforestation, and mining; 3) heightened biosecurity risk of spread owing to the transportation of machinery associated with these activities, which act as a pathway. These factors suggest that the impacts of red imported fire ants in Papua New Guinea would likely be greater than predicted, and more difficult to deal with from a biosecurity perspective (i.e. surveillance and emergency response). Similar complexities related to larger land area, accessibility and development also likely contribute to increased impacts for other PICTs such as Solomon Islands, Vanuatu, and Timor Leste relative to other PICTs.

Table 2: Projected annual red imported fire ant costs in USD by sector and PICT (- indicates sector information not available), derived using extrapolation analysis [7]. Wylie and Janssen-May [7] estimated that between 30% and 60% of the population would be stung by red imported fire ants. The higher % is reported here due to the typically more outdoors-oriented lifestyles of Pacific peoples. The cost of medical attention is based on estimated annual medical costs per household. For each PICT, cells are shaded to indicate the potential GDP percentage cost of red imported fire ants: white=0-1%; light grey=1-2%; mid grey=>2%.

PICT	Health		Schools	Crops & beehives	Livestock	Electrical	Tourism	TOTAL	% of GDP
	People affected	Cost of medical attention							
American Samoa	33,385	138,606	838,235	495,205	108,527	728,446	25,409	2,334,428	0.37
Cook Islands	10,428	72,808	225,959	130,686	329,302	225,262	-	984,016	0.29
FSM	63,326	245,390	1,363,043	-	569,175	898,151	35,098	3,110,858	0.93
Fiji	543,301	2,631,615	7,252,555	8,140,184	7,639,069	10,313,625	1,249,484	37,226,532	0.74
French Polynesia	169,804	1,116,817	-	2,019,977	540,126	3,519,844	400,505	7,597,270	0.22
Guam	98,537	619,188	298,849	687,700	64,576	2,150,070	2,968,862	6,789,245	0.12
Kiribati	69,839	270,625	699,744	2,110,695	135,458	990,516	6,877	4,213,916	2.28
Nauru	6,815	26,410	65,601	35,193	28,925	148,711	-	304,839	0.27
New Caledonia	165,753	1,159,025	-	1,651,761	1,317,703	3,435,868	258,904	7,823,260	0.29
Niue	971	7,281	14,578	440,067	22,324	20,971	-	505,221	2.97
CNMI	33,086	233,109	233,248	-	-	721,940	1,414,276	2,602,573	0.16
Palau	13,037	85,748	182,225	-	-	278,784	247,548	794,306	0.27
PNG	4,950,697	21,717,681	2,310,613	86,468,111	21,301,360	12,962,807	-	144,760,572	0.70
RMI	31,876	397,150	801,790	500,378	-	2,237,442	22,875	3,959,636	1.94
Samoa	117,864	595,494	2,332,480	3,932,779	2,278,200	2,571,773	225,720	11,936,447	1.42
Solomon Islands	366,806	1,550,588	9,220,585	8,662,401	666,216	1,840,838	33,244	21,973,872	1.69
Timor-Leste	777,787	3,117,851	-	14,989,515	8,997,393	10,691,840	90,771	37,887,371	1.28
Tokelau	780	3,488	21,867	48,204	9,540	17,019	-	100,118	1.11
Tonga	64,812	264,365	998,593	1,858,656	1,136,491	1,258,626	78,010	5,594,740	1.31
Tuvalu	6,715	26,021	218,670	148,503	136,308	143,594	2,964	676,060	1.73
Vanuatu	165,746	802,834	8,360,483	8,543,342	2,960,252	1,193,464	161,558	22,021,934	2.55
Wallis & Futuna	7,064	35,689	182,225	508,252	308,381	146,424	-	1,180,971	1.97
TOTAL USD	**7,698,431 people**	**35,117,783**	**35,621,343**	**141,371,608**	**48,549,327**	**56,496,016**	**7,222,107**	**324,378,185**	
% of TOTAL		**11**	**11**	**44**	**15**	**15**	**2**	**mean 14,744,463**	**mean 1.12**

To understand the relative impact a potential cost of 1-2% of GDP for a single invasive species, we can compare spending on higher priority sectors such as Healthcare and Education. For example, an assessment of government spending in nine PICTs between 1997 and 2003 found that 5.2-17.8% of GDP was attributed to Education and 2.8-12.5% to Healthcare [Table 3; 28]. Thus, for these nine PICTs, the potential economic cost of red imported fire ant could range from 4% (Palau) to 86% (Vanuatu) of the total Healthcare budget. Naturally, these predictions vary widely depending on the level of spending on Healthcare and Education in those PICTs. Also, in some cases, particularly LDCs, the GDP spending on key sectors such as Healthcare and Education are also bolstered by significant donor contributions (not included in the figures in Table 3). Regardless of this additional support, red imported fire ant could potentially have considerable financial impact on the development of LDCs.

Wyle and Janssen-May [7] estimated that between 30% and 60% of the population would be stung by red imported fire ants. Of those stung, 1-3% were expected to be hypersensitive and require urgent medical treatment. However, others less seriously affected could also be expected to seek medical attention or be unable to work or school. As Pacific peoples' lifestyles are highly outdoor-oriented, we have reported the higher figure of 60%. The potential medical care required by people stung annually by red imported fire ants (Table 2) would add a further burden and cost to the healthcare systems of our focal PICTs. Given the open types of housing in many PICTs, and the amount of time people spend outside, the risk of being stung, and the medical costs, may well be higher than we have estimated.

Table 3: World Bank assessment of annual spending on Health and Education (1997-2003) for nine PICTs as a percentage of GDP [28]. Figures for all East Asia and Pacific countries, and all low- and middle-income countries are provided as a comparison. LDC PICTs in this group of countries are highlighted in grey.

PICT	% of GDP				Impact as % of Healthcare
	Education	Healthcare	Combined	Red imported fire ant impact	
Federated States of Micronesia	10.5	5.8	16.3	0.8	14%
Fiji	5.2	2.8	8.0	0.7	25%
Kiribati	17.8	12.5	30.3	2.1	17%
Palau	7.7	8.2	15.9	0.3	4%
Republic of Marshall Islands	13.1	11.3	24.4	1.5	13%
Samoa	5.3	4.1	9.4	1.4	34%
Solomon Islands	7.3	5.1	12.4	1.6	31%
Tonga	4.9	3.2	8.1	1.2	38%
Vanuatu	5.7	2.9	8.6	2.5	86%
Low- and middle-income	3.9	2.8	6.7	-	-
East Asia and Pacific	2.6	1.8	4.5	-	-

In PICTs evidence of the socio-economic impacts that we have predicted would be gradual, as it takes time for ants to reach a density and distribution for widespread impacts to be obvious, or considered serious enough to eradicate. For example, although red imported fire ants probably arrived in the United States sometime in the 1930s, eradication efforts only began in the 1960s [29]. Since that time, a greater awareness of the difficulties of eradicating ants over a scale of more than a few hectares [30, 31], combined with our improved knowledge of their impacts, and better preparedness [15], would hopefully result in faster and more successful responses to an incursion of red imported fire ants in PICTs in the 21st century.

However, recent responses to the spread, and outbreaks, of invasive ants in the Pacific indicate a significant degree of inertia. For example, little fire ants have been spreading slowly over Vanuatu for over 30 years [32, 33]. In Atafu, Tokelau, difficulties in communicating the problem and in obtaining funding resulted in a delay of several years before action was taken on yellow crazy ants, by which time the ant had significantly increased in distribution [34]. This type of inertia will likely be exacerbated by detections being reported much later in developing PICTs than in other countries, due to a lack of awareness and limited surveillance capacity. For example, yellow crazy ants may have been in Kiritimati, Kiribati for many years prior to being detected during an awareness and surveillance exercise in 2014 [3]. Little fire ants were likely present in Hawai'i at least six years before detection [35], and in Yap [36] for at least four years before they were detected in 2017. The detection in Yap occurred as a result of an awareness campaign (Tamdad Sulog; personal communication). Little fire ant may have arrived in the Solomon Islands sometime between 1931 and 1968, where they were initially considered - and still are by some people (Bob Macfarlane; personal communication) - a useful biological control agent in coconut plantations [37].

Without appropriate surveillance and public awareness, it is possible that red imported fire ants may spread beyond an area from which they can be eradicated [38] . The time from establishment to spread to an area too large for eradication is likely to be much shorter than in developed countries, due to the restricted access PICTs have for funding. Any extended time required to obtain funding results in invasive ants having an extended opportunity to spread within their new environment, making eradication harder or impossible. As a result, in some cases, such as the little fire ant in the Solomon Islands, communities become accustomed to the ant over time, and change their agricultural and other practices to compensate [8]. A further consequence of this inertia is that the economic impacts will be greater.

We intended to extend our extrapolation to other invasive ant species. However, much less comprehensive information was available for species other than red imported fire ant (of 101 records, 44 were for red imported fire ants alone). As well as being sparse, we found a great deal of variability in the data, and the basis on which the figures were calculated, or projected, or could be estimated. Based on the potential unreliability of conclusions drawn from these data, we did not explore these analyses further.

We had also planned to conduct a robust analysis to compare the costs of impacts, management and prevention to justify additional emphasis on biosecurity in PICTs, but this has proven difficult for several reasons:

- Prevention costs for ants alone are difficult to identify as these costs are typically part of the wider biosecurity budget. The costs related to prevention interventions specific to ants were only able to be derived from information on New Zealand. The New Zealand Ministry of Primary Industries spends approximately 460,000 USD per annum specifically targeted towards prevention and incursion response against ants (Nicky Fitzgibbon, MPI, personal communication). The programme includes regular port surveillance (and incursion response readiness and action if needed), and the Sea Container Hygiene System (which Australia co-champions, and to which a number of PICTs are also party).
- The question of the relative costs of impact, management and prevention is also difficult to answer because of the difference in 'invadedness' between countries. For example, of the invasive ants most commonly targeted in management programmes (the so-called 'worst five'[3]), only Argentine ants are present in New Zealand, which has also so far avoided red imported fire ant establishment, despite several incursions [39, 40]. When Argentine ants were discovered in New Zealand in 1990, the decision was made to not implement a national eradication programme. Efforts are made to prevent Argentine ant establishment in conservation lands in New Zealand, and to control or eradicate them, where possible [41]. But the costs of control, eradication or economic impact are not publicly available. Although the costs of managing Argentine ants were estimated to be NZD 68 million per annum in 2002 [42], we do not know if these costs have been realised. Therefore, comparing the costs of managing invasive ants with the costs of prevention in New Zealand is not very informative on the cost-benefit of prevention. Australia, by contrast, is invaded by all the 'worst five' invasive ants, and as a result incurs a large management cost for these species [43]. This inequity in degree of 'invadedness' between countries makes it difficult to directly compare the cost-benefit of prevention.

Several studies have identified benefit-cost ratios for the management or eradication of invasive ants. For example, the benefit-cost ratio of eradicating little fire ants in Queensland, Australia [14:1; 44]. When the impact on ecosystem services was taken into account the benefit-cost ratio of eradication of red imported fire ants in Australia was even greater [390:1; 45], with a range of 289:1-436:1. Spending USD 8 million in the next few years on little fire ant control on the big island of Hawai'i was predicted to result in a benefit-cost ratio saving of 167:1 in the following 10 years [18]. We have not, however, estimated the potential costs of managing or eradicating invasive ants in PICTs, relative to the costs of impacts.

However, for the more remote PICTs in particular, the costs of management will be significantly higher than in developed countries, due to remote access, and small workforce.

Qualitative socio-economic and environmental impact analyses

We used three approaches to qualitatively assess the impacts of invasive ants: 1) Socio-Economic Impact Classification for Alien Taxa [SEICAT - 23]; 2) Environmental Impact Classification for Alien Taxa [EICAT - 24, 46]; and 3) the Generic Impact Scoring System [GISS - 25], which combines socio-economic and environmental assessments. We included all ant species in our assessment, and included all studies that reported the impacts of ants.

Socio-economic impacts

SEICAT analysis

The SEICAT and EICAT methodologies categorize invasive species by the magnitude of their impacts, sub-divided according to the mechanism of these impacts. For SEICAT, the mechanisms are the components of human wellbeing affected by the target species and include: safety; material and non-material assets; health; and social, spiritual, and cultural relations. Each record is assigned one of five impact categories ranked by increasing magnitude, with the largest impact recorded as 'massive'. Records are also categorized by degree of confidence in the original source (low, medium, high).

We collected 550 records for socio-economic impacts of ants from 401 sources that documented the socio-economic impacts of ants for a total of 79 species (Table 4). When records involved two or more species and the impacts of individual species were not discriminated, the source was assessed as a multi-species record, and each individual species inherited the categorisation. Of the 550 records, 465 were applicable for assessment using the SEICAT methodology. Records of impacts were from 50 countries and territories, with the United States (36%), Brazil (22%), Australia (5%) and Malaysia (5%) the most studied. Of the 80 taxa recorded, red imported fire ant was the most studied species, and appeared in 94 records (20.2%; Table 4). Forty-eight taxa (59%) appeared in only one study. The most frequently identified socio-economic impact categories were health (60.6% of records) and material assets (35.1%). The remaining impacts were on non-material assets (1.9%), social (4.7%), spiritual (0.4%), and cultural relations (2.4%)[1]. No records identified safety as a mechanism of impact.

Our SEICAT assessment assigned the little fire ant as the most serious socio-economic threat, with potentially massive impacts. This is mostly attributable to occasional reports of people leaving their land in French Polynesia. However, we know that abandoning land is not always the case, as communities in the Solomon Islands have instead adapted their lifestyle and agricultural methods in response to the ant [8]. Red imported fire ant and yellow crazy ant were ranked second equal in the SEICAT analysis as having major socio-economic impacts (Table 4). We consider these species accurately reflect the most serious risks to the Pacific. We did not assess the risk of incursion for each PICT, as this was not within our scope. However, these factors also influence risk and should be assessed.

All other ant species were ranked as having moderate or minor impacts. Interestingly, the tawny crazy ant (*Nylanderia fulva*) ranked fourth equal on our list (among 6 other species), despite having been reported as a problem only recently, and relatively understudied compared to other species. This relatively high ranking despite few studies indicates that the tawny crazy ant could be a major 'horizon' or emerging threat species for the Pacific, dependent on habitat- and climate-matching, as well as probability of arrival. Indeed, in the southern United States some anecdotal reports indicate the public perception of tawny crazy ant impact is worse than red imported fire ants, due to the high numbers that they attain.

[1] Percentages exceed 100 as records can be categorised according to multiple mechanisms.

Table 4: Statistics for socio-economic impact rankings of ants assessed using the SEICAT methodology, ordered by decreasing order of SEICAT magnitude: 1) Massive (MV); 2) Major (MR); 3) Moderate (MO); 4) Minor (MN); and 5) Minimal Concern (MC). Divisions between SEICAT impact categories are indicated with dotted lines. Ant species considered the most serious threat globally [1-3] (including the Pacific region) are shaded in orange tones, as described earlier. Ants appearing the Global Invasive Species Database (GISD) are indicated in bold. GISD species for which no impacts were found are not presented. Trait-based invasiveness indicates ranking according to predicted invasiveness probabilities used by trait-based modelling [47]. - indicates species absent from the AntProfiler database, from which trait-based invasiveness was derived.

Scientific name	Common name	# records	% of records	Present in PICTs[2]	SEICAT ranking	Trait-based invasiveness
Wasmannia auropunctata	**Little fire ant, electric ant**	**37**	**7.90%**	**7**	**MV**	**0.86 ± 0.02**
Anoplolepis gracilipes	**Yellow crazy ant**	**17**	**3.60%**	**21**	**MR**	**0.86 ± 0.02**
Solenopsis invicta	**Red imported fire ant**	**94**	**20.20%**	**0**	**MR**	**0.83 ± 0.02**
Linepithema humile	**Argentine ant**	**30**	**6.40%**	**1**	**MO**	**0.86 ± 0.02**
Monomorium pharaonis	**Pharaoh ant**	**32**	**6.90%**	**17**	**MO**	**0.86 ± 0.02**
Nylanderia fulva	Tawny crazy ant	14	3.00%	0	MO	
Solenopsis geminata	**Tropical fire ant**	**13**	**2.80%**	**18**	**MO**	**0.83 ± 0.02**
Technomyrmex albipes	**White-footed house ant**	**6**	**1.30%**	**17**	**MO**	**0.83 ± 0.02**
Trichomyrmex destructor	**Singapore ant**	**8**	**1.70%**	**16**	**MO**	**0.83 ± 0.02**
Myrmecia pilosula		1	0.20%	0	MO	
Myrmecia pyriformis		1	0.20%	0	MO	-
Brachymyrmex patagonicus		4	0.90%	0	MN	
Brachymyrmex sp.		4	0.90%	?	MN	
Brachyponera chinensis	**Chinese needle ant**	**7**	**1.50%**	**0**	**MN**	**0.13 ± 0.04**
Brachyponera sennaarensis		5	1.10%	0	MN	-
Camponotus sp.		2	0.40%	?	MN	
Camponotus vittatus		3	0.60%	0	MN	-
Crematogaster victima		2	0.40%	0	MN	-
Hypoponera punctissima		5	0.40%	16	MN	-
Lasius neglectus	**Invasive garden ant**	**2**	**1.50%**	**0**	**MN**	**0.83 ± 0.02**
Monomorium floricola	**Bi-coloured trailing ant**	**7**	**5.40%**	**21**	**MN**	**0.16 ± 0.02**
Paratrechina longicornis	**Black crazy ant**	**25**	**4.90%**	**22**	**MN**	**0.86 ± 0.02**
Pheidole megacephala	**African big-headed ant**	**23**	**1.90%**	**20**	**MN**	**0.70 ± 0.05**
Solenopsis saevissima		9	0.40%	0	MN	
Solenopsis sp.		2	0.40%	?	MN	
Tapinoma indicum		2	8.20%	2	MN	-

[2] Number of focal PICTs where the species has been reported.

Scientific name	Common name	# records	% of records	Present in PICTs[2]	SEICAT ranking	Trait-based invasiveness
Tapinoma melanocephalum	**Ghost ant**	**38**	**0.40%**	**22**	**MN**	**0.86 ± 0.02**
Tapinoma sp.		2	1.10%	?	MN	
Technomyrmex difficilis	**Difficult white-footed ant**	**5**	**0.60%**	**4**	**MN**	0.83 ± 0.02
Technomyrmex jocosus		3	0.40%	0	MN	
Technomyrmex vitiensis	Fijian white-footed ant	2	0.90%	10	MN	-
Tetramorium bicarinatum	Bi-coloured pennant ant	4	0.90%	22	MN	0.23 ± 0.21
Tetramorium simillimum	Similar groove-headed ant	4	0.90%	21	MN	0.16 ± 0.02
Tetraponera rufonigra	Bi-coloured arboreal ant	4	0.20%	0	MN	-
Doleromyrma darwiniana		1	1.10%	0	MN	
Acromyrmex niger		1	0.20%	0	MN	-
Acromyrmex sp.		1	0.20%	0	MN	
Anochetus targionii		1	0.20%	0	MN	-
Anoplolepis steingroeveri		1	0.20%	0	MN	
Anoplolepis custodiens		1	0.20%	0	MN	
Brachymyrmex obscurior		1	0.20%	8	MN	
Camponotus compressus		1	0.20%	0	MN	-
Camponotus rufipes		1	0.20%	0	MN	-
Camponotus spp.		1	0.20%	?	MN	
Camponotus variegatus	Carpenter ant	1	0.20%	1	MN	-
Cardiocondyla emeryi		1	0.20%	11	MN	0.16 ± 0.02
Cardiocondyla sp.		1	0.20%	?	MN	
Cephalotes clypeatus		1	0.20%	0	MN	-
Cephalotes pusillus		1	0.20%	0	MN	-
Crematogaster peringueyi		1	0.20%	0	MN	
Dorymyrmex flavus		1	0.20%	0	MN	
Monomorium subopacum		1	0.20%	0	MN	-
Myrmica rubra	**European fire ant**	**1**	**0.20%**	**0**	**MN**	**0.86 ± 0.02**
Neoponera goeldii		1	0.20%	0	MN	-
Nylanderia sp.		1	0.20%	?	MN	
Ochetellus glaber		1	0.20%	3	MN	
Odontomachus bauri		1	0.20%	0	MN	
Odontomachus sp.		1	0.20%	?	MN	

Scientific name	Common name	# records	% of records	Present in PICTs[2]	SEICAT ranking	Trait-based invasiveness
Oecophylla smaragdina	Green tree ant	1	0.20%	2	MN	
Pachycondyla striata		1	0.20%	0	MN	-
Nylanderia bourbonica	Bourbon ant	1	0.20%	19	MN	
Paratrechina spp.		1	0.20%	?	MN	
Pheidole nubila		1	0.20%	0	MN	-
Pheidole oxyops		1	0.20%	0	MN	-
Pheidole sculpturata		1	0.20%	0	MN	-
Pheidole sp.		1	0.20%	?	MN	
Pheidole spininodis		1	0.20%	0	MN	-
Pseudomyrmex curacaensis		1	0.20%	0	MN	-
Solenopsis globularia		1	0.20%	0	MN	-
Solenopsis molesta		1	0.20%	0	MN	
Solenopsis richteri		**1**	**0.20%**	**0**	**MN**	**0.13 ± 0.04**
Solenopsis xyloni		1	0.20%	0	MN	
Tapinoma nigerrimum		1	0.20%	0	MN	
Tapinoma sessile		1	0.20%	0	MN	
Technomyrmex setosus		1	0.20%	0	MN	-
Technomyrmex vexatus		1	0.20%	0	MN	-
Tetraponera spp.		1	0.20%	?	MN	
Pheidole spp.[3]		4	0.90%	0	MN	
Solenopsis spp.		1	0.20%	?	MC	
Lepisiota frauenfeldi[4]	Browsing ant	0	0.00%	1	?	

[3] Likely multiple species rather than 4 records of one species.
[4] Included in the list as it has been ranked as a potential threat and is subject to eradication in Australia, although it has no documented impacts.

Comparison of SEICAT-based rankings with other invasive ant lists

The Global Invasive Species Database (GISD) lists 19 ant species of concern. The ants for which we recorded moderate or higher socio-economic impacts already appear in the GISD database. We ranked eight species listed on the GISD as having minor or moderate impact. Based on these criteria many other species with low-level impacts could be added to the GISD list, but this is possibly too prescriptive for the purposes of the GISD. It should also be noted that the information on which the GISD list is based is as much as 15 years old, and based on impact analysis at that time, for which some of the source material is no longer accessible, so cannot be verified.

Of the 19 species list in the GISD, three ant species did not appear in our SEICAT list: *Acromyrmex octospinosus*, *Nylanderia pubens*, and *Solenopsis papuana*. *Solenopsis papuana* is native to Papua New and, like many of the small, inconspicuous ant species it is widely distributed in our focal PICTs, with no reports of impacts. It appears to have been included on the GISD list due to it being detected in New Zealand on coconut and taro from the Pacific.

Nylanderia pubens and *N. fulva* have historically been confused as they can only be distinguished morphologically by male genitalia, and this lack of distinction has caused issues for identification. *Nylanderia pubens* is listed in the GISD as "Caribbean crazy ant, hairy crazy ant, Rasberry crazy ant", but *Nylanderia fulva* is not listed at all. When first detected in the United States, there was confusion as to whether the species was *N. pubens* or *N. fulva*, and some early publications were later found to incorrectly identify *N. fulva* as *N. pubens* [48]. This confusion has been promulgated by a recent publication on trait-based invasiveness that identified *N. pubens* as being "superinvasive", and again not mentioning *N. fulva* [47]. This is perhaps owing to the authors taking the taxonomic lists from the GISD. As we already have evidence that *N. fulva* is invasive in the United States and elsewhere, with considerable impacts [49, 50], it should be included in the GISD list. The two species are very similar ecologically, and it may well be correct to include *N. pubens* as a potential future invasive species, but currently we only have evidence for *N. fulva*. Again, this reflects the GISD information being outdated.

Acromyrmex sp. (which could be *A. octospinosus*) and *A. niger* each appeared once in our records. It is possible that *Acromyrmex octospinosus* did not appear because the original sources for it on the GISD (and elsewhere) do not mention impacts, or are in French (and our search was solely in English), or are no longer accessible online. *Acromyrmex octospinosus* does not possess a trait profile common to other invasive ants [47], and is not easily transported inadvertently by people (55). Although cited in one paper as having major impacts on agriculture [47], the reference provided does not discuss the impact of the species, indeed, it was not even included among the list of species used for that assessment [51]. Their additional evidence for crop impacts cites a paper that mapped the distribution of the ant, while discussing impacts of leaf-cutter ants generally, and *Atta* species specifically, with no mention of impacts of *A. octospinosus* [52]. We agree with the authors of the predictive trait-based modelling work, who suggest that the presence of *A. octospinosus* on the IUCN list should be questioned [47]. However, we base this suggestion on the lack of evidence of impacts, as well as it not meeting the popular definition of an invasive species. Since the GISD list information was compiled, the literature and general knowledge of ants, their invasiveness, impacts and management has increased substantially.

Trait-based modelling of potential future invasive ants included some of the species we found impacts for, and categorised our three species with major and massive impacts as 'superinvasive'[47]. Our list included many species not ranked as invasive by the trait-based modelling (Table 4). Of the named species, 23 were not present in the AntProfiler database used for the trait-based modelling [53]. As well as the GISD listed species mentioned above, we did not find evidence of impacts for nine of the species ranked as invasive or superinvasive according to the trait-based modelling (*Lepisiota canescens, Formica yessensis, Aphaenogaster spinosa, Cardiocondyla minutior, Cardiocondyla wroughtonii, Neivamyrmex pilosus, Azteca trigona, Technomyrmex laurenti, Technomyrmex lujae*). The approaches of the two studies are different (traits versus impacts) and we emphasise that these lists are complementary. However, as the definition of an invasive species is one that causes harm, assessments based on traits must also take known impacts into account.

We also found no evidence of socio-economic impacts for browsing ant, which has been included in a list of priority invasive ant species for the Pacific [3]. This ant is targeted for national eradication in Australia. The Pacific list of priority invasive ant species [3] also does not include any of the nine species ranked as invasive or 'superinvasive' by the trait-based modelling, or *Acromyrmex octospinosus*, *Nylanderia pubens*, and *Solenopsis papuana*.

Maslow's hierarchy of needs

Maslow's hierarchy of needs is a psychological model of human motivation [54, 55], and has been recommended as a complementary perspective to SEICAT of the impacts of invasive species on people [23]. The model theorises that human motivations can be divided into eight categories, typically visualised as a pyramid ranging from the most universal and fundamental to more personal and esoteric human needs: 1) biological and physiological; 2) safety; 3) love / belonging; 4) esteem; 5) cognitive; 6) aesthetic; 7) self-actualization; and 8) transcendence. Although not necessarily reflecting a stepwise progression, it is naturally difficult for people to fulfil more esoteric (growth) needs when fundamental physiological needs cannot be met.

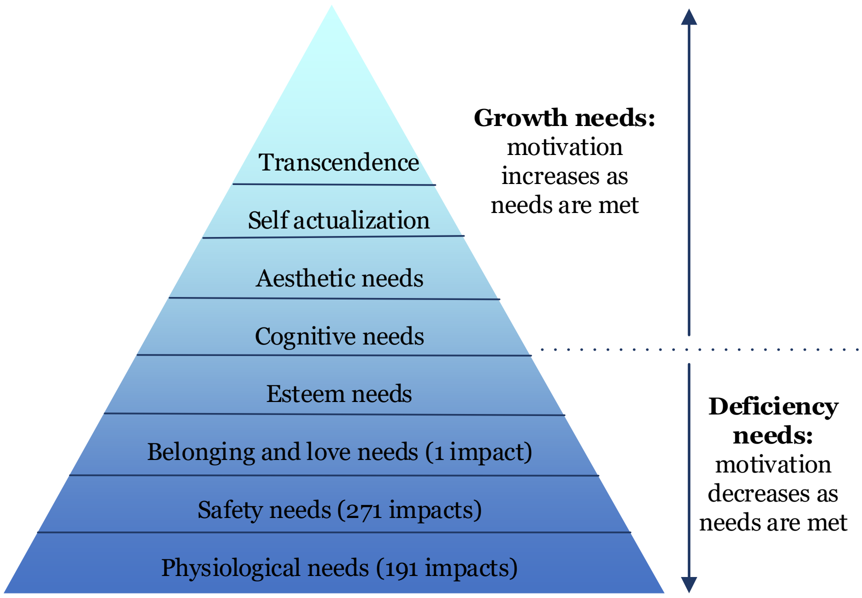

Figure 1: Maslow's hierarchy of needs and classification of the SEICAT records according to those needs.

We categorised 463 SEICAT records according to Maslow's eight categories. One record did not fit in any category (impacts on feral and free-roaming dogs that were not considered pets). The majority of SEICAT records were assessed as impacting people's most fundamental requirements: biological and physiological needs and safety (Figure 1). The impacts are all in the category of deficiency needs, meaning they would potentially limit or interfere with people's desires for fulfilment. However, we cannot predict to what extent people's lives would be affected. Although a number of studies report the physical and physiological effects of ants on people [9, 18], very few studies have quantified perceptions of people on the effects that invasive ants have on their lives and well-being, and how they respond to these effects [8, 34].

Environmental impacts

EICAT analysis

We collected 731 records from 474 sources that documented the environmental impacts of ants. Of the 731 records, 646 were applicable for assessment using the EICAT methodology. Records of impacts were from 55 countries and territories, with an additional nine laboratory-based studies, through which impacts were inferred. Most studies were sourced from the United States (50%), Australia (7%), Spain (6%) and China (3%). Of the 71 taxa recorded, red imported fire ant was the most studied species (215 records; 33.8%; Table 5). Forty-three taxa (61%) appeared in only one record. Most records were categorised as having impacts on animal and plant populations (58%), single species (32%) and ecosystems (10%). The most common impact mechanisms reported were predation (40%) and competition (36%), followed by multiple mechanisms (10%, mostly predation and competition), interaction with other species (7%) and poisoning/toxicity (2%), while the mechanisms were unclear in 5% of the studies.

As well as the six species typically considered to have major impacts (red imported fire ant, little fire ant / electric ant, Argentine ant, yellow crazy ant, African big-headed ant, and tropical fire ant), the EICAT analysis identified an additional 17 species as having major environmental impacts. Red imported fire ant, yellow crazy ant and African big-headed ant were categorised as having massive impact, and have caused extinctions or extirpations of endemic species. As with our SEICAT analysis, we found no evidence of impacts of browsing ant for our EICAT analysis. Once again, browsing ant did not feature at all in our EICAT analysis, for potential reasons discussed earlier in relation to the SEICAT analysis.

Comparison of EICAT-based rankings with other invasive ant lists

We recorded major to massive environmental impacts for 14 of the 19 GISD species of concern, moderate impacts for one, and minor impacts for the others (Table 5). Two species on the GISD did not appear in our EICAT rankings: *Acromyrmex octospinosus* and *Nylanderia pubens*, which we have discussed in relation to our SEICAT findings. Unlike the SEICAT analysis, *Solenopsis papuana* appeared in our EICAT analysis and was identified as a species with the potential for major impacts, perhaps justifying its inclusion in the list. Based on this justification an additional 10 species that we ranked as having major impacts could also be added to the GISD list. As with our SEICAT analysis, based on these criteria, numerous species with low-level impacts could be added to the GISD list, but in light of the age of the GISD assessment this seems unnecessary, and it would be preferable to revise the GISD list based on our results and those of other studies [e.g. the results of trait-based modelling, 47] and government risk assessments.

Our rankings were similar to the trait-based modelling of potential future invasive ants, and eleven of the trait-based 'superinvasive' ant species have major or massive environmental impacts [47]. Our list included many species not ranked as invasive by the trait modelling (Table 5), however most of these were assessed by us through only one study. Of the named species we found evidence for, 23 were not present in the AntProfiler database used for the trait-based modelling [53]. As well as the two species listed in the GISD that appeared on the trait-based list, we did not find evidence of impacts for nine of the species ranked as 'invasive' or 'superinvasive' according to the trait-based modelling; the same species not found by the SEICAT analysis. All of these could be considered potential horizon species for the Pacific, but their specific risk profiles will be dependent on trading links within their current distribution, climate matching and habitat suitability, which we have not explored.

Table 5: Statistics for environmental impact rankings of ants assessed using the EICAT methodology, ordered by decreasing order of EICAT magnitude: 1) Massive (MV); 2) Major (MR); 3) Moderate (MO); 4) Minor (MN); and 5) Minimal Concern (MC). Divisions between EICAT impact categories are indicated with dotted lines. Ant species considered the most serious threat globally [1-3] (including the Pacific region) are shaded in orange tones. Ants appearing the Global Invasive Species Database (GISD) are indicated in bold. GISD species for which no impacts were found are not presented. Trait-based invasiveness indicates ranking according to Predicted invasiveness probabilities [47] - indicates species absent from the AntProfiler database, from which the trait-based invasiveness was derived.

Scientific name	Common name	# records	% records	Present in PICTs[5]	EICAT ranking	Trait-based invasiveness
Anoplolepis gracilipes	**Yellow crazy ant**	**80**	**17.20%**	21	**MV**	**0.86 ± 0.02**
Pheidole megacephala	**African big-headed ant**	**39**	**8.40%**	20	**MV**	**0.70 ± 0.05**
Solenopsis invicta	**Red imported fire ant**	**215**	**46.10%**	0	**MV**	**0.83 ± 0.02**
Azteca sericeasur		4	0.90%	0	MR	
Cardiocondyla wroughtonii		2	0.40%	4	MR	
Formica aquilonia		2	0.40%	0	MR	
Formica paralugubris		2	0.40%	0	MR	
Lasius neglectus	**Invasive garden ant**	**16**	**3.40%**	0	**MR**	**0.83 ± 0.02**
Linepithema humile	**Argentine ant**	**132**	**28.30%**	1	**MR**	**0.86 ± 0.02**
Monomorium floricola	**Bi-coloured trailing ant**	**2**	**0.40%**	21	**MR**	**0.16 ± 0.02**
Myrmica rubra	**European fire ant**	**10**	**2.10%**	**0**	**MR**	**0.86 ± 0.02**
Nylanderia bourbonica	Bourbon ant	2	0.40%	19	MR	
Nylanderia fulva	Tawny crazy ant	3	0.60%	0	MR	
Brachyponera chinensis	**Chinese needle ant**	**6**	**1.30%**	0	**MR**	**0.13 ± 0.04**
Paratrechina longicornis	**Black crazy ant**	**5**	**1.10%**	22	**MR**	**0.86 ± 0.02**
Plagiolepis alluaudi		2	0.40%	9	MR	
Solenopsis geminata	**Tropical fire ant**	**17**	**3.60%**	**18**	**MR**	**0.83 ± 0.02**
Solenopsis papuana		**3**	**0.60%**	**13**	**MR**	**0.16 ± 0.02**
Tapinoma melanocephalum	**Ghost ant**	**4**	**0.90%**	22	**MR**	**0.86 ± 0.02**
Technomyrmex albipes	**White-footed house ant**	**7**	**1.50%**	17	**MR**	**0.83 ± 0.02**
Tetramorium bicarinatum	Bi-coloured pennant ant	5	1.10%	22	MR	0.23 ± 0.21
Tetramorium simillimum	Similar groove-headed ant	2	0.40%	21	MR	0.16 ± 0.02
Wasmannia auropunctata	**Little fire ant, electric ant**	**31**	**6.70%**	7	**MR**	**0.86 ± 0.02**

[5] Number of focal PICTs where the species has been reported.

Scientific name	Common name	# records	% records	Present in PICTs[5]	EICAT ranking	Trait-based invasiveness
Camponotus conspicuus zonatus		1	0.20%	0	MR	-
Crematogaster spp.		1	0.20%	?	MR	-
Monomorium monomorium		1	0.20%	2	MR	
Nylanderia spp.		1	0.20%	?	MR	-
Pheidole radoszkowskii		1	0.20%	0	MR	
Philidris sp.		1	0.20%	?	MR	-
Plagiolepis cf. *alluaudi*		1	0.20%	?	MR	-
Solenopsis wagneri		1	0.20%	0	MR	-
Solenopsis richteri		**4**	**0.90%**	0	**MO**	**0.13 ± 0.04**
Brachymyrmex cf. *obscurior*		1	0.20%	?	MO	-
Conomyrma pyramicus		1	0.20%	0	MO	-
Iridomyrmex pruinosus		1	0.20%	0	MO	-
Lasius neoniger		1	0.20%	0	MO	-
Nylanderia sp.		1	0.20%	?	MO	-
Nylanderia vaga		1	0.20%	18	MO	
Pheidole dentata		1	0.20%	0	MO	
Pheidole metallescens		1	0.20%	0	MO	
Pheidole morrisi		1	0.20%	0	MO	-
Prenolepis imparis		1	0.20%	0	MO	
Solenopsis pergandei		1	0.20%	0	MO	0.13 ± 0.04
Pogonomyrmex occidentalis		2	0.40%	0	MN	
Solenopsis saevissima		2	0.40%	0	MN	
Trichomyrmex destructor	**Singapore ant**	**2**	**0.40%**	16	**MN**	0.83 ± 0.02
Solenopsis spp.		2	0.40%	0	MN	
Brachymyrmex obscurior		1	0.20%	8	MN	
Diacamma vagans		1	0.20%	0	MN	-
Dolichoderus bituberculatas		1	0.20%	0	MN	-
Dorylus laevigatus		1	0.20%	0	MN	-
Ectatomma ruidum		1	0.20%	0	MN	
Odontomachus sp.		1	0.20%	?	MN	-
Oecophylla smaragdina	Green tree ant	1	0.20%	2	MN	

Scientific name	Common name	# records	% records	Present in PICTs[5]	EICAT ranking	Trait-based invasiveness
Pheidole fervens		1	0.20%	17	MN	
Pheidologeton affinis		1	0.20%	0	MN	-
Polyrachis dives		1	0.20%	1	MN	-
Polyrachis sp.		1	0.20%	?	MN	-
Pseudomyrmex elongatus		1	0.20%	0	MN	
Pseudomyrmex gracilis		1	0.20%	0	MN	
Pseudomyrmex simplex		1	0.20%	0	MN	
Wasmannia sp.		1	0.20%	?	MN	-
Cardiocondyla emeryi		1	0.20%	11	MC	0.16 ± 0.02
Cardiocondyla nuda		1	0.20%	15	MC	
Cardiocondyla venustula		1	0.20%	0	MC	
Dorymyrmex pyramicus		1	0.20%	0	MC	-
Hypoponera opaciceps		1	0.20%	8	MC	
Hypoponera punctatissima		1	0.20%	16	MC	
Monomorium pharaonis	**Pharaoh ant**	**1**	**0.20%**	17	**MC**	**0.86 ± 0.02**
Monomorium sp.		1	0.20%	?	MC	-
Ponera swezeyi		1	0.20%	5	MC	-

Potential biodiversity impacts in the Pacific

Ant introductions and outbreaks in the Pacific region currently and potentially constitute a serious threat to numerous vulnerable species. The impacts of invasive ants on biodiversity are well-documented, as indicated by the number of studies in our EICAT assessments. Invasive ants are also predicted to have major impacts if they should invade new areas. For example, an analysis of potential biodiversity impacts in Queensland alone found that of 123 vertebrates (47 birds, 16 mammals, 32 reptiles, 19 amphibians, four freshwater fishes) and five invertebrates, 45% of birds, 38% of mammals, 69% of reptiles and 95% of amphibians were vulnerable to population declines caused by red imported fire ants [43]. Using the IUCN red list as a reference [56], we identified a total of 377 threatened species of birds, reptiles, amphibians, mammals, land snails, crabs, and insects that could be vulnerable to introductions and outbreaks of significant threat ants in our focal PICTs (Table 6).

Invasive ants are well known to reduce the diversity of resident ant and other invertebrate communities [e.g. 1, 57, 58-65]. Although many ant assemblages in the Pacific include many introduced species [e.g. 34, 61, 66, 67], changes in the nature of these introduced communities (relative abundance and diversity) may have consequent broader impacts on native biodiversity and human well-being. Many crabs and snails are also susceptible to invasive ants [5, 68, 69]. Current and historical impacts on fauna such as land snails may be cryptic. For example, ants have been implicated in the declines and extinctions (as many as 14 species) of land snails in Rarotonga [70, 71]. Surprisingly, land snails in the Cook Islands are not listed in threatened categories (Table 6).

The most frequently cited impacts on native vertebrates are attributable to four species: red imported fire ant [e.g. 72, 73-75], yellow crazy ant [e.g. 34, 76, 77-79], Argentine ant [e.g. 80, 81, 82], and little fire ant [e.g. 83, 84], with fewer impacts recorded for tropical fire ant [e.g. 78, 85] and other species. Invasive ants negatively affect seabirds [6, 34, 76, 78, 86], land birds [72-75, 79], endemic reptiles [80, 83, 84], and mammals [77, 87-89].

Seabirds are a key component of Pacific ecosystems as one of the few sources of nutrient addition to the environment [90], and are an important traditional food resource [e.g. 91]. Seabirds may be particularly vulnerable to harm from ants as most of the bird species nest in colonies which provide plentiful food resources for ants (e.g. guano, boluses, eggs, chicks, and dead adults) [78], but these interactions are still relatively under-studied. The Pacific region is home to several endemic and endangered seabirds, particularly in the family Procellariidae (fulmarine petrels, gadfly petrels, prions, and shearwaters). A number of invasive ant species already present in the Pacific region harm seabirds. When they are abundant, ants severely reduce the reproductive success and survival of ground-nesting seabirds such as wedge-tailed shearwater, *Ardenna pacifica* [6, 78]; sooty tern, *Sterna fruscata*; least tern, *Sterna albifrons* [86]; and the tree-nesting white tern, *Gygis alba* [34, 76]. The effects of ants on seabird colonies may often be undetected [6]. Ants that are distributed widely throughout the Pacific [e.g. yellow crazy ant, tropical fire ant and African big-headed ant; 3, 92, 93, 94], including unpopulated areas, may have potential undetected conservation impacts that are widespread and significant.

Critically endangered birds in the Pacific are already threatened by ants. In French Polynesia the Tahiti Monarch, *Pomarea nigra*, is at risk from little fire ant [95]. The Fatu Hiva Monarch, *Pomarea whitneyi*, close to extinction with only six remaining breeding pairs, is threatened by yellow crazy ants (Tom Ghestemme, Société d'Ornithologie de Polynésie [SOP Manu], personal communication). Comparing the Pacific-wide distributions of two of our three EICAT ranked species with massive impacts (yellow crazy ants and African big-headed ants) [3], with that of critically endangered bird species in the Pacific, suggests that the majority of our focal PICTs are at risk of outbreaks or new introductions of those ants contributing to extinctions.

Table 6: Number of species (birds, reptiles, amphibians, mammals, land snails and crabs, and insects) that could be vulnerable to ants in each country/territory (377 species overall, some present in multiple PICTs). We assessed potential biodiversity impacts by extracting records on threatened species distribution data for our focal PICTs (except Tokelau) from the IUCN Red List [56]. Data on the threatened species of Tokelau were obtained from a conservation survey [96]. Only those species in the highest IUCN threat classification categories are included: Critically Endangered (CR); Endangered (EN); Vulnerable (VU). - indicates no data.

PICT	**Birds**			**Reptiles**			**Amphibians**			**Mammals**			**Land snails and crabs**			**Insects**			**TOTAL**
	CR	**EN**	**VU**	**CR**	**EN**	**VU**	**CR**	**EN**	**VU**	**CR**	**EN**	**VU**	**CR**	**EN**	**VU**	**CR**	**EN**	**VU**	
American Samoa	2	2	9	1	4	1	0	0	0	0	1	0	0	0	0	0	0	0	20
Cook Islands	0	2	16	1	2	1	0	0	0	0	0	0	0	0	0	0	0	0	22
Federated States of Micronesia	2	6	10	1	3	3	0	0	0	2	2	3	2	0	0	0	0	0	34
Fiji	3	5	15	3	8	5	0	1	0	1	2	1	2	6	2	0	0	0	54
French Polynesia	12	13	15	0	1	2	0	0	0	0	0	0	12	1	2	0	0	0	58
Guam	2	7	8	2	1	2	0	0	0	0	2	0	3	0	0	0	0	0	27
Kiribati	1	6	12	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	21
Nauru	1	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	9
New Caledonia	7	4	14	15	22	17	0	0	1	1	2	3	0	0	0	0	1	2	89
Niue	1	2	9	0	2	2	0	0	0	0	0	0	0	0	0	0	0	0	16
CNMI	5	6	9	1	1	2	0	0	0	0	2	0	0	0	0	0	0	0	26
Palau	0	5	2	1	2	1	0	0	0	0	1	0	2	1	0	0	0	0	15
Papua New Guinea	1	5	37	1	3	7	2	0	10	9	16	11	0	0	0	0	4	7	113
Republic of Marshall Islands	0	0	7	0	2	2	0	0	0	0	0	0	0	0	0	0	0	0	11
Samoa	6	6	18	2	6	2	0	0	0	0	2	0	0	0	0	0	0	0	42
Solomon Islands	2	5	23	1	1	4	0	0	2	6	7	3	0	0	0	0	1	4	59
Timor-Leste	2	4	2	1	3	0	0	0	0	0	1	2	0	0	0	0	0	0	29
Tokelau	1	2	7	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	10
Tonga	1	3	12	1	4	2	0	0	0	0	1	0	2	0	0	0	0	0	26
Tuvalu	1	2	9	0	2	1	0	0	0	0	0	0	0	0	0	0	0	0	15
Vanuatu	1	3	9	1	4	1	0	0	0	0	3	2	0	0	0	0	0	0	24
Wallis and Futuna	1	2	10	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	15

Combined socio-economic and environmental impact analysis

The GISS analysis is a combined impact assessment for environmental and socio-economic sectors. Records are classified according to six socio-economic categories, each with six subcategories (impacts on: agricultural production; animal production; forestry production; human infrastructure and administration; human health; human social life), and six environmental categories (impacts on: plants or vegetation; animals through predation, parasitism, or intoxication; other species through competition; ecosystems; through transmission of diseases or parasites to other species; through hybridization). Impact is measured on a scale of 0 to 5, with 0 indicating no detectable impact and 5 the most severe impact.

We found 1205 records of invasive ant impacts relevant to our GISS analysis, covering 99 species (Table 7) from 80 geographical areas. The vast majority of studies were conducted in the United States (515; 43%), with fewer studies from Brazil (105; 9%), Australia (92; 8%), Spain (38; 3%) and others. The ant with the highest total score across GISS environmental impact categories was yellow crazy ant, while the highest socio-economic impact was for red imported fire ant, which is consistent with the data in our other analyses. The six highest results for socio-economic impacts were, as expected, those ant species classified among lists of the worst invasive ants (Table 7).

The GISS framework provided a quantitative measure indicating that the most damaging invasive ants can have very high impacts compared to the many other species assessed worldwide. For example, red imported fire ant was assigned 35 impact points, while 13 species (Table 7) had GISS scores > 10 impact points. The mean impact of the 20 highest scoring species of ants was 17 points, compared to the mean impact of the 20 highest scoring species of mammals [97], birds and arthropods [98] in Europe, which scored 11, 4 and 8 respectively.

The records we assessed resulted in a combined total of 2,517 impact points (Table 8). Overall, 1509 impact points (60%) originated from environmental impacts and 1008 (40%) originated from economic impacts. Among the environmental categories, invasive ants had the largest documented impact on other animals via predation (48%) and competition (33%), followed by impacts on plants or vegetation (13%) and ecosystems (6%). From a socio-economic perspective, the impacts were on human health (43%), agricultural production (25%), human infrastructure and administration (19%), human social life (7%), and animal production (5%). The overall confidence level on the GISS 1-3 scale was 2.0±0.9 (mean±SD).

Table 7: Ant species ranked by GISS impact scoring system, ordered by maximum GISS impact. The 12 GISS categories are impacts on (or through): 1.1. plants or vegetation; 1.2. animals through predation, parasitism, or intoxication; 1.3. other species through competition; 1.4. ecosystems; 1.5. transmission of diseases or parasites to native species; 1.6. hybridization; 2.1. agricultural production; 2.2. animal production; 2.3. forestry production; 2.4. human infrastructure and administration; 2.5. human health; 2.6. human social life. The shading of the cells indicates the relative magnitude of the cell values by column. Increasing red intensity indicates the increasing impacts.

Species	**GISS category. Impacts on:**														**TOTAL**
	1.1. plants or vegetation	**1.2.** animals through predation, parasitism, or	**1.3.** other species through competition	**1.4.** ecosystems	**1.5.** transmission of diseases or parasites to native species	**1.6.** hybridization	**2.1.** agricultural production	**2.2.** animal production	**2.3.** forestry production	**2.4.** human infrastructure and administration	**2.5.** human health	**2.6.** human social life	**Environmental impact**	**Socio-economic impact**	
Maximum GISS impact	**4**	**5**	**5**	**4**	**0**	**0**	**5**	**3**	**2**	**4**	**3**	**5**	**18**	**19**	**35**
Solenopsis invicta	**3**	**5**	**5**	**3**	**0**	**0**	**4**	**3**	**2**	**4**	**3**	**3**	**16**	**19**	**35**
Anoplolepis gracilipes	**4**	**5**	**5**	**4**	**0**	**0**	**3**	**2**	**0**	**3**	**3**	**3**	**18**	**14**	**32**
Wasmannia auropunctata	**2**	**4**	**4**	**3**	**0**	**0**	**5**	**2**	**0**	**3**	**3**	**5**	**13**	**18**	**31**
Linepithema humile	**3**	**4**	**4**	**4**	**0**	**0**	**2**	**2**	**0**	**3**	**2**	**3**	**15**	**12**	**27**
Pheidole megacephala	**4**	**5**	**4**	**3**	**0**	**0**	**3**	**0**	**0**	**3**	**2**	**0**	**16**	**8**	**24**
Solenopsis geminata	**3**	**4**	**3**	**0**	**0**	**0**	**3**	**0**	**0**	**0**	**3**	**3**	**10**	**9**	**19**
Paratrechina longicornis	3	3	5	0	0	0	2	0	0	3	2	0	11	7	18
Nylanderia fulva	1	3	3	0	0	0	2	0	0	4	2	3	7	11	18
Tapinoma melanocephalum	3	3	5	0	0	0	2	2	0	0	2	0	11	6	17
Technomyrmex albipes	4	1	5	0	0	0	3	0	0	0	2	0	10	5	15
Monomorium floricola	3	3	5	0	0	0	0	0	0	0	2	0	11	2	13
Myrmica rubra	3	3	4	0	0	0	0	0	0	0	2	0	10	2	12
Tetramorium bicarinatum	3	3	4	0	0	0	0	0	0	0	2	0	10	2	12
Lasius neglectus	1	0	4	3	0	0	0	0	0	2	1	0	8	3	11
Tetramorium simillimum	0	2	5	0	0	0	0	1	0	0	2	0	7	3	10
Pachycondyla chinensis	2	3	4	0	0	0	0	0	0	0	0	0	9	0	9
Trichomyrmex destructor	1	0	0	0	0	0	0	0	0	3	2	3	1	8	9
Monomorium pharaonis	0	0	0	0	0	0	3	0	0	0	3	3	0	9	9
Camponotus conspicuus zonatus	3	3	0	0	0	0	0	0	0	0	0	0	6	0	6
Formica aquilonia	3	0	3	0	0	0	0	0	0	0	0	0	6	0	6
Formica paralugubris	0	2	4	0	0	0	0	0	0	0	0	0	6	0	6
Paratrechina bourbonica	0	0	4	0	0	0	0	0	0	0	2	0	4	2	6
Cardiocondyla wroughtonii	0	0	5	0	0	0	0	0	0	0	0	0	5	0	5

Species	GISS category. Impacts on:														TOTAL
	1.1. plants or vegetation	**1.2.** animals through predation, parasitism, or	**1.3.** other species through competition	**1.4.** ecosystems	**1.5.** transmission of diseases or parasites to native species	**1.6.** hybridization	**2.1.** agricultural production	**2.2.** animal production	**2.3.** forestry production	**2.4.** human infrastructure and administration	**2.5.** human health	**2.6.** human social life	**Environmental impact**	**Socio-economic impact**	
Plagiolepis alluaudi	0	0	5	0	0	0	0	0	0	0	0	0	5	0	5
Brachymyrmex obscurior	0	0	3	0	0	0	2	0	0	0	0	0	3	2	5
Solenopsis richteri	0	3	0	0	0	0	0	0	0	0	2	0	3	2	5
Tetraponera rufonigra	0	0	0	0	0	0	0	2	0	0	3	0	0	5	5
Anoplolepis longipes	0	4	0	0	0	0	0	0	0	0	0	0	4	0	4
Azteca sericeasur	0	0	4	0	0	0	0	0	0	0	0	0	4	0	4
Solenopsis wagneri	0	0	4	0	0	0	0	0	0	0	0	0	4	0	4
Technomyrmex jocosus	0	0	0	0	0	0	0	0	0	2	2	0	0	4	4
Technomyrmex vitiensis	0	0	0	0	0	0	0	2	0	0	2	0	0	4	4
Conomyrma pyramicus	0	3	0	0	0	0	0	0	0	0	0	0	3	0	3
Iridomyrmex pruinosus	0	3	0	0	0	0	0	0	0	0	0	0	3	0	3
Lasius neoniger	0	3	0	0	0	0	0	0	0	0	0	0	3	0	3
Nylanderia vaga	0	0	3	0	0	0	0	0	0	0	0	0	3	0	3
Pheidole dentata	0	3	0	0	0	0	0	0	0	0	0	0	3	0	3
Pheidole metallescens	0	3	0	0	0	0	0	0	0	0	0	0	3	0	3
Pheidole morrisi	0	3	0	0	0	0	0	0	0	0	0	0	3	0	3
Pheidole radoszkowskii	0	0	3	0	0	0	0	0	0	0	0	0	3	0	3
Prenolepis imparis	0	0	0	3	0	0	0	0	0	0	0	0	3	0	3
Solenopsis papuana	0	3	0	0	0	0	0	0	0	0	0	0	3	0	3
Solenopsis pergandei	0	3	0	0	0	0	0	0	0	0	0	0	3	0	3
Solenopsis saevissima	0	1	0	0	0	0	0	0	0	0	2	0	1	2	3
Brachyponera chinensis	0	0	0	0	0	0	0	0	0	0	3	0	0	3	3
Brachyponera sennaarensis	0	0	0	0	0	0	0	1	0	0	2	0	0	3	3
Solenopsis xyloni	0	0	0	0	0	0	0	0	0	3	0	0	0	3	3
Dorylus laevigatus	0	2	0	0	0	0	0	0	0	0	0	0	2	0	2
Ectatomma ruidum	0	0	2	0	0	0	0	0	0	0	0	0	2	0	2
Monomorium destructor	0	0	2	0	0	0	0	0	0	0	0	0	2	0	2
Monomorium monomorium	0	2	0	0	0	0	0	0	0	0	0	0	2	0	2

Species	GISS category. Impacts on:														TOTAL
	1.1. plants or vegetation	**1.2.** animals through predation, parasitism, or	**1.3.** other species through competition	**1.4.** ecosystems	**1.5.** transmission of diseases or parasites to native species	**1.6.** hybridization	**2.1.** agricultural production	**2.2.** animal production	**2.3.** forestry production	**2.4.** human infrastructure and administration	**2.5.** human health	**2.6.** human social life	**Environmental impact**	**Socio-economic impact**	
Pheidole fervens	0	0	2	0	0	0	0	0	0	0	0	0	2	0	2
Pheidologeton affinis	0	2	0	0	0	0	0	0	0	0	0	0	2	0	2
Pogonomyrmex occidentalis	1	0	0	1	0	0	0	0	0	0	0	0	2	0	2
Pseudomyrmex elongatus	0	2	0	0	0	0	0	0	0	0	0	0	2	0	2
Pseudomyrmex gracilis	0	2	0	0	0	0	0	0	0	0	0	0	2	0	2
Pseudomyrmex simplex	0	2	0	0	0	0	0	0	0	0	0	0	2	0	2
Oecophylla smaragdina	0	1	0	0	0	0	0	0	0	0	1	0	1	1	2
Acromyrmex niger	0	0	0	0	0	0	0	0	0	0	2	0	0	2	2
Anochetus targionii	0	0	0	0	0	0	0	0	0	0	2	0	0	2	2
Anoplolepis steingroeveri	0	0	0	0	0	0	2	0	0	0	0	0	0	2	2
Anoploloepis custodiens	0	0	0	0	0	0	2	0	0	0	0	0	0	2	2
Brachymyrmex patagonicus	0	0	0	0	0	0	0	0	0	0	2	0	0	2	2
Camponotus compressus	0	0	0	0	0	0	2	0	0	0	0	0	0	2	2
Camponotus rufipes	0	0	0	0	0	0	0	0	0	0	2	0	0	2	2
Camponotus variegatus	0	0	0	0	0	0	0	0	0	0	2	0	0	2	2
Camponotus vittatus	0	0	0	0	0	0	0	0	0	0	2	0	0	2	2
Cardiocondyla emeryi	0	0	0	0	0	0	0	0	0	0	2	0	0	2	2
Cephalotes clypeatus	0	0	0	0	0	0	0	0	0	0	2	0	0	2	2
Cephalotes pusillus	0	0	0	0	0	0	0	0	0	0	2	0	0	2	2
Crematogaster peringueyi	0	0	0	0	0	0	2	0	0	0	0	0	0	2	2
Crematogaster victima	0	0	0	0	0	0	0	0	0	0	2	0	0	2	2
Doleromyrma darwiniana	0	0	0	0	0	0	0	0	0	2	0	0	0	2	2
Dorymyrmex flavus	0	0	0	0	0	0	0	0	0	0	2	0	0	2	2
Hypoponera punctatissima	0	0	0	0	0	0	0	0	0	0	2	0	0	2	2
Lepisiota frauenfeldi	0	0	0	0	0	0	0	0	0	2	0	0	0	2	2
Monomorium subopacum	0	0	0	0	0	0	0	0	0	0	2	0	0	2	2
Myrmecia pilosula	0	0	0	0	0	0	0	0	0	0	2	0	0	2	2
Myrmecia pyriformis	0	0	0	0	0	0	0	0	0	0	2	0	0	2	2

Species	GISS category. Impacts on:														TOTAL
	1.1. plants or vegetation	**1.2.** animals through predation, parasitism, or	**1.3.** other species through competition	**1.4.** ecosystems	**1.5.** transmission of diseases or parasites to native species	**1.6.** hybridization	**2.1.** agricultural production	**2.2.** animal production	**2.3.** forestry production	**2.4.** human infrastructure and administration	**2.5.** human health	**2.6.** human social life	**Environmental impact**	**Socio-economic impact**	
Neoponera goeldii	0	0	0	0	0	0	0	0	0	0	2	0	0	2	2
Ochetellus glaber	0	0	0	0	0	0	0	0	0	0	2	0	0	2	2
Odontomachus bauri	0	0	0	0	0	0	0	0	0	0	2	0	0	2	2
Pheidole nubila	0	0	0	0	0	0	0	0	0	0	2	0	0	2	2
Pheidole oxyops	0	0	0	0	0	0	0	0	0	0	2	0	0	2	2
Pheidole sculpturata	0	0	0	0	0	0	2	0	0	0	0	0	0	2	2
Pheidole spininodis	0	0	0	0	0	0	0	0	0	0	2	0	0	2	2
Pseudomyrmex curacaensis	0	0	0	0	0	0	0	0	0	0	2	0	0	2	2
Solenopsis globularia	0	0	0	0	0	0	0	0	0	0	2	0	0	2	2
Solenopsis molesta var. validiuscula	0	0	0	0	0	0	0	0	0	0	2	0	0	2	2
Tapinoma indicum	0	0	0	0	0	0	0	0	0	0	2	0	0	2	2
Tapinoma nigerrimum	0	0	0	0	0	0	2	0	0	0	0	0	0	2	2
Tapinoma sessile	0	0	0	0	0	0	0	0	0	0	2	0	0	2	2
Technomyrmex difficilis	0	0	0	0	0	0	0	0	0	0	2	0	0	2	2
Technomyrmex setosus	0	0	0	0	0	0	0	0	0	0	2	0	0	2	2
Technomyrmex vexatus	0	0	0	0	0	0	0	0	0	0	2	0	0	2	2
Diacamma vagans	0	1	0	0	0	0	0	0	0	0	0	0	1	0	1
Dolichoderus bituberculatas	0	1	0	0	0	0	0	0	0	0	0	0	1	0	1
Dorymyrmex pyramicus	0	0	1	0	0	0	0	0	0	0	0	0	1	0	1
Polyrachis dives	0	1	0	0	0	0	0	0	0	0	0	0	1	0	1

Table 8: Ant species ranked by GISS impact scoring system, ordered by total number of GISS impact points. The 12 GISS categories are impacts on (or through): 1.1. plants or vegetation; 1.2. animals through predation, parasitism, or intoxication; 1.3. other species through competition; 1.4. ecosystems; 1.5. transmission of diseases or parasites to native species; 1.6. hybridization; 2.1. agricultural production; 2.2. animal production; 2.3. forestry production; 2.4. human infrastructure and administration; 2.5. human health; 2.6. human social life. The shading of the cells indicates the relative magnitude of the cell values by column. Increasing red intensity indicates the increasing impacts.

Species	**GISS category**														
	1.1. plants or vegetation	**1.2.** animals through predation, parasitism, or	**1.3.** other species through competition	**1.4.** ecosystems	**1.5.** transmission of diseases or parasites to native species	**1.6.** hybridization	**2.1.** agricultural production	**2.2.** animal production	**2.3.** forestry production	**2.4.** human infrastructure and administration	**2.5.** human health	**2.6.** human social life	**Environmental impact**	**Socio-economic impact**	**TOTAL**
Maximum GISS impact	**132**	**645**	**640**	**92**	**0**	**0**	**216**	**35**	**2**	**171**	**521**	**63**	**1509**	**1008**	**2517**
Solenopsis invicta	14	294	135	9	0	0	79	15	2	40	71	5	452	212	664
Linepithema humile	39	70	186	40	0	0	17	4	0	27	20	9	335	77	412
Anoplolepis gracilipes	10	73	88	23	0	0	17	4	0	25	9	6	194	61	255
Wasmannia auropunctata	3	30	50	6	0	0	34	2	0	13	26	25	89	100	189
Pheidole megacephala	21	32	48	3	0	0	21	0	0	15	20	0	104	56	160
Tapinoma melanocephalum	3	6	5	0	0	0	8	4	0	0	62	0	14	74	88
Solenopsis geminata	5	32	3	0	0	0	12	0	0	0	15	3	40	30	70
Monomorium pharaonis	0	0	0	0	0	0	3	0	0	0	59	6	0	68	68
Paratrechina longicornis	3	6	9	0	0	0	2	0	0	3	43	0	18	48	66
Nylanderia fulva	1	3	3	0	0	0	2	0	0	16	9	6	7	33	40
Lasius neglectus	4	0	20	7	0	0	0	0	0	2	1	0	31	3	34
Technomyrmex albipes	7	1	7	0	0	0	7	0	0	0	6	0	15	13	28
Myrmica rubra	4	8	12	0	0	0	0	0	0	0	2	0	24	2	26
Monomorium floricola	3	3	5	0	0	0	0	0	0	0	14	0	11	14	25
Tetramorium bicarinatum	3	6	4	0	0	0	0	0	0	0	8	0	13	8	21
Trichomyrmex destructor	1	0	0	0	0	0	0	0	0	11	6	3	1	20	21
Anoplolepis longipes	0	19	0	0	0	0	0	0	0	0	0	0	19	0	19
Solenopsis saevissima	0	1	0	0	0	0	0	0	0	0	18	0	1	18	19
Pachycondyla chinensis	4	4	8	0	0	0	0	0	0	0	0	0	16	0	16
Brachyponera chinensis	0	0	0	0	0	0	0	0	0	0	15	0	0	15	15
Tetramorium simillimum	0	2	5	0	0	0	0	1	0	0	6	0	7	7	14
Doleromyrma darwiniana	0	0	0	0	0	0	0	0	0	10	0	0	0	10	10
Hypoponera punctatissima	0	0	0	0	0	0	0	0	0	0	10	0	0	10	10

Species	GISS category														
	1.1. plants or vegetation	**1.2.** animals through predation, parasitism, or	**1.3.** other species through competition	**1.4.** ecosystems	**1.5.** transmission of diseases or parasites to native species	**1.6.** hybridization	**2.1.** agricultural production	**2.2.** animal production	**2.3.** forestry production	**2.4.** human infrastructure and administration	**2.5.** human health	**2.6.** human social life	**Environmental impact**	**Socio-economic impact**	**TOTAL**
Plagiolepis alluaudi	0	0	9	0	0	0	0	0	0	0	0	0	9	0	9
Solenopsis richteri	0	7	0	0	0	0	0	0	0	0	2	0	7	2	9
Brachyponera sennaarensis	0	0	0	0	0	0	0	1	0	0	8	0	0	9	9
Tetraponera rufonigra	0	0	0	0	0	0	0	2	0	0	7	0	0	9	9
Technomyrmex difficilis	0	0	0	0	0	0	0	0	0	0	8	0	0	8	8
Brachymyrmex obscurior	0	0	5	0	0	0	2	0	0	0	0	0	5	2	7
Brachymyrmex patagonicus	0	0	0	0	0	0	0	0	0	0	7	0	0	7	7
Camponotus conspicuus zonatus	3	3	0	0	0	0	0	0	0	0	0	0	6	0	6
Formica aquilonia	3	0	3	0	0	0	0	0	0	0	0	0	6	0	6
Formica paralugubris	0	2	4	0	0	0	0	0	0	0	0	0	6	0	6
Solenopsis papuana	0	6	0	0	0	0	0	0	0	0	0	0	6	0	6
Paratrechina bourbonica	0	0	4	0	0	0	0	0	0	0	2	0	4	2	6
Camponotus vittatus	0	0	0	0	0	0	0	0	0	0	6	0	0	6	6
Technomyrmex jocosus	0	0	0	0	0	0	0	0	0	2	4	0	0	6	6
Azteca sericeasur	0	0	5	0	0	0	0	0	0	0	0	0	5	0	5
Cardiocondyla wroughtonii	0	0	5	0	0	0	0	0	0	0	0	0	5	0	5
Solenopsis wagneri	0	0	4	0	0	0	0	0	0	0	0	0	4	0	4
Crematogaster victima	0	0	0	0	0	0	0	0	0	0	4	0	0	4	4
Lepisiota frauenfeldi	0	0	0	0	0	0	0	0	0	4	0	0	0	4	4
Tapinoma indicum	0	0	0	0	0	0	0	0	0	0	4	0	0	4	4
Technomyrmex vitiensis	0	0	0	0	0	0	0	2	0	0	2	0	0	4	4
Conomyrma pyramicus	0	3	0	0	0	0	0	0	0	0	0	0	3	0	3
Iridomyrmex pruinosus	0	3	0	0	0	0	0	0	0	0	0	0	3	0	3
Lasius neoniger	0	3	0	0	0	0	0	0	0	0	0	0	3	0	3
Nylanderia vaga	0	0	3	0	0	0	0	0	0	0	0	0	3	0	3
Pheidole dentata	0	3	0	0	0	0	0	0	0	0	0	0	3	0	3
Pheidole metallescens	0	3	0	0	0	0	0	0	0	0	0	0	3	0	3
Pheidole morrisi	0	3	0	0	0	0	0	0	0	0	0	0	3	0	3
Pheidole radoszkowskii	0	0	3	0	0	0	0	0	0	0	0	0	3	0	3

Species	GISS category														
	1.1. plants or vegetation	**1.2.** animals through predation, parasitism, or	**1.3.** other species through competition	**1.4.** ecosystems	**1.5.** transmission of diseases or parasites to native species	**1.6.** hybridization	**2.1.** agricultural production	**2.2.** animal production	**2.3.** forestry production	**2.4.** human infrastructure and administration	**2.5.** human health	**2.6.** human social life	**Environmental impact**	**Socio-economic impact**	**TOTAL**
Prenolepis imparis	0	0	0	3	0	0	0	0	0	0	0	0	3	0	3
Solenopsis pergandei	0	3	0	0	0	0	0	0	0	0	0	0	3	0	3
Solenopsis xyloni	0	0	0	0	0	0	0	0	0	3	0	0	0	3	3
Dorylus laevigatus	0	2	0	0	0	0	0	0	0	0	0	0	2	0	2
Ectatomma ruidum	0	0	2	0	0	0	0	0	0	0	0	0	2	0	2
Monomorium destructor	0	0	2	0	0	0	0	0	0	0	0	0	2	0	2
Monomorium monomorium	0	2	0	0	0	0	0	0	0	0	0	0	2	0	2
Pheidole fervens	0	0	2	0	0	0	0	0	0	0	0	0	2	0	2
Pheidologeton affinis	0	2	0	0	0	0	0	0	0	0	0	0	2	0	2
Pogonomyrmex occidentalis	1	0	0	1	0	0	0	0	0	0	0	0	2	0	2
Pseudomyrmex elongatus	0	2	0	0	0	0	0	0	0	0	0	0	2	0	2
Pseudomyrmex gracilis	0	2	0	0	0	0	0	0	0	0	0	0	2	0	2
Pseudomyrmex simplex	0	2	0	0	0	0	0	0	0	0	0	0	2	0	2
Oecophylla smaragdina	0	1	0	0	0	0	0	0	0	0	1	0	1	1	2
Acromyrmex niger	0	0	0	0	0	0	0	0	0	0	2	0	0	2	2
Anochetus targionii	0	0	0	0	0	0	0	0	0	0	2	0	0	2	2
Anoplolepis steingroeveri	0	0	0	0	0	0	2	0	0	0	0	0	0	2	2
Anoploloepis custodiens	0	0	0	0	0	0	2	0	0	0	0	0	0	2	2
Camponotus compressus	0	0	0	0	0	0	2	0	0	0	0	0	0	2	2
Camponotus rufipes	0	0	0	0	0	0	0	0	0	0	2	0	0	2	2
Camponotus variegatus	0	0	0	0	0	0	0	0	0	0	2	0	0	2	2
Cardiocondyla emeryi	0	0	0	0	0	0	0	0	0	0	2	0	0	2	2
Cephalotes clypeatus	0	0	0	0	0	0	0	0	0	0	2	0	0	2	2
Cephalotes pusillus	0	0	0	0	0	0	0	0	0	0	2	0	0	2	2
Crematogaster peringueyi	0	0	0	0	0	0	2	0	0	0	0	0	0	2	2
Dorymyrmex flavus	0	0	0	0	0	0	0	0	0	0	2	0	0	2	2
Monomorium subopacum	0	0	0	0	0	0	0	0	0	0	2	0	0	2	2
Myrmecia pilosula	0	0	0	0	0	0	0	0	0	0	2	0	0	2	2
Myrmecia pyriformis	0	0	0	0	0	0	0	0	0	0	2	0	0	2	2

Species	**GISS category**														
	1.1. plants or vegetation	**1.2.** animals through predation, parasitism, or	**1.3.** other species through competition	**1.4.** ecosystems	**1.5.** transmission of diseases or parasites to native species	**1.6.** hybridization	**2.1.** agricultural production	**2.2.** animal production	**2.3.** forestry production	**2.4.** human infrastructure and administration	**2.5.** human health	**2.6.** human social life	**Environmental impact**	**Socio-economic impact**	**TOTAL**
Neoponera goeldii	0	0	0	0	0	0	0	0	0	0	2	0	0	2	2
Ochetellus glaber	0	0	0	0	0	0	0	0	0	0	2	0	0	2	2
Odontomachus bauri	0	0	0	0	0	0	0	0	0	0	2	0	0	2	2
Pheidole nubila	0	0	0	0	0	0	0	0	0	0	2	0	0	2	2
Pheidole oxyops	0	0	0	0	0	0	0	0	0	0	2	0	0	2	2
Pheidole sculpturata	0	0	0	0	0	0	2	0	0	0	0	0	0	2	2
Pheidole spininodis	0	0	0	0	0	0	0	0	0	0	2	0	0	2	2
Pseudomyrmex curacaensis	0	0	0	0	0	0	0	0	0	0	2	0	0	2	2
Solenopsis globularia	0	0	0	0	0	0	0	0	0	0	2	0	0	2	2
Solenopsis molesta var. validiuscula	0	0	0	0	0	0	0	0	0	0	2	0	0	2	2
Tapinoma nigerrimum	0	0	0	0	0	0	2	0	0	0	0	0	0	2	2
Tapinoma sessile	0	0	0	0	0	0	0	0	0	0	2	0	0	2	2
Technomyrmex setosus	0	0	0	0	0	0	0	0	0	0	2	0	0	2	2
Technomyrmex vexatus	0	0	0	0	0	0	0	0	0	0	2	0	0	2	2
Diacamma vagans	0	1	0	0	0	0	0	0	0	0	0	0	1	0	1
Dolichoderus bituberculatas	0	1	0	0	0	0	0	0	0	0	0	0	1	0	1
Dorymyrmex pyramicus	0	0	1	0	0	0	0	0	0	0	0	0	1	0	1
Polyrachis dives	0	1	0	0	0	0	0	0	0	0	0	0	1	0	1

Climate change-related impacts of ants in the Pacific region

Climate change is considered an existential issue for some Pacific states [99]. Recently the Pacific Islands Forum Boe Declaration identified climate change as the most serious security threat to the Pacific [100].

Change in ecological and environmental systems is influenced by multiple factors, such as climate change, biological invasions, and anthropogenic influences. The interplay of threats, system complexity, and scientific and societal unknowns, and an increasing pool of potential introduced species due to international trade [101], make it difficult to accurately predict the trajectories of invasive species under climate change [102, 103]. Increasing recognition is being given to the multiplicity of impacts of invasive species on many aspects of human interest, including environment, human health, agriculture, culture and economies. New methodologies, such as SEICAT and EICAT incorporate a more holistic and integrated perspective on these impacts [e.g., 23, 25]. Holistic approaches are highly relevant when considering PICTs, as culture, health and food security are innately intertwined within the concept of environment [e.g., 104]. The potential influences of climate change on invasive species and their impacts must therefore be viewed with a broader lens that includes the complexity of factors that influence species ecology, as well as diverse perspectives of human interest.

A general, yet still largely untested expectation is that climate change will exacerbate the threat posed by invasive species. Climate change and invasive species are expected to act synergistically, magnifying worldwide the impacts on biodiversity, human societies and economies [105, 106]. Climate change can alter introduced species' transport, climatic constraints, potential and realised distributions, impacts, and the effectiveness of management strategies [102].

Because the distribution of many species is currently restricted by thermal barriers, climate change could promote biological invasions [107], and enable invasion of higher latitudes and elevations [105]. Moreover, recent weather trends and the predicted increase in the frequency of extreme weather events (such as periods of very high temperature, torrential rains and droughts) are predicted to favour invasive species and pests, enhancing their dispersal and impacts [102, 108]. Evidence of these predictions is perhaps beginning to emerge for ants, with species that were previously considered relatively innocuous having impacts through mutualisms with plant pests subsequent to extreme weather events [e.g. white-footed house ants; 109].

The distributions of species predicted to vary with changes in climate [e.g. 110, 111] can be exacerbated with land-use change due to development, including native forest losses [112, 113]. Some invasive ants, such as red imported fire ants, prefer semi-open habitats and intact forest is a barrier to their spread [114, 115], so changing land use can increase their distribution or likelihood of establishment. Ecological disturbance can facilitate the establishment and spread of invasive ants [e.g. 47, 116, 117-119].

Although the distributions of some of invasive ant species are not predicted to increase under current climate scenarios, other species are predicted to benefit from increased climate suitability [14]. Moreover, the increased frequency of extreme weather events due to a more unstable climate can promote variation in population dynamics of many species [e.g. 120, 121]. Previously innocuous introduced species, or even native species, may become problematic [e.g. 47, 109] if their population dynamics are disrupted, either by climate-related events and / or development related activities. The impacts of invasive species have been predicted to increase in magnitude concurrently with the effects of a changing climate [e.g., 122, 123]. However, for invasive and pest ants, climate change-related impacts might also be amplified by development activities and potential increases in the frequency of extreme weather events.

Since the 1980s, a growing number of studies have modelled the distribution of invasive species under different climate change scenarios [124]. Several recent studies have predicted geographical areas suitable to key invasive ants, both regionally [125] and globally [14, 106], and the increased distribution of emerging threats [126]. As a result of climate change, invasive ants could increase the extent of their distribution either through quantity or quality of suitable areas [106]. However, not all ants might benefit from climate change, with some predicted to have range contractions [e.g. African big-headed ant; 127].

A global assessment predicting future distributions (i.e. distributions in 2080) of 15 of the worst invasive ant species suggests that, under current conditions, around 15% of land is climatically suitable for these species [106]. Contrary to general expectations, the potential distribution of only five ant species is predicted to increase (up to 35.8%), with most species declining by up to 63.3%. Of the species typically cited as the 'worst' invasive ants [African big-headed ant, little fire ant, yellow crazy ant, Argentine ant, red imported fire ant; 1, 2], climatically suitable area worldwide is predicted to increase only for red imported fire ant [106]. However, this analysis treated Oceania as a single area, and did not to discriminate current distributions of other ants, such as little fire ant, within the Pacific [106]. Overall, these findings indicate that invasive ants will not systematically benefit from climate change at a global scale, but rather follow the trend of biodiversity in general, which is predicted to decline [105]. However, given that many of the current and predicted major impacts are attributable to red imported fire ant, this indicates increased risk of this species through climate change.

The continental regions differ greatly in their susceptibility to ant invasions, and the Pacific region may be particularly vulnerable. Overall, the northern hemisphere is predicted to have a relatively low proportion of suitable area for most species in future, whereas most of Oceania and South America is predicted to be suitable to almost all invasive ant species [105]. Pacific Biosecurity explored the potential to apply the published climate models for invasive ants to a more fine-grained assessment of the Pacific. The lack of fine-grained data, and the computing resources available at the time made this type of analysis infeasible. However, in general, tropical regions are highly suitable for most invasive ant species, which currently are predominantly of tropical or subtropical origin. Therefore, extrapolating expectations for tropical areas in general to our focal PICTs seems reasonable (perhaps with the exception of high elevation areas such as the highlands of Papua New Guinea).

Apart from changing climate and habitat suitability, other factors will naturally influence the realised distributions and severity of invasive ant impacts. Climate change may aggravate the impact of invasive ants directly and indirectly. Warming temperatures and the potential increase in extreme weather events could favour invasive ants both by expanding their range and by creating more suitable conditions in areas where these species are already present. For example, a large increase in global landmass suitability has been predicted for species such as Singapore ant, red imported fire ant, and tropical fire ant [106]. On the other hand, the total area of potential distribution of the European fire ant was forecast to stay the same over the next thirty years, but the level of climatic suitability within its range could greatly increase, and result in a higher likelihood of establishment [128]. Thus, as this species is not currently present in the Pacific, it is therefore unlikely to pose a biosecurity risk. In addition, the future localised impact of some species might also be greater for those predicted to undergo potential distribution contraction, such as Argentine ant, because there is potential for an expansion in its realized niche [103]. Again, as this species is not present in our focal PICTs, it is therefore unlikely to pose a greater biosecurity risk in the future than it does currently.

Variation in competitive and exploitative interactions through new assemblages (due to climate change or increased trade linkages) could also affect distributions and impacts. For example, ants possess differences in behavioural strategies that can influence the outcome of novel competitive interactions [110]. Mutualisms are also a key driver of variation in ant abundance [e.g. 129]. Climate change might worsen the impact of ant invasions by favouring interactions between ants and other plant pests or invasive species. For example, it was found that a mutualism between the ghost ant and mealybugs was stronger in a warmer environment [130], and recent plant pest-associated outbreaks of white-footed house ants in the Pacific could be attributable to extreme weather events [109]. Experimental evidence suggests that climatic warming can alter ant community structure, increasing the prevalence of heat-loving species [131]; impoverish and homogenize ant community structure [132], or magnify the impacts of invasive ant abundance [132, 133]. However, these studies are from different ecological systems to those of the Pacific, and these scenarios might or might not be realised in the Pacific.

Finally, the impact of many realised ant invasions on ant communities are density-dependent [e.g. 57, 58-65, 134], and densities vary markedly over space and time [34, 61, 135-140]. We do not have a clear understanding of the factors that drive these observed variations in abundance [140], let alone how competitive interactions change with this variation, and what the flow-on effects to people and their environments might be. Clearly, future invasive ant distributions and impacts will be influenced by multiple factors.

PICT and regional agency priorities

We reviewed invasive species priorities for our focal PICTs and regional agencies initiatives (SPREP and SPC) to estimate the likely degree of support for additional mechanisms to prevent incursions of unwanted ants, and identify gaps in preparedness. Ideally, we would also have conducted a review of biosecurity policies, legislation, plans and activities for our focal PICTs, but this such ana analysis was not part of the project scope. However, such a review would further inform on the priorities currently identified for prevention, actions being undertaken (e.g. surveillance and incursion response / Early Detection and Rapid Response preparedness), and possibly uncover gaps that could be addressed through existing capacity-building projects. An alignment and strengthening of biosecurity approaches across PICTs would be hugely beneficial.

PICT invasive species priorities

Many PICTs include invasive ants as priorities in their Environment and / or Agriculture strategies, policies and action plans. SPREP supports the development of National / Territory Invasive Species Strategy and Action Plans (NISSAPs / TISSAPs) to provide a framework for generating support from potential funders and to prioritise actions against invasive species. These plans are typically, but not always, the responsibility of the Environment departments. The creation and maintenance of these plans, and the participation of biosecurity departments is strongly encouraged by SPREP. The plans follow the Guidelines for Invasive Species Management in the Pacific [141], which includes biosecurity, and research on priority species, as well as management of existing invasive species. More recent plans have seen the inclusion of international biosecurity actions and suggestions to harmonise domestic and international security. Although at the national levels the reporting or focal points can be very different for Environment and Agriculture (the latter is where biosecurity is managed in most cases), this is not always the case, and in smaller PICTs (e.g. Kiribati, Tuvalu, Tokelau) these different departments work more closely together, or are part of the same unit.

We reviewed finalised and draft NISSAPs / TISSAPs and publicly accessible information for 13 of our 22 focal PICTs: Cook Islands, French Polynesia, Guam, New Caledonia, Kiribati, Republic of Marshall Islands, Niue, Palau, Samoa, Tokelau, Tonga and Vanuatu to determine the actions desired, and priority species (for management or prevention) in relation to ants.

- The Republic of the Marshall Islands NISSAP 2016-2021 identified little fire ant as a priority species, and control of unspecified ants to protect Coconut Crab *Birgus latro* populations as an action [142].
- The Tokelau (draft) TISSAP 2019 identified priorities to control yellow crazy ant and black crazy ant to acceptable levels, and six-monthly targeted surveillance of ants as an action item [143]. Tokelau is somewhat buffered to arrivals of new ants in the Pacific as all trade is via Samoa.
- Niue's NISSAP 2013-2020 noted that yellow crazy ants threaten native invertebrates including the coconut crab, and suggests a potential attempt to restrict the spread of the ant, as well as considering the potential of eradication or control. Although the document noted that the little fire ant threatens tourism on several Pacific islands, no biosecurity actions are identified [144].
- The Palau National Invasive Species Committee Action Plan [145] differs from most plans such as the NISSAPs as it covers high-level strategic actions, such as development of biosecurity legislation, rather than specific invasive species. National and domestic biosecurity co-ordination is mentioned also.
- In Samoa, only yellow crazy ants (present in the country) are identified in a priority list of invasive or potentially invasive species[146]. Given this list was compiled over 10 years ago, it would probably

be updated to now include the little fire ant (present in American Samoa as of 2019). Samoa also has a draft incursion response plan for invasive species that mentions little fire ant and red imported fire ants as priority unwanted pests, recommends surveillance and suggests generic response actions [147].

- Tonga identifies Early Detection and Rapid Response (EDRR) actions for ants as an action in its NISSAP (2013-2020), however no species are identified [148]. Tonga has reported outbreaks of yellow crazy ant in the past, for which help was requested (V. Hakaumotu, personal communication).
- Vanuatu's NISSAP [149] lists little fire ant (already present and spreading, despite attempts at containment) as a significant threat species, and also mentions African big-headed ant and yellow crazy ant as threats. Past surveys and control efforts of little fire ant are described, as well as future plans to undertake more surveys as a pre-cursor to considering eradication. Creation of awareness materials for red imported fire ant is mentioned, as well as surveillance for ants, and general emergency response actions.
- A French Polynesia list of the 46 introduced species declared legally to be biodiversity threats [whether already present or not; 150] does not include yellow crazy ant (which is present) or red imported fire ant (which is absent). Only little fire ant, which has significant environmental impacts in French Polynesia already, appears in the list. No prevention actions were mentioned.
- The draft Cook Islands NISSAP [71] identified surveillance for ants, and little fire ant management advice to communities as actions (even though the ant has not been reported from there), and tropical fire ant and yellow crazy ant as priority invasive ants. The narrative also cited the African big-headed ant as a major threat to biodiversity and agriculture, and yellow crazy ant as a threat to invertebrates [71].The NISSAP noted that invasive ants have been implicated in the declines and extinctions of land snails on Rarotonga, but there was no direct evidence of this, or of which species might have been the cause [70].
- The (interim) Guam Invasive Species Management Plan 2017-2019 [36] identified little fire ant as a priority species (in a list of 7), but included no ant species in prevention priorities. Surveillance for little fire ants was mentioned for CNMI.
- A New Caledonia poster listing 70 *established* invasive species identified little fire ant as a high priority invasive species ; and other ants as lower priority (African big-headed, tropical fire ant and yellow crazy ant) [151]. In this poster they referred to red imported fire ant (which is not present), but referred to the species name as *Solenopsis geminata* (tropical fire ant). This type of confusion is likely to be widespread throughout the Pacific (as tropical fire ant is widespread) [3], and is a challenge for awareness raising and discrimination between the two species by the general public. The Ouvea Atoll Biosecurity Plan recommended targeted surveillance for invasive ants in general, but did not identify priority species [152].
- The Kiribati NISSAP identified yellow crazy ant on Kiritimati as a priority for eradication and movement control, and red imported fire ant and little fire ant as additional priorities for prevention [153]. Little fire ant and red imported fire ant are also identified as a priority in the country's Biosecurity Emergency Response Plan, with surveillance planned and preparedness resources in place [154].
- Wallis & Futuna's Biodiversity Strategy [155] mentions African big-headed ants, little fire ants among a total of four invasive ant species (i.e. two species are un-named). The Strategy refers to Action Plans for Invasive Species, but these have not yet been developed.

We have not conducted a review of biosecurity policies, legislation, plans and activities for our focal PICTs as this was outside the scope of this project. However, such a review would likely uncover gaps that could be addressed through current capacity- and capability-building projects. Given that many PICTs are comprised of archipelagos with both domestic and international biosecurity links, harmonisation of international and domestic biosecurity actions within PICTs seems a sensible approach.

In general, most PICTs identify ants already present as an environmental problem, however, in many cases preventive actions are not specified. However, we know that more developed countries such as Fiji and Samoa have dedicated Biosecurity organisations, whose priorities include invasive ants. For example, we understand that Fiji is implementing an incursion response programme for red imported fire ants (which SPC is involved in), but are unaware of the details of this programme. Despite this, there is little mention in the NISSAPs of red imported fire ants, indicating that a lack of awareness of its potential harm in the Pacific region.

Regional agency initiatives

The work programmes of SPREP and SPC are based on requests and priorities set by their member countries and territories. Both SPC and SPREP have priorities for enhanced biosecurity in the Pacific over the coming years, which are being supported through a variety of activities. We have not reviewed other Council of Regional Organizations in the Pacific (CROP) agency initiatives, as most biosecurity-related work in undertaken by SPREP and SPC.

SPC's Strategy 2016-2020 includes a goal to support to PICTs to improve their capacity to meet phytosanitary and biosecurity standards to safeguard trade [156]. SPC has secured European Development Fund (EDF) funding to continue improvements to biosecurity in general. Although no specific ant species are mentioned, the EDF priorities include work to identify gaps in incursion response readiness [157].

SPREP has recently implemented a Pacific Regional Invasive Species Management Support Service (PRISMSS), with current projects funded until 2024 by the Global Environment Fund (GEF) [158]. PRISMSS was established as a coordinating regional mechanism to more effectively address invasive species issues in the Pacific region, contributing to the overall goal of significantly reducing the socio-economic and ecological impact of invasive species. PRISMSS has a theme dedicated to biosecurity (Protect our Islands), which Pacific Biosecurity leads, and to which SPC contributes. Other partners are welcome to join where their goals and actions assist with the PRISMSS objectives. While SPREP's regional mandate is to assist with domestic biosecurity (and their stakeholders are typically environment departments), they recognise that domestic biosecurity must be supported by international biosecurity. Both SPREP and SPC recognise that continued knowledge sharing and collaboration between the two groups will more effectively assist with improvements to regional biosecurity.

The GEF-funded PRISMSS projects include a major component on EDRR for Niue, Republic of the Marshall Islands, Tonga and Tuvalu. While priority species are yet to be finalised (as this is dependent on the perceptions of the in-country stakeholders), red imported and little fire ant prevention is likely to be a priority focus, as Pacific Biosecurity is involved in this work.

An invasive ant prevention programme for the Pacific

An invasive ant prevention programme for the Pacific has been proposed as a mechanism for ongoing support to PICTs. A Pacific Ant Prevention Plan (PAPP) was initiated in 2003 through a workshop facilitated by Manaaki Whenua - Landcare Research, New Zealand. This resulted in the compilation of a draft plan [159], which was endorsed by 21 PICTs at a PPPO meeting in 2004. The PAPP facilitated a co-ordinator based at SPC, and an update in 2006 reported some significant achievements, including collections of ants from all nine participating PICTs, supported by identification workshops and surveillance exercises with 70 biosecurity staff, conducted through an MFAT PSF project [160]. However, the efforts of the project have not always been able to be sustained. Surveillance in many countries is apparently not done regularly or has been abandoned altogether. Naturally, sustainability is always an issue for project-based initiatives, and the lack of sustained effort is not the fault of the PAPP project. As a consequence, to promote sustainability, a number of practitioners have proposed that a permanent programme be established for invasive ants in the Pacific.

Since the PAPP project in 2004, a several attempts have been made to reinvigorate the work. In 2014, the PPPO member states and territories endorsed the concept of an ant prevention programme, with SPC designated as the lead organisation to secure funding, as an ant prevention programme naturally fits with the SPC mandate. The effort towards this reinvigoration stalled somewhat, perhaps owing to the lack of an obvious avenue for permanent funding, and insufficient clarity of how such a programme would be implemented. The dissolution of the team at SPC who were then responsible for biosecurity (Biosecurity and Trade Support team) may have contributed to further inertia.

A second plan was drafted in 2017 [161], supported by the Pacific Invasives Partnership (PIP). The objectives of the current plan (renamed A Biosecurity Plan for Invasive Ants in the Pacific) include:

1. Prevent the entry of invasive ants into the Pacific region and prevent their subsequent spread to new locations within the region;
2. Implement an efficient and effective early detection and incursion response system for invasive ants that operates at regional, jurisdictional, and island scales;
3. Mitigate the impacts of priority invasive ants already present in the region;
4. Increase awareness of invasive ant issues and increase the level of public, community, and legislative support;
5. Enhance capacity for invasive ant biosecurity and management, and;
6. Develop an active research program that provides practical improvements in detection and management of invasive ants.

Past and on-going activities to enhance prevention of invasive ants in PICTs

Since the PAPP in 2004, several initiatives have been (or are currently being) undertaken to address the biosecurity risks posed by invasive ants in the Pacific region (some not involving our focal PICTs). We are aware of some key activities, but no doubt there are others. Several other biosecurity-related programmes with a broader scope also naturally contribute to the long-term objectives of enhancing biosecurity against ants in the Pacific. The following list is not comprehensive, as we have not undertaken an exhaustive assessment, but it is intended to provide a snapshot of the type of work being undertaken and potential opportunities to add to these activities.

- The Hawai'i Ant Lab (HAL) has an on-going programme to manage little fire ants in Hawai'i and has provided support for the recent incursions in Palau, Yap and American Samoa. The United States Forest Service partly funded a programme through HAL for workshops and awareness information to CNMI, Palau and Federated States of Micronesia. This also included development of emergency response plans (Cas Vanderwoude, HAL, personal communication).
- From 2014-2019 PB, along with partners SPC and SPREP (and others) were funded by MFAT to manage yellow crazy ant in Kiribati and Tokelau and assist with improvements to biosecurity. The project assisted Kiribati with implementing surveillance for ants, and developing a simplified Emergency Response Plan, and ran a regional Pest Diagnostic Workshop with MPI. A key output was the development of the Pacific Invasive Ant Toolkit (PIAT), which is noted in Australia's National Invasive Ant Biosecurity Plan as an example of where Australia can collaborate on a regional level [162]. Many researchers and practitioners from throughout the region and further afield contributed to the development of the toolkit. MFAT owns the resource and is pursuing possible arrangements for its ongoing support by SPC, with MPI providing SPC with technical support. Pacific Biosecurity have advised MFAT that there are opportunities to include a wider group of contributors from the community of invasive ant and biosecurity practitioners in the region.
- ACIAR is currently funding the Pacific Plant Biosecurity Capacity Building Program (PPBCBP) programme implemented by Kalang to enhance plant protection in the region. Pacific Biosecurity had been asked to participate in a 2020 workshop, where we intended to promote this socio-economic analysis among in-country stakeholders, as well as emphasising the importance of EDRR against ants. Although the COVD-19 pandemic deferred this workshop, it will be delivered via online elearning. This type of collaboration provides an example of how complementary activities can enhance the effectiveness of multiple projects. Kalang are involved in several other biosecurity-related projects in the region and have promoted the development of a co-ordinated platform for biosecurity in the region.
- MFAT is currently funding a PSF Activity (led by MPI and implemented by Pacific Invasives Initiative [PII]) to enhance capacity for responding to invasive ant incursions and develop incursion response plans (EDRR) for invasive ants in the Pacific, to be rolled out in the three sub-regions,

commencing with Melanesia. Scoping for workshops is scheduled for early 2020. From our colleagues at SPC we learned in 2019 that a red imported fire ant response plan was being developed by Fiji, although we are unaware of the details.

- The SPREP PRISMSS Protect our Islands initiative is intended to provide a platform for ongoing technical support of invasive species management in the Pacific, domestic biosecurity, including EDRR, and provision for further capability-building in future. The current GEF-funded biosecurity-related sub-projects include Niue, Republic of Marshall Islands, Tuvalu, and Tonga. International biosecurity, including EDRR, is included in the scope for Niue and Republic of Marshall Islands.
- SPC has secured funding through EDF to assist countries with a number of biosecurity capability-building initiatives, including improved import risk assessment, emergency response plans, post-entry quarantine facilities and surveillance, with priority species to be identified.

It must be noted that a significant number of research initiatives are also undertaken as part of management programmes, such as improving detection through detector dogs, attempts to develop genomic control technologies to control ants (e.g. RNA interference [RNAi]; gene drives), and continuing work on new delivery technologies (drones, hydrogel-based treatments). A comprehensive review of these research activities was outside the scope of this project, but are mentioned here as targeted research is an objective of the PAPP, and research is also incorporated in the SPREP/SPC Guidelines for Invasive Species Management in the Pacific [141].

Taken together, these various initiatives suggest that there continues to be broad regional support for a dedicated invasive ant programme for the Pacific, and many of the objectives of the original PAPP (variously renamed and now called the Biosecurity Plan for Invasive Ants in the Pacific [BPIAP]) are informally being progressed. However, co-ordination of all these activities is lacking and would be of tremendous benefit for invasive ant management in PICTs.

Conclusions on socio-economic and environmental impacts

As outlined in the project scope document, the anticipated short-term outcomes of our analysis were to enable:

1. Greater, and more predictive, understanding of social impacts including human health, employment or ability to grow crops;
2. Greater understanding impacts on biodiversity and ecosystem services;
3. Justification for a sustained programme for invasive ants in the Pacific that will benefit both PICTs and also donor countries.

In our extrapolation analysis, we found that if red imported fire ant was to expand their distribution into our focal PICTs, adverse impacts on the economy, including plant and animal industries, infrastructure, schools and health could cost some PICTs more than 2% of GDP. Annually, more than 7 million people in these PICTs could potentially need medical attention resulting from red imported fire ant stings.

We acknowledge that many aspects of life differ in the Pacific relative to developed countries, from where most of the socio-economic impacts were sourced. Indeed, PICTs themselves are not homogeneous, owing to their cultural diversity, varying development ratings, and environmental heterogeneity (e.g. ranging from small atolls to large, high volcanic islands). However, when compared to developed countries, developing PICTs are characterized by a more outdoor oriented lifestyle, reduced access to health services, simplified infrastructure (often with issues around maintenance due to cost and access) and less automated agricultural practices. On balance, such differences are likely to be reflected in higher impacts than we have predicted, particularly non-tangible impacts, such as cultural practices and lifestyle.

Climate change is considered an existential issue for Pacific states [99], and recently the Boe Declaration identified climate change as the most serious security threat to the Pacific [100]. The regions that are most vulnerable to climate change-related impacts are also typically those with the least capacity to mitigate or prevent those impacts. This is recognised by programmes established to promote climate change resilience and mitigation in developing countries (e.g. The United Nations Framework Convention on Climate Change [UNFCCC] Green Climate Fund [GCF]). These programmes acknowledge that climate change is an amplifier of already existing development-related problems, for example food security, deforestation, pollution and waste [21, 163-165]. However, specific programmes have not yet been established by regional agencies to actively mitigate climate change-related invasive species impacts. Partly, this gap may exist because such programmes require justifications that centre on human-focussed concerns about health, safety and food security. The only major invasive ant species that is predicted to potentially increase its distribution due to climate change is the red imported fire ant. Based on past trends, there is little doubt that little fire ant will continue to spread in the region. Yellow crazy ant and African big-headed ant, although already present in the majority of PICTs, will likely also continue to spread.

Our analyses, together with trait-based modelling [47] have identified potential new species that could threaten the Pacific. Perhaps all of these can be considered horizon species, although their specific risk profiles will be dependent on trading links of PICTs to countries within their current distributions and climate and habitat suitability, which we have not explored. It may be of value to conduct risk assessments for these species for focal PICTs, and perhaps more importantly, those countries with trading links to Australia and New Zealand. However, given the overwhelming indications that red imported fire ant is the major threat not already present in our focal PICTs, these other species would be a much lower priority for specific prevention actions.

Prevention and management of the impacts of invasive ants are a priority for many PICTs and the regional agencies. We outlined a number of examples of past and on-going activities related to these priorities, which indicates significant effort is being focused on biosecurity generally, and invasive ants specifically. However, there is potential to improve co-ordination in these efforts, to streamline the effectiveness of capability-building and reduce potential gaps and overlaps. Even if our findings do not eventuate in a dedicated ant prevention programme, we consider that activities in the region could be better co-ordinated.

Overall, our study confirms that the ant species of most serious concern continue to be the red imported fire ant, little fire ant, yellow crazy ant and African big-headed ant. Our results provide further justification for actions to manage and prevent spread of these ants in the Pacific region. While we were not able to extend our analysis to ecosystem services due to a lack of information, taken together our analyses suggest that socio-economic and environmental threats posed to PICTs by invasive ants justifies a co-ordinated effort to ensure effective prevention. Our review of current activities on ant-related biosecurity, the priorities and plans of PICTs and regional agencies also suggest that an invasive ant programme would be supported by SPREP and SPC member countries.

Several additional observations related to the advance of little fire ant over the last several years suggest that the Pacific in general is not prepared for incursions of red imported fire ants: 1) Little fire ants continue to spread across the Pacific despite being identified as a priority species by many PICTs; 2) Certain countries are not meeting their obligations under international agreements to declare the presence of little fire ant, thereby increasing the biosecurity risk to their trading partners; 3) Incursion response plans for ants remain sparse, or generic and inconsistently supported (by on-going awareness and surveillance efforts), or too complex for PICTs to implement given the demands on small biosecurity teams that are under-resourced; 4) New incursions are detected long after the arrival of the ants, and not at primary entry points (although this may at least partly be due to the way the ant is being transported [160]). Similar conditions are evident from the Coconut Rhinoceros Beetle (CRB) 'G-type' spread throughout the Pacific. These observations, and the fact that red imported fire ant can so easily be mistaken for tropical fire ant, suggest the Pacific is not sufficiently prepared. In some ways, given the recent incursions in China, Korea and Japan, it is surprising that red imported fire ant is still absent from our focal PICTs.

Recommendations to assist in achieving longer-term outcomes

In our project scope, we identified several longer-term outcomes that our work would potentially support, including:

1. Strengthened regional biosecurity: justification for financial commitment to surveillance and rapid response;
2. Better management of invasive ants on Pacific Island Nations will reduce the risk of introduction between Pacific Island Nations as well as to Australia and New Zealand. This will also indirectly benefit a number of trade agreements by reducing biosecurity risk of traded goods (e.g. PICTA and PACER-Plus);
3. Pacific Island Nations' inhabitants have ready access to effective tools and resources to manage invasive ants into the future so that impact is minimised, and the inertia in response to these invasions is relieved.

In order for these longer-term outcomes to be realised, it is important to acknowledge issues that need to be considered to ensure these outcomes can be achieved:

- **Detections of invasive ants are occurring too late**. By the time impacts of invasive ants are widely noticed it is often not possible to eradicate invasive species [38, 166], without significant effort and cost. Even when it might be possible to easily eradicate an ant species (i.e. early detection and a very limited distribution), the relative geographic remoteness of many developing PICTs, and access to resources for eradication, including financial capacity and people, means that successful eradications are unlikely, or would be exceedingly expensive. Pacific peoples are resilient. While people might initially consider the problem of invasive ants to be extreme, over time they may modify their lifestyle and agricultural practices in response [167]. However, this response is not a choice, rather it is a solution for a problem that is otherwise insoluble. Recent and historical examples (e.g. the spread of little fire ant through Vanuatu, and incursions into Palau, Yap and American Samoa within the last five years), indicate that efforts to increase awareness and improve early detection need a greater focus in the Pacific.
- **Human resource and organisational issues**. PICT government departments often have a relatively small workforce, high staff turnover and multiple demands on their time. These human resource issues are particularly acute in least developed countries with smaller populations. Biosecurity staff in the Pacific are generally well-trained and competent, with many opportunities for increasing capability-building. However, several factors suggest that capability-building does not result in significantly enhanced biosecurity *capacity*. While in some PICTs trained staff share learnings from workshops, knowledge is often not institutionalised. High staff turnover also contributes to loss of institutional knowledge. Even with adequate skills and knowledge, the multiple demands on staff to complete day-to-day tasks (issuing permits, biosecurity checks), means that more complex tasks like regularly scheduled surveillance, and risk analysis may be delayed or neglected. Surveillance as undertaken in countries like New Zealand and Australia involves significant technical expertise, effort and resources. For example, New Zealand port surveillance can require identification thousands of ant samples. Even with the appropriate skills in identification, the effort required for similar exercise in many of our PICTS would be unrealistic, both due to the numbers of staff required and time to complete identifications (with the aforementioned competing demands on their time). Sometimes, something as simple as securing transport to the port to undertake surveillance can be a barrier.
- **Dependence on development assistance**. The PICTs we focused on are all to a greater or lesser degree dependent on some development assistance from donor countries. The apparent level of preparedness and capacity in PICTs, the inability or inertia in response to little fire ant, and our prior experiences with yellow crazy ants in Tokelau [34] and Kiribati, reinforces the difficulty of dealing with these ants. Moreover, if red imported fire ant arrives in some of our focal PICTs, in-country stakeholders will probably not be able to independently conduct an emergency response adequately to achieve eradication, without rapid access to considerable technical and financial

support. We would hope that given the profound impacts to date of red imported fire ants, that this support would be made available swiftly if the species was to be detected in developing PICTs. However, improving prevention actions to mitigate this level of preparedness will potentially reduce the risk of future costs of incursion response to donor countries in the region.

- **PICTs are not homogeneous**. Activities to prevent red imported fire ants need to take country-specific differences into account. Some aspects that need to be considered include: differences in levels of risk (both to PICTs themselves and to countries like Australia and New Zealand) due to the nature of trading relationships; varying levels of technical capacity in-country (including the workforce and organisational issues noted above); existence and effectiveness of policy and legislation that provides justification and support for emergency response; a wide range of entry-point scenarios (including more easily managed port activities, but less easily managed yacht landings); support of change at Director level and above to ensure changes suggested can be embedded.

Based on our findings, we suggest that the highest priority actions should be to prevent further spread of yellow crazy ants and little fire ants, and to prevent establishment of red imported fire ants in the Pacific region. This should be the primary focus of any dedicated ant prevention programme at this time, and to be successful would need to be sustained for the foreseeable future. To be considered attractive by potential funders of the programme, it would need to demonstrate that it capitalises on existing efforts and systems, rather than creating a novel mechanism.

Australia is expending considerable effort to eradicate invasive ants such as red imported fire ants, little fire ant, browsing ant and yellow crazy ant [43]. Enhanced biosecurity in PICTs will also assist in preventing re-invasions of these species, and provide an additional risk management mechanism for Australia (and other countries, including New Zealand). Prevention of red imported fire ant incursions will also protect future market access opportunities for PICTs.

Potential future actions

The most cost-effective way to reduce the risk of unwanted species arriving is to have effective pre-border interventions. This is especially important for developing PICTs, whose ability to respond to incursions is poor relative to developed trading partners.

Naturally, pre-border actions are not foolproof, so must be supported by prompt detection and response. We suggest several actions that would contribute to enhanced biosecurity against red imported fire ant and other invasive ant incursions in PICTs. Some of these, like improved co-ordination of projects, should be relatively simple and inexpensive to implement, while others, like the extension of the SCHS, would require significant investment in infrastructure and change to systems. The adoption of these suggestions will naturally depend on the priorities of in-country stakeholders, their trading and transport links with Australia (and New Zealand) and higher risk countries around the region (China in particular). Initial actions suggested are:

1. *Improved co-ordination of ant prevention activities* across the region to capitalise on existing and future capability-building activities. While numerous activities are undertaken with the support of several donors, these efforts are not comprehensively coordinated. Greater coordination with increase the effectiveness of capability-building and reduce potential gaps and overlaps;
2. *Targeted support for Early Detection and Rapid Response (EDRR).* The ability to detect invasive ant incursions as early as possible is the key to success of eradication efforts;
3. *Simplified import permitting processes* to support pre-border risk reduction. Import Health Standards (IHS), as used by New Zealand and Australia, are not the norm in PICTs. Instead, they typically rely on import permits. Streamlining of these importing processes through IHS will reduce the effort required, promote compliance and enhance the effectiveness of importing processes;
4. *Promotion of Sea Container Hygiene System (SCHS) throughout the Pacific*. Australia and New Zealand effectively use SCHS for reducing the risk of ant incursions. Extending the SCHS so that Pacific countries are also protected will reduce this risk for both PICTs and their trading partners.

Two of these suggestions (3 and 4) have also been discussed with New Zealand MFAT, SPC and SPREP representatives as part of other work [168]. These suggestions were supported in principle by all three parties, although suggestions were not taken further at the time. While we are not aware of related activities in the Pacific since these suggestions were made, actions may be occurring.

The actions we propose appear to align well with current policies in Australia and New Zealand. For example, we note that Australia's National Invasive Ant Biosecurity Plan (NIABP) [162] indicates support for actions on an international shipping container standard (1.4) and engaging with trading partners on incidental contamination (1.5). Also noted in the NIABP is the opportunity to collaborate on a regional basis for information sharing.

Given recent re-emphasis on security in the Pacific signalled by New Zealand's *Pacific Reset*, and Australia's *Step Up* policies, this may be an optimum time to seek funding for the actions we propose. We also note that MFAT's Climate Change Programme intervention areas [169] include supporting PICTs "to increase the resilience of ecosystems and reduce the impact of invasive species, in order to strengthen food security, protect the coast and reduce disaster risk". A joint approach by the New Zealand and Australian governments could have significant benefits for both parties. As a first step, getting reaffirmed support from the PPPO for our recommended actions would seem appropriate.

Improved co-ordination of ant prevention projects

Even in the absence of a dedicated ant prevention programme in the Pacific, the examples of past and on-going activities indicate significant effort is being focused on biosecurity generally, and invasive ants specifically in the region. However, there is clearly potential to improve co-ordination of these efforts, to increase the effectiveness of capability-building and reduce potential gaps and overlaps. Even if our analyses do not provide sufficient justification for a dedicated prevention programme, we still consider that activities in the region could be better co-ordinated, perhaps by ensuring that all projects and activities related to biosecurity and invasive species / pest management are reported to a single entity, and that entity proactively identifies areas where activities that could complement and enhance each other. It would be most sensible if this co-ordination was through a regional organisation or mechanism (who have relationships with each other, potential donors, in-country stakeholders and consultants). Potential options for co-ordinating agencies could be:

- **SPC**. SPC's mandate includes international biosecurity, but does not include in-country invasive species management (as outlined as an objective of the PAPP). SPC staff do not have in-depth in-house technical expertise in ant management;
- **SPREP**. SPREP's mandate includes domestic biosecurity and in-country invasive species management. They also do not have in-depth in-house technical expertise in ant management;
- **SPREP / SPC** joint approach. Although led by SPREP, SPC is a key partner in PRISMSS. This could provide an appropriate co-ordinating mechanism, and has the potential for additional technical partners to be involved. PRISMSS enables the regional agencies to have access to technical support needed, while not requiring the staff to provide that support within SPREP or SPC (i.e. a cost-effective approach). The PRISMSS associate could be the appropriate focal point for such a co-ordination role. Some of the objectives of the PAPP (targeted research for example) are not within the scope of PRISMSS, however, which is more concerned with direct action as mandated by member countries. However, it would be useful for any co-ordinator to be aware of these out-of-scope activities, even if the they could not assist with implementation. For example, improved detection is needed to support early detection.

At a minimum, we recommend a review of the current activities in the region to identify gaps and overlaps and ensure consistent and targeted capability-building. Countries and territories are not homogenous in their capacity to prevent and respond to ant invasions, and require different levels and types of support.

Targeted support for Early Detection and Rapid Response

Several actions are occurring in the region with a view to supporting EDRR for invasive ants in the Pacific. To our knowledge these are in the form of regional or sub-regional workshops for capability-building, including developing response plans, without actions in specific countries. As PICTS have different risk profiles and levels of capacity, generic plans that are developed need to be supported through follow up work in-country. Some actions that might be needed include:

- **Identifying issues and gaps in preparedness**. This might include identifying legislation changes to ensure special powers, identifying additional key points for surveillance, ensuring environmental permits are obtained for treatment products (note that treatment solutions might differ among countries due to differing access to and restriction on specific active ingredients – for example fipronil based products are banned from American-aligned PICTs);
- **Ensuring plans have appropriate stakeholder support**. Stakeholder support is essential to ensure full implementation is agreed at the appropriate level (ministerial or above);
- **Supporting on-going surveillance**. This might entail regular visits to ensure that surveillance occurs, assisting with awareness programmes among stakeholders, reinforcing identification skills;
- **Ensuring readiness for incursion response**. This would include simulation exercises and training in application of treatment products, and potentially ensuring an initial supply of treatment products.

Some of these actions might need to be repeated more frequently. It would be useful to target more intensive actions to PICTs with the highest risk profiles (i.e. based on trading links to Australia and to other countries and territories with established little fire ant, yellow crazy ant, and red imported fire ant populations, or LDC PICTs that are less likely to be able to independently conduct an incursion response).

The ability to detect invasive ants as early as possible is the key to success of EDRR. Improved or simplified detection and identification tools would be extremely useful for the Pacific, and could be an aspect of targeted research. Developed countries (particularly the eradication programmes for little fire ants and red imported fire ants in Queensland) have found detector dogs to be a highly effective tool for detection within eradication programmes. However, such an approach might not be workable in the Pacific, where people and dogs usually have a very different relationship.

Simplified import permitting processes

Many PICTs use individual import permits as a form of pre-border control and risk management. Import permits are issued based on risk analysis, and for regularly imported items (meat from Australia and New Zealand for example) the process is straightforward, if time-consuming. However, when new risk analysis is required, PICTs typically do not have the human resources or financial capacity to undertake this analysis without support, which can lead to inertia in responding to new threats. SPC's EDF project appears to go some way to assisting with capacity-building in this area, and the PPBCBP project is also contributing to capability-building for risk analysis.

Another challenge is the need for individual permits, which can be required for every single import (e.g. small amounts of meat imported into Kiribati by private individuals). This approach requires significant effort for teams that are already understaffed, causes frustration for importers, and potentially promotes disregard for legislation or smuggling. Import Health Standards (IHS) provide a simpler way to control imports and minimise the effort involved in permitting. Moreover, New Zealand and Australia have Import Health Standards for many of the products traded around the Pacific, so risk analysis becomes much more straightforward, as these can be used as guidelines.

We support the implementation of a set of generalised IHS guidelines and examples, which has previously been suggested for the Pacific [168]. Ideally, Import Health Standards could then be implemented in all countries, but if not (or in the interim), they could still be used to assist with import permits for new or changing threats. Some countries (e.g. Samoa) have import permit templating tools, which could also be implemented more widely to decrease staff workloads [168].

Promotion of Sea Container Hygiene System throughout the Pacific

One key mechanism that currently assists in prevention of invasive ant entry to New Zealand and Australia is the Sea Container Hygiene System (SCHS), which operates at key ports in PICTs, as a pre-border risk reduction tool.

We advocate for the extension of the scope of the SCHS, both geographically and in the types of containers treated. We consider this has benefits for protecting New Zealand and Australia as well as enhancing market access potential for PICTs. As originally conceived, the SCHS ensures empty sea containers imported into a country are free from pests. However, the principles of the SCHS can be applied as more general measures to improve biosecurity and facilitate trade. For example, in Tonga containers from produce exporters are cleaned prior to export; managed areas at ports and other transit areas can be used both for pre-export and internal biosecurity.

In 2018, Fiji was developing Import Health Standards for sea containers that would require exporters in countries like Kiribati and Tuvalu to re-export clean containers back to Fiji. These two countries did not (and to our knowledge still do not) have the infrastructure in place to comply with these standards. Implementation of the SCHS in Tuvalu (both for exports to Fiji and for inter-island biosecurity) has been suggested as a pilot for bringing other PICTs into the SCHS [168].

Appendices

Methods

Data gathering

To identify peer-reviewed information sources for our analyses, we conducted systematic and exhaustive searches on Web of Science, JSTOR and Google Scholar, using the English language. We searched for all articles up to March 2019. The most recent version of the FORMIS, a curated database of all literature pertaining to ants [170], was also scanned. In our search terms we initially included the scientific names and common names of six ant species included in a selection of the world's worst invasive species [2], and cited as the worst invasive ant species [1]. These six are also the species most frequently targeted for eradication [31, 171]. To this list we added species whose impacts are occasionally reported, and have been identified as potential future threats to the Pacific region [3]. We also searched using the same terms in Google with the additional key words "sting", "bite", "damage", "cost*" and "impact*". The search on ant names was open i.e., the common name was not in brackets, and so all ant impacts would have been returned in the results. Further additional sources were identified from the reference lists of the papers returned in the search results, which also added species to the initial search list. As our goal was to forecast potential impacts in novel locations, we did not restrict our searches with terms such as "invasive", "alien" or "introduced". Thus, our search criteria were extended based on the data available and we did not selectively search for negative impacts of certain species.

Quantitative socio-economic analysis

We quantified the potential financial impacts of invasive ants in the Pacific with an extrapolation analysis using methods similar to Wylie and Janssen-May [7] for red imported fire ants in Australia, applied to our selected focal countries in the Pacific (Table 1). Briefly, this methodology derived all the costs to the United States of red imported fire ant in all available sectors and related these costs to equivalent sectors in Australia. Sectors including forestry and roads were not included as there is insufficient data to estimate impacts. Although activities such as organic cropping and apiculture are growing in the Pacific, currently insufficient data is available to estimate impacts. We considered that because red imported fire ants are likely to invade most habitats (apart from dense rainforest and highest elevations[29, 172]), this would be true for PICTs also. Studies have concluded that if red imported fire ants invade Hawai'i, they will likely negatively affect agriculture, parks, residential and other private properties, tourist destinations, and biodiversity, and would likely be the most destructive introduced ant species in Hawai'i if they were to arrive [173]. We considered impacts would also be similar across the Pacific region. We made similar assumptions to Wylie and Janssen-May [7], namely that: 1) red imported fire ant is able to colonize all suitable habitats in the focal countries, which is supported by climate modelling; 2) impacts in target focal countries will be similar to those experienced in the United States; and 3) governments will adopt a management approach to the ant i.e. with no current coordinated eradication or containment.

We included countries for extrapolation analysis based on their membership of the Pacific Community (SPC; all except Timor-Leste), and Pacific members of the African, Caribbean, Pacific (ACP; all except American Samoa, French Polynesia, Guam, New Caledonia, CNMI, Pitcairn Islands, Tokelau, and Wallis & Futuna). We excluded Pitcairn Islands from the final list due to the difficulty of obtaining development data. These Pacific ACP and SPC country groups are typically the focus of development projects and programmes targeted in the region (Table 1). We included Timor-Leste owing to its development status and frequent inclusion with SPC and Pacific ACP states in capacity-building development.

Socio-economic sectors assessed by Wylie and Janssen-May [7] that we included as applicable to Pacific island countries and territories were cropping, tourism, livestock production (including apiculture), health and schools. Statistical data for our selected focal countries were primarily sourced from the Food and Agriculture Organisation (FAO) statistics (FAOSTAT) databases [174], and World Bank databases. The 2017 FAOSTAT data were used for animal production, crops, forestry and population. Data on tourism (international tourism, number of arrivals) were obtained from World Bank figures. Household access to electricity was obtained from World Bank and New Zealand Ministry of Foreign Affairs and Trade statistics. As access to electricity varies widely among Pacific Island countries and territories, we based projections on households with access to electricity rather than the per capita approach of Wylie and Janssen-May [7]. Costs to tourism were limited to the health costs for stung tourists, and we were not able to quantify e.g. the damage (electrical, structural) to tourist facilities, that would incur costs similarly to households. Therefore, we assume that the current impact both in environmental and socio-economic categories is underestimated. Some countries' data were not available in these sources (i.e. number of schools), so we also consulted Pacific government and regional agency websites and contacted government officers directly. Sources for all data are available on request.

Gross Domestic Product data were obtained from World Bank statistics unless otherwise indicated (Table 1). To account for inflation for figures estimated prior to 2017 we used www.usinflationcalculator.com. Although this is based only on United States inflation rates, too little consumer price index (CPI) information is available for Pacific Island countries to meaningfully calculate these costs on an equivalent basis for all the individual countries (which was the approach used by Wylie and Janssen-May [7]).

We had originally intended to apply the above analyses to major donor countries in the region e.g. New Zealand, Australia, United States, Japan, China, Taiwan. However, these countries already recognise the threat posed by invasive ants and have significant biosecurity measures in place, so instead we focussed on developing PICTs. The analyses for these countries would also have required modelling of habitat suitability, something we had not provided for.

Qualitative analyses

We used the three approaches to qualitatively assess socio-economic and environmental impacts of invasive ants: 1) Socio-Economic Impact Classification for Alien Taxa [SEICAT - 23]; 2) Environmental Impact Classification for Alien Taxa [EICAT - 24, 46]; and 3) the Generic Impact Scoring System [GISS - 25]. The SEICAT/EICAT and GISS methodologies qualitatively assess the impacts of invasive species. GISS and EICAT assessments can lead to very similar impact levels, but scores from the schemes are not equivalent. Small differences are attributable to discrepancies in interpretation of the language used in the descriptions of scores [175]. Different scoring schemes assess different aspects and may influence assessment outcomes [176], and it has been recommended that different schemes should be applied together for a holistic assessment of impacts [97]. Therefore, we used a combination of methods to assess the global impacts of invasive ants.

The methodologies have been utilized to assess the impacts of a range of taxa. The SEICAT methodology has been used to assess socio-economic impacts for marine fishes [177], feral mammals [97] and amphibians [23]. The EICAT methodology has been used to assess the magnitude of environmental impacts of many species [417 species; 176], including a global analysis of introduced birds [178], and gastropods [along with SEICAT; 178] and crabs in South Africa [179]. The GISS methodology was first applied to mammals and birds [180], and subsequently to terrestrial arthropods [98] and all invasive species in Europe [181]. The GISS methodology has also been applied along with the SEICAT/EICAT methodology in South Africa [along with the SEICAT/EICAT approach; 97].

Evaluation outcomes are subject to reporting biases that of multiple sources. More frequently studied species are more likely to show evidence for impacts than would species with fewer studies. Similarly, those species with assumed high impact or those that were the subject of a high number of publications continue to receive most attention from scientists [182]. Although these trends can bias the total impact score, they also give us an indication of the sampling effort [25]. Literature search criteria also contribute to variation in classifying species' impacts. A comparison between two independent global impact assessments of amphibians showed that most of the differences between assessments could be attributed to different literature search strategies [175].

Moreover, although the SEICAT/EICAT and GISS methodologies provide a structured way to assess impact, the assessments can be subjective depending on the views of individual assessors, regardless of their expertise in the subject matter. Two co-authors (MC, DS) extracted the text citations / impact descriptions from the sources and initially assessed each impact description. To minimize the possibility of bias two or more additional co-authors assessed a subset of citations according to the SEICAT and GISS approaches. The final scores were agreed by consensus. As recommended [175], we assessed impacts for all ants species that yielded relevant information. This approach overcomes the potential for publication bias and improves the applicability of the results to management and prioritization of future research.

For the environmental impact analyses, we included only papers documenting negative impacts of ants. A minor body of literature documenting positive impacts of ants (e.g. predation of pests in crops, negative impacts of other pest species, dispersion of native/endemic plant seeds) was not included, as positive impacts cannot be assessed with the assessment schemes used. Where papers examined multiple species, we created one impact record for each species if impacts were reported for the whole group, and individual impacts for each species, as appropriate.

SEICAT analysis

The SEICAT and EICAT methodologies categorize invasive species by the magnitude of their impacts, sub-divided according to the mechanism of these impacts. For SEICAT, the mechanisms are the components of human wellbeing affected by the target species and include: safety; material and non-material assets; health; and social, spiritual, and cultural relations. Each record is assessed in one of five impact categories ranked by increasing magnitude of impact: 1) Minimal Concern (MC); 2) Minor (MN); 3) Moderate (MO); 4) Major (MR) and; 5) Massive (MV). Taxa with little information are classified as Data Deficient (DD). Each record is also categorized by degree of confidence in the original source (low, medium, high) following a 1-12 points rationale. For each record, whenever in doubt, the highest impact score with lower confidence was recorded. For each record, the highest impact score was recorded. For the SEICAT/EICAT, only the maximum impacts across all mechanisms for each species were considered when reporting [23].

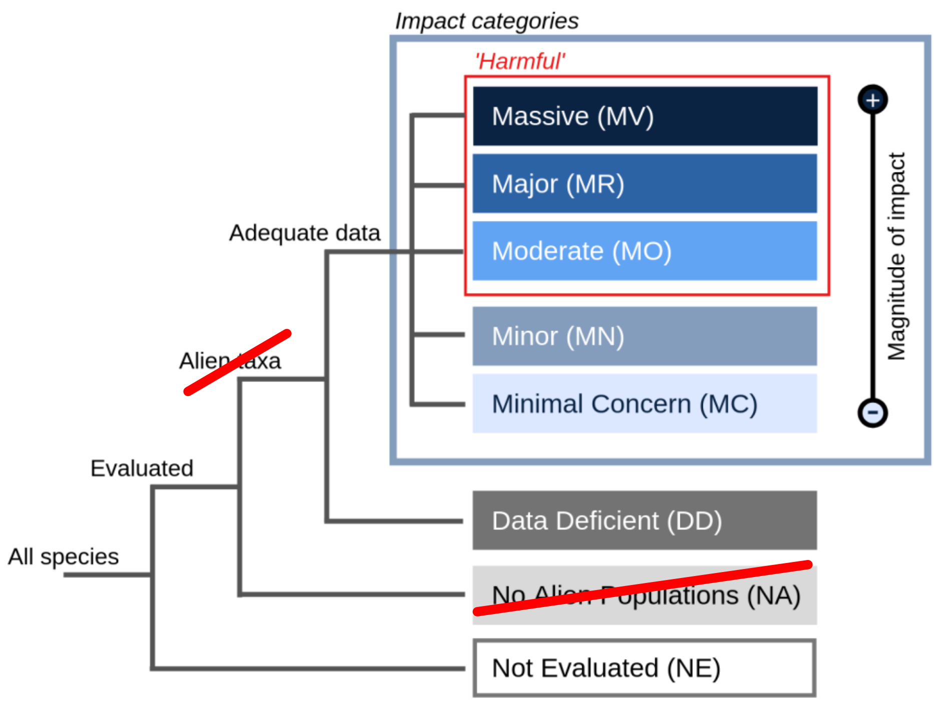

Figure 2: Impact categories for SEICAT and EICAT analyses [183]. As we undertook a global analysis to identify risk species, we did not distinguish between 'alien' and other taxa.

EICAT analysis

For EICAT, the mechanisms are categorised according to the way in which the target species cause impacts at the species, population, or ecosystem level, and include: competition; predation; hybridization; transmission of disease to native species; parasitism; poisoning / toxicity; bio-fouling; grazing / herbivory / browsing; chemical, physical, or structural impact on ecosystem; and interaction with other introduced species.

We also recorded our confidence in the impact level. Laboratory-only studies documenting impacts were typically assigned to the EICAT low confidence group (4: "the impact is recorded at the local scale"). Generally, studies describing negative co-occurrence patterns between invasive ants and other taxa were assigned to the EICAT medium confidence group (7: "the interpretation of the data is to some extent ambiguous or contradictory"), as often ant impacts seem to correspond with impacts due to more general environmental degradation (e.g. associations with disturbance). Studies that described negative co-occurrence patterns and provided additional information suggesting direct impacts of ant invasions (e.g. laboratory experiments, density-dependent effects) were assigned to the EICAT high confidence group. It was generally difficult to score maximum confidence (12: "data/information are not controversial, contradictory"), as most of the studies were correlational and/or short-term. Likewise, it was generally difficult to score maximum impact (Massive: "Causes at least local extinction of species, and irreversible changes in community composition; even if the alien species is removed the system does not recover its original state").

GISS analysis

The GISS methodology is a combined impact assessment for environmental and socio-economic sectors. For socio-economic assessments, records are classified into six socio-economic categories, each with six subcategories (impacts on: agricultural production; animal production; forestry production; human infrastructure and administration; human health; human social life) and six environmental categories (impacts on: plants or vegetation; animals through predation, parasitism, or intoxication; other species through competition; ecosystems; through transmission of diseases or parasites to other species; through hybridization). Impact is measured on a scale of 0 to 5, with 0 indicating no detectable impacts and 5 the most severe impacts. As recommended by the authors when prioritizing species [25], the GISS final impact score for each ant species was obtained by summing the highest scores for each of the 12 impact categories. With this approach, the maximum theoretical impact score for a species is 60. Yet, given the gaps in our knowledge of impacts of different taxa through different mechanisms, impact scores are generally much lower (see results).

Ecosystem services

To obtain an alternative perspective on environmental impacts, we intended to assess records to infer the type of ecosystem services affected. Ecosystem services are defined according to one of four categories: supporting (services needed for the provision of all other ecosystem services, including biodiversity, nutrient function); provisioning (products derived from ecosystems, including agriculture); regulating (processes that regulate ecosystem function, including control of pests); and cultural (non-material benefits, including recreation, education and spiritual benefits). Where more than one ecosystem service was recorded as affected, the more fundamental service was chosen, e.g., supporting over provisioning. However, as we found very few studies that specifically assessed ecosystem services and it was difficult to infer these categories from general studies, we have not reported these results.

Maslow's hierarchy of needs

To assess whether the impacts affected necessities of human life, or more cognitive and aesthetic needs (as suggested by Bacher et al. [23]), we also categorised socio-economic impacts according to Maslow's hierarchy of needs [54, 55]. This theoretical model of human motivations is divided into eight categories, overlapping and not necessarily intended to be linearly progressive. The hierarchy is typically visualised as a pyramid, and ranges from the most universal and fundamental to the most esoteric human needs: 1) biological and physiological; 2) safety; 3) love / belonging; 4) esteem; 5) cognitive; 6) aesthetic; 7) self-actualization; and 8) transcendence. Maslow hypothesised that although individuals may be motivated to address the fulfilment of fundamental needs before those 'higher' level in the hierarchy, individuals are motivated to fulfil multiple types of needs at one time [184].

Biodiversity impacts

We assessed potential biodiversity impacts by extracting records on threatened species distribution data for our focal PICTs (except Tokelau) from the IUCN Red List [56], with guidance from BirdLife International and Island Conservation. Data on the threatened species of Tokelau were obtained from a conservation survey [96].

Comments on qualitative methodologies used

Our primary objective was to develop a global view of the potential and realised socio-economic and environmental impacts of invasive and pest ants for selected PICTs. Typically, the SEICAT / EICAT / GISS methodologies are used to identify existing impact in a pre-determined geographical area. Clearly our goal was much broader than this, and we now have a global assessment of the impacts of potential and currently identified invasive ants that will be of considerable use to others. Most of us did not realise at the outset of this work how time-consuming and complex this task would be.

For example, we collected 550 records for socio-economic impacts of ants from 401 sources that documented the socio-economic impacts of invasive ants, and 731 records from 474 sources that documented the environmental impacts of ants. Other studies using SEICAT / EICAT and / or GISS have generally reported fewer records for the focal taxa than we have, with one exception, which was a meta-analysis of other studies [181]. It could be considered that our results reflect a greater impact of ants as a taxonomic group. However, the main reason we found so many more records than other studies is also influenced by our methods: we did not specify a geographic location or assess a predetermined list of species. Taxonomic diversity also contributes to this larger species pool: there are over 15,000 described ant species, but far fewer amphibians, fish and mammals (which have been the focus of previous studies).

In addition, other studies have focussed on specific geographic areas, i.e. documenting impacts of already established invasive species rather than potential invasive species, as we have done. For example, the Nentwig, Bacher, Kumschick, Pyšek and Vilà [181] study, a meta-analysis of all previous GISS-based studies, as well as unpublished data, focussed on impacts already documented in Europe. Bacher, Blackburn, Essl, Genovesi, Heikkilä, Jeschke, Jones, Keller, Kenis, Kueffer, Martinou, Nentwig, Pergl, Pyšek, Rabitsch, Richardson, Roy, Saul, Scalera, Vilà, Wilson and Kumschick [23] assessed 20 records of seven amphibians, based on an *a-priori* selection of 104 non-native species using SEICAT. Hagen and Kumschick [97] focussed on 11 feral mammals in South Africa and assessed 77 records on global socio-economic impacts (SEICAT / GISS). Galanidi, Zenetos and Bacher [177] assessed 65 studies for invasive marine fishes already in the Mediterranean (SEICAT).

Predefining a geographic location is useful for several reasons, including predicting habitat suitability and likelihood of establishment, limiting spread across land borders, and defining administrative borders for biosecurity and management. However, our broader approach is useful to identify species that are potential invaders from outside the focal geographic location (with the caveat that habitat suitability needs to be considered). We suggest that when prevention of initial establishment is a priority, impact assessments should consider the widest geographic range.

Finally, the methodologies we used are typically applied to specific species that have already been defined as invasive. While useful for prioritization of localized management activities, this approach has limited utility in predicting potential future threats. Given the difficulty of managing ants, let alone eradicating them, the effort to identify threats using these methodologies, and putting in place actions to prevent them seems a worthwhile approach.

Impact assessments are based on studies from data that are typically bound in time as well as space. Neither GISS not SEICAT / EICAT differentiate between short-term acute impacts and long-term chronic impacts, which may serve to both underestimate chronic impacts and over-estimate acute impacts. For example, many outbreaking insect species, including ants, have impacts that vary considerably over time and space [e.g. 109, 135, 136, 138, 139, 185]. Also, the approach of ranking only the most severe impact may result in overestimating the impact of species with one or few studies with massive impact relative to a species with many studies with lower impact, but which might have cumulatively larger impacts over the long term.

References

The following literature was referred to when writing the report. The references collected for the review are recorded separately and available on request, as is the data for the analyses.

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