SPREP

South Pacific Regional Environment Programme

# *Invasive species in the Pacific: A technical review and draft regional strategy*

# *Invasive species in the Pacific: A technical review and draft regional strategy*

Technically edited by

**Greg Sherley**

Published by the South Pacific Regional Environment Programme
with funding assistance from the Government of Australia

SPREP Library Cataloguing-in-Publication Data

Invasive species in the Pacific: a technical review and draft regional strategy / technically edited by Greg Sherley. - Apia, Samoa : SPREP, 2000.

vi, 190 p. ; 29 cm

ISBN: 982-04-0214-X

1. Pests - Control. 2. Pests - Integrated control. 3. Alien plants - Oceania. 4. Plant introduction - Oceania. I. Sherley, Greg. II. South Pacific Regional Environment Programme (SPREP).

632.9

Published in June 2000 by the
South Pacific Regional Environment Programme
PO Box 240
Samoa
website: www.sprep.org.ws

Produced by the South Pacific Regional Environment Programme with funding assistance from the Government of Australia

Prepared for publishing by SPREP's Publications Unit
Editing and layout by Geoff Gregory,
Word Therapy, Paraparaumu, New Zealand

Typeset in 11/13.2 Times Roman
Printed on 115 gsm Satin Matt Art by
Graphic Press & Packaging Ltd, Levin, New Zealand

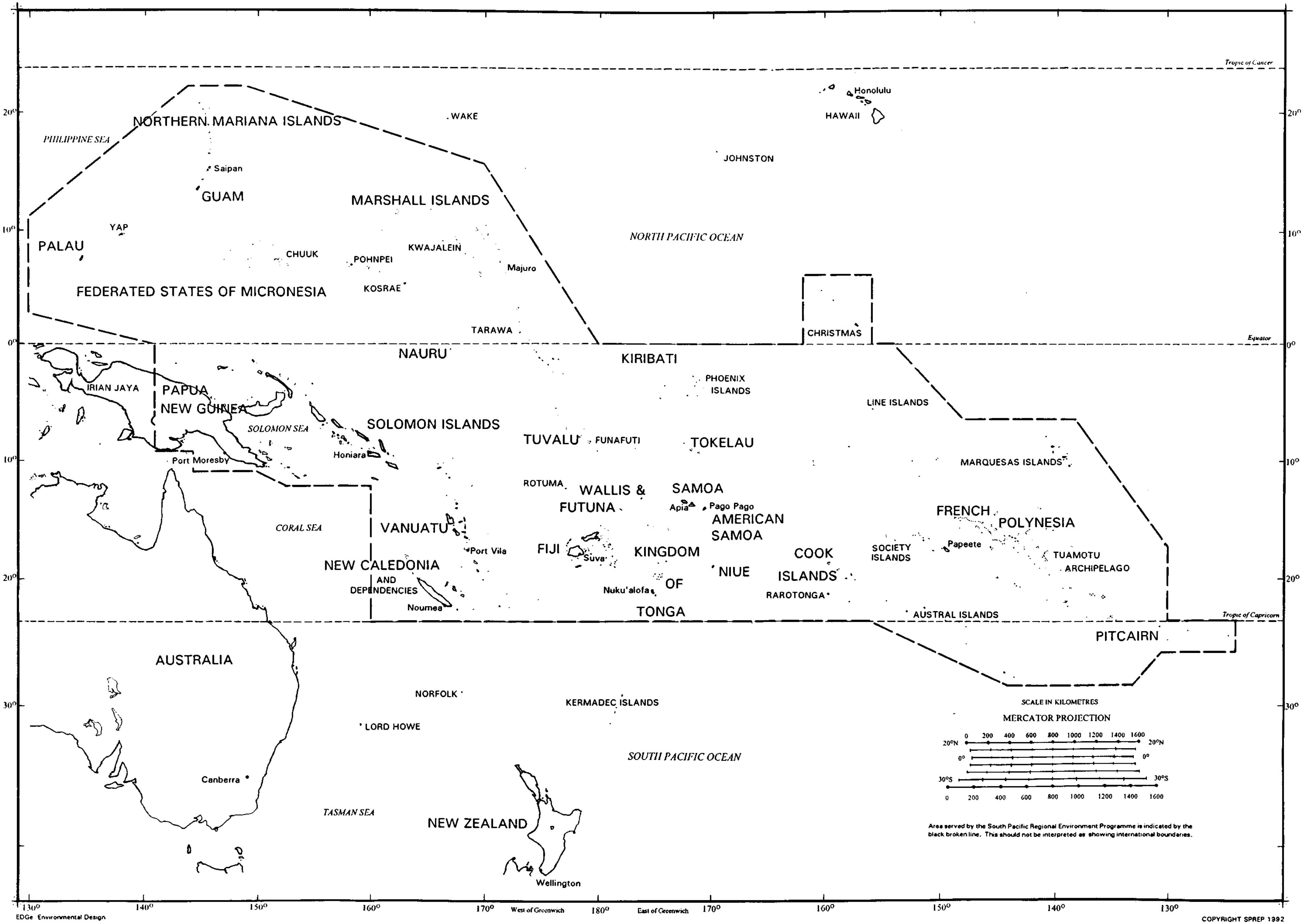
Copies of this publication can be obtained by contacting:
The Information Resource Centre Manager
South Pacific Regional Environment Programme
Ph: (685) 21 929
Fax: (685) 20 231
Email: IRC@sprep.org.ws



Original text: English

# Contents

# AREA SERVED BY THE SOUTH PACIFIC REGIONAL ENVIRONMENT PROGRAMME



# Foreword

This publication has been produced to conveniently combine related documents on invasive species in the Pacific islands for ease of reference. The publication contains a series of technical reviews of land and freshwater invasive species, non-technical summary of the same together with an account of legislation about invasive species, and the pathways by which these species gain access to countries. Also included is a draft regional strategy for invasive species.

The invasive species reviews were based on desk research using available literature and personal communications. Inevitably there will be omissions in the reviews, but at least they may serve as a start for national managers and policy makers in their decision-making. The scope of the reviews and the process leading to the creation of the draft regional strategy were planned in collaboration with the IUCN Invasive Species Specialist Group and noted regional experts in invasive species.

After the technical reviews had been completed, they were summarised in a paper (including sections on legislation and 'pathways') which was circulated to SPREP member countries together with an invitation to participate in a workshop to draft a regional strategy to mitigate the threat from invasive species. This draft strategy is here presented verbatim from the workshop (except for format editing and the correction of some typographical errors).

The draft strategy also meets SPREP's obligations to its governing body—the SPREP Meeting—during its tenth meeting in Apia, 1998, which required the Regional Invasive Species Programme (RISP) to produce a Regional Invasive Species Strategy (RISS) through a regional workshop. The draft strategy will be submitted to the 11th SPREP Meeting in Guam, 2000, for endorsement. Thus the RISS will serve as a tool for guiding the RISP and SPREP member countries who wish to use it in deciding priorities for in-country projects. The scope of the technical reviews has been limited to the South Pacific, including the territorial waters of the 22 Pacific SPREP member countries and territories. However, the delegates to the strategy workshop felt that the strategy was relevant to all Pacific islands and its usefulness should not be considered restricted to only the South Pacific.

The review and draft strategy were restricted to terrestrial invasive species and freshwater habitats, and to those invasive species which pose threats to conservation values of native species and their habitats. This is because invasive species in other habitats (such as the ocean) have been largely catered for in the PACPOL Strategy and Workplan (produced by SPREP's Pacific Ocean Pollution Prevention Programme). Also, invasive species which threaten human health and agriculture, and other economic interests, have already received extensive funding and mention in technical reports. By contrast, invasive species which threaten native species and their habitats have historically received little attention or funding. Thus the focus of these technical reviews and the RISS is on the issue of invasive species with respect to the conservation of terrestrial and freshwater native species and their habitats.

The programmes which paid the consultants who undertook the technical reviews of invasive species in the South Pacific, the workshop which generated the Draft Regional Invasive Species Strategy, and the position of Programme Officer Avifauna Conservation and Invasive Species, were funded by the Governments of New Zealand and Australia.

Tamari'i Tutangata

Director
South Pacific Regional Environment Programme

# Acknowledgements

Thanks are due to the Australian Government, which funded under its AusAID programme the technical review and regional workshop which produced the Regional Invasive Species Strategy. The New Zealand Government had the foresight to fund a Programme Officer Avifauna Conservation and Invasive Species (POACIS) for the south Pacific region. This enabled the co-ordination of the technical review and workshop and subsequent instigation of in-country projects to implement the Regional Invasive Species Strategy.

The International Union for the Conservation of Nature's Invasive Species Specialist Group has provided valuable advice in designing the technical review and helped to organise and run the Regional Invasive Species Strategy Workshop. Particular thanks in this regard are due to Ms Sarah Lowe.

The New Zealand Department of Conservation (NZDOC) assisted the creation of the Regional Invasive Species Strategy by allowing Susan Timmins to attend the workshop. Her expert advice and help in facilitating the workshop was invaluable. NZDOC also released Dr Greg Sherley on Special Leave Without Pay to fill the POACIS position in keeping with the Memorandum of Understanding between it and the South Pacific Regional Environment Programme.

Thanks are due to the authors of the review papers for their co-operation in writing the papers and during their review. Special acknowledgement is due to Dr Jean-Yves Meyer and to his employer, the French Polynesian Government, which allowed Dr Meyer time to write the plant review free of charge.

Finally, Mr Geoff Gregory (Word Therapy) expertly edited the original manuscripts to SPREP specifications and significantly improved the quality of the writing in the publication. The SPREP publishing team also improved the text.

# Draft Invasive Species Strategy for the Pacific Islands Region

**Written by delegates[1] to the Regional Invasive Species Workshop, Nadi, Fiji, 1999**

**Compiled by Greg Sherley[2], Susan Timmins[1], and Sarah Lowe[1]**

*[1]Contact details may be found in Annex II*

*[2]Contact for further information on the published version: PO Box 240, Apia, Samoa.*
*Ph: +685 21-929. Fax: +685 20-231. Email: greg@sprep.org.ws*

## 1. Introduction

Pacific island countries are particularly vulnerable to the effects of invasive species. After habitat destruction or modification, invasive species are responsible for more species extinctions than any other cause. Further, the rate of extinction of native species has been higher on islands than anywhere else in the world. Invasive species have also degraded native ecosystems.

Mitigation of the effects of invasive species on biodiversity is best coordinated regionally. In response to this need, the New Zealand government funded an Invasive Species Programme to be managed by SPREP for three years, starting from September 1998, with the intention of extending funding for another three years after 2001. One of the objectives of this programme (agreed to by SPREP member countries during the SPREP Meeting in 1998) was to develop a strategy for invasive species for use by all countries and relevant agencies in the region. Thus this strategy is intended for use until 2004.

To facilitate the production of the strategy, a regional workshop was held 26 September–1 October 1999 in Nadi, Fiji, funded mainly by AusAID, with some extra support from the United States Government. It aimed to draw together the pressing invasive species issues being experienced in South Pacific countries and to derive strategic solutions.

All SPREP member countries and territories and non-government organisations working in the Pacific and with a known interest in invasive species were invited to send a delegate to the regional workshop. Prior to the workshop, several technical reviews were commissioned to describe the status of terrestrial and freshwater invasive species in the South Pacific. The reviews, which were restricted to those invasive species threatening the conservation of native species and natural ecosystems, were compiled into a summary issues and options paper, which was circulated to all workshop delegates and appears in this publication.

The workshop restricted itself to invasive species issues related to conservation of native biodiversity on land and freshwater habitats, to the SPREP member countries, and to the development of strategic responses. The strategy has been produced exactly as written by the workshop except for some formatting and editing of this section and the acknowledgements.

The strategy will be used immediately for implementing the Regional Invasive Species Programme (and other programmes administered by SPREP). It will also be useful for other invasive species initiatives in the Pacific region, or indeed, for other regions in the world, especially those mainly composed of islands.

## 2. Invasive species issues in the Pacific

The following is a summary of the generic issues underpinning the invasive species problems in the Pacific region. They are described in greater detail in Annex 1. Fundamental to these problems in the Pacific island countries is the shortage and inaccessibility of scientific information on basic biology for assessment of risks and management of invasive species. A related problem is the lack of awareness on the impacts of invasive species on biodiversity. There are insufficient networking mechanisms established for the dissemination of information to the relevant decision-makers and government officials. Coordination and collaboration within the region on the management of invasive species threats to biodiversity is not yet well developed.

Existing legislation, regulations and cross-sectoral policies in Pacific island countries and territories do not fully address the impact of invasive species on biodiversity. Enforcement of these legislative instruments is sometimes inadequate.

There is a shortage of technically trained personnel in Pacific island countries and there are inadequate quarantine and risk assessment facilities. There is insufficient funding for training of personnel, establishment of infrastructure, development of risk assessment procedures, and management and research on invasive species.

# 3. Strategic directions

## 3.1 Aim of the regional strategy

To promote the efforts of Pacific island countries and territories in protecting and maintaining the rich and fragile natural heritage of the Pacific islands from the impacts of invasive species through cooperative efforts to:

- Develop and maintain an effective, coordinated network of information and technical expertise.
- Prevent the introduction of new invasive species.
- Reduce the impact of existing invasive species.
- Raise awareness.
- Build the capacity required to manage the threats posed by invasive species.

## 3.2 Components of the regional strategy

### Strategy 1: Information

Strengthen both basic and applied research on invasive species by identifying high-priority research needs, and encouraging work on high-priority problems. Establish biological surveys for all member countries and territories. Emphasise prevention and early detection, and evaluation of exotic species that are present or are potential problems. Establish long-term monitoring of high-risk native areas for incursions of recognised invasive species.

Strengthen linkages between Pacific island countries and scientific institutions, sources of technical and research assistance or other bodies of information. Share information regionally through the establishment of mutually accessible databases and web sites.

Develop a regional clearinghouse for information on invasive species that is easily accessible, perhaps through a web-based information system.

### Strategy 2: Awareness

Raise public awareness of invasive species threats to conservation.

Work with economic interests (operating in agriculture, aquaculture, forestry, horticulture, public health, shipping, military, some biocontrol operations, and genetically modified organisms technology) to raise their awareness of risks to biodiversity of invasive species. Represent invasive species issues at regional and national meetings, and with funding organisations in order to increase awareness.

Develop awareness of the accidental movement of invasive species into new relatively pest-free areas, especially their inter-island transfer within one country.

Promote awareness of the inter-island transfer problem by education programmes in identification, establishing networks (national and regional), and early warning databases.

Develop awareness of the dangers of accidental introduction of invasive species to biodiversity. For example by the movement of machines and in particular the inter-island transfer of pests, especially from invaded areas to new or pest-free areas. The establishment of an effective communication network and a manual of existing and potential invasive species may assist with identification, behaviour, where to look, how to exclude, eradicate and control them.

Further communication of the problem can be achieved by networking, international linkages, national working groups, regional expert groups, and an early-warning database.

### Strategy 3: Infrastructure

At the national and regional level, develop ongoing training programmes in the areas of species identification, field detection, quarantine inspections, monitoring and the like, and a network of resources that allow for the transfer of information to appropriate field workers.

Develop and upgrade regional and national facilities such as reference collections and specialised facilities for border control.

Promote and strengthen initiatives that facilitate the use and sharing of existing regional facilities by government agencies in-country and between countries (e.g. South Pacific Regional Herbarium, Bishop Museum collections, quarantine facilities).

### Strategy 4: Protocols

Develop and strengthen protocols and procedures – particularly:

- Develop and strengthen procedures to process applications for species introduction to assess their potential impact on native species or ecosystems.
- Promote the use of existing protocols for pest risk assessment, modified to accommodate Pacific island countries and territories, before pests are introduced into a country.
- Develop early-warning and response systems for invasive species.
- Develop guidelines for pest management that consider the full biological and conservation consequences of control or eradication operations, including restoration.
- Collaborate with other organisations to develop appropriate policies to address the potential con-

servation/environmental risks of genetically modified organisms.

### Strategy 5: Legislation

Survey existing environmental and other relevant legislation in each Pacific island country to determine its adequacy for protecting biodiversity from the threats of invasive species. Develop model legislation which includes provision for mitigating these threats and which makes use of principles developed for invasive species by other organisations (such as IUCN) and countries. Produce country-specific recommendations for modifying or developing new legislation which adequately regulates the following:

- importation of all living organisms,
- surveillance for new incursions,
- risk analysis of import applications,
- assessment of environmental risks prior to introduction of genetically modified organisms,
- quarantine procedures,
- export of pests,
- movements of species between islands,
- control or eradication of invasive species,
- monitoring.

### Strategy 6: Funding

Develop long-term external funding mechanisms that will ensure Pacific island countries are able to undertake work for the management of threats from invasive species.

Make representation to government leaders to improve long-term funding to address the pressing issues of invasive species of conservation concern in the region. Demonstrate the extent of the invasive species problem in the region, cast in economic cost/benefit terms and the necessity of taking action. Secure support for invasive species issues among local communities (including village councils) as well as at national, regional and political levels (e.g. South Pacific Forum). In order to make these representations for more funding, determine and develop a regional resource of materials, in easy-to-read language, that identifies the magnitude of the invasive species problems in the region. Needed information includes: the area of natural ecosystems degraded by invasive species, their conservation impact, and the consequences of not taking action.

Maximise funding self-sufficiency by promoting full participation of local communities in project development, management and implementation to ensure a long-term local commitment.

Promote invasive species as a criterion in national, regional, and international disaster management plans.

### Strategy 7: Linkages

Establish and maintain a network among Pacific island countries and territories and organisations that improves communication, cooperation and information sharing, and that maximises the effectiveness of invasive species work in the Pacific. Specific actions include: develop-ment of common standards of border control, staff exchange programmes, nomination of an invasive species position within appropriate organisations, and establishment of national working groups and a regional expert group.

Regional participation is needed in the development of international standards and programmes that govern the movement of invasive species in commerce (e.g. Convention on Biological Diversity, International Plant Protection Convention, World Animal Health Organization, and others).

## 4. Concluding comments

The workshop confirmed the need for a regional invasive species strategy as a platform for obtaining funds for in-country projects. The country issues have been successfully tabled for those countries that participated (see Annex 1). The regional invasive species strategy may now be used as a vehicle to: (1) seek funds from international agencies and donor countries, (2) reinforce and guide national biodiversity management plans (such as the National Biodiversity Strategic Action Plans), (3) complement other regional invasive species programmes, especially the United States of America's Invasive Species Management Plan, and (4) guide the Regional Invasive Species Programme administered by the South Pacific Regional Environment Programme in writing its annual workplans.

Finally, the workshop identified at least one regional generic need: a marine regional invasive species strategy and implementation plan which, together with the terrestrial regional species plan, may include wetlands habitats such as intertidal zones (e.g. mangrove forests and estuaries).

## 5. Acknowledgements

Thanks are due to the foresight of the countries funding the workshop: Australia, New Zealand, and the United States of America. Particular thanks must go to Susan Timmins and Sarah Lowe (New Zealand Department of Conservation and IUCN, respectively) and to their employers. Gaye Harford (Xpand Management NZ Ltd) expertly facilitated the workshop, and Ruta Tupua-Couper (SPREP) managed the administration.

# Annex 1. List of invasive species issues developed at the workshop

## 1. Information

- Lack of information on the basic biology (including distribution) of many invasive species and of the best control methods – particularly biological control methods. Part of this lack of information includes a lack of accessibility and coordination of information within the region and outside the region.
- Lack of monitoring of high-risk areas for invasive species (vulnerable sites).

## 2. Public awareness

- Lack of understanding, from the public, politicians, and other sectors, of the major threats posed by pests to conservation assets. This results in a lack of public commitment for both biodiversity protection and management of invasive pests.
- Competition with conservation interests from agriculture, aquaculture, forestry, horticulture, some biocontrol operations, public health considerations, traditional practices, shipping, military and genetically modified organisms technology.
- Accidental introduction of invasive species: by movement of machines, boats and materials from pest-invaded areas to pest-free areas, trampers, animals, and smuggling operations.

## 3. Lack of infrastructure

- Lack (quality and quantity) of technically trained personnel on the ground, and of species identification, field detection, quarantine inspections, control operations, monitoring, and research. Lack of mechanisms for transfer of information to field workers.
- Inadequate facilities to house confiscated species, fumigate, and implement adequate border control (amongst other things), but no support for upgrading some regional facilities and thus these facilities do not reach their full potential.

## 4. Protocols

- Lack of a system to warn of impending threats.
- Lack of adequate pest risk assessment procedure which is accurate and can cope with all variables.
- Intractable problem of inability to predict invasiveness (risk assessment) of new species, including genetically modified organisms, at the border, or as a target for eradication or for control.
- Inadequate quarantine procedures, which are too cumbersome, and are not fully implemented (inadequate checks). Lack of collaboration in some instances (between different agencies/countries) and inefficient use of limited resources in some Pacific island countries and territories. No protocol to ensure detection/assessment of organisms/commodities being brought into a country, including illegally, and lack of emphasis on (recognition of) conservation threats at quarantine.
- No protocols to determine the priorities for eradication and control.
- Lack of early detection and evaluation action on new pest incursions may lead to bigger problems later.
- Lack of appropriate processes to implement legislation.
- Inter-island movement of pests is not controlled due to a lack of protocols and regulations.
- No control of the export of pests.
- Lack of knowledge or planning for the full biological and conservation consequences of control operations.
- Poorly defined or no standards of phytosanitary measures, or pest risk analysis.

## 5. Legislation

- Absence of, or inadequate or ineffective legislation to protect conservation values.
- Lack of legislation that regulates exports and imports against the risks of invasive species.
- Not enough enforcement of legislation, for various reasons.

## 6. Inadequate funding

- Lack of funding for technical work such as research on control methods, taxonomy (identification), impact of invasive species, survey work, monitoring, eradication or control.
- Inadequate distribution of funding siphoned off by other activities (other than invasive species) within the country or by other countries.
- Projects dependent on outside sources of funding.
- Poor mechanisms to ensure adequate and timely funding, such as not coinciding with the timing of the life cycle of the invasive species.
- Not enough funding for resources and personnel or the mechanism in place for these people to set priorities to maximise the benefits for conservation.

## 7. Linkages

- Pacific island countries and territories and regional organisations do not yet share enough information or consult with each other, e.g. sharing information and making agreements to set common standards for border control.
- Too little cooperation between quarantine officers and the public.
- Difficulties cooperating across international borders due to disputes and differing conservation values.

# Annex 2. List of participants at the Regional Invasive Species Workshop, Nadi, Fiji, 26 September–1 October 1999

***American Samoa***

Peter Craig, Ecologist, National Park of American Samoa, Pago Pago, American Samoa 96799.
Phone: (684) 633 7082 Fax: (684) 633 7085
Email: peter_craig@nps.gov

Manu Tuiono'ula, Forest Health Coordinator, PO Box 6997, Pago Pago, American Samoa 96799.
Phone: (684) 699 1394 Fax: (684) 699 4595/5011
Email: mtuiono@Yahoo.com

***Australia***

Paul Trushell, Senior Policy Officer, Multilateral Team/Policy & International Division, AQIS, Dept of Agriculture, Fisheries, Forestry, GPO Box 858, Canberra ACT 2601, Australia.
Phone: (612) 6272 3255 Fax: (612) 6272 3307
Email: paul.trushell@aqis.gov.au

***Cook Islands***

Mark Brown, Secretary of Agriculture, Ministry of Agriculture, PO Box 96, Rarotonga, Cook Islands.
Phone: (682) 28711 Fax: (682) 21881
Email: cimoa@oyster.net.ck

***Fiji***

Marika Tuiwawa, Curator, South Pacific Regional Herbarium, University of the South Pacific, Box 1168, Suva, Fiji.
Phone: (679) 212 874 Fax: (679) 300 373
Email: Tuiwawa_M@usp.ac.fj

Kesaia Tabunakawai, People & Plant Officer, WWF South Pacific Program, Private Mail Bag, GPO, Suva, Fiji.
Phone: (679) 315 533 Fax: (679) 315 410
Email: ktabunakawai@wwfpacific.com.fj

Phil Shearman, World Wide Fund for Nature South Pacific, Private Mail Bag, GPO, Suva, Fiji.
Phone: (679) 315 533 Fax: (679) 315 410
Email: shearma@ozemail.com.au

Cedric Schuster, World Wide Fund for Nature South Pacific, Private Mail Bag, GPO, Suva, Fiji.
Phone: (679) 315 533 Fax: (679) 315 410
Email: cschuster@wwfpacific.com.fj

***Federated States of Micronesia***

Estephan Santiago, Dept of Economic Affairs, PO Box PS12, Palikir, Pohnpei FM 96941, Federated States of Micronesia.
Phone: (691) 320 2620 Fax: (691) 320 5854
Email: fsmrd@mail.fm

***French Polynesia***

Jean-Yves Meyer, Research Scientist, Délégation à la Recherche, BP 20981, Papeete, Tahiti.
Phone: (689) 460 089 Fax: (689) 433 400
Email: Jean-Yves.Meyer@services.gov.pf or Jean-Yves.Meyer@polynesie.gov.pf

***Guam***

Robert D. Anderson, Chief, Division of Aquatic and Wildlife Resources, 192 Dairy Road, Mangilao, Guam 96923.
Phone: (671) 735 3955/56, 3979 (direct line)
Fax: (671) 734 6570 Email: boba@ns.gov.gu

***Hawaii - USA***

Julie S. Denslow, Team Leader, Ecology Non-Indigenous Plant Species Team, USDA Forest Service, Institute of Pacific Islands Forestry, Hilo, Hawaii 96720, USA.
Phone: (808) 933 8121 Fax: (808) 933 8120
Email: jdenslow/psw_ipif@fs.fed.us

Lucius G. Eldredge, Bishop Museum, 1525 Bernice St, Honolulu, Hawaii 96817, USA.
Phone: (808) 848 4139 Fax: (808) 847 8252
Email: psa@bishop.bishop.hawaii.org

***Niue***

Colin Etuata, Quarantine Officer, Department of Agriculture, Forestry & Fisheries, PO Box 74, Fonuakula, Alofi, Niue.
Phone: (683) 4032 Fax: (683) 4079
Email: mfn.agriculture@mail.gov.nu

***New Zealand***

Sean Goddard, Senior Policy Analyst, Department of Conservation, PO Box 10-420, Wellington, New Zealand.
Phone: (644) 471 3096 Fax: (644) 471 3130
Email: sgoddard@doc.govt.nz

Susan Timmins, Scientist, Science & Research Unit, Department of Conservation, Wellington, New Zealand.
Phone: (644) 471 3234 Fax: (644) 471 3279
Email: stimmins@doc.govt.nz

Sarah Lowe, IUCN Invasive Species Specialist Group, School of Environmental & Marine Sciences, University of Auckland (Tamaki Campus) Private Bag 92-019, Auckland, New Zealand.
Phone: (649) 373 7599 ext: 6814 Fax: (649) 373 7042
Email: s.lowe@auckland.ac.nz

Gaye Harford, Professional Facilitator, XPAND Management, Auckland, New Zealand.
Phone: (649) 522 5001 Fax: (649) 522 5025
Email: gaye@xpand.nzl.com

***Northern Mariana Islands***

Estanislao C. Villagomez, Director of Agriculture, Division of Agriculture, Department of Lands & Natural Resources, Caller Box 10007, Saipan, MP 96950.
Phone: (670) 256 3317/18/19
Fax: (670) 256 7154/322 2633
Email: stanvill@gtepacifica.net

***Papua New Guinea***

John A. Aruga, Manager, Office of Environment & Conservation, PO Box 6601, Boroko NCD, Papua New Guinea.
Phone: (675) 325 0195 Fax: (675) 325 0182
Email: asomake@datec.com.pg

***Samoa***

Afele Faiilagi, Biodiversity Officer, Division of Environment & Conservation, Dept of Lands, Surveys & Environment, Private Mail Bag, Apia, Samoa.
Phone: (685) 23358/23800 Fax: (685) 23176
Email: envdlse@samoa.ws

***Solomon Islands***

John Rockson Pita, CASO – Arnavon Marine Conservation Area, Department of Forests, Environment & Conservation, PO Box G24, Honiara, Solomon Islands.
Phone: (677) 25 848/27084 Fax: (677) 21 245
Email: amca@welkam.solomon.com.sb

***United States of America***

Richard Orr, Animal & Plant Health Services, USDA APHIS PPD, 4700 River Road Unit 117, Riverdale, MD 20737, USA.
Phone: (301) 734 8939 Fax: (301) 734 5899
Email: richard.l.orr@usda.gov

James C. Space, Program Manager, Pacific Islands Ecosystems at Risk Project, Institute of Pacific Islands Forestry, USDA Forest Service, 11007 E. Regal Dr., Sun Lakes, AZ 85248-7919, USA.
Phone: (480) 802 6573 Fax: (480) 802 5203
Email: jspace@netvalue.net or
jim_space@rocketmail.com

***Vanuatu***

Donna Kalfatak, NBSAP Project Coordinator, Environment Unit, PMB 063, Port Vila, Vanuatu.
Phone: (678) 25302 Fax: (678) 23565
Email: environ@vanuatu.com.vu or
environment@vanuatu.gov.vu

***SPREP Secretariat***

PO Box 240, Vaitele, Apia, Samoa.

Phone: (685) 21929 Fax: (685) 20231
Email: sprep@sprep.org.ws

Greg Sherley, Programme Officer (Avifauna Conservation and Invasive Species)
Email: greg@sprep.org.ws

Ruta Tupua-Couper, SPBCP Secretary
Email: rutat@sprep.org.ws

# Towards a regional invasive species strategy for the South Pacific: issues and options

**Greg Sherley[1] and Sarah Lowe[2]**

*[1]Programme Officer, Avifauna Conservation and Invasive Species, SPREP, PO Box 240, Apia, Samoa*

*[2]Invasive Species Specialist Group, IUCN, University of Auckland (Tamaki Campus), Private Bag 92-019, Auckland, New Zealand*

## 1. Introduction

The purpose of this paper was to assist workshop participants from the SPREP member countries whose task was to create a regional strategy for invasive species in the South Pacific. The paper uses non-technical language to provide a summary of the status of invasive species in the South Pacific Region. This summary is compiled from the technical reviews which follow in this publication.

The technical reviews were commissioned by SPREP, but planned and designed by an ad-hoc working group, which included the Invasive Species Specialist Group (ISSG) of the Species Survival Commission of the International Union for Conservation of Nature (IUCN). This partnership is consistent with Resolution 15 of the Sixth Pacific Conference on Nature Conservation and Protected Areas, which specifically charges IUCN and SPREP to undertake such work.

The terrestrial invasive species technical reviews dealt with the following subject areas: vertebrates; plants; insects; molluscs (snails and bivalves); and frogs, toads and other animal species which invade freshwater systems. Little published information is available on the paths invasive species take to enter countries, and the types of invasive species legislation which exist in the South Pacific. We attempt to provide brief summaries of these areas, and have also summarised the main findings from each technical review so that their conclusions may be easily understood.

## 2. What is a "strategy" for the South Pacific?

The term *strategy* is a military one but has a usage in business or politics as "a plan of action or policy". Implicit in our interpretation of *strategy* is a statement of "how to achieve a declared end point". A strategy which applies to an area the size of the South Pacific will necessarily be general. The main benefits in having an agreed strategy which has been designed by Pacific island delegates include: (1) ensuring acceptance by Pacific island countries when it is being implemented, (2) avoiding ad-hoc actions, and (3) gaining the maximum efficiency for the limited resources available. The objective of the Regional Invasive Species Strategy is that in-country projects will bring benefits to countries. It is the intention of the Regional Invasive Species Programme administered by SPREP that the strategy (developed at the Nadi workshop) be adhered to in decisions where funding is required. We would hope that other agencies such as those representing the governments of France and the United States of America would also consider the RISS in their decision-making.

The main components of a strategy include a central aim or statement of purpose, listing the actions to be taken towards achieving a set of desired outcomes. For the purposes of the RISS it is suggested that a practical time frame for making significant progress would be five years from 2000. This will approximately match the funding period of the current invasive species programme administered by SPREP. The rest of the strategy is basically a set of generic actions which are required to redress identified invasive species issues within the region. Specific time frames may be set for actions, and there may be some prioritisation of implementation. Each of the actions will, in some way, partly satisfy the overall aim of the strategy, and collectively they should meet its overall aim.

## 3. Technical summaries

This section summarises the main biological information presented in the technical papers which follow. We describe the current level of knowledge about different groups of invasive species in the region, and the important points which need to be understood in order to create a regional strategy to reduce their threat.

### 3.1 Vertebrates

The impact of large vertebrates on Pacific island ecosystems has been dramatic. Ecosystems have been wholly changed by the importation of animals such as pigs, cattle, and goats for food, or mongooses for control of other pests such as rats. While many people may culturally or economically value an animal such as the pig, it is important to understand the devastating ecological, and thus often long-term cultural, social, and economic effects they have.

Cattle, goats and pigs are ecologically very destructive in their habits. They will eat tree seedlings, so slowing or even halting the replacement of forest canopies, and reducing native plant diversity. Goats are present on at least nine island groups within the SPREP region. Wherever they are present in dense populations, they may cause great destruction to vegetation and landscapes (often through the ensuing soil erosion), resulting in total habitat loss. Thus may forests be changed into grasslands, as has happened on Isabela Island (Galapagos), or be made more vulnerable to further invasion by weeds, or to cyclone damage. In such cases, a goat eradication operation could help preserve the integrity of a whole island ecosystem.

Perhaps the worst of the larger vertebrates is the pig. Pigs eat and uproot tree seedlings, and break open tree-fern trunks, looking for starch. Rooting also provides gaps for invasive weed seeds to become established, and pigs facilitate this process by eating, and then spreading in their droppings, seeds such as guava (particularly *Psidium* species). A further consequence of the uprooting and wallowing habit of pigs is the appearance of holes in which water may settle, and where mosquitoes (possibly carrying avian malaria) may breed. Such gross habitat disturbance destroys the habitats of populations of large native invertebrates such as earthworms and snails. In addition, pigs eat their eggs, juvenile growth stages or adults. Pigs are recorded digging seabirds from their burrows, and eating eggs, chicks and adults. They damage crops and tree plantations, and may spread disease to other animals.

Many of these species become part of more complex ecological interactions, and failure to notice or understand these has led, in the past, to inter-species “chain reactions” of problems. An example of this was the introduction of monitor lizards to Micronesia after World War II, in an attempt to control Pacific and ship rats; but the monitors were diurnal, the rats nocturnal, so the two never met. The monitors, which were seeking food, ate local chickens. To avoid this, cane toads were brought in to provide an alternative food source for the monitors. The toads’ poison killed many of them, by which time it was discovered that the monitors had been both controlling the grubs of rhinoceros beetles (that had been damaging coconut palms) and preying on coconut crabs (which had been controlling giant African snails). As the monitors died off, the toads increased in number and were eaten by pigs, cats and dogs, which were then also poisoned. Without these predators, rat numbers increased—the original problem—and the snails began to scavenge on the cat and dog carcasses (Lever 1994). It is obvious that the consequences of the monitor lizard introduction were much more far-reaching than anybody had anticipated.

A further example of species interactions is provided by the Macquarie parakeet. This bird had managed to survive for many years on subantarctic Macqaurie Island in the presence of cats, but was made extinct only after the colonisation of the island by rabbits. Rabbits provided enough food to enable the cat population to increase in numbers, and thus to prey on more birds too.

Various endemic ground-dwelling birds live on many of the remote islands, and these, as well as ground-nesting seabirds, are often especially vulnerable to introduced mammals including pigs, cats and dogs, and may be driven to extinction by them. The three species of rats in the region—Norway, Pacific and ship rats—also all prey on seabirds to varying degrees. The Norway rat preys on eggs, young, and sometimes adults of ducks, wading birds and seabirds.

Both the Pacific rat and ship rat consume a wide range of prey, including many invertebrate and plant items such as earthworms, centipedes, larvae of some butterflies and moths, ants, beetles, weevils, cicadas, snails, spiders, lizards and birds, plus fleshy fruit and other seeds, flowers, stems, and roots. They may also prey on the eggs and young of forest birds.

It is well known that rats and other vertebrates can swim between islands, though it is not completely clear what distances different species can cover under different conditions. A nineteenth century attempt to save a threatened bird species by translocation to an offshore island is known to have failed because of the choice of an island too close to an infested area: the flightless ground parrot of New Zealand (kakapo or *Strigops habroptilus*) was taken in the late 1800s to Resolution Island, but stoats were later able to colonise from the nearby mainland. The parrot was lost from that island and later became extinct on the mainland (although it survived—just—on Stewart Island).

Archaeological remains from islands show past distributions of birds which no longer survive. On Aitutaki, for example, Steadman (1991) records: “six archaeological sites up to 1000 years old…have yielded bones of 15 species of birds, five of which no longer occur on the island…Of these, only (two) survive anywhere in the Cook Islands today". Mammals found there currently include the Pacific rat, dog and pig. Recent archaeological work on Fiji (Worthy et al. 1999) also revealed many species that have become extinct since human colonisation: a crocodilian, tortoise, frog and iguana, as well as a giant pigeon and giant megapode, the latter both flightless.

The brown tree snake is a species that is widely recognised as having caused ecological devastation on Guam. Introduced to that island by mistake in the late 1940s, historical evidence of its slow spread across the island was gained from records of the gradual absence of bird species from the forests. Eventually it was discovered that the snake had caused the extinction of 9 of 11 of Guam's original native forest bird species, by preying on eggs, nestlings and adults. The brown tree snake also causes power outages, and has occasionally been found biting infant humans. Whilst it was previously thought to be a specialist predator, research has shown that the snake is actually more of a generalist. It is now known to take small mammals and lizards as well as birds, and on Guam is thought to have caused the extinction of three species of skink and two species of gecko. This flexibility in its diet has no doubt assisted in its ability to spread rapidly. These snakes can travel between islands concealed in aircraft undercarriages and in containers. Individuals have already been seen in Spain, Texas (USA) and Hawaii. It is imperative that vessels arriving to any state from Guam, or from countries of the snake's native range (northern Australia, the Solomon Islands or Papua New Guinea), be thoroughly checked every time for snakes.

Mongooses are currently distributed only through Fiji and Hawaii, where they have a wide sphere of influence: they eat the young of the endangered Hawaiian crow, as well as eggs and incubating females of the Nene goose. They also attack hawkesbill turtle hatchlings and ground-dwelling birds, and spread the seeds of strawberry guava.

There is no doubt about the serious impact that cats, rats, pigs, mongooses and brown tree snakes have on the wildlife of any island they reach. Little appears to be known, however, about the effects of species such as the house mouse, cane toad, and musk shrew.

Little is known either about introduced birds. The greatest threats they pose to native birds seem to be hybridisation, competition for food or nest sites, or introduction of disease. The mallard duck is known to have hybridised with the grey duck in New Zealand, the Hawaiian duck in Hawaii, and an endemic race of the Pacific spot-billed duck in the Mariana Islands, so that each of these endemic forms has been threatened or replaced. There have been no studies of competition between native birds and introduced myna birds or red-vented bulbuls, although it is believed that interactions must occur. However, there are records of common mynas eating the eggs of wedge-tailed shearwaters, and the eggs and chicks of landbirds in New Zealand, as well as being predators of the Tahitian flycatcher. The greatest numbers of introduced birds occur in Hawaii (47), the Society Islands (12), and the Fijian islands (11).

## 3.2 Plants

Invasive plants may have the following effects on the native flora and communities (including the processes which occur in them): decreased dominance of native species; decreased overall species richness (of native plants and those other native plants and animals that depend on them); fewer vertical tiers of plants (canopy, sub-canopy, etc); lower range of biodiversity over areas; competition with native species; displacement of native species; changes to processes such as water table levels, fire regimes, soil quality and nutrient cycling.

Some phenomena in the plant world are not well understood—such as the ability of naturalised exotic plants to establish in their new country without at first compromising conservation values, but then changing their behaviour over a short period of time and becoming pest species. Thus caution should be observed in considering species for importation: if a species is a problem in one country, it is likely to become a problem in another. This is true of any species but is especially well known in plants. Risk analysis methods exist to reduce the risk of plant importation, given that many may, in future, become pests. On the other hand, introduced plant species which are not pests in one country may in fact turn out to be so in another – probably because the environmental conditions in the new location are more favourable.

Some of the key weed species which have been identified as aggressive invasive species in many South Pacific countries include:

- trees and shrubs: acacias, African tulip tree (*Spathodea*), wild tamarind (or lead) tree (*Leucaena*), guava species (*Psidium*), *Miconia* (velvet tree), red sandalwood tree (*Adenanthera*), Koster's curse (*Clidemia*), *Lantana*, giant sensitive plant (*Mimosa*);
- vines: mile-a-minute (*Mikania*), passion-fruit species (*Passiflora*), *Merremia*;

- grasses: elephant grass (*Pennisetum*), *Paspalum*;
- aquatic plants: water hyacinth (*Eichhornia*).

Many others exist, but the above species are considered to be significant threats to conservation values in at least three, and often many more, Pacific island countries.

An important distinction between types of invasive plants needs to be made. Some may only be significant in areas which are already modified, and will not be important in, for example, continuous native forest. Others may be a problem in both modified and unmodified habitat (disturbance may simply accelerate the rate of colonisation). This broad colonising capability is partly due to their more aggressive nature and capability to actively invade.

Before control or eradication operations can begin, technical information is required about the ecology of the weed. For example, burning may not be a desirable method of control because many plants are fire adapted. Thus they may actually be given an advantage over native species that are not fire adapted. Other considerations that relate to the ecology of the species may be quite subtle. For example, some pest plants in a locality may be only of one sex, so their removal will be permanent (unless the species has the ability to reproduce without seeds) because there is unlikely to be a seed bank from which they can recolonise.

## 3.3 Insects and other hard-bodied bugs

There is little information on the impacts of invasive insects and similar animals, but it is certain that they have been invading since humans began colonising islands, and it seems likely that their impacts on native species have been dramatic. The impacts of harmful insects are difficult to assess, partly because there is very incomplete knowledge of which species occur naturally in various countries. Thus it is hard to link the presence of introduced insect species with any decline in native species, or other effects such as habitat changes.

The types of insects that are most likely to become pests are the predators (those that feed on other animals), although those that feed on plants, or use other animals or plants as a host or for shelter, can also greatly affect conservation values. The most likely types of insects to colonise a new island are those which are adaptable, and species which do not necessarily need males and females for reproduction. The most favourable situation for invasion is one where suitable host plants or animals and matching climatic conditions already exist. Some insects, such as aphids and white-flies, may act as vectors of viruses and mycoplasma-like organisms (microscopic sub-cellular life forms which may become pathogenic in a plant's cell) which may cause even more damage than the insect itself.

### Ants

Ants present one of the greatest threats to many native species (not just other insects or bugs), and their effects on native communities have been relatively well-documented. The pest ant species meet many of the classic characteristics of successful colonising pest species: they are adaptable, generalist feeders, tolerant of widely varying environmental conditions, and are aggressive colonisers. The ecological significance of this group is that they prey on almost any other insect or "bug" and may also prey on birds and other large animals. Thus they may affect whole communities at once, and may dramatically and irreversibly change these through their ability to cause many local extinctions. It is worth noting too, that the removal of whole groups of insects and other "bug" species will probably cause flow-on effects in the community to remaining species which would normally depend on them, e.g. native birds. Ants also feed on the sugary secretions from bugs feeding on woody plant species, and so may protect these insects from their natural predators, allowing them to reach unusually high densities on the plants, which may then become stressed and die. In other words, the whole structure of the native habitat may be affected.

Some of the ant species have biological characteristics which make them particularly easy to accidentally introduce to new islands, where they may become established. The species are tiny, and difficult to intercept at quarantine, especially if officers are not forewarned of the characteristics of ants and how to find them in, or on, materials entering the country. Some of the pest species, unlike other ants, have many queens to a "super-nest", any one of which may be transported to start up new colonies. Some of these pest ant species are not territorial but tolerate ants from different nests, so they may reach extremely high densities and have a major impact on native species.

The problem of ant range expansion is compounded because some people have a mistaken belief that these ant species can be used in agriculture for biological control of pest insects which are attacking commercial crops. In some parts of the world, local people actively spread ant species, hoping to take advantage of their aggressive biological characteristics to remove all the pest insects in the area. There has been little or no scientific study on the effectiveness of this method, but there is more than enough evidence to show the undesirable effects on native ecosystems that result from ants being imported into a region.

The following species present a grave threat to conservation values because they will invade native communities and affect many or all of the animals and plants in that community: big-headed ant; long-legged or crazy ant; Argentine ant; fire ant; *Solenopsis papuana*; glaber ant; little fire ant (*Wasmannia auropunctata*). This last-named species may be one of the biggest threats to the conservation of native communities because of its aggressive behaviour, pervasive effects on all sectors of the community, and ease of spread to new islands.

Pest ant species are known to have a widespread distribution in the Pacific. However, given the lack of specialised survey and identification expertise available, the distribution is almost certainly greater than currently reported. For any strategy against ants, the essential points to consider are that: (1) no individual species has colonised all island groups, and therefore it is well worthwhile protecting the remaining islands from further invasions, given the severe impact these insects have on native communities, and (2) the rate the ant species are spreading to new island groups is extremely fast and is therefore presenting a serious threat to native biodiversity.

#### Wasps

Wasps belong to the same large group of insects as ants, and hence share many of their biological characteristics and present much the same problem to native species and habitats.  Some wasp species create queens which lie hidden in dark shelters until the next nest-making season. At this time they may find hideaways on packing cases or containers and thereby effectively introduce themselves to a new island. Wasps are very efficient predators and colonisers; as they can fly further than ants, they probably are able to colonise faster.

Two main groups of wasps present threats to conservation values: the *Vespula* and *Polistes* groups. Both form colonies called "nests", but the former group creates much larger nests than the latter. The sting of these wasps is usually extremely painful to people and therefore the wasps present a public nuisance problem. In New Zealand the *Vespula* wasp can occur in such high densities in the forest areas of plentiful honeydew where they feed that they exclude people. *Vespula* wasps may be controlled by poisoning techniques, although it is much more cost-effective, as with all pest species, to keep them out.

#### Mosquitoes

Certain mosquitoes may transmit the one-celled organism which causes avian malaria. This disease can cause the extinction of bird species, as has happened on Hawaii. The most likely way that bird malaria may arrive in a country is through the introduction of non-native birds (such as cage birds or pets) infected with the disease.

#### Other groups of insects

The beetle group is one of the most diverse Orders of (mainly) terrestrial animals in the world. This group, and also moths/butterflies, scale insects, mealybugs, aphids and white-flies, are extremely successful invaders. Many of these groups have the biological characteristics of the ants, and many species in these groups are known as serious pests, but the great majority of documented cases have been pests of agriculture. Little is known about their impacts on native habitats and species but it is certain that they present a grave threat. For example, the Asian gypsy moth threatens all forests (exotic as well as native) in temperate countries through the effects of its larva feeding in huge densities on the leaves of trees. Overall, the interception of exotic beetles and moths or butterflies is essential to prevent their having an impact on native habitat.

### 3.4 Land snails

The snail fauna on many Pacific islands is being destroyed very quickly by invasive snails, resulting in a loss of diversity between and within island groups. Introduced land snails may be extremely efficient predators, causing the relatively rapid extinction of native land snail species, while other introduced land snails may be extremely efficient at feeding on plants and may destroy the native habitat. In general, the invasive species also have exceptionally fast rates of reproduction, often faster than the native species of snail they prey on. Many of the native snail species grow and reproduce at extremely slow rates, so the depredations of the introduced snails will mean a long period is required to allow recovery. Other invasive land snails may cause reduction in numbers of native species because they live in high population densities, and so force competition for resources. It is not often realised how devastating the effect of such activity by such small species can be.

The high islands appear to harbour the highest diversity of native land snails (as well as other small native animals such as insects) and are therefore at greatest risk from the effects of introduced snail species. However, there are major gaps in knowledge of the distribution of introduced land snails, including in the following countries: Palau, Fiji, Tonga, Solomon Islands, Society Islands (French Polynesia), some of Samoa, New Caledonia and Papua New Guinea.

The giant African land snail has been considered to be a threat to agriculture and a nuisance. It has also been implicated in the transmission of a form of meningitis. This has prompted the introduction of at least two species in various countries to reduce its numbers: a predatory snail (called the "rosy wolf snail", *Euglandina rosea*) and a flatworm, *Platydemus monokwari*. There has been poor documentation of the success or otherwise of these introduced species in controlling the giant African snail, and there are cases where they have been introduced despite the lack of prior testing to ensure that they would attack only the giant African landsnail and not native species.

Agricultural practices have been identified as the cause of entry for other invasive species of snails, moved for example in soil adhering to the rootstock of horticultural products. One species of freshwater snail carries a parasite of cattle, the liver fluke. This tempts officials to try to control snail numbers using predatory species, but these introductions do not restrict their prey to the snail carrying the fluke, and therefore place native species at risk.

Deliberate introduction usually happens for two reasons: (1) a species is seen as a beneficial food or "improvement" on locally available hunting stocks, and (2) it is an ill-advised, or sometimes illegal, attempt to remedy a previous such introduction of food species which has turned disastrous, such as the predators to control the giant African snail. Species have also been introduced by the aquarium trade. All introductions for commercial reasons have resulted in escapees establishing populations in the wild. Probably between 100 and 200 non-native species of land snail have been introduced to islands around the Pacific. However, a lack of information on the ecology of many invasive species of land snail means it is difficult to predict which islands are at risk and therefore where to focus conservation efforts. For much the same reason, the eradication of pest snail species is probably technically impossible at present except perhaps on a small scale. Prevention of entry, rather than later control, is the most important means of stopping the spread of pest snails.

## 3.5 Invasive freshwater fish, toads, frogs, and crayfish

The reasons for fish being introduced include: aquaculture ("farming" an aquatic species for export or local markets), sport, the "improvement" of wild stock (introducing a new food species into a waterway), the aquarium trade, the control of pest species, and accidental introductions.

Introduced fish may have the following impacts: modification of habitat (such as removal of key plant species and lowering of water quality); introduction of parasites, pathogens and diseases; changes in the availability of food for native fish species; hybridisation with native fish species; and forced change in the distribution of native fish species. Nine fish species have been introduced into four or more territories and three species, namely the Mozambique tilapia, mosquito fish and guppy, into 10 or more territories in the South Pacific. The tilapia has been introduced to control mosquitoes and weeds, and as a bait fish, but has become a pest in most instances. Reductions in the numbers of native fish and bird species have been linked to its introduction. Similar effects have been observed with other fish groups, including guppies, which are popular with the aquarium industry. Aquarium and aquaculture species introduced into the wild are likely to have had the same impacts, such as destruction of populations of native species.

Native frogs and toads are virtually non-existent east of the Melanesian islands. The most widespread introduced species is the cane toad, usually intended to control pest insects of agriculture. Little or no robust scientific evidence exists to show that the toads are actually controlling pest species, whereas scientific studies in Papua New Guinea show that their introduction there has been more disastrous than beneficial: they have become a nuisance and have been responsible for dog, cat, and even some human, deaths. Native snakes taking the toad are probably also at risk from poisoning.

Another introduction, tree frogs from the Caribbean, is potentially disastrous because of the frogs' predatory impacts on native insect species and competitive interactions with birds.

At least five species of freshwater crayfish or prawn-like species have been introduced to Pacific island freshwater systems. These include the giant Malaysian prawn and the giant freshwater prawn, which have both been introduced for aquaculture. These and other species may escape into freshwater habitats or establish there through deliberate introductions, and are known to carry diseases and parasites which are foreign to the native species and potentially devastating. They may also be voracious predators on native freshwater fauna such as snails.

Because there are relatively few (compared to continental islands or continents) freshwater or brackish habitats in the Pacific islands, a premium is placed on their conservation.

## 4. Legislation

No systematic review exists of all SPREP Pacific island country legislation which focuses on invasive species. Two projects which at least partly address this are under way, but at the time of writing no results were available. However, twenty-one countries were surveyed to determine whether they had legislation which specifically dealt with preventing the introduction of alien species—whether or not that species was a potential threat to conservation, human health or economic interests such as agriculture. There was no information available for nine countries. Of the remaining 12, all had legislation which dealt with the quarantine of new organisms being brought into the country. Most of these seemed to be focused on species which might affect agricultural interests. The Cook Islands had one statute which dealt specifically with containers and the special threat they pose as vehicles for invasive species.

A review of environmental legislation of the Cook Islands, Federated States of Micronesia, Kingdom of Tonga, Republic of the Marshall Islands, and Solomon Islands (Boer 1996) includes descriptions of legislation covering wildlife, natural areas, agriculture and forestry, and fisheries. Hence, this legislation nominally dealt with invasive species affecting conservation values. Almost none of the legislation from these countries which addressed wildlife and its habitat included regulations dealing with invasive species which might threaten these values. Invasive species were dealt with in the legislation for agriculture and forestry, and fisheries (mainly marine), and thus ignore natural areas and conservation values. Interestingly, of the recommendations made in that report on the form new legislation should take, none included upgrading the statutes dealing with invasive species – let alone mention of invasive species which threaten native wildlife and its habitat. Exceptions to the lack of legislation banning importing wildlife except under permit included Yap and Kosrae (both dealing with parrots).

## 5. Pathways: how invasive species get to new localities

This section describes how exotic species gain entry into new islands or countries. The information has been drawn from the technical reviews for the various major groups of animals and plants, from discussions with quarantine officers and law enforcement officers, and from personal experience.

### 5.1 Intentional introductions

Many pest species have gained widespread distribution in a country due to the planned and coordinated efforts of people—often officials—introducing one species for the control of another pest species. This practice is referred to as “biocontrol”. For example, the cane toad was introduced in Fiji to control insect pests which were thought to occur in sugar cane fields. The problem is that the species introduced may prey instead on native or non-pest species and itself become a pest, as has in fact occurred in Fiji with cane toads. Plants, too, are widely used and distributed by humans. Many trees used for plantation forestry (e.g. eucalypts, acacias) or for soil stabilisation (e.g. some grasses) become invasive. In New Zealand, for example, about three-quarters of the weeds of concern to conservation were brought in for horticultural uses. Occasionally a species is planted with the best of intentions, such as the creation of wildlife habitat: unique mudflat habitat has been destroyed on Rodrigues Island (Indian Ocean) by the planting of mangrove trees for wildlife, in areas where the mangrove did not naturally occur.

Imported species (such as prawns and fish) which are intended as new food “products” may become pests because they inevitably escape or are released into native habitat, perhaps when the introduction becomes uneconomic and the venture is abandoned. Some of these profit-driven introductions have been made by government employees who have by-passed normal approval channels in an attempt to ease the establishment of commercial ventures.

Illegal imports may include protected species in contravention of the Convention on International Trade in Endangered Species of Wild Flora and Fauna (CITES). These species may not be rare (although still protected in their home country), but nonetheless will be successful at colonising a new country and will become pests. This risk relates to the fact that most captive animals at some stage end up being released into the wild. It is a common human reaction to want to “release” an unwanted pet into the wild rather than have it killed. What are border officials to do with intercepted rare or protected species? To kill them would be to reduce the population still further. To sell them would mean that smugglers may be able to buy them for a small fee and continue smuggling. To keep them in captivity for the rest of their lives is expensive and perhaps inhumane. To repatriate them is usually unthinkable—where exactly did they come from, and have they been exposed to disease on the way? To release them is to risk introducing any disease they might be carrying.

Genetically modified organisms (GMOs) may also be invasive species in the wild or may become invasive species (for example, if genetically modified pollen fertilises related local plants). Thus rigorous risk assessment procedures (such as are used by Australia) need to be carried out before such species or their seeds are imported. One of the issues associated with GMOs is whether the importer or the exporter should carry out risk assessments on the likelihood of organism escape, hybridisation, and establishment in the wild. Two considerations in resolving this issue are the high cost (and who should carry it while retaining scientific rigour) of scientifically assessing what the risks are, and of the availability of required technical expertise, especially in developing countries.

## 5.2 Unintentional introductions by humans

Unintentional introductions are avoidable if standard operating procedures are followed. Cases where the development of a procedure is vitally important include the following:

(1) Military use (naval and aerial) of islands for exercises and the inadvertent importation of alien species. This is aggravated by the military's often assumed "right" to "go anywhere at any time" regardless of the risks, in this case, to native fauna.

(2) Discharge to local waterways of ships' ballast water containing new species which are often aggressive invaders. Standard operating requirements, such as ballast discharge in blue waters, may reduce this risk.

(3) Importation of timber chip and timber (especially if the bark is present), bringing in insects and disease organisms. Such imports should (a) be subject to regular checks for the presence of disease and (b) never be complete with bark, which acts as an excellent shelter for insects and other species.

(4) Tourist activities, which may introduce invasive species to pristine islands. These introductions may be from tour guides not checking visitors' boots and equipment, or yachts making unauthorised visits, and from either type of visitor failing to observe standard practices for visiting pest-free islands.

(5) Packaging and containers which may carry invasive species. The organisms may occupy the goods, packaging, or container itself at the port of origin or en route, especially if the goods, packaging, or container are left to "stand" in locations where invasive species can gain access to them.

(6) Horticultural imports such as seed (without a purity test), root crops (which may contain soil residue and its associated organisms), and live plant material (which might harbour invasive species on or inside the material, or be a weed species itself).

(7) Many countries are entering into free-trade agreements which may involve effectively "dropping their guard" against the risks of importing invasive species. Thus each new agreement needs to be professionally and critically reviewed to check that no extra risk of invasive species is involved.

## 5.3 Negligence and other factors

Despite existing regulations (such as quarantine), enforcement may not be implemented, perhaps through negligence, ignorance, or a lack of facilities to carry out the tasks required. Proper enforcement of existing legislation is often enough to block a pathway previously open to invasive species. Current training of quarantine officers is generally not extensive enough to include invasive species that threaten conservation values; it is mostly limited to pests which threaten agricultural, forestry, fishery or human health values. Though overlap occurs, training programmes need to recognise the inter-relatedness of these fields, and to accord importance to conservation values in their own right.

## 5.4 Biological dispersal, or self-introduction of species

Plants and animals have evolved highly sophisticated means of dispersal and will, of their own accord, colonise new habitat and islands once humans have helped by taking them to a new country or island group.

Introductions of new or even existing species of animals to islands or countries may, unwittingly, involve the introduction of associated parasites or disease organisms. The problem is reduced with proper quarantine procedures.

Many invasive species may be spread by native or exotic animals. An example is the bulbul (itself an invasive species), which will feed on fruits of invasive plants and spread the seeds through its droppings. Similarly, pigs will spread seeds this way, and at the same time will accelerate the spread of invasive plants by changing the conditions in an area through pugging and rooting of the ground. Browsing species such as goats and cattle have the same effect by removing the native species from near the ground, allowing unpalatable weed species to colonise the area.

## 6. Issues arising from this review of invasive species

### 6.1 Information

Because of the nature of the Pacific islands region (i.e. huge area, scattered island groups), there are problems with the gathering of information and with communication. The vast ocean distances between small island nations mean that frequent visits for monitoring purposes are not practical. Remote islands are less well known biologically, while the bigger, more populated islands are usually better known, so information is unevenly spread between islands.

To be able to predict and warn of possible new species invasions, basic information is needed about which taxa are on which islands, and which pathways exist between islands. However, this information is generally lacking. There are not many analyses of shipping patterns and container routeing, noting sources, destinations, and trans-shipment stations. Such work, plus an analysis of success rates of species interceptions (including data on what is being sent to whom and from where) for mail and customs at air and seaports, would be very useful. After more invasive species information has been collected, care should also be taken to store and disseminate it accessibly, so that managers and decision-makers can make optimum use of it. Dissemination of information could be achieved using databases such as the Pacific Island Ecosystems at Risk database (http://www.hear.org/pier/) or the ISSG/GISP Global Invasive Species Database and Early Warning System (http://www.issg.org) although it needs to be borne in mind that not all island countries have ready access to the internet.

Technically, communication is often a problem: telephone lines may be of poor quality with perhaps only one line serving a whole organisation. Culturally, many people prefer to communicate directly with people they know, face to face, rather than with strangers by letter or telephone. In the effort to improve conservation information and techniques within the Pacific, it is the local people who can provide the understanding of how to link conservation practice and culture, in order to improve the status of threatened species, or restore partially destroyed ecosystems.

National borders are an obvious place to start the search for newly arriving species. Each nation needs to consider whether its resources are being used as effectively as possible at borders, and to ask in general: how is it best to monitor an island or island group for newly introduced species, and who has responsibility for reporting and dealing with such incursions? Border control officers need to know what kind of organisms they are looking for, how they might behave and where they may be hidden. But at the same time they must continue to search for any new organisms not previously known as invasive species. As many incoming goods should be checked as resources allow. In addition, the wider region would benefit if individual nations inspected their exports before dispatch. In summary, there should be a dedicated team, specifically monitoring border entry sites and looking for founder populations. In island nations, it is also important to monitor inter-island traffic. An IUCN Environmental Policy and Law paper observes of one government department within the Pacific region: “The plant and animal quarantine section of the Division is poorly staffed, and under-equipped. Inter-island movement of goods is relatively unfettered. Quarantine regulations are little known and rarely used. Enforcement is infrequent.” (Boer 1996). Better information will begin to solve some of these problems.

As well as border surveillance, it is useful to have a network of people alert for any new records of species. If there are no conservation workers or field officers regularly “covering” an area, there may be guides, tour leaders, or dive operators who could at least be asked (and educated) to watch for out-of-the-ordinary animals or plants, and perhaps even to perform a monitoring role.

Education of the public, land managers, politicians and decision-makers should aim to demonstrate the value of biodiversity, and the implications of its loss through invasive species. One important question is: what are the best methods ***within the Pacific cultural context***, for education of the general public or specialists (e.g. quarantine officers)? Such education should be strongly focused on the conservation aspects of invasive species, not solely the agricultural/economic or human health aspects. National media may help with this, as have the newspapers in Tahiti, in reporting about *Miconia*, known locally as the “green cancer”. Tahiti’s Ministry of Health and the military have helped, with their efforts to clear some areas of this pervasive tree, which now covers windward Tahiti.

Today, we believe we recognise the problems that introduced species can cause, and yet there remain many cases, perhaps still due to ignorance or insufficient scientific knowledge, where seemingly harmful decisions are taken. To confound matters, poor technical information may be given to biological control practitioners. The predatory rosy wolf snail was introduced on the basis of "technical advice" to control the giant African snail, which is a crop pest. No proper screening process had been followed (even though such protocols existed) to ensure that the introduced snail attacked only the intended prey. Rosy wolf snails, though much smaller than the giant African snails, do prey on them. However, for whatever reason, they made a much better living preying on native and endemic snails, including families such as the Partulid tree snails (of Moorea and Tahiti), which are now either locally extinct or very threatened. Similarly, "technical advice" has been given by "reputable" sources about the flatworm *Platydemus monokwari*. After introduction as a biocontrol agent, it was found to consume native snails. The result of this poor information has been widespread losses of many species of snails, a number of which were genetically unique to separate valleys.

These cases of bad practice include (1) taking guidance from projects which are poorly reported, or in which the technical information was incomplete or never gathered; (2) farmers or landowners taking it upon themselves to introduce species for their own ends, regardless of any regulations which might exist to prevent such actions; (3) simply ignoring previous bad experiences with the same introductions despite contrary advice.

Intelligence gathering related to illegal practices such as smuggling is required. Western Pacific rim countries and Pacific island countries already have cooperative joint security committees. Invasive species should be placed on their agenda as a legitimate national security issue. Similarly, the issues (as described above) for GMOs need urgent consideration, to keep pace with dramatically increasing commercial pressures to develop and use GMOs and their products.

## 6.2 Research

Before policy can be set, there is a great need for background knowledge and basic research. Which species are "native" in a country? In order to answer this question, there is a need for palaeoecological studies (to discover which species were living at certain times), and biosystematic studies of locally occurring native taxa.

Once there is good local knowledge of native species distribution, decisions can be more easily made about where the remaining populations of native or endemic taxa exist, so that these areas can be made a priority for conservation. It is also important to carry out "baseline surveys" and monitoring, in order to anticipate possible damage from newly arrived species.

Compiling an inventory of islands which are candidates for restoration should be attempted, namely those with a relative absence of pests, or with biologically important communities of flora or fauna. These islands then need surveying for pest species and their impacts (especially on islands of over five hectares), and a priority-setting system should be developed which permits identification of target islands for restoration projects and funding.

New "early detection" methods (intercepting pest species at low densities) are required so that founder populations can be efficiently detected and destroyed, and so that the monitoring of invasive species during control and eradication operations is possible. Some of the most devastating groups of organisms for which there should be a special watch are ants, wasps, the brown tree snake, rats, *Miconia calvescens*, and *Mikania micrantha*.

Other research topics which would greatly aid this work include:

(1) design of suitable bait types (distributed in weatherproof bait stations) for use in the tropics against rats;

(2) new techniques for border control officers for the detection of new invasive species which may threaten conservation values;

(3) risk assessment of species proposed for importation using models such as exist in Australia and New Zealand. Emphasis should be placed on assessing their risk to conservation values rather than to economic interests and human health. If current risk assessment methods are inadequate for this purpose, new methods need to be designed.

## 6.3 Policy, Legislation, Advocacy

Invasive species are known to threaten human health, economic values and conservation values, all of which are inter-related. Until now, there has tended to be least recognition of the huge impact of invasive species on natural flora and fauna. Future policy and legislation should reflect the extra need to protect conservation values.

Legislation is required in most cases to demonstrate the seriousness of the need to prevent invasive species that harm conservation values, and to effect change. Once legislation exists, there is a serious need for resources (e.g. enforcement officers, isolation facilities, search equipment) for its implementation. Enforcement is the cornerstone of this legislation; legal statutes are useless if compliance mechanisms do not exist.

When such legislation is drafted, local people and customary landowners need to be convinced of the uniqueness and importance of their local environment. If they are consulted about how best to monitor for invasive species, and to work within local custom, the project stands the greatest chance of success, and the least expense will be required for enforcement.

## 6.4 Trade

As trade volumes increase within the region, and the commodities traded become increasingly "westernised", people within the region are exposed to a greater choice and quantity of imported goods. With a larger volume of materials being moved, and new levels of consumption involving more packaging, the likelihood of transporting new species is heightened. With it comes the risk of destruction of the local environment (not only from pest species but also from non-perishable waste). Traffic between islands in archipelagos is increasing, but there is little or no recognition of the individuality of islands—some may be free of rodents or a particular invasive plant, even though these species occur elsewhere in the island group. The value of excluding an invasive plant from an as yet pest-free island is great.

Dumping of the increased amounts of waste products in landfills also provides extra colonisation sites and food for pioneer plants and animals such as rats. If these dumps lie next to harbour areas, as is often the case, this presents a prime opportunity for the spread of species such as rats, which can be so destructive to fauna and flora.

With the growth in affluence of many of the world's nations, pursuits such as the keeping of aquaria and unusual pets have become more popular, and trade in tropical fish and invertebrates has also increased. Aquaculture facilities and the farming of aquatic organisms is becoming more widespread. It is not true that such species, imported for captive use, will always remain captive. Inevitably, some escape and find their way into streams or the ocean.

## 6.5 Solutions

Protocols need to be developed, explained, and distributed for use during activities such as:

(1) building construction (where the cleaning of machinery between sites is of great importance);

(2) new road construction during logging;

(3) slash and burn practices.

All of these may accelerate the spread of invasive species. Protocols are also needed for inter-island shipping, to counter rat invasions, and should cover variables such as bait stations, emergency supplies of bait, contingency plans upon discovery of rodents, freight inspection, education of passengers departing on inter-island travel, etc. This work should be developed by motivated and knowledgeable people.

The risks of transferral of invasive species *within* island-groups must be reduced by procedures designed to stop their spread. In Hawaii, for example, there are some very harmful invasive plants which are present on some islands, but thankfully absent from others. A lot of time and money could be saved by taking a little care to exclude these plants and yet, in general, the benefits of inter-island quarantine are not recognised.

Pest monitoring stations should be established at air and sea ports using methods which will intercept targeted "high risk" species. For example, pheromone traps would catch and indicate the presence of Asian gypsy moth and other similar species, and pitfall traps would catch ants. Permanent rat poison stations should be established first at key ports from which regular inter-island ferry services leave for rat-free islands, and secondly at the destination islands.

Whole pest-free islands, or island groups, should have reporting and contingency plans designed for them. One national contact position (person) should be made responsible for liaison with outside groups and can be "primed" to look out for new arrivals of pest species. As an extension to this, it would be helpful if *in situ* personnel or positions could be identified, and those people given responsibility for actively setting up new initiatives to counter invasive species. Such people could also identify key native species—the ones which are threatened by invasive species—and ensure that these are monitored so that "baseline" information on their populations is collected over the years, enabling any decline in numbers to be noticed.

In an attempt to reduce the risk of within-country spread of invasive species and other problems, it would be valuable to identify and set up possible "model projects" on islands which are recognised as having high conservation values. These projects can serve to test methods, educate others, and act as a resource to promote the value of invasive species projects. For the sake of maximum efficiency, as many projects as possible should be integrated, so that work and resources are not duplicated, but are shared. Other conservation programmes, as well as quarantine and general education programmes, could have invasive species messages integrated into them.

As indicated earlier, it is important to note that the invasive species problem is a national security issue, and hence needs to be tackled using a holistic approach. Economic and human health issues are part of the problem, and should be dealt with, but without neglecting the serious impacts on native species and ecosystems. The problem has grown rapidly as trade and transport have become so fast and global, but resources to deal with the problem have not developed as quickly.

If a new species is showing invasive or harmful effects, a decision must be made about whether eradication is possible. It is important to note the technical differences between eradication and control. Eradication may be defined as the permanent removal of all individuals of a species with little or no risk of re-invasion. An eradication programme may take more than one year. However, eradication is usually designed to be a one-off operation, and hence requires detailed knowledge of the target species' biology and lifecycle. For example, rats may be most easily removed from an island after they have just experienced a harsh season with little food. At this time they will be most willing to consume poison baits. Weather is also important. If rains are expected for a certain season, that may be precisely the wrong time to use poisons which can be broken down quickly and washed away. The initial cost of eradication is high, but if it is carefully done and effective, there will be no ongoing costs.

Control refers to ongoing reduction in numbers or density of a species to pre-determined levels. These levels will have been assessed so that the threat(s) to the conservation values (such as native species or ecosystems) can be reduced to whatever is deemed an acceptable level. In the case of weeds (and possibly other groups of invasive species) "control" has meant containing the weed species within a defined distribution. Thus ongoing control of invasive species presents a radically different scenario from that of eradication. The decision to undertake long-term control of an invasive species should not be taken lightly. On a remote island or atoll which is rarely serviced by shipping it may be unaffordable or unsustainable. Thus control involves a continued commitment, and access to funding. It raises the potential of risks to non-target species, through the use of broadcast poison baits, for example, and, because of this environmental exposure, also leads to the possibility of resistance to toxins building up in invasive species.

In conclusion, as mentioned earlier in this paper, prevention is the most important practice, followed by eradication, and then control. Once a species is established and doing damage, its removal is mostly very difficult, expensive, and time-consuming; and usually also has some cost to the environment.

## 7. Acknowledgements

Our thanks to Susan Timmins, Rob Cowie, Wilco Liebregts, Jim Space, and Geoff Gregory for their critical review of the text. We acknowledge this paper is in part a summary, in everyday language, of the technical information contained in the specialist group reviews in this publication. However, we take full responsibility for accuracy and any opinions expressed.

## 8. References

Boer, B.W. (ed.) 1996. *Environmental law in the South Pacific: Consolidated report of the reviews of environmental law in the Cook Islands, Federated States of Micronesia, Kingdom of Tonga, Republic of the Marshall Islands and Solomon Islands.* IUCN, Gland and Cambridge. 273 p.

Lever, C. 1994. *Naturalised Animals*. Poyser Natural History, London.

Steadman, D. W. 1991. Extinct and extirpated birds from Aitutaki and Atiu, Southern Cook Islands. *Pacific Science 45(4)*: 325–347.

Worthy, T. H.; Anderson, A.J.; Molnar, R.E. 1999. Megafaunal expression in a land without mammals—the first fossil faunas from terrestrial deposits in Fiji. *Senckenbergiana biologica 79*: 237–242.

# Land vertebrates as invasive species on islands served by the South Pacific Regional Environment Programme

**Ian A. E. Atkinson and Toni J. Atkinson**

*Ecological Research Associates of New Zealand Inc., PO Box 48-147, Silverstream, Upper Hutt 6430, New Zealand*

## Abstract

This report reviews available information on the adverse effects of 14 alien vertebrates considered to be 'significant invasive species' on islands of the South Pacific and Hawaii, supplementing our own experience with that of other workers. The biological characteristics of each of these invasives are outlined together with what is known of their impacts on native plants and animals. The most widespread are goats, pigs, cattle, cats, dogs, mice, and three species of rats. Island groups are listed in alphabetical order with summary comments on their habitats, status with respect to damage by these invasives, and potential for restoration where known.

More information is needed on the impacts of invasives on indigenous species and habitats so that priorities can be decided for controlling or eradicating those posing the most serious threats. Preventing the further spread of invasive vertebrates and keeping relatively unmodified islands free of invasives are discussed. Island governments need to protect islands from further invasions for reasons of economic interest and human health as well as maintaining conservation values. A specific recommendation is made for establishing an effective strategy that will reduce or prevent further establishment of invasive animals. Suggestions are made for restoring particular islands; searches should be made to identify those islands where it appears feasible to restore and maintain indigenous vegetation and wildlife.

## 1. Introduction

This review of the invasive land vertebrates present on islands of the South Pacific Regional Environment Programme (SPREP) region is part of a larger review of the invasive plants and animals that have affected these islands adversely. Numerous alien species of mammals, birds, reptiles and amphibians have been introduced to this region.

Some of these have become widespread and exerted serious negative impacts on native plants and animals. These are goats, pigs, cattle, cats, dogs, three species of rats, and mice. Some other introductions either capable or potentially capable of serious negative impacts are at present restricted to a few islands. These are rabbits, brown tree snakes, mongooses, musk shrews and cane toads, all of which could be spread further by human activity. These 14 alien vertebrates are referred to in this report as "significant invasive species". The report outlines the biological characteristics of each, their distribution among islands of the SPREP region, and what is known of their impacts on native plants and animals of these islands. We stress, however, that this list of 14 species is based on what we know at present and does not mean that other species not covered in detail are necessarily insignificant in their effects. If New Zealand had been reviewed, for example, sheep would have been included as a significant invasive species; donkeys are very significant in the Galapagos Islands; and both Hawaii and New Zealand have suffered significant conservation losses from deer. Effects of introduced birds on the native plants and animals of islands in the Region are still not clarified.

Information in this report is derived largely from searching the literature but is supplemented by direct communication with other workers in this field as well as the experience of the writers. Detailed information is lacking for some of the invasive species discussed, particularly musk shrews, cane toads, and introduced birds. Information for the islands is also uneven in detail. The checklist of islands published by Douglas (1969) has been invaluable but the naming of some islands remains unclear and some of the island areas she quoted are incorrect. We have not listed islands where we have no information on invasive species.

We are sure that many of the information gaps in the island section of this report can be filled by either communication with knowledgeable residents or through visits by an informed person. In the time available, we have not been able to find what we regard as adequate information for several groups of islands: Caroline Is, Chesterfield Is, D'Entrecasteaux Reefs (northwest of New Caledonia, not to be confused with the D'Entrecasteaux Islands of eastern New Guinea), Gambier Is, Loyalty Is, Marquesas Is, Marshall Is, New Caledonia, Palau Is, Santa Cruz Is, Solomon Is, Tonga, Tuamotu archipelago, Tuvalu, and Vanuatu. New Guinea and its surrounding islands are more difficult and may require communication with a larger group of people, if not a field study, to obtain a more complete picture.

Islands under French control may not have had sufficient attention because French is not our first language.

Question marks alongside dog, cat, pig, or mouse indicate that these animals are likely to be present in the island group and are likely to be free-ranging or feral. But we have not been able to find written confirmation of this belief.

We were asked to include Hawaii as a source of examples although these islands are outside the SPREP region. Impacts of invasive animals have been more extensively studied in Hawaii than elsewhere in the Pacific.

# 2. Ecology of significant invasive animals

## 2.1 Cattle (*Bos taurus*)

### Characteristics and spread in the Pacific

Cattle of various breeds (originally native to Asia) have been introduced to a number of islands in the Pacific as the basis for a meat industry. They are particularly important in Hawaii and New Caledonia.

### Impacts on conservation values

Unless well contained by adequate fences, cattle wander into native vegetation wherever suitable food is available. If unchecked this can result in the formation of feral herds roaming wild through extensive areas of country. In Hawaii, feral cattle are present in remote forests, subalpine scrub and on inaccessible lava flows (Tomich 1969). Scott et al. (in Stone 1984) regarded domestic and feral cattle as the "single most destructive agent to Hawaiian ecosystems, particularly to koa forests". Regeneration of young koa (*Acacia koa*) trees is completely suppressed in some forests of Hawaii (Baldwin and Fagerlund 1943). Cattle grazing was considered to be a primary factor in the decline of an endemic leguminous vine (*Vicia menziesii*) on the island of Hawaii (Warshauer and Jacobi 1982). Snowcraft (1983) found that cattle browsing was more destructive to mammane (*Sophora chrysophylla*) forests on Mauna Loa volcano, Hawaii, than sheep browsing. Anson visited Tinian Island, Northern Mariana Islands, in 1742 and attributed the island's park-like scenery to overgrazing by cattle (Walter and Robins 1974). In New Caledonia, Barrau (1981) considered that open-range cattle grazing had destroyed much of the pre-colonial landscape in which savanna woodlands had been present.

### Prevention/control

Well maintained fences can give adequate protection from cattle to areas of native woody vegetation. Dogs and shooting are a standard method of control.

### Current researchers and control experts

B.D. Bell, Wildlife Management International, PO Box 14-492, Wellington, New Zealand.

## 2.2 Feral goat (*Capra hircus*)

### Characteristics

Feral goats on Pacific islands are derived from domestic goats (originally native to Asia), introduced to an island for their milk or released as potential food for people marooned by shipwrecks. Goats usually move in groups that can build to large herds as their numbers increase. Home ranges, i.e. the areas searched for food, can vary from 100 m to 20 km in width. Males are bearded and have a strong smell during the breeding season. They do not defend territories and wander more widely than females (Rudge 1990). Studies in New Zealand show year-round breeding; a population recovering after control was able to double in about two years (Rudge and Smit 1978).

Grasslands, scrub and forest are all used extensively by goats as feeding areas. Goats particularly like open areas in which to rest or sun themselves, but at night, or in bad weather, they may seek shelter under rocky outcrops or other places where they can keep their fur dry. In Hawaii, goats are present on all main islands from low to high altitudes, where they destroy or damage communities in both dry and wet zones (Stone 1984).

### Spread in the Pacific

Feral goats have become established on at least 9 island groups within the SPREP region.

### Impacts on conservation values

Goats have been recognised as "the single most destructive herbivore" introduced to the islands of the world (King 1985). By eating young trees in a forest they prevent the replacement of adult trees that form the forest canopy. In extreme cases, such as on

Isabela Island in the Galapagos group, a mosaic of low forest and an open woodland has been replaced by grassland and depleted woodland or other kind of non-forest vegetation, within a 10-year period (F. Cruz, pers. comm.). Goats were present on Cuvier Island, east of Auckland, New Zealand, between 1910 and 1960, when they were eradicated. A 36-year study of forest recovery since the eradication showed that more than two-thirds of the tree and shrub species present had been reduced by goats, some to very low numbers. At least six other plant species on the island had probably been eliminated by goats (Atkinson, in prep.). In addition, early collections indicate that at least six plant species became extinct on the island as a result of the goats. Goat impacts of this kind have affected many other islands throughout the world, although they are seldom properly documented.

### Prevention/control

Goats are extremely difficult to exclude from an area with fencing. They can be controlled effectively by hunting with dogs, or shooting from the air, but the operation must be planned carefully to ensure that conservation values most at risk from goats are protected. Removal of goats can lead to rapid recovery of suppressed vegetation on an island (Coblentz 1978). Feral goats have been eradicated from 16 New Zealand islands (Parkes 1990), the largest of which is Raoul Island (2938 ha) in the Kermadec group.

### Current researchers and control experts

Dr I. Atkinson, Ecological Research Associates of NZ, PO Box 48-147, Silverstream, Upper Hutt 6430, New Zealand.

B.D.Bell, Wildlife Management International, PO Box 14-492, Wellington, New Zealand.

J.P.Parkes, Landcare Research Ltd., PO Box 69, Lincoln, New Zealand.

Dr B.E. Coblentz, Dept. of Fisheries and Wildlife, Oregon State University, Corvallis, Oregon 97331, USA.

## 2.3 Pig (*Sus scrofa*)

### Characteristics

Pigs (originally native to Europe), are large omnivorous mammals with powerful bodies and coarse hairy coats. Their thick necks, wedge-shaped heads and mobile snouts enable them to root up the ground when feeding. They lack the multiple stomachs found in ruminants such as cattle and goats. In New Zealand they breed throughout the year, with a litter size of 6-10 piglets, but usually only half this number survive. They reach breeding age at between 10 and 12 months (Wodzicki 1950). Pigs are normally social animals but adult boars over 18 months old are invariably solitary (McIlroy 1990).

### Spread in the Pacific

Pigs have been introduced to the great majority of island groups in the Pacific. Their spread began with colonisation of these islands by Polynesian and Micronesian peoples and continued with Spanish settlement in the 17th century and the subsequent influx of other European peoples. However, pigs introduced by early seafarers have often been displaced by domestic pigs that have gone wild. Absence of records of pigs on a particular island should not be taken to mean they are not present; pigs are sometimes considered too commonplace to be remarked upon.

### Impacts on conservation values

Anderson and Stone (1993) regarded feral pigs as "currently the most pervasive and disruptive alien influence on the unique native forests of the Hawaiian Islands". Pigs damage forests by eating or uprooting tree seedlings as well as other plants with palatable leaves or stems, including ferns and some orchids (Kirk 1896). They break open tree-fern trunks in searching for starch (Griffin 1977). Savidge (1984) records damage to understoreys in the limestone forests of Guam. A secondary but very significant impact results from their consumption of the fruit of some species of invasive weed such as guava (particularly *Psidium* spp.); the seeds pass through the gut and into droppings, thus spreading those weeds far more rapidly. Pig damage to vegetation was recorded on Tinian Island, Northern Mariana Islands, as far back as 1742 (Walter and Robins 1974). Pigs also impact on large native invertebrates, such as earthworms and landsnails (e.g. Meads et al. 1984) by destroying their habitat, and eating their eggs, juvenile growth stages, or adults. However, as with plants, these impacts have seldom been quantified and no such studies on Pacific islands are known to us. Pigs are very effective predators of both surface- and burrow-nesting seabirds. On subantarctic Auckland Island, south of New Zealand, pigs dig petrels from their burrows to eat them (Rudge 1976) and similarly in the Galapagos Islands on the equator, pigs dig out and consume dark-rumped petrels (*Pterodroma phaeopygia*) from their burrows (Coulter et al. 1985 and I. Atkinson, pers. obs.). On Christmas Island, Pacific Ocean, pigs eat eggs, nestlings and adults of sooty terns (*Sterna fuscata*). Moors and Atkinson (1984) concluded that pigs probably also eat the eggs and young of other surface-nesting seabirds such as albatrosses, shags and boobies, but adequate documentation is lacking.

In addition to their impact on native wildlife and native plant/animal communities, pigs adversely affect agricultural crops, including sugar cane. They also damage planted forests by digging up young trees and eating their roots (McIlroy 1990). They have the potential to spread diseases to other animals, both domestic and native, and are reputed to facilitate attacks on trees by the dieback disease caused by the fungus *Phytophthora cinnamomi* (Auld and Tisdell 1986).

### Prevention/control

Pigs are very mobile animals and their home ranges are not fixed in locality. Under stress they may disperse considerable distances. In Australia, feral pigs have been recorded moving 20 km in 48 hours when suffering from food shortage (Auld and Tisdell 1986). This mobility can mean that it is uneconomic for an individual landowner or controlling agency to control a pig population because animals destroyed are soon replaced by pigs moving in from adjacent properties. In New Zealand, pigs have been eradicated from Kapiti Island (1970 ha) and Great Mercury Island (1860 ha) as well as many smaller islands. Standard methods of control are hunting with dogs and poisoning with compound 1080. In Hawaii, snaring has been used to control pigs within 600–800 $km^2$ fenced exclosures located in remote areas of rain forest in the Haleakala National Park, Maui (Anderson and Stone 1993).

Many people place a high cultural/food value on pigs so that removing them from designated areas may not be acceptable without a clear presentation and discussion of the benefits. Snaring would also not always be an acceptable method of control.

### Current researchers and control experts

B.D. Bell, Wildlife Management International Ltd, PO Box 14-492, Wellington, New Zealand.

## 2.4 Dog (*Canis familiaris*)

### Characteristics

Dogs taken to Pacific islands by the early Polynesians may have been about the size of a small collie, but shorter in the leg (Anderson 1990). They have long since been replaced by or crossed with various breeds from Europe. Dogs can range through a wide variety of habitats, whether open country or thick forest.

### Spread in the Pacific

Dogs have been taken to most inhabited islands in the Pacific but the extent to which they have become feral on forested islands is unclear. R. Hay (pers. comm. 1999), for example, saw little evidence that dogs on Niue were penetrating the forest to any great degree, but this may have been because of the sharp pinnacles and cracks in the limestone substrate. On Tinian Island, Northern Mariana Islands, feral and domestic dogs have been present since the mid-1700s (Wiles et al. 1990).

### Impacts on conservation values

It is important to recognise that, even though there may be no truly feral dogs on an island, an uncontrolled domestic dog can wreak havoc among ground birds. In New Zealand, during study of kiwi in a Northland forest, the loss of 13 out of 23 kiwi fitted with transmitters was found to be a result of predation by a German shepherd dog. It was estimated that this single dog alone had killed 500 out of 900 birds, although this estimate was considered to be possibly conservative (Taborsky 1988). Seabirds are included among the prey taken by dogs. In Hawaii, Sincock and Swedberg (1969) found Newell's shearwaters (*Puffinus puffinus newellii*) were subject to predation by dogs. Tomkins (1985) records dogs killing adult dark-rumped petrels (*Pterodroma phaeopygia*) on several islands in the Galapagos group. Remains of boobies and shearwaters were found in the stomachs and droppings of dogs on Isla Isabela, Galapagos group, by Barnett (1982).

### Prevention/control

Feral packs of dogs can be hunted and shot. Control of domestic dogs is dependent on their owners knowing what native birds and other native animals are at risk from dogs on the island where they live.

### Current researchers and control experts

We know of no-one who is actively researching the impact of uncontrolled domestic dogs or feral dogs on native wildlife.

## 2.5 House cat (*Felis catus*)

### Characteristics

Members of the cat family feed mainly on vertebrates such as small mammals and birds. House cats live in a very wide range of habitats if food is available. They are less dependent on water than many other mammals introduced to Pacific islands because of the extent to which they obtain moisture from their food. The sizes of home ranges used by cats in searching for food vary enormously, depending on the kind of habitat (Fitzgerald and Karl 1986). In good conditions cats may have two to three litters per year, with a most common litter size of 4 kittens (Fitzgerald 1990).

### Spread in the Pacific

Many ships of the 18th and 19th centuries were infested with rats and so carried cats to control them. Considering also the extent to which cats are valued as pets it is not surprising that they are possibly now present in all of the island groups considered in this report. Within an island group, however, many uninhabited islands are still free of cats.

### Impacts on conservation values

Worldwide, cats prey on petrels, shearwaters and prions including seabirds as large as the black petrel (*Procellaria parkinsoni*) (Imber 1975, I. Atkinson, pers. obs.). They also prey extensively on landbirds, particularly those that nest or feed on or near to the ground. The only study of foods eaten by cats on islands in the SPREP region appears to be that of Kirkpatrick and Rauzon (1986) on Howland and Jarvis Islands, both of which lie close to the equator. Here cats were having a significant impact on surface-nesting seabirds by killing young and adult birds and occasionally taking eggs as well. In New Zealand their diet includes rabbits, rats, mice, birds, skinks and geckos as well as larger insects and spiders. On islands, birds are likely to be the most important food because the number of small mammals is often limited. Cats lived for over 40 years on Herekopare Island (28 ha), east of Stewart Island, where they fed mainly on seabirds but eliminated 6 species of landbird (Fitzgerald and Veitch 1985). Cats are known to have eliminated saddlebacks (*Philesturnus carunculatus*) from both Cuvier Island (170 ha) and Little Barrier Island (3083 ha) last century.

### Prevention/control

Routine inspection of cargoes and luggage should provide adequate protection against cats reaching an island where they are not already present. Cats can be controlled by live-trapping, shooting, or killed with Victor 'soft-catch' leghold traps baited with tinned catfood or fish (Veitch 1985, Innes et al. 1999). Cats were eradicated from Baker Island (145 ha) in the Line group in 1964 following which the large colonies of sooty terns (*Sterna fuscata*) and lesser frigatebirds (*Fegata ariel*), which had been greatly reduced by the cats, re-established (Forsell 1982). Cats have been eradicated from quite large islands, both forested, such as Little Barrier Island (Veitch 1985), New Zealand, and those lacking forest, such as Marion Island (29 000 ha) in the Indian Ocean. Four methods were used to kill cats on Marion Island: the viral disease feline panleucopaenia, shooting, cage-traps and gin traps (Bloomer and Bester 1992).

### Current researchers and control experts

Dr B.M. Fitzgerald, Ecological Research Associates of NZ, PO Box 48-147, Silverstream, Upper Hutt 6430, New Zealand.

B.D. Bell, Wildlife Management International Ltd, PO Box 14-492, Wellington, New Zealand.

C.R. Veitch, 48 Manse Rd, Papakura, New Zealand.

## 2.6 Pacific rat (*Rattus exulans*)

### Characteristics

Pacific rats are the smallest of the three rats closely associated with humans. Body weights are usually between 60 and 80 g, but occasionally heavier. The fur is brown and tail length is only slightly longer or shorter than the combined head and body length. A useful feature distinguishing them from other rats is the dark outer edge of the upper side of the hind foot near the ankle, the remainder of the foot being pale. In New Zealand on Tiritiri Island, litter size is usually between 4 and 9 with an average of 3 litters per year (Moller and Craig 1986). The density of these rats on an island is very dependent on the presence of cats, or other rodents, particularly mice (Taylor 1975). Pacific rats can live in a wide range of habitats including grassland, scrub and forest. They are able to climb trees easily where at least some of their feeding is done, but are not good swimmers.

### Spread in the Pacific

Pacific rats originated in the Indo-Malaysian region where they are still present. They have subsequently been spread by people to numerous islands in the Pacific, particularly by Polynesians and Micronesians. Pacific rats may have been present in the Mariana Islands for at least 3500 years, introduced by the Chamorro people (Spoehr 1957). There is no evidence to suggest that this rat is native to any of the islands included in this study, as implied by Case (1996: 73). There appear to be no island groups that were reached by the Polynesians that did not receive *Rattus exulans* (Atkinson 1985). However, a number of islands within groups, particularly those uninhabited, are still free of it. There is some evidence to suggest that the decline of *R. exulans* in mainland New Zealand during the 19th century was a result of competitive exclusion by mice (Taylor 1975).

### Impact on conservation values

Though considered by early naturalists a "harmless vegetarian", this rat is harmless to neither animals nor plants. Pacific rats eat a wide range of foods including earthworms, centipedes, larvae of some butterflies and moths, ants, beetles, weevils, cicadas, snails, spiders, lizards and birds. They also eat fleshy fruit and other seeds, flowers, stems, leaves, roots and other plant parts. These facts do not in themselves prove that survival of the animal or plant species affected will necessarily be reduced significantly. However, many studies have shown that this is sometimes the case. Particular examples are the detrimental effects on burrowing petrels, described for Hawaii and New Zealand (Woodward 1972, Imber 1975) and on red-tailed tropicbirds (*Phaethon rubricauda*) (Fleet 1972). In the Leeward Islands of Hawaii, Fleet and Woodward have shown that predation on seabirds only becomes significant after storms have reduced the fruiting of food plants. Fatal attacks by Pacific rats on adult Laysan albatrosses (Kepler 1967) appear likely to be associated with the same factor. Many species of lizard in New Zealand have been reduced in numbers, sometimes becoming locally extinct, as a result of predation by this rat (Whitaker 1973, Towns 1991). On Henderson Island, Pitcairn group, Brook (1995) recorded intense predation by *R. exulans* on newly hatched Murphy's and Kermadec petrel chicks. A recent study (Campbell and Atkinson 1999) shows that in New Zealand, *R. exulans* has adversely affected the recruitment of at least 5 species of coastal tree, some of which are now rare.

### Prevention/control

Pacific rats have been eradicated from islands of less than a hectare in size, up to the size of Kapiti island (1970 ha), near Wellington, New Zealand (Empson and Miskelly 1999). These authors discuss the risks, costs and benefits of using brodifacoum to eradicate rats. Compound 1080 has not proved effective against this rat, but they are susceptible to anticoagulent poisons such as brodifacoum and bromodialone.

### Current researchers and control experts

Dr I. Atkinson, Ecological Research Associates of NZ, PO Box 48-147, Silverstream, Upper Hutt 6430, New Zealand.

D.J. Campbell, Ecological Research Associates of NZ, PO Box 48-147, Silverstream, Upper Hutt 6430, New Zealand.

Dr D.R. Towns, Department of Conservation, Auckland Regional Conservancy, Private Bag 68908, Newton, Auckland.

I. McFadden, Department of Conservation, PO Box 10-420, Wellington, New Zealand.

B.D.Bell, Wildlife Management International, PO Box 14-492, Wellington, New Zealand.

## 2.7 Norway rat (*Rattus norvegicus*)

### Characteristics

Also known as the brown rat, and originally from Mongolia, Norway rats are the largest of the three rats that have been dispersed by humans to the Pacific islands. Their body weight is most commonly between 200 and 300 g, but weights up to 450 g (and rarely greater) are not unusual. Their fur colour is brown with grey colours on the belly. The tail is significantly shorter than the combined head and body length, and they have a uniformly grey upper side to the hind foot. Litter size in New Zealand averages 6–8, but published information is sparse (Moors 1990). Although they do climb tree trunks and branches to some extent, they are not agile climbers in the manner of ship rats. Characteristically they nest below ground in burrows, sometimes forming quite elaborate burrow systems. They are by far the best swimmers of the three rat species, sometimes diving for shellfish and other food in the intertidal zone. However, they may be more dependent on fresh water than are the other rat species.

### Spread in the Pacific

Norway rats do not appear to have reached the Pacific islands until the 19th century and even now have not established on all inhabited islands in the Pacific (Atkinson 1985). Their distribution is thus more restricted than that of the other two rats, although they are almost invariably present where there is any substantial human habitation.

### Impacts on conservation values

Norway rats are omnivorous and eat a wide range of plant and animal foods. They prey on the eggs, young, and sometimes adults of ground birds such as rails, ducks and wading birds (e.g. Pye and Bonner 1980, Brown 1949). Ducks, in particularly, appear to be more vulnerable to Norway rats than to other species of rat. Norway rats also eat seabirds and their eggs, including storm petrels, diving petrels, prions, shearwaters, tropicbirds, gulls, and terns (Moors and Atkinson 1984). It is probable that they have caused catastrophic declines in the numbers of ground-nesting birds on some islands, such as Campbell Island, New Zealand, but no particular case has been properly documented.

### Prevention/control

Norway rats are more wary of new items in their territories, such as traps, poison-bait tunnels, than either of the other two rat species. "Second-generation" anticoagulant poisons have been used very effectively against this rat, for example, the eradication of Norway rats from Kapiti Island (1970 ha), New Zealand, in 1997 (Empson and Miskelly). The largest island from which Norway rats have been eradicated is, to date, Langara Island (Queen Charlotte Islands, British Columbia), 3105 hectares in area. The eradication campaign for *R. norvegicus* was begun (after preparation and trials) in July 1995 and the island was declared free of rats in May 1997 (Kaiser et al. 1997).

The undesirable consequences of any ongoing use of such poisons should always be considered: primary or secondary poisoning of non-target species we are aiming to protect, secondary poisoning of other vertebrate pests such as cats, and development of resistance to the poison by the rats.

### Current researchers and control experts

R.H. Taylor, c/- Landcare Research Ltd., Private Bag 6, Nelson, New Zealand.

I. McFadden, Department of Conservation, PO Box 10-420, Wellington, New Zealand.

## 2.8 Ship rat (*Rattus rattus*)

### Characteristics

This rat was originally native to India and is also known as the black rat or roof rat. Ship rats are rather larger than Pacific rats, with body weights between 120 and 160 g although occasionally exceeding 200 g. They may be grey-brown on the back with either a similarly coloured or creamish-white belly, or they may be black all over. These three distinct colour forms can be found in rats of the same litter; they are not, as was once thought, three different subspecies. The tail is always much longer than the head and body length combined. The hind foot is uniformly coloured over the whole foot and usually dark. Litter size is 3–10, averaging 5–8 (Innes 1990), with the breeding season in New Zealand restricted to the September to April period. Ship rats are widespread in forest and woodlands as well as being able to live in and around buildings. There is nothing to support the statement by Pernetta and Watling (1978) that ship rats "are restricted in their distribution to a close association with humans"; these authors appear not to have trapped for rodents in native forest. Ship rats are extremely agile climbers, usually nest in bunches of leaves and twigs built in trees well above ground level, and spend more time searching for food in tree crowns than either of the other two introduced rats.

The work of Yosida (1980) and his co-workers has shown that there are two forms of *R. rattus* that differ in chromosome number. The Asian form has 42 chromosomes and is present in SE Asia and Japan. The more widespread Oceanic form has 38 chromosomes and is the ship rat of Europe, the Mediterranean region, America, Australia and New Zealand. Present indications are that it is the Oceanic form that has reached islands in the South Pacific, but studies are needed to confirm this. The Asian form has probably reached some islands north of the equator, e.g. the Caroline Islands: on the basis of colour variation in rats on Ponape and Koror Islands, described by Johnson (1962) as *Rattus rattus mansorius*, we suspect that these rats may be the Asian form of *R. rattus*.

### Spread in the Pacific

Ship rats first reached the Pacific islands with early European navigators in the 17th century but apparently established on only a few islands. The major spread of this rat did not take place until after 1850 (Atkinson 1985). Among all the invasive animals covered in this report, ship rats are now second only to Pacific rats in the extent of their spread, having established on at least 28 groups of islands.

### Impacts on conservation values

Like the other two species of rat included here, ship rats are omnivorous and capable of eating a wide range of plant and animal foods. These include native snails, beetles, spiders, moths, stick insects and cicadas and the fruit of many different plants (Innes 1990). They also prey on the eggs and young of forest birds, a behaviour long suspected in New Zealand but only proved beyond doubt comparatively recently through use of video cameras at night (Innes et al. 1999). In the recovery programme for the endangered Rarotonga flycatcher or kakerori (*Pomarea dimidiata*), Robertson et al.(1994) identified ship rats as the most important predator affecting the breeding success of this bird. Several cases are known where predation on seabirds can be reliably attributed to ship rats. These include sooty terns in the Seychelles Islands (Feare 1979), Bonin petrels in Hawaii (Grant et al. 1981), Galapagos dark-rumped petrels in the Galapagos Islands (Harris 1970), and white-tailed tropicbirds in Bermuda (Gross 1912).

The ship rat is the rat most frequently identified with catastrophic declines of birds on islands. The best documented examples in the Pacific region are Midway I. in the Leeward Is of Hawaii (Johnson 1945, Fisher and Baldwin 1946), Lord Howe Island (Hindwood 1940, Recher and Clark 1974) and Big South Cape Island, New Zealand (Atkinson and Bell 1973). There are undoubtedly other examples of such declines on islands which, if noticed at the time, were never documented. Atkinson (1977) brought together circumstantial evidence suggesting that ship rats, rather than disease, were responsible for the decline of many species of Hawaiian native birds during the 19th century. There are few indications of rat-induced declines in native birds on islands nearer the equator (latitude 15°N to 20°S). This zone coincides with the distribution of native land crabs, animals that also prey on birds and their eggs. The long co-existence between land crabs and some island birds may have resulted in the development of behaviours among the birds that gives them a degree of protection against rats. Atkinson (1985) suggested that this might be the reason why rat-induced catastrophes are less apparent within the equatorial zone, but this hypothesis has never been tested.

### Prevention/control

"Second-generation" anticoagulant poisons are used widely for ship rat control, but possible consequences of any ongoing control should always be considered. These consequences include primary or secondary poisoning of species we are aiming to protect or other non-target species, secondary poisoning of other vertebrate pests such as cats, and development of resistance to these poisons by ship rats. Eradications of ship rats have so far only been attempted on small islands (Veitch and Bell 1990) and it is not known whether their tree-climbing habits will make eradication more difficult.

### Current researchers and control experts

Dr J. Innes, Landcare Research, Private Bag 3127, Hamilton, New Zealand.

Dr I. Atkinson, Ecological Research Associates of NZ, PO Box 48-147, Silverstream, Upper Hutt 6430, New Zealand.

I. McFadden, Department of Conservation, PO Box 10-420, Wellington, New Zealand.

G. McCormack, Cook Islands Natural Heritage Project, Prime Minister's Department, Rarotonga, Cook Islands.

R.H. Taylor, c/o Landcare Research NZ, Private Bag 6, Nelson, New Zealand.

## 2.9 House mouse (*Mus musculus*)

### Characteristics

This well-known animal, which probably originated in Asia or Africa, is now among the most widespread of all mammals, a result of its close association with humans and the relative ease with which it can be spread in cargoes. Apart from their occupation of buildings, mice can live in a wide range of environments, from grassland to forest. In Hawaii they are abundant over a wide range of habitats from sea level to 3920 m (Tomich 1969, van Riper and van Riper 1982).

Mice can be sexually mature at 8 weeks. Litter size varies between 2 and 12 but the commonest litter sizes are 5 and 6. In more temperate climates mouse numbers fluctuate seasonally, but individual mice rarely live longer than 18 months in the wild (Murphy and Pickard 1990).

### Spread in the Pacific

Mice have probably reached all inhabited islands in the Pacific as well as some uninhabited islands. Their spread into the Pacific did not begin until the arrival of Europeans.

### Impacts on conservation values

The impact of feral house mice on native plants and animals has probably been underestimated on Pacific islands through lack of studies and attention to larger pest animals. Mice eat a variety of seeds, fungi, insects (including beetles and moth caterpillars), spiders and other small animals. Lizards and sometimes eggs of small birds are also taken. In a recent study, Fitzgerald et al. (in press) demonstrated significant increases in the numbers of four species of beetle, larvae of two species of moth, and two species of spider following eradication of mice from Allports Island (16 ha), Cook Strait, New Zealand. After mice were eradicated from Mana Island (217 ha), New Zealand, the endangered McGregor's skink (*Cyclodina macgregori*) increased significantly and more Cook Strait giant wetas (*Deinacrida rugosa*), a large flightless grasshopper, were caught in lizard traps (Newman 1994). On subantarctic Antipodes Island (2025 ha), SE of New Zealand, M.J. Imber (in Moors and Atkinson 1984), found mice to be eating eggs of grey-backed storm petrels (*Garrodia nereis*), although it is not known whether this was having a significant effect on the petrel population.

### Prevention/control

In the wild, mice can be controlled with anti-coagulant poisons such as brodifacoum. In New Zealand, mice have been eradicated from a few islands, most notably Mana Island (217 ha), for which details are given by Hook and Todd (1992), and Enderby Island (710 ha) in the Auckland Islands group.

### Current researchers and control experts

Dr B.M. Fitzgerald, Ecological Research Associates of NZ, PO Box 48-147, Silverstream, Upper Hutt 6430, New Zealand.

I. McFadden, Department of Conservation, PO Box 10-420, Wellington, New Zealand.

Dr E.C. Murphy, Department of Conservation, Auckland Regional Conservancy, Private Bag 68-908, Newton, Auckland, New Zealand.

## 2.10 Rabbit (*Oryctolagus cuniculus*)

### Characteristics

Rabbits are small herbivorous mammals weighing between 1 and 2 kg. Like rats and mice, they have a pair of sharp cutting teeth that grow continuously throughout life. Their droppings, when produced at night, are fibrous pellets. However, during the day the droppings are soft and are eaten, thus allowing the animal to extract the maximum value from its food. A female rabbit can produce up to 50 young in one year, but where rainfall is erratic, as on many islands, breeding is restricted to periods following rain. Young rabbits grow rapidly and can start breeding between 3 and 4 months of age (Gibb and Williams 1990).

Rabbits thrive best where rainfalls are less than 1000 mm and where the vegetation is short, preferably grazed. Although usually an animal of open country, in New Zealand rabbits have survived in low numbers on a few forested islands where the forest is low and not very dense.

### Spread in the Pacific

Two thousand years ago rabbits were confined to Spain and Portugal but they have since been spread by people to many parts of the world. Sailing ships of the 18th and 19th centuries sometimes carried live rabbits for food. If put ashore for shipwrecked people they usually died out, but they persisted on some islands to cause great damage to native vegetation, especially on islands of low rainfall. Rabbits have reached at least five of the island groups considered in this study. Their worldwide distribution is given by Flux and Fullager (1983).

### Impacts on conservation values

Rabbits reached Laysan Island in the Hawaiian group at the beginning of the 20th century. Between 1903 and 1923 (when they were eradicated) rabbits apparently eliminated 26 species of plants, a rate of loss exceeding one species per year (Christophersen and Caum 1931). A subsequent visit by Lamoureaux (1963) indicates that not all of these species became extinct on Laysan Island; presumably regeneration from seed had been possible. Prior to their eradication, rabbits were the only introduced mammal on Phillip Island in the Norfolk Island group. There the average rate of extinction of plant species between 1830 and 1977 was approximately one species every 10 years (Fullager 1978). Extensive soil erosion frequently follows the loss of plant cover that results from browsing by rabbits, as was the case with both these islands. Thus, apart from the plant losses, rabbits often destroy the habitat of many small animals. Rabbits can also become additional food for animals such as cats, enabling these predators to increase their numbers and thus eat more native animals, including lizards and birds. This is an example of a flow-on effect, where the introduction of one problem animal results in an increase of another invasive species already established. Such an effect is believed to be the reason why the parakeet of Macquarie Island, in the subantarctic ocean NE of the Ross Dependency, became extinct following the introduction of rabbits. The bird had managed to survive in the presence of cats on the island for many years previous to the arrival of rabbits (Taylor 1979).

### Prevention/control

Accidental introduction of rabbits to an island is unlikely. They are relatively easy to detect in cargo or baggage and strict surveillance at ports of entry will prevent most attempts to introduce this animal. Where rabbits are present with other grazing animals, removal of the latter will often result in the growth of rank vegetation unsuitable for rabbits; this can be used as a method of partial rabbit control. Shooting of rabbits is an inefficient method of control but unlike poisoning it does not kill predators of rabbits such as cats. In New Zealand, poisoning has most often been carried out with compound 1080 added to carrots or oats and spread from the air. In 1998, a virus, rabbit haemorrhagic disease (RHD, formerly called RCD), was introduced to the country illegally. In some areas it has killed many rabbits, but whether it will continue to be effective in the long-term is doubtful. Myxomatosis, a contagious and often lethal disease specific to rabbits is sometimes suggested for rabbit control. This not only requires flea or mosquito vectors but causes considerable suffering to the animals affected. Furthermore, eradication by such means is unlikely. We would not recommend use of either RHD or myxomatosis on Pacific islands. On small islands, acute poisons such as phosphorus, cyanide, strychnine and compound 1080 are all likely to kill non-target species. Second-generation anticoagulant poisons such as brodifacoum have been used successfully against rabbits although precautions are often necessary to protect non-target species (Flux 1993). Flux (1993) examined the relative effectiveness of various methods of rabbit control using a sample of 607 islands distributed throughout the world. He found that more islands had been cleared of rabbits by traditional methods of trapping, shooting, and poisoning than by introduced predators, competitors, or disease.

Rabbits have been eradicated from a number of islands including Enderby Island (710 ha) in the Auckland Islands group, Phillip Island (190 ha) in the Norfolk Island group and Round Island (151 ha), Mauritius. Both the Enderby Island and Round Island campaigns used brodifacoum as Talon 20P® baits. Merton (1987) gives details of the Round Island operation including bait preference and acceptance trials, and tolerance of reptiles to the anticoagulant poison used.

### Current researchers and control experts

Dr J.E.C. Flux, Ecological Research Associates of NZ, PO Box 48-147, Silverstream, Upper Hutt 6430, New Zealand.

I. McFadden, Department of Conservation, PO Box 10-420, Wellington, New Zealand.

B.D. Bell, Wildlife Management International, PO Box 14-492, Wellington, New Zealand.

## 2.11 Small Indian mongoose (*Herpestes javanicus*)

### Characteristics

The small Indian mongoose is an agile light brownish-grey animal with short legs, small rounded ears, and an adult length (including the 26 cm bushy tail) of about 65 cm. It was introduced to many islands in the West Indies from 1872 onwards with the intention of controlling rats in sugar-cane fields. In 1883 it was introduced to several of the larger Hawaiian islands for the same reason. They are agile animals and are known for their attacks on chickens as well as native animals. Mongooses can live in both dry and wet conditions including forest, scrub, grassland and gardens.

### Spread in the Pacific

In the SPREP region, the mongoose appears to be restricted to Fiji, where it was introduced in 1883, again with the expectation that they would control rats in sugar-cane fields.

### Impacts on conservation values

Mongooses are generally solitary and hunt small animals by day. They have been seen to climb trees in Hawaii, and remains of forest birds have been found in their gut contents. The frequency and thus the significance of this behaviour has yet to be assessed (C. Hodges, pers. comm. 1999). In addition to birds, they prey on all kinds of terrestrial vertebrates as well as a wide variety of invertebrates: moths, grasshoppers, beetles, wasps, flies and spiders (Baldwin et al. 1952, Seaman and Randall 1962, Gorman 1975,) but the extent of this impact has not been measured. On some islands they have had a major effect on native snakes and diurnal lizards, i.e. those feeding during the daytime. Case and Bolger (1991) compared lizard abundance on a number of Pacific islands with and without mongooses and found a nearly 100-fold reduction of lizards where mongooses were present. In the Virgin Islands, in the Caribbean, mongooses caused the near-extinction of the ground-nesting quail dove (*Geotrygon mystacea*) (Nellis and Everard 1983) and in the Virgin Islands National Park, a study by Small (1982) showed that 23% of the eggs and hatchlings of hawkesbill turtles (*Eretmochelys imbricata*) were destroyed by mongooses. In Hawaii, mongooses are known to eat the young of the endangered Hawaiian crow (Giffen 1983 in Stone 1984) and both eggs and incubating females of the nene goose (Banko 1982). Wherever mongooses have come in contact with the endangered Hawaiian dark-rumped petrel (*Pterodroma phaeopygia*) they have eliminated it (Baldwin et al. 1952). On Viti Levu in Fiji, there is circumstantial evidence for implicating mongooses in the decline of several species of ground-dwelling birds (Pernetta and Watling 1978).

Mongooses are also implicated in the spread of strawberry guava and other alien plants by eating fruit and thus dispersing seeds (Baldwin et al. 1952).

### Prevention/control

On the island of St John, US Virgin Islands, Coblentz and Coblentz (1985) trapped mongooses using 15 x 15 x 45 cm live traps and fresh bait. They concluded that, where eradication of mongooses is not possible, protection of vulnerable insular species can be achieved with intensive localised trapping. Live traps are also used to capture mongooses and avoid loss of non-target species in Haleakala National Park, Hawaii (C. Hodges, pers. comm. 1999). We are not aware of any attempts to eradicate mongooses.

### Current researchers and control experts

Cathleen Hodges, Wildlife Biologist, Haleakala National Park, PO Box 369, Makawao, Hawaii 96768.

Tom Telfer, Wildlife Biologist, Division of Forestry and Wildlife, 3060 Eiwa St, RM 306, Lihue, Hawaii 96766.

Tonnie Casey, 101 Aupuni St, # 227, Hilo, Hawaii 96718.

## 2.12 Musk shrew (*Suncus murinus*)

### Characteristics

This animal, also known as the house shrew, is a native of NE Africa, SE Asia, the Philippines and Indonesia. It is small, secretive and mouse-like with a long pointed nose. They are generally solitary and have a high metabolic rate necessitating frequent feeding. Foods include a wide range of invertebrates, but they scavenge for other foods.

### Spread in the Pacific

Musk shrews are common in villages and farmyards throughout the warmer parts of eastern Asia and on many of the islands fringing that coast (Johnson 1962). Within the SPREP region, they appear to have been recorded only from Guam, Palau, and the Northern Mariana Islands. They were first detected on Guam in 1953 and had spread over most of the island within three years (Peterson 1956).

### Impacts on conservation values

Musk shrews are omnivorous, taking mainly insects, but also take carrion. They are reported to have killed small birds in captivity (Barbehenn 1962, Lance 1976), and are likely to eat skinks (Barbehenn 1974). In searching for underground prey they can excavate holes using their pointed nose. No studies of the impact of musk shrews on native fauna and flora are known to us. Barbehenn (1962) considered that shrews were potential predators of mice and young rats.

### Prevention/control

Sodium monofluoroacetate (compound 1080) was used unsuccessfully against musk shrews in an attempt to eradicate them from the small island of

Ilse'Aigrette, Mauritius, in 1988. One of us helped with this attempt; the shrews showed no interest in the paste bait used.

### Current researchers and control experts

None known to us.

## 2.13 Brown tree snake (*Boiga irregularis*)

### Characteristics

The brown tree snake is slender, nocturnal, commonly 0.9–1.2 m in length, and is secretive and arboreal, hunting for food at all levels within a forest (Fritts 1988, McCoid 1991).

### Spread in the Pacific

This snake, native to Australia, Indonesia, New Guinea and the Solomon Islands, was accidentally introduced to Guam, Mariana Islands, in the late 1940s. It has now spread to a further 10 central and South Pacific islands including Wake Island (before 1955), Saipan, Tinian, Rota, Kwajalein and Pohnpei (Bech 1995).

### Impacts on conservation values

A comprehensive study of this snake's impact on a native bird fauna was made by Savidge (1987) and her co-workers (Savidge et al. 1992) on the island of Guam. She concluded that, between 1963 and 1986, predation of eggs, nestlings and adults resulted in declines or extinctions of 10 of the 11 species of native forest bird previously present. Brown tree snakes also eat small mammals and lizards. On Guam, consumption of these foods allowed the snake to reach high population densities thus increasing their impact on birds. Juvenile tree snakes prey predominantly on lizards and this effect has resulted in the extinction on Guam of three species of skink and two species of gecko (T.H. Fritts in Case and Bolger 1991). The cultural, economic and health effects of this snake, as well as secondary effects on Guam's fauna and flora, are discussed by McCoid (1991).

### Prevention/control

Tree snakes can hide easily in ships moving between islands, but the principal way they are currently being dispersed to islands is in aircraft cargoes. Several tree snakes have been detected at Honolulu airport in recent years. Preventing their further spread depends on maintaining very strict cargo checks of boats and searches at airports ***at all times***. An effective control method is not yet available. Efforts are being made to develop artificial attractants, while snake barriers have been used in some situations, and detector dogs are also being used in the Northern Mariana Islands (Perry 1998). The Global Invasive Species Programme is fostering cooperative effort among experts in Guam, Australia, Hawaii and mainland USA in an effort to combat this pest. In 1995 the brown tree snake was listed by the US Department of Agriculture as "among the top three pests requiring control and eradication."

### Current researchers and control experts

Dr Joan Whittier, Centre for Conservation Biology, University of Queensland, St Lucia, Queensland 4072, Australia.

G. Perry, Ohio State University, PO Box 8255, MOU-3, Dededo, Guam 96912.

## 2.14 Cane toad (*Bufo marinus*)

### Characteristics

This large toad produces glandular secretions that are poisonous to some animals. In Fiji, viable populations of this species are restricted to the flatter coastal areas. Pernetta and Watling (1978) suggest that this may be because this toad has a free-swimming tadpole stage liable to be swept away during the flash floods characteristic of montane areas. Nevertheless, large adult cane toads are present in lowland forests.

### Spread in the Pacific

The cane toad is native to Mexico and Central America but has been introduced to Hawaii, Fiji, Samoa, Guam, the Northern Marianas, and the Caroline and Solomon Islands groups. These introductions were made as early attempts to use biological control against various beetle pests of sugar cane, banana and other cash crops (Hinkley 1962).

### Impacts on conservation values

The major items of diet are insects, including grasshoppers, caterpillars, and ants, together with millipedes and landsnails (Hinkley 1962). Hinkley considered that cane toads would eat "almost any terrestrial animal", although more likely to consume those active at ground level during the night. Toads have been implicated in the decline of populations of monitor lizards in Guam (Jackson 1962, Dryden 1965). Pernetta and Watling (1978) consider that the toads do not interact with native frogs because they use different habitats; the frogs are either along stream banks or in the foliage of dense forest. Villadolid (1956) found rats and mice in stomachs of toads in the Philippine Islands. Hinkley concluded that this toad is "economically neutral" because it consumes both "harmful" and "beneficial" invertebrates. No proper studies of the effects of cane toads on native fauna appear to have been made.

### Prevention/control

The CSIRO Division of Wildlife and Ecology was assessing the pathogenicity and specificity of viruses against toads in 1994.

### Current researchers and control experts

Alex Hyatt/Brian Green, CSIRO Animal Health Laboratory, Geelong, Victoria, Australia.

## 2.15 Introduced birds

The numbers of introduced birds that have established on islands in the Pacific can be compared in Table 1. The Hawaiian Islands are quite exceptional with respect to both attempted and successful introductions. The red jungle fowl (*Gallus gallus*) was spread widely on Pacific islands by Polynesians, but is apparently the only bird introduced by pre-European people.

The most widespread bird introduced to the SPREP region in European times is the common myna (*Acridotheres tristis*)*, native to India and south-east Asia. It is now established in islands of the Fiji, Cook, Tubuai, Society, Marquesas, Solomon and New Caledonia groups, Samoa and possibly Vanuatu (Lever 1987). R. Hay (pers. comm.) reports that this species reached Wallis Island for the first time in 1999, suggesting that common mynas are still spreading. Jungle mynas (*A. fuscus*)*, also native to India and south-east Asia, are established in Fiji and Samoa (Long 1981), and have apparently colonised Tonga in the early 1980s without human assistance (Rinke 1986). On Upolu Island, Samoa, Gill (1999) has recorded that jungle mynas are apparently being replaced by common mynas, the latter species having been first recorded in Samoa in 1988 (Beichle 1989). Both species are perceived as problems, at least to commercial crops.

Two other introduced birds are moderately widespread on islands in the region. The red-vented bulbul (*Pycnonotus cafer*), native to the Indian sub-continent, is established in Fiji, Tonga and possibly Tahiti (Lever 1987) and Samoa; the common waxbill (*Estrilda astrild*) is in New Caledonia and the Society Islands (Long 1981). The bulbul is seen as a potential problem for some native birds, particularly the Tahiti flycatcher (R. Hay, pers. comm.) whereas the waxbill is not.

Potential effects of birds introduced to an island include: effects on native birds, or other animals, through competition for the same foods or for nest sites; introduction of diseases against which the native birds have no resistance; predation on native birds by eating adults, young or eggs. Occasionally they may hybridise with a native bird to which they are related and change both the appearance of the native bird and the way in which it lives. The best documented example of hybridisation in the Pacific region concerns mallard ducks (*Anas platyrhynchos*). Their hybridisation with grey ducks (*A. superciliosa*) in New Zealand (Rhymer et al. 1994), Hawaiian ducks (*A. wyvilliana*) in Hawaii (Griffin et al. 1989), and an endemic race of the Pacific spot-billed duck (*A. poecilorhynchos*) in the Mariana Islands (Riechel and Lemke 1994) have either threatened or replaced each of these endemic forms.

Pernetta and Watling (1978) considered the question of food competition between introduced and native birds in Fiji. They pointed to the separation of native birds from those introduced that results from the almost exclusive use of native forest by non-predatory native landbirds. This separation led them to conclude that interspecific competition was relatively unimportant in the majority of cases.

However, no in-depth studies of possible negative interactions between introduced birds and native animals (including birds) appear to have been made on islands in the region. There can be no doubt that such interactions sometimes occur.

***TABLE 1: Numbers of introduced bird species established on islands or island groups in the SPREP region.***

| Island/ island gp | No. of species | Reference |
|---|---|---|
| Cook Is | 3 | Case (1996) |
| Fijian Is | 11 | Pernetta and Watling (1978) |
| Guam | 7 | Case (1996) |
| Hawaii | 47 | Case (1996) |
| Henderson I., Pitcairn group | 0 | Case (1996) |
| Line Is | 1 | Long (1981) |
| Marquesas Is | 5 | Case (1996) |
| Nauru I. | 1 | Long (1981) |
| New Britain I. | 1 | Long (1981) |
| New Caledonia | 6 | Case (1996) |
| New Guinea (PNG and Indonesia) | 1 | Case (1996) |
| Palau Is | 4 | Case (1996) |
| Pitcairn I. | 0 | Long (1981) |
| Rotuma (Fiji) | 1 | Case (1996) |
| Samoa | 3 | Case (1996) |
| Society Is | 12 | Case (1996) |
| Solomon Is | 4 | Long (1981) |
| Tongan Is | 3 | Long (1981) |
| Vanuatu | 4 | Long (1981) |

* Pernetta and Watling (1978) appear to have interchanged the scientific names of common (Indian) mynas with jungle mynas in one table (p. 240).

Byrd (1979) records significant predation by common mynas on the eggs of wedge-tailed shearwaters (*Puffinus pacificus*) in Hawaii. Heather and Robertson (1996) record common mynas eating eggs and chicks of landbirds in New Zealand. Mynas are present in the habitat of kakerori (*Pomarea dimidiata*) on Rarotonga, but a study of this bird's breeding success (Saul et al. 1998) found no evidence of mynas causing nesting failures.

The possibility that common mynas and red-vented bulbuls cause some native birds to abandon their nests (Gaze 1998), at least in intermediate secondary forest or forest margin environments, should be investigated.

There are other examples of introduced birds having negative effects on native species. The New Caledonian crow (*Corvus moneduloides*) was introduced to Mare in the Loyalty Islands, where it caused considerable losses of pigeons by killing their young and eggs (Delacour 1966). In Palau, the endangered Rock Island palm (*Galubia palauensis*) is attacked by the introduced sulphur-crested cockatoo (*Cacatua galerita*) which chews through and topples the crown shaft (Owen 1978). On Tetiaroa Island, Tahiti, Thibault (1976) records the introduced harrier (*Circus aeruginosus = C. approximans*) as preying on white terns. There are probably more examples either unrecorded or unknown to us.

# 3. Islands

This section is arranged alphabetically, by and within each island group. Islands are included if we have information on invasive species present. Geographic details of islands are from Douglas (1969), unless otherwise stated. A summary of significant invasive animals is given in Table 2.

## Austral Islands and Rapa/Tubuai Islands (French Polynesia)

(Five plus two islands in group) 650 km south of Tahiti.

### *Significant invasive land vertebrates*

Cattle, goat, pig, dog, Pacific rat, ship rat, rabbit. Indian myna (Lever 1987: 499, following Holyoak and Thibault 1984).

Also: Horse, sheep.

#### Raivavae

*20.7 km² (8 sq. mi.). High volcanic, 463 m (1434'), with barrier reef and reef islets. Tree covered, coffee and copra cultivation.*

"Feral goats, pigs, cattle, horses and rats" (Douglas 1969). Pacific rat (R.H. Taylor, letter 1982).

#### Rapa

*22 km² (8.5 sq. mi.). High volcanic, 633 m (2077'), no reef. Stunted flora. Grassland. Temperate and moist. Various cultivation.*

?Cattle, ?sheep (C. Blanvillain pers. comm. 1999). "Feral goats and horses" (Douglas 1969). Pacific rat (R.H. Taylor, letter 1982), ship rat (A.C. Ziegler pers. comm. 1973).

#### Rimatara

*18.1 km² (7 sq. mi.). Low, 95 m (315'), volcanic and elevated reef limestone (makatea). Fringing reef. Taro, bananas and citrus cultivation.*

"Feral rats and goats (?)" (Douglas 1969).

#### Rurutu

*31.1 km² (12 sq. mi.). High volcanic, 369 m (1300'), also some elevated reef limestone (makatea) which is wooded. Most endemic forest burnt, taro cultivation, vanilla, coffee.*

"Feral goats and cattle etc." (Douglas 1969). Ship rat (Ziegler pers. comm. 1973). Indian myna (Lever 1987: 499).

#### Tubuai

*49.2 km² (19 sq. mi.). High volcanic, 399 m (1309'), barrier reef with islets. Lower slopes densely wooded, higher slopes grasslands and fern. Very fertile – taro, copra, etc. grown.*

"Feral goats, pigs, cattle, horses" (Douglas 1969). Pacific rat (R.H. Taylor, letter 1982), possibly other rat species (Aitken 1930). Indian myna (Lever 1987: 499).

Pig, dog, Pacific rat, chickens, said to have been present before Europeans (Aitken 1930).

Little copra produced due to lack of attention to the trees and to damage by rats (Aitken 1930).

### *Opportunities for island restoration*

"Interesting vegetation on makatea (elevated reef limestone), a possible site for conservation" on Rurutu Island (Douglas 1969: 358).

## Baker and Howland Is (USA)

(Two islands in group)

#### Baker

*1.7 km² (0.65 sq. mi.). Atoll with one island, no lagoon, fringing reef. Sparse rainfall. Worked for guano late last century. Occupied by US before and during war, until attacked by Japanese in 1942 (Douglas 1969). Nearly swept clean of vegetation during WWII – used heavily by US troops (King 1973).*

### *Significant invasive land vertebrates*

Cat, Norway rat. No other rats (King 1973).

***Table 2: Distribution of significant invasive animals by island group.***

| Islands | Cattle | Goat | Pig | Dog | Cat | Pacific rat | Ship rat | Norway rat | Mouse | Rabbit | Mongoose | Musk shrew | Brown tree snake | Cane toad | Indian myna | Jungle myna | Bulbul |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Austral Is and Rapa (French Polynesia) | + | + | + | + | | + | + | | | + | | | | | + | | |
| Baker and Howland (USA) | | | | | + | + | | + | | | | | | | | | |
| Caroline Is (USA, Fed. St. Micron.) | + | + | + | + | + | + | + | + | + | | | | | + | | | |
| Chesterfield Is (French) | | | | | | | | | | | | | | | | | |
| Cook Is (NZ) | | + | + | + | + | + | + | + | + | | | | | | + | | |
| D'Entrecasteaux Reefs (French) | | | | | | | | | | | | | | | | | |
| Fiji | + | + | + | + | + | + | + | + | + | | + | | | + | + | + | + |
| Gambier Is (Fench Polynesia) | | | | p | p | + | | | | + | | | | | | | |
| Gilbert Is (Kiribati) | | | p | + | + | + | + | | | | | | | | | | |
| Guam (USA) | | | + | + | + | + | + | + | + | | | + | + | + | | | |
| Hawaii (USA) | + | + | + | + | + | + | + | + | + | + | + | | | | + | | + |
| Line/Equatorial Is (Kiribati) | | f | + | + | + | + | + | | + | | | | | | | | |
| Loyalty Is (French) | | | p | p | p | + | + | + | + | | | | | | | | |
| Marquesas (French Polynesia) | + | + | + | p | + | + | + | + | | | | | | | + | | |
| Marshall Is | | | p | p | p | + | + | + | + | | | | | | | | |
| Nauru | | | p | p | p | + | + | | + | | | | | | | | |
| New Caledonia (French) | + | + | + | + | + | + | + | + | + | | | | | | + | | |
| Papua New Guinea | p | p | + | + | + | + | + | | | | | | | | | | |
| Niue (NZ) | | | p | p | p | + | + | + | | | | | | | | | |
| Northern Mariana Is | + | + | + | + | + | + | + | + | + | | | + | ? | + | | | |
| Ocean/Banaba (Kiribati) | | | | | | | + | | | | | | | | | | |
| Palau Is | | + | + | + | + | + | + | + | + | | | + | | + | | | |
| Phoenix Is (Kiribati) | | + | + | + | + | + | + | ? | | + | | | | | | | |
| Pitcairn Is (UK) | | + | f | | + | + | | | + | f | | | | | | | |
| Rennell and Bellona (Solomon Is) | | | | | | + | | | | | | | | | | | |
| Rotuma (Fiji) | + | + | + | + | + | + | | | | | | | | | | | |
| Samoa (W: Indep.; E: USA) | | | + | + | + | + | + | + | | | | | | + | ? | + | + |
| Santa Cruz Is (Solomon Is) | | | + | | | + | + | | | | | | | | | | |
| Society Is (French Polynesia) | + | + | + | + | + | + | + | + | + | | | | | | + | | ? |
| Solomon Is | | | + | p | + | + | + | | + | | | | | + | + | | |
| Tokelau Is (NZ) | | | + | + | + | + | | | | | | | | | | | |
| Tonga | | | + | + | + | + | + | + | + | + | | | | | | + | + |
| Tuamotu (French Polynesia) | | | p | + | + | + | + | + | + | | | | | | + | | |
| Tuvalu (Ellice) (UK) | f | | p | | + | + | + | + | + | | f | | | | | | |
| Vanuatu, incl. Banks, Torres | | | + | | | + | + | + | + | | | | | | + | | |
| Wake Is (USA) | | | | | + | + | + | | | | | | ? | | | | |
| Wallis and Futuna (French) | | | + | | + | + | ? | ? | | | | | | | + | | |

+ currently existing, p probably existing, ? possibly existing, f formerly existing

Norway rat – introduced pre-1887. Present in considerable numbers: "had evidently cleared out the small native rats, found in hordes on most of the Central Pacific Islands; and no doubt accounted for the comparative absence of sea birds" (Ellis 1936: 26). "Bird life [is] … much less abundant on Baker than on other similar islands in the Central Pacific, due to the presence of large voracious Norway rats … "(Bryan 1942). The rats subsist on eggs and small birds, terns, and noddies (Hague 1862, Bryan 1942).

Cat - implied introduction time of 1942–44 (Forsell 1982). In 1964 the last of a small cat population was removed by the Pacific Ocean Biological Survey

Program (POBSP). There has been a spectacular recovery of the seabird population since removal of cats (Forsell 1982). However, King (1973) reports that in 1966 after a visit by the US military, at least two cats reappeared on the island. It is unclear whether cats are present today.

#### Howland

*Also called Worth I. after Captain Worth of the whaleship* Oeno*, when he found the island in 1922. Then named after the lookout who first saw the island from the New Bedford whaler* Isabella*, in 1842 (Ellis 1936). Polynesian remains on the island (Emory 1934). An airstrip and lighthouse were built, intended for use by Amelia Earhart (King 1973: 100).*

*1.9 km² (0.73 sq. mi.). Atoll with one island, no lagoon. Dry. Worked for guano late last century. Occupied by US before and during war, until attacked by Japanese in 1942 (Douglas 1969). Little sign of human occupancy (King 1973: 100).*

### *Significant invasive land vertebrates*

Cat (King 1973), Pacific rat (Douglas 1969, Hague 1862).

The Pacific rat, *R. exulans*, has been so numerous as to cause distress to persons living on the island (Bryan 1942). Ellis (1936: 24) reports that it is the worst place in their experience for the Pacific rat. Natives occasionally had soles of feet eaten by them while asleep. “Round the labourers’ quarters at dusk the ground was literally alive with them” (Ellis 1936: 24).

Hague (1862) spent several months there between 1859 and 1861. He noted that rats were about as numerous as the birds, and were very small, hardly larger than a mouse. He caught over 100 per night for many nights, and over 3300 were killed by a few men in one day.

Cats were introduced by colonists, extirpated by POBSP in 1964, reappeared in 1966 after a visit by the US Military (King 1973). Thus, the present population of house cats was introduced in 1966, and must have had great impact on rat numbers, for Kirkpatrick and Rauzon (1986: 73,74) state: “Mammals other than cats were not observed during cat collection activities on Howland Island”, and no rat remains were found in cat stomachs.

### *Opportunities for island restoration*

“Baker has excellent potential as a seabird colony, but it is kept nearly devoid of birds by the presence of at least two cats” (King 1973: 100).

Howland “would quickly become among the most significant colonies in the central pacific if the cats were removed and the island were given protection from disturbance” (King 1973: 100).

## Caroline Islands (Federated States of Micronesia - USA)

(70 islands in group)

Robertson (1877: 48, 53) commented in relation to the Yap group: “Pigs are plentiful, and there is also a kind of half domesticated fowl which can be procured cheaply. Deer and goats are seen, but the natives do not protect them, as they destroy their plantations…. The number of rats on these islands is almost beyond belief, and they are so tame that when the people are eating they come and sit round them waiting for any morsels that fall. The houses are built without sides, being merely roofed, and the supports are carefully smoothed down to prevent the rats climbing up and eating the provisions which are stored away on shelves above”.

### *Significant invasive land vertebrates*

Cattle, goat, pig, dog, cat, Pacific rat, Norway rat, ship rat, mouse, cane toad.

Also: Micronesian deer (*Rusa marianna*) [?now called Rusa deer *Cervus timorensis*], *Rattus tanezumi* (Flannery 1995), monitor lizard (Johnson 1962: 37), red junglefowl (*Gallus gallus*) (Buden 1996).

Writing of the east Caroline islands, including Pohnpei (Ponape) and Pingelap, Jackson (1962) states: “Domestic pigs, carabao, and cats have arrived since contact with the Western world was first established in 1529; and some have found their way into the forest and become feral. The several breeds of cattle and goats present are not common, and none is feral. Horses were introduced at one time but did not survive. Dogs were introduced by the Micronesians. … The monitor lizard (*Varanus indicus*) introduced in the hope that it would control rats, became established, and is reported to have been common and widespread for some time. However, it is now relatively scarce and restricted to a few areas on Ponape. It exercises no conspicuous control on the rats but damages domestic chickens…. The giant toad (*Bufo marinus*), native to Mexico and Central America, has been a highly successful introduction on many islands across the Pacific … and is present on Ponape in all areas except reef islets. … its introduction is said to have been made in the hope of controlling the monitor lizard. The monitor is reported to have declined on Guam following the introduction of the toad, and it may have declined on Ponape also …”

Archaeological study by Steadman and Intoh (1994) suggests that around nine seabirds and three landbirds are extinct on Fais Island, Yap State.

### Ant

*1.8 km$^2$ (0.7 sq. mi.). Atoll with several small islets. Visited for copra collection.*

Pig, dog, cat, Pacific rat, ship rat (Marshall 1962, Johnson 1962, Buden 1996a).

Also: Red junglefowl (*Gallus gallus*) (Buden 1996a).

"I saw rats frequently … on nearly every island [islet?] from Nikalap Aru westward to Pamuk, but none on Wolouna and Pasa, which apparently are the only rodent-free islands" (see Buden 1996a: 33 for more detail).

Probably feral cats (Buden 1996a: 33).

"I observed about 30 semiferal pigs on Nikalap Aru …" (Buden 1996a: 34).

### Ifaluk

*1.5 km$^2$ (0.57 sq. mi.). Atoll with 3 islets. Falarik and Falalap are inhabited, Ella not.*

Pacific rat. Another species of rat? (see Burrows and Spiro 1953).

Also: Monitor lizard.

Bates and Abbott (1958) comment: "… of the animals on Ella, the rats made the strongest impression on me. ….The rats, once one started to notice them, were everywhere, in overwhelming numbers. These rats … are one of the great plagues everywhere in Polynesia and Micronesia. They were present on Falarik and Falalap … but the numbers on Ella were really fantastic."

The Japanese introduced monitor lizards to Ifaluk to help control rats, but monitors were not established on Ella at the time of Bates and Abbott's (1958) visit. They comment that after seeing Ella: "I was ready to believe that they [monitor lizards] might be responsible for the relative scarcity of rats on the main islands."

### Kapingamarangi

*1.3 km$^2$ (0.5 sq. mi.). Atoll with 33 islets. 3 largest inhabited by Polynesian population.*

Cat. Pacific rat - present but uncommon on the densely populated islets of Toutou and Wema where cats are said to be keeping them under control (Niering 1956).

### Kusaie/Kosrae

*110 km$^2$ (42.33 sq. mi.). High volcanic, 628 m (2061'), reef. Inhabited and coastal plain cultivated.*

Pacific rat, ship rat (Marshall 1962). Ship rat introduced pre-1931? (Koroia 1934).

Also: *Rattus tanezumi* (Flannery 1995).

"When the Japanese took over the islands, a period of extreme exploitation began" (Mayr 1945a). Many sources give rats as the reason for extinction of the Kusaie starling (*Aplonis* sp.): "A handsome, glossy black starling … is thought to have been exterminated by rats that came ashore on Kusaie from whaling ships in the 19th century (Austin 1961). "Two species, a rail and a starling, were extirpated from Kusaie Island between 1828 and 1880. Both were confined to that island …" (Greenway 1967).

Kusaie crake and Kusaie starling both extinct 1828 (King 1981).

### Lamotrek/Nomatik

*1 km$^2$ (0.38 sq. mi.) Atoll with three islets.*

Mouse, introduced pre-1931 (Koroia 1934).

### Mokil

*1.3 km$^2$ (0.5 sq. mi.) Atoll with three main islets, densely populated.*

Pacific rat (Johnson 1962, Marshall 1962).

### Mortlock

Pacific rat (R.H. Taylor, letter 1982).

### Namoluk

Pigs, dogs, cats, Pacific rat, ship rat (Marshall 1975).

"Rats occur in great abundance on the three largest islets, … Trapping efforts in 1971 gave credence to local stories claiming Lukan Islet to be rat-free" (Marshall 1975). Rats are present on Umap Islet – possibly all ship rat. On the main atoll both Pacific rat and ship rat are present (Marshall 1975).

### Oroluk

*0.5 km$^2$ (0.2 sq. mi.). Atoll with ring of small islets.*

Ship rat (Marshall 1962, Johnson 1962).

### Pakin

*1 km$^2$ (0.42 sq. mi.). Atoll with at least 5 islets.*

Pig, dog, cat, Pacific rat (Buden 1996b)

Also: Monitor lizard, red junglefowl (*Gallus gallus*) (Buden 1996b).

"…the islanders say feral cats are widespread…" (Buden 1996b: 46).

"Pigs … are common on the larger islands, being absent only from the Tomwena group and the tiny scrub-covered islets on the eastern end of the atoll. They are allowed to roam free over the islands, and I saw two swimming across the channel between Karot (an uninhabited island) and Osetik" (Buden 1996b: 47).

### Pingelap

*1.7 km$^2$ (0.66 sq. mi.). Atoll with 2 islands and one islet. Densely populated.*

Pacific rat (Marshall 1962, Johnson 1962).

### Ponape/Pohnpei

*Very high numbers of whalers visited the island between 1824 and 1860, mostly from America. In 1858, 50–60 whaleships were visiting Ponape each year (Hezel 1979).*

*334 km$^2$ (129 sq. mi.). High volcanic, 791 m (2595'), reef islets and lagoon islets. Lowland cultivated.*

Pacific rat, Norway rat (introduced pre-1932), ship rat (introduced pre-1932), mouse (introduced pre-1932) (Koroia 1934, Marshall 1962, Johnson 1962).

Also: *Rattus tanezumi* (Flannery 1995).

### Truk (Moen)

*19 km$^2$ (7.25 sq. mi.). High volcanic, 370 m (1215'). Admin. centre. Douglas (1969) recommends protection of savanna areas.*

Pacific rat, ship rat (introduced pre-1932), mouse (Koroia 1934, Marshall 1962, Johnson 1962). Musk shrew (introduced pre-1967) (Barbehenn 1974: 46).

Also: *Rattus tanezumi* (Flannery 1995).

### Ulithi

*4.7 km$^2$ (1.8 sq. mi.). Atoll with 40 islets in 4 main groups. Is the largest atoll (but not island) in the Carolines. Used by US during WWII.*

Pacific rat (probably) (Lessa 1961), ship rat (introduced pre-1931) (Koroia 1934, Marshall 1962).

Also: *Rattus tanezumi* (Flannery 1995).

### Wolea/Woleai

*4.5 km$^2$ (1.75 sq. mi.). Atoll with 21 islets.*

Pacific rat (Koroia 1934).

### Yap

*56.2 km$^2$ (21.68 sq. mi.). Volcanic, 176 m (579'), reef. Much disturbed and cultivated.*

Pig, Pacific rat, Norway rat (introduced pre-1947), ship rat (introduced pre-1931) (Koroia 1934, Hartmann 1947). Mouse (introduced pre-1931).

#### *Opportunities for island restoration*

Possibly one of the islets of Kapingamarangi.

Wolouna and Pasa [?islets of Ant] are apparently rodent-free (see Buden 1996a:33).

## Chesterfield Islands (France)

(11 islets)

*Cohic (1959) reports a 4-hour visit made to these islands in 1957, commenting: "There was a complete lack of information on these islands, so it was obvious that a visit would be fruitful."*

*The islands are situated halfway between Australia and New Caledonia, "completely uninhabited and isolated from shipping routes, and avoided as a danger to navigation" (Cohic 1959: 1). Cohic believes that the last French vessel to visit "surveyed the island and prepared a map in 1939".*

*Total area: < 1000 ha. Coral. Largest islet is Longue I., and was the only one visited by Cohic: "a narrow tongue of sand, approximately 1800 m long and 130 m wide…"*

These islands "are at the junction of several biogeographic regions, Australian, New Caledonian and New-Hebridean". (See Cohic (1959) for a surprisingly extensive survey of flora and fauna, considering the duration of the visit.)

#### *Significant invasive land vertebrates*

None.

"The land fauna of Longue Island is very small. There are no mammals, amphibians or land reptiles. The few groups represented are birds, turtles – which come on land to lay eggs, sea snakes, a few Arachnida and insects" (Cohic 1959: 4).

#### *Opportunities for island restoration*

Removal of the extraordinary botanical introductions made during Cohic's 1957 visit: "During our short visit to Longue Island, a few plants were introduced by the Service d'Agriculture of New Caledonia. These were: coconuts, *Araucaria columnaris* (Forst.) Hook., *Sesbania grandiflora* Pers. and *Leucaena glauca* (L.) Benth." (Cohic 1959: 4).

## Cook Islands (New Zealand)

(15 islands in two groups - Southern and Northern)

*Total area: 241 km$^2$ (93 sq. mi.). Southern Cook Islands – volcanic, and Northern Cook Islands – atolls. Fruit growing: citrus, bananas, pineapples, etc.; also copra.*

#### *Significant invasive land vertebrates*

Goat, pig, dog, cat, Pacific rat, ship rat, Norway rat, mouse. Indian myna.

Pigs reported as only significant invasives on Manuae (E.K. Saul, pers. comm. 1999).

"Rats (species unknown) were believed by Mr Tama and Mr Turer to be a problem to a greater or lesser extent to the copra crops on Penrhyn, Manihiki, Rakahanga, Pukapuka, Nassau, Aitutaki, Mitiaro and possibly Atiu. Mangos on Aitutaki, Atiu, Mauke and Rarotonga and pineapples on Atiu and Mangaia were also stated to be troubled by rodents" (Daniel 1978).

Three bird species introduced. At least 10 bird species extinct (Case 1996: 71).

Indian myna present on: Aitutaki, Atiu, Mangaia, Manuae and islets of Manuae and Auotu, Mauke, Rarotonga (Lever 1987: 499, following Holyoak and Thibault 1984).

## Southern Cook Islands

### Aitutaki/Aitutake

*Discovered by Bligh in the* Bounty*, 1789. Effective contact began with arrival of first missionaries in October 1821. Two whaling ships wrecked in 1847. Party of 900 US Marines and 400 negroes present from 1942 to 1944 (Stoddart 1975).*

*18 km² (7 sq. mi., 4461 acres). Main island volcanic, 137 m (450'), including 13 reef islets. Large lagoon. Fertile. Citrus, banana, cocunuts, tomatoes grown.*

?Cat, Pacific rat, Norway rat, ship rat, mouse. Indian myna (Lever 1987: 499).

Introduction time/spread - Skeletal material of *R. exulans* and *Mus musculus* collected from the island by Marples in 1956, but no *R. norvegicus* or *R. rattus* (Marples 1955). In 1963, *R. exulans, R. norvegicus* and *R. rattus* trapped on island (Alicata and McCarthy 1964).

Rats a problem to copra crop, mangoes also troubled by rodents (Daniel 1978).

"Six archaeological sites up to 1000 years old on Aitutaki … have yielded bones of 15 species of birds, five of which no longer occur on the island … Of these, only [two] survive anywhere in the Cook Islands today" (Steadman 1991). Mammals found include Pacific rat, dog, pig (Steadman 1991: 328).

Pauline McColl (pers. comm.) says this is the only island where lorikeet (the nun bird) breeds.

### Atiu

*Discovered by Cook in 1777.*

*28 km² (10.9 sq. mi., 6654 acres). Central volcanic plateau, 91 m (300'), surrounded by mile wide makatea (elevated reef limestone). Fringing reef. Citrus fruit, coffee.*

Rats present (species unknown). Indian myna (Lever 1987: 499).

Mangoes and pineapples troubled by rodents (Daniel 1978).

### Mangaia

*Discovered by Cook in 1777.*

*51.8 km² (20 sq. mi.) (Merlin 1991: 131). Low volcanic. Swamps. Intensive cultivation. Main settlement on makatea (elevated reef limestone), pineapple growing on volcanic areas.*

?Cat, Pacific rat, ship rat (Alicata and McCarthy 1964). Indian myna (Lever 1987: 499).

No dogs or pigs in pre-European times (Heyerdahl 1952).

One Norway rat arrived 1852, and was trapped:

"In many of the islands the indigenous breed has been exterminated by the imported rat. In 1852 a solitary male *R. norvegicus* got ashore from a wreck at Mangaia, and made war on the native rat, 30 of these were found dead under the floor of a room; the *R. norvegicus* was eventually trapped (Gill 1876: 316). In 1963, *R. rattus* trapped on Mangaia (Alicata and McCarthy 1964).

Rats feed on "cocoa-nuts, bananas, arrow-root, candlenuts, and papas apples" (Gill 1876: 317). Pineapples troubled by rodents (Daniel 1978).

"On the island of Mangaia … only 2 species of land bird exist today; I have found fossil evidence of 8 extinct species" (Steadman and Zousmer 1988), including 2 species of flightless rail (Steadman 1987).

Rats trapped, singed baked and eaten. A common expression when speaking of anything delicious: "It is as sweet as a rat" (Williams 1839).

### Manuae (Hervey)

*Discovered by Cook in 1773.*

*6 km² (2.3 sq. mi., 1524 acres). Atoll with twin islets. Closed lagoon, almost totally covered by coconut plantation.*

Pig. Rats present (species unknown). Only Pacific rat? "Manuae – almost certainly *R. exulans*" (W.R. Sykes, letter, 1982). Indian myna - also present on islets of Manuae and Auotu (Lever 1987: 499).

Pigs reported as significant invasives on Manuae (E.K. Saul, pers. comm. 1999).

### Mauke

*Discovered by the Rev. John Williams in 1823.*

*18 km² (7.1 sq. mi., 4552 acres). Low volcanic, 30 m (100'), surrounded by ring of makatea (elevated reef limestone), swampy zone between volcanics and limestone. Fringing reef. Well wooded. Citrus fruit, peanuts grown.*

Cat, pig, goat, dog (all introduced 1823–25). Pacific rat only? Indian myna (Lever 1987: 499).

Bloxam (1925) saw many rats "running about the woods" in daylight. Was estimated that on Mauke, "80 per cent of the coconuts are lost through rat damage" (Iyengar and Menon 1957). Pauline McColl (pers. comm. 1985) just returned from a visit to Mauke – "locals say only the small rat is there".

A starling *Aplonis mavornata*, and fruit dove *Ptilinopus rarotongensis* cf. *goodwini*, collected by Bloxam in 1925, presumably now extinct (Olson 1986).

### Mitiaro

*22 km² (8.6 sq. mi., 5500 acres). Low volcanic core, surrounded by lake and swamp complex. Small amount of cultivated land.*

Rats present, probably Pacific rat (W.R. Sykes, letter 1982).

Rats a problem to copra crop (Daniel 1978).

### Palmerston

*Discovered by Cook in 1774. Palmerston is 434 km (270 miles) from Rarotonga, intermediate in postion between the "northern" and "southern" Cooks.*

*2.59 km$^2$ (1 sq. mi., 500 acres). Atoll with lagoon and 8 islets. Well wooded with some native vegetation. Copra production?*

Pacific rat? (Observed by Anderson in 1777) (Beaglehole, no date: 851).

### Rarotonga

*Fletcher Christian called there with* Bounty *mutineers in 1789. They are credited with its discovery. No other ships called until 1813 or 1814 (D.L. Stoddart 1975).*

*67 km$^2$ (25.8 sq. mi., 16 602 acres). High volcanic, 643 m (2110'), with at least 7 central summits. Fringing lowland, with inner swampy ring. Cloud forest above 400 m (proposed Te Manga Nature Reserve of 118 ha - 80% of cloud forest). Fringing reef. Main settlement coastal, tropical fruit growing. Administration centre for Cook Islands.*

Pig, ?dog, cat, Pacific rat, Norway rat, ship rat, mouse (Robertson et al. 1994). Indian myna (Lever 1987: 499).

All three rats trapped on Rarotonga in 1963 (Alicata and McCarthy 1964).

Williams (1839) writing of Rarotonga in about 1827–28 states that rats were exceedingly numerous; "we never sat down to a meal without having two or more persons to keep them off the table". Rats destroyed a pair of bellows and also a pair of shoes belonging to the missionaries. They complained to the authorities, who organised an extermination campaign against the rats: "After school, man, woman, and child armed themselves with suitable weapons, and commenced their direful operations. Baskets were made of coconut leaves, about five or six feet in length, in which to deposit the bodies of the slain, and in about an hour, no less than thirty of these were filled. But notwithstanding this destruction, there did not appear the slightest diminution…" (Williams 1839).

Cats were introduced by early missionaries. They were useful in keeping down the abundant native rat. When the rats became scarce, the cats took to the birds and exterminated several species (Gill 1885: 127).

Williams (1839) brought both pigs and cats to the island (in 1827–28) and considered that the pigs were more effective than the cats in destroying the rats.

## Northern Cook Islands

### Manihiki

*Discovered by Patrickson in 1822. Early 19$^{th}$ C whaling port of call (Douglas 1969).*

*5 km$^2$ (2.0 sq. mi., 1344 acres). Atoll with lagoon islets. Pearl shell and copra.*

?Cat, Pacific rat, Norway rat.

Norway rats reached Manihiki c. 1850–1885. "Norway rats lately introduced to Manihiki by wrecked kidnapping vessels (Gill 1885: 163).

Rats a problem to copra crop (Daniel 1978).

### Nassau

*Discovered by Sampson in the* Nassau*, 1835, although it may have been known to earlier whalers (Bryan 1942).*

*1 km$^2$ (0.45 sq. mi., 300 acres). Atoll without lagoon, flat. Owned by Pukapuka people, inhabited almost continuously from Pukapuka, copra growing.*

?Cat. Rats present (species unknown).

Rats a problem to copra crop (Daniel 1978).

### Penryn (Tongareva)

*Discovered by Lever in 1778. Island almost depopulated by Peruvian slavers in 1864, who took 1000 men, women and children (Smith 1889). WWII airstrip (Douglas 1969).*

*16 km$^2$ (6.2 sq. mi.) (King 1973: 97). Large atoll with many islets. Coconut groves. Copra growing.*

Pig, dog, cat, Pacific rat (numerous in 1965) (Clapp 1977).

In 1853 the natives "had never seen an animal larger than a very small rat, that lives principally in the coconut trees …" (Lamont 1867, in Clapp 1977: 2).

"Comments by Ward (1967) and Lamont (1867) suggest that the pigs may have been introduced to Tongareva in 1835 from the ship-wrecked vessel *Chatham*" (Clapp 1977: 2).

Rats a problem to copra crop (Daniel 1978).

### Pukapuka

*Discovered by the Spanish explorer Mendana during or after 1595 (Beaglehole and Beaglehole 1938).*

*5 km$^2$ (2.0 sq. mi., 1250 acres). Atoll with 3 groups of islets. Main islet inhabited, others used for plantations. Copra, banana growing.*

Pig, Pacific rat (Beaglehole and Beaglehole 1938).

Rats a problem to copra crop (Daniel 1978).

### Rakahanga

*Discovered by the Spanish explorer Quiros in 1606.*

*4 km$^2$ (1.55 sq. mi., 1000 acres). Atoll, small lagoon with islets. Coconuts.*

Pacific rat (Gill 1885, Bryan 1942).

Rats a problem to copra crop (Daniel 1978).

### Suwarrow (Suvarov)

*Discovered by Lazarev in 1814, who reported islets with no sign of inhabitants, but overrun with crabs, rats and large flocks of birds (Bryan 1942).*

*40 hectares (100 acres). Atoll with 25 islets on reef. Uninhabited. Some wet atoll forest, otherwise coconuts.*

Feral chickens and pigs on main island (Douglas 1969).

Pacific rat (Neale 1966).

"Mrs. Thievery" (a cat), ?temporarily on Suwarrow, catching rats (Neale 1966).

### *Opportunities for island restoration*

Suwarrow Atoll was considered as 'Atoll for Science' candidate. It was a Bird Sanctuary (informal?) occupied in the past by T. Neale, author of *An Island to Oneself*, 1966 (Douglas 1969).

## D'Entrecasteaux Reefs (France)

*Discovered 1793 by the French explorer, D'Entrecasteaux.*

*130 km (80 miles) northwest of New Caledonia. (A group of the same name is situated at the east end of New Guinea.) Total area: 64.8 hectares (160 acres). Four atolls, the largest is Huon. Uninhabited.*

### *Significant invasive land vertebrates*

No information found.

### *Opportunities for island restoration*

Unknown.

## Fiji

(c. 190 islands in group)

*The Fiji Islands were first sighted by Tasman in 1643, but nothing more was seen or heard of them until the 1775–1800 period. A sandalwood trade existed between 1801 and 1810, by which time the sandalwood thickets had all been cut. A United States Exploring Expedition surveyed practically all the coasts of the principal islands in 1840. Port facilities became available at Suva c. 1880. Prior to that the main port was Levuka on Ovalau. Levuka was the earliest European settlement on Fiji and at one time the capital (Derrick 1951).*

*Total land area: 18 272 km$^2$ (7055 sq. mi.), mostly in two major islands (Viti Levu, Vanua Levu). The group is a mixture of high volcanic and smaller limestone islands. High mountains of main islands (1200+ m) create a rainshadow to the west (Pernetta and Watling 1978).*

### *Significant invasive land vertebrates*

Cattle, goat, pig, dog, cat, Pacific rat, ship rat, Norway rat, mouse, mongoose, cane toad, Indian myna, jungle myna, red-vented bulbul.

Also: Fallow deer, horse, red deer, sheep, chickens, ducks, geese, turkeys (Pernetta and Watling 1978)

For extensive, detailed information on species introduced to Fiji, their distribution within Fiji, their impact on native flora and fauna, and some information on extinctions, see Pernetta and Watling (1978).

**Rats**

It appears that *R. rattus* had not reached Fiji by 1840, but mice were present (Cassin 1858).

Williams (1974) states that *R. exulans* is clearly the most widespread species of rat in Fiji. *R. rattus* is fairly widespread on the main islands. *R. norvegicus* appears to be a relatively unimportant rat in Fiji's rural environment.

Following Pernetta and Watling (1978):

*R. exulans,* aboriginal, all islands, abundant, all habitats
*R. norvegicus,* 19$^{th}$ century, main islands, common, agric., urban, suburban, coastal
*R. rattus,* 19$^{th}$ century, main islands, locally abundant, agric., plantation, urban, suburban, coastal
*M. musculus,* 19$^{th}$ century, Viti Levu, Vanua Levu, locally abundant, urban, suburban, agricultural

"The more recently introduced rats and mice have no apparent effect on the distribution of the prehistorically introduced *Rattus exulans,* as all three species may be found in the same habitats. There is some indication that the Norway rat is more abundant in suburban situations than the other two species... that the black rat may preferentially inhabit plantations and coconut palm crowns ... and that these species are restricted in their distribution to a close association with humans ..." (Pernetta and Watling 1978: 233).

In the Lau group, where *R. rattus* is absent, the "Virtual absence of rat-damaged coconuts on Matuku and Lakeba supported … trapping results as it was established that *R. rattus* was responsible for most of the damage in mature coconut groves" (Williams 1974).

In 1933, in a detailed study of rat damage on copra crops, it was commented: "The extent of the damage done by rats varies considerably in different localities" (Paine 1934: 26). "Rat damage to coconuts in Fiji has, in the past been greatly underestimated, or else it has become very much more severe than it was five or more years ago" …. "on Taveuni, it appears likely that at present rats are destroying something like one-third of the total potential copra crop at various stages in its preparation" (Paine 1934: 33)

**Other domestic animals**

"Domestic animals such as horses and cattle are also widespread throughout the islands and may roam in a relatively unrestricted manner over the unfenced grasslands of the dry and intermediate zones. In a number of localities in the intermediate zone of Viti Levu and Kadavu, feral goats are found in small numbers. These animals are also found on various islands, such as Goat Island in the Yasawas, and Namara Island in the Kadavu group. Although European introductions of dogs and cats have resulted in their widespread distribution throughout the islands, no feral populations of these animals are known at present. European breeds of domestic pigs and sheep are maintained under agricultural conditions, as are large numbers of fowl, ducks, geese, and turkeys" (Pernetta and Watling 1978: 229).

**Mongooses**

Mongooses were introduced in 1883 to control rats in sugar cane (Gorman 1975a, in Pernetta and Watling 1978: 229). Mongooses are present only on Viti Levu and Vanua Levu (Pernetta and Watling 1978: 228). "… it is possible to state conclusively that the banded rail, *Rallus phillopensis*, sooty rail, *Porzana tabuensis*, white-browed rail, *Poliolimnas cinereus*, and purple swamphen, *Porphyrio porphyrio*, were all common on Viti Levu in the last century. These now survive in any numbers only on islands that are free of the mongoose" (Pernetta and Watling 1978: 229–230).

**Introduced birds**

(greater detail in Pernetta and Watling 1978)

Indian myna (*Acridotheres tristis*) - introduced c. 1890, present and common on the main islands.

Jungle myna (*Acridotheres fuscus*) - introduced c. 1890, present and common on the main islands, except Taveuni.

Red-vented bulbul (*Pycnonotus cafer*) - introduced c. 1900, common on Viti Levu, Ovalau, Wakaya, present but rare on Beqa and Taveuni.

**Extinct fauna**

Recent archaeological work on Viti Levu (Worthy et al. 1999) reveals many extinct species of bird and reptile. They describe an unexpectedly rich pitfall fauna from Viti Levu that includes a crocodilian, a tortoise, a giant frog, a giant iguana like that of the Galapagos Islands, a giant flightless megapode, and a giant flightless pigeon.

### Beqa

*Just south of Viti Levu.*

Pacific rat. Williams (1974) caught *R. exulans* only. Red-vented bulbul (rare) (Pernetta and Watling 1978).

### Kadavu

*A large island south of Viti Levu. Used for some years (c. 1870-80) "for the trans-shipment of passengers, mails, and cargo for New Zealand and the islands" (Derrick 1951:4).*

Goat, pig, dog, cat, Pacific rat, ship rat.

Thomson (1889) explored the island during 1884: "Of domestic animals, there is the pig, the goat, the dog, and the cat..."

Williams (1974) trapped both *R. exulans* and *R. rattus*.

### Lakeba (Lau group)

*South-east of Vanua Levu.*

Pacific rat. Norway rat (introduced 1875-1900?)

Williams (1974) trapped *R. exulans*.

Norway rat trapped on Lakeba – the only one of the Lau group where this species was found. " …Village elders thought that it migrated from ships that were wrecked late in the 19th century" (Williams 1974).

### Laucala

*Laucala is immediately east of Taveuni.*

Pacific rat, ship rat. Williams (1974) trapped *R. exulans* and *R. rattus*.

### Matuku

*Matuku is east of the Kadavu group.*

Pacific rat.

Williams (1974) trapped *R. exulans* only.

### Moala

*Moala is east of the Kadavu group. Volcanic, 8 peaks over 1000', rugged. Forest. Fringing reef. Copra and banana cultivation.*

Pacific rat, ship rat.

Williams (1974) trapped *R. exulans* and *R. rattus*.

### Ovalau

*Ovalau is off the north-east coast of Viti Levu. Levuka on Ovalau was the earliest European settlement on Fiji and at one time the capital (c. 1840) (Derrick 1951: 7). In 1835 "missionaries and their wives and families arrived by way of Tonga" (Derrick 1951).*

*Volcanic, rugged, fertile, forest. Pineapple, copra, coconut, sugar cultivation. Much timber felled.*

Norway rat (introduced pre-1876), ship rat (introduced pre-1876). Red-vented bulbul (common) (Pernetta and Watling 1978).

Moseley (1944 (1879): 266) observed that "the black rat and the Norway rat are abundant here."

### Taveuni

*Volcanic, 914 m (3000'), steep slopes, crater lake, forest and a rich bird fauna. Cultivation of cotton, coffee, lifestock. Ravilevu National Park, mountain area with mixed forest.*

?Pig, ?dog, ?cat, Pacific rat, Norway rat, ship rat, mouse (Williams 1974). Indian myna (common), red-vented bulbul (rare) (Pernetta and Watling 1978).

Mongooses absent, more *R. norvegicus* present than on Viti Levu or Vanua Levu (J. M. Williams, pers. comm.).

Greatest concentration of *R. norvegicus* was in a "plantation habitat … on Waitavala Estate, Taveuni … *R. exulans, R. rattus* and *Mus musculus* were also trapped in the same area indicating that the relatively simple habitat of a well maintained mature coconut plantation is capable of supporting four rodent species" (Williams 1974).

#### Vanua Balavu

*Vanua Balavu is east of Taveuni.*

Pacific rat, ship rat.

Williams (1974) trapped *R. exulans* and *R. rattus*.

#### Vanua Levu

*American whaler, the* Faun, *wrecked in August 1830.*

*Volcanic, amalgamation of several islands, up to 835 m (2740'), wet forest, arid plains. Coconut plantations.*

Cattle, pig, dog, cat, Pacific rat, Norway rat, ship rat, mouse, mongoose, cane toad, Indian myna, jungle myna (both common) (Pernetta and Watling 1978).

Pernetta and Watling (1978) record *norvegicus* as "common", *rattus* as "locally abundant", *exulans* as "abundant" and *M. musculus* as "locally abundant".

#### Vatulele

*Vatulele is immediately south of Viti Levu.*

*Limestone, wedge of honeycombed land, vertical cliffs, reef.*

Pacific rat.

Williams (1974) trapped *R. exulans* only.

#### Viti Levu

*Age (via C14) of the oldest known Lapita pottery site on Viti Levu is 1590 BC (± 100) (Green 1979). Port facilities opened at Suva in about 1880–81 (Derrick 1951).*

*Volcanic, 1323 m (4341'), Mountain backbone causing rainforests and rainshadow. Savannas.*

Cattle, goat, pig, dog, cat, Pacific rat, Norway rat (pre-1876), ship rat (pre-1876), mouse, mongoose, cane toad, Indian myna, jungle myna (both common) (Pernetta and Watling 1978). Red-vented bulbul (common) (Pernetta and Watling 1978).

The journal of Henry Thurston (1924: 396) describing a journey through the interior of Viti Levu in 1865, mentions natives killing a "wild cat". Also mentioned are wandering pigs and a domesticated dog.

Moseley (1944 (1879): 280) recorded that "Black rat and Norway rat are abundant at Viti, Fiji..."

Pernetta and Watling (1978) record *R. exulans* as "abundant", *R. norvegicus* as "common", *R. rattus* as "locally abundant", *M. musculus* as "locally abundant".

Gorman (1975b) provides data on the habitat distribution of introduced birds on Viti Levu.

The Viti Levu rail (*Nesoclopeus poecilopterus*) became extinct during the "last 100 years" – 1845–1945 (Mayr 1945a).

#### Yacata (Lau Group)

*Yacata is between Taveuni and Vanua Balavu.*

Pacific rat.

Williams (1974) trapped *R. exulans* only.

#### Yasawa Group – Nauya Lailai, Naukacuvu, Yasawa

*Nauya Lailai – site of shipwreck in 19th century.*

Following Williams (1974):

| | |
|---|---|
| Nauya Lailai | *R. exulans, R. rattus, R. norvegicus* |
| Naukacuvu | *R. exulans* only |
| Yasawa | *R. exulans* only |

Other islands in the group were not trapped.

### *Opportunities for island restoration*

Williams (letter, 1982): "Within Fiji I do not know of any islands which are altogether rat free. However, there are 320 in the group, counting all the tiny dots along the reefs, so clearly some of the very small ones will not have rats – but they support very little else either. I visited and trapped 17 of the inhabited islands and found at least *R. exulans* on them all …. I trapped *R. rattus* on eight of the smaller islands – and *R. norvegicus* on only three."

Lakeba may be the only island in the Lau Group which has *R. norvegicus* (Williams 1973).

Paine (1934), writing of Kanacea (in the northern Lau group), stated: "It is interesting to record here, in comparison with Nabavatu, that on Kanacea, an island only twelve miles distant, there are no rats. The present manager of this estate has energetically guarded against the landing of rats from ships calling at Kanacea, and on at least one occasion, succeeded in intercepting would-be colonies brought ashore inside packing cases".

## Gambier (Mangareva) Islands (French Polynesia)

(11 islands in group)

*Seven volcanic islands, and three low coral atolls.*

Significant invasive land vertebrates:

?Dog and cat ("probably", C. Blanvillain, pers. comm. 1999). Pacific rat, rabbit.

Rabbits have been introduced to Manui I. – a volcanic island which is visited for bird hunting (Douglas 1969, J.E.C. Flux pers. comm.).

### Mangareva

Mangareva was inhabited before the 16th century (Douglas 1969).

*13 km² (5 sq. mi.). The largest island of the group. High volcanic, 441 m (1447'). Cultivation of coffee, bananas and vegetables.*

Pacific rat.

Buck (1938) stated that rats were present in such large numbers that methods were adopted to protect food from them.

Mangareva kingfisher, extinct 1841 (King 1981).

#### *Opportunities for island restoration*

Consider rabbit eradication from the presumably uninhabited Manui I.

## Gilbert Islands (Kiribati)

(16 islands in group)

*Nukunau discovered by Admiral Byron in 1765. Visited next by Europeans in 1788. About 1827 the neighbourhood of the Gilbert group became a favourite fishing-ground for ships engaged in sperm-whale fishing. Wilkes expedition surveyed the islands in 1841. Now part of Kiribati, with Line and Phoenix Islands.*

*Total area: 295 km² (114 sq. mi.). All atolls, all inhabited, coconut plantations over most of the islands. Droughts common.*

#### *Significant invasive land vertebrates*

?Pig, dog, cat, Pacific rat (Woodford 1895), ship rat (J.M. Williams, letter 1982).

"On some islands [in the Marshall and Gilbert groups] feral dogs and cats exist" Amerson (1969).

In 1841, Peale (in Poesch 1961) described Pitt Island (now Makin I.) with the words "Rats were running in all directions."

"The arrival of *R. rattus* in the Gilbert and Ellice Islands … mostly occurred during the 1940s. …. At present ship rats occupy only three islands in Kiribati – Tarawa, Butaritari, Abaiang – but all the 16 inhabited islands are occupied by *R. exulans*" (Williams, letter 1982). Smith (1968) states that ship rats have reached four islands in the group, but does not state which.

Islands have always had "a poorer avifauna than some of their dependencies such as Christmas Island" but "seabirds in particular have been further reduced in recent years by rats and other introduced predators and an expanding human population" (Bourne in Morris 1964).

**Summary of rat species on Gilbert Is**

| | |
|---|---|
| Makin (Pitt I.) | *R. exulans* |
| Butaritari (Taritari) (Touching I.) | *R. exulans*, *R. rattus* (1940–49) |
| Maraki (Matthew I.) | *R. exulans* |
| Abaiang (Apaing) (Charlotte I.) | *R. exulans*, *R. rattus* (1940–49) |
| Tarawa (Cook I.) | *R. exulans, R. rattus* (1940–49) "numerous" (Smith 1968) |
| Maiana (Hall I.) | *R. exulans* |
| Kuria (Woodle I.) | *R. exulans* |
| Apamama (Hopper I.) | *R. exulans* |
| Aranuka (Henderville I.) | *R. exulans* |
| Nonuti (Sydenham I.) | *R. exulans* |
| Taputuea (Drummond I.) | *R. exulans* |
| Peru (Francis I.) | *R. exulans* |
| Nukunau (Byron I.) | *R. exulans* |
| Onoatoa (Clerk I.) | *R. exulans* |
| Tamana (Rotcher I.) | *R. exulans* |
| Arorai (Hurd I.) | *R. exulans* |

**Tarawa** atoll: "In common with other Pacific territories, increasing rat damage in recent years is a matter of considerable concern." But "… damage to the coconut crop appears to be of little economic importance on islands where only the Polynesian rat is known to be present." "…evidence to date suggests that the establishment of [the ship rat] occurred during World War II" (Smith 1968).

Williams (letter 1982): "*Norvegicus* has not been trapped in the Gilbert Islands – even at the main port of Betio in Tarawa."

#### *Opportunities for island restoration*

Possibly eradicate ship rats from some of the 3 (following Williams, letter 1982) or 4 (following Smith 1968) islands in the group on which they are present.

## Guam (USA)

*Discovered by Magellan in 1521 (he called it Ladrones). Spain took possession in 1565. Became a provisioning port for the next century for Spanish galleons. First Spanish missions in 1668, a Spanish colonial outpost for the next 200 years. Ceded to USA in 1898 after the Spanish–American war. May have been inhabited by a long-forgotten people as long as 5000 years ago.*

*541 km² (209 sq. mi.). Raised limestone, weathered volcanics, 393 m (1290'). Forest. Savanna. US Naval Base.*

#### *Significant invasive land vertebrates*

Pig, dog, cat, Pacific rat, Norway rat, ship rat, mouse, musk shrew, cane toad (Jackson 1962), brown tree snake.

Also: Micronesian deer (*Rusa mariana*) [?same as rusa deer *Cervus timorensis* (G. Nugent, pers. comm. 2000)] (Johnson 1962: 37, Flannery 1995), *Rattus tanezumi* (Flannery 1995), monitor lizards (Savidge 1987: 664).

Guam has become a major shipping and air travel hub for the western Pacific. Its vulnerability to increasing introductions of alien species is shown by records of 17 species of introduced amphibians and reptiles, 15 of which have been recorded since World War II. Nine species of introduced amphibian and reptile are now established on Guam, including the brown tree snake (McCoid 1993).

Baker (1946) describes in detail the impact of war on Guam, including the probable extinction of the Marianas mallard (*Anas oustaleti*).

**Brown tree snake (*Boiga irregularis*)**
Greenway writing before the impact of the brown tree snake (1967: 79) noted: "The remarkable fact is that no species or subspecies is known to have been totally extirpated in spite of permanent habitations by Europeans for almost 300 years". More recently, Case (1996: 71) commented: "7 bird species introduced, at least 7 native bird species extinct".

The brown tree snake was "…probably transported to Guam as a passive stowaway in military cargo in the late 1940s or early 1950s" (Savidge 1987: 662). By 1982 had colonised whole island (Savidge 1987: 663). Its habitat is forest and small fields, but it is uncommon in savanna (Savidge 1987: 665).

Seven bird species have become extinct since brown tree snakes were introduced. (One wetland species last seen in 1970, six forest species last seen in early to mid-1980s.) "The remaining forest avifauna is extremely rare" (Savidge 1987: 661). The brown tree snake preys on eggs, nestlings, and adult birds (Savidge 1987: 662), and also reptiles and invertebrates. The snake has "few competitors and no significant predators" on Guam (Savidge 1987: 666). McCoid (1991) discusses possible secondary (or "flow-on") effects of its introduction on Guam.

***Natural areas at risk*** – The surrounding small islands in the Mariana group, and probably all other tropical Pacific islands (excepting those of Australia, Indonesia, New Guinea and the Solomon Islands, where the brown tree snake is native). The risk is greatest on islands with direct air or sea links to Guam.

Cocos Island (2.5 km south of Guam) is a "natural exclusion experiment" … rats present, monitors and snakes absent (Savidge 1987: 660, 664).

**Pacific rat**
Irregularly distributed all over the island, but more numerous in cultivated or formerly cultivated land. Always was less numerous than *R. rattus* and never found in isolated populations (Crabb and Emik 1946).

**Ship rat**
Common all over Guam (Crabb and Emik 1946). Several observations of "swarms on coast" (e.g. de Freycinet 1824).

**Norway rat**
Introduced by late 50s (Barbehenn 1974).

It is noteworthy that Baker (1946) commented: "On Guam, where this animal [*R. norvegicus*] does not occur, there was less commerce before the war and ships usually anchored offshore. Now that docks are present on Guam and shipping has increased, there is greater chance for this pest to be introduced".

**Musk shrew (*Suncus murinus*)**
Barbehenn (1974) provides an excellent discussion of the invasion of Guam by the musk shrew. It was first "discovered on Guam in May 1953 … spread was facilitated by the transportation of goods. Colonization of the island was essentially complete by 1958 … with every conceivable habitat being occupied.… the major food of the shrew on Guam consists of invertebrates but it is capable of feeding on any small vertebrate. Ground-dwelling skinks are a likely target … At 6.2/acre, *Suncus* was the most abundant species." Mice may have declined in number since the establishment of the musk shrew.

Barbehenn (1974: 48–59) comments that the musk shrew, commonly regarded "as a commensal ('domestic') species", has had an unpredictable effect in Micronesia, becoming an "instant success" across all terrestrial habitats.

Micronesian megapode extinct or nearly so (Douglas 1969).

### *Opportunities for island restoration*

The vegetation of Guam is so altered that only a skilled botanist can tell which plants are indigenous and which are introduced.

## Hawaiian Islands (USA)

(21 islands in group)

*Total area: c. 13 558 km$^2$ (5235 sq. mi.) (Case 1996: 71).*

### *Significant invasive land vertebrates*

Cattle, goat, pig, dog, cat, Pacific rat, Norway rat (introduced 1825–35), ship rat (introduced c. 1870–80, possibly as early as 1840) (Atkinson 1977), mouse, rabbit, mongoose.

Indian myna, red-vented bulbul (Lever 1987).

Also: Horse, sheep, mouflon, axis deer, mule deer, donkey, pronghorn, rock wallaby (*Petrogale pencillata*), Indian buffalo (*Bubalus bubalis*).

Palaeontological work by Olson and James suggests that: "Some 50 per cent of the original bird species were lost in prehistoric times, while the much publicized extinctions in historic times involved only some 15 per cent of the original species". Reasons for prehistoric extinctions will include habitat destruction, introduction of predators, and hunting for food and plumage (Boag 1983).

Cassin (1858 – US Exploring Expedition) recorded mice as present.

Hawaiian brown rail, extinct 1864, Hawaiian spotted rail, extinct 1893 (King 1981).

See Tomich (1986) for distribution (historic and present) of introduced animals, and detailed case studies of impacts and control methods of each (summarised in Table 3).

## Northwestern Hawaiian Chain

(from west to east)

### Kure Atoll

*0.85 km² (0.33 sq. mi.). Wildlife sanctuary.*

"Dogs have been kept as pets intermittently, and a pig, scheduled as the prime attraction at a feast, also became a pet, but these have not caused undue damage" (King 1973:74). "The Polynesian rat … population on Kure fluctuates widely from season to season (20–77 rats per acre). Kepler (1967) reports this rat preys on [several seabirds]".

### Midway Islands

*8 km² (3.1 sq. mi.). 2 main islands (Sand and Eastern), 21 islets. US Naval Station since 1903. Has had "continuous human occupancy since 1903 and is the most altered of the Northwestern Hawaiian Chain" (King 1973: 92–93).*

?Dog, Pacific rat, ship rat (Sand I. and Eastern I.), mouse (Sand I. and Eastern I.) (Tomich 1986). Indian myna (Lever 1987).

Also: (Formerly donkey on Eastern I.) (Tomich 1986).

No native mammals. According to Johnson (1945) the earliest introduction was mice. Ship rats were first reported in March 1943. "In August 1943, even though rats were not common, it was noted that there was a reduction in numbers of the small flightless Laysan rail... As rats have increased in numbers they have entirely destroyed the Laysan rail and the Laysan finch. They have nearly exterminated canaries and doubtless affected other bird species on the islands" (Johnson 1945). The last Laysan rail was last seen in November 1943 (Munro 1945).

"The Laysan finch was considerably more abundant than the rail. Its disappearance followed that of the

***Table 3: Distribution of wild or feral populations of mammals on Hawaiian islands. Modified after Tomich (1986).***

| | Hawai'i | Maui | Molokini | Kaho'olawe | Lana'i | Moloka'i | O'ahu | Ford | Manana | Popoi'a | Mokumanu | Mokuolo'e | Mokoli'i | Moku'auia | Kaua'i | Ni'ihau | Lehua | Ka'ula | Nihoa | Tern | Laysan | Lisianski | Sand (Midway) | Eastern (Midway) | Green (Kure) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Cattle | x | f | | | | x | f | | | | | | | | x | | | | | | | | | | |
| Goat | x | x | | x | f | x | x | | | | | | | | x | f | | | | | | | | | |
| Pig | x | x | | f | f | x | x | | | | | | | | x | x | | | | | | | | | |
| Dog | x | x | | | x | x | x | | | | | | | | x | | | | | | | | | | |
| Cat | x | x | | x | x | x | x | | | | | | | | x | x | | | | | | | | | |
| Pacific rat | x | x | | x | x | x | x | | | x | x | | | | x | p | | x | | | | | | | x |
| Ship rat* | x | x | | x | x | x | x | x | | | | x | x | x | x | x | p | | | | | | x | x | |
| Norway rat | x | x | | | x | x | x | x | | | | | | | x | p | | | | | | | | | |
| Mouse** | x | x | | x | x | x | x | x | x | | | x | | | x | p | | x | | | | | x | x | |
| Rabbit | | | f | | | | | f | x | | | | | | | | x | | | | f | f | | | |
| Mongoose | x | x | | | | x | x | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | |
| Horse | f | f | | | | | | | | | | | | | f | | | | | | | | | | |
| Donkey | x | | | | | f | | | | | | | | | f | | | | | | | | | f | |
| Sheep | x | | | f | | | | | | | | | | | | | | | | | | | | | |
| Mouflon | x | | | | x | | | | | | | | | | | | | | | | | | | | |
| Pronghorn | | | | | x | | | | | | | | | | | | | | | | | | | | |
| Axis deer | | x | | | x | x | x | | | | | | | | | | | | | | | | | | |
| Mule deer | | | | | | | | | | | | | | | x | | | | | | | | | | |
| Water buffalo | | | | | | f | | | | | | | | | | | | | | | | | | | |
| Wallaby | | | | | | | x | | | | | | | | | | | | | | | | | | |
| Guinea pig | | | | | | | | | | | | | | | | | | | | | f | | | | |

× currently existing, p probably existing, f formerly existing

* Also found on Kaohikaipu (near O'ahu). **Also known from Kekepa and Kapapa (near O'ahu).

rail, and was likewise abrupt.... The canary population in 1943 was about 500" ... but by October 1944, only 2 canaries appeared to be left. "There are no records or reports of signs of disease among these birds, in connection with their decrease and disappearance" (Munro 1945).

Rats are said to have come ashore with practically every cargo of food or soap (Johnson 1945). Ship rats known to prey on Bonin petrel eggs (Grant et al. 1981).

"Cats are forbidden on Midway" (King 1973: 93). Dogs brought from Sand islet to Eastern islet: "for the purpose of running them through the incubating albatrosses" (King 1973: 93).

Indian myna "first recorded on Kure and Midway Atolls in 1974; on the latter, they had increased to several hundred by mid-1980" (Lever 1987: 498).

### Pearl and Hermes Atoll

*0.36 km$^2$ (0.14 sq. mi.). Uninhabited.*

"No rats occur there in spite of military activity" … "Rabbits were introduced in the early 1920s but were extirpated within three years" (King 1973: 92). Or as Tomich (1986: 35) states, rabbits were introduced prior to 1916, and exterminated in 1928.

### Lisianski

*175 hectares (432 acres). Atoll with one island on extensive reef platform.*

No introduced predators. (Formerly rabbits.)

Flux and Fullager (1992: 172–173) describe debate about the fate of rabbits on Lisianski: "Domestic rabbits introduced from Laysan after 1903 had destroyed the vegetation by 1913, when only a few living but many dead rabbits were seen. In 1923 only bleached and weathered bones were found, and the vegetation was starting to return (Watson 1961). Tomich (1986) suggests that the population on Lisianski, having had less control than that on Laysan, ate all the vegetation and starved sooner. According to Clapp and Wirtz (1975), Munter removed the last seven rabbits in March 1915 and none have been seen since."

### Laysan

*4 km$^2$ (1.56 sq. mi.) (King 1973). Atoll with one island and central saline lagoon.*

No introduced predators. (Formerly rabbits, guinea pig, and pig.)

Rabbits introduced by M. Schlemmer, the former manager of the guano company about 1903. Domestic rabbits, Belgian hares, and English hares. The rabbits have crossed and produced many strange-looking animals both in form and colour.… Man-o-war birds catch them, and young found dead on nest of red-footed booby (Dill and Bryan 1912).

Flux and Fullager (1992: 172) quote Watson's (1961) description of the removal of rabbits: "In 1911 a scientific expedition found Rabbits extremely abundant and recommended their removal before the vegetation was severely damaged. Four men shot 5000 rabbits in 2 months in 1912–13, but could not eliminate them. In 1923 the island was 'a barren waste of sand with a few stunted trees', only four of 26 plant species could be found, and three land birds had died out. A few hundred rabbits remained and these were killed. By 1936 the island was re-covered with vegetation." See also Lamoureux (1963: 22): The "members of the Tanager Expedition … exterminated the rabbits and planted several kinds of seeds and cuttings" in 1923.

Tomich (1986) states that "vegetation of both islands [Laysan and Lisianski] has made a remarkable recovery", quoting Lamoureux (1963) regarding Laysan: "Not only are many of the original species still present, but the structure of the vegetation appears similar to that described before the island was devastated by rabbits".

Pigs "allowed to roam over the island" and "were found foraging on an abundant 'yam' (=*Boerhavia*)" (Tomich 1986: 121). Guinea pigs, also introduced by M. Schlemmer, [were] rather abundant at one place on the south end of the island (Dill and Bryan 1912).

"Formerly 5 endemic birds incl. rail, honeyeater and warbler: all now extinct…" (Douglas 1969).

### French Frigate shoals

*0.44 km$^2$ (0.17 sq. mi.).*

Tern islet – dogs, (formerly pigs and cats) (King 1973: 91).

### Nihoa

*0.65 km$^2$ (0.25 sq. mi.).*

"No introduced predators" (King 1973: 90).

### Kaula Island

*0.54 km$^2$ (0.21 sq. mi.). Avifauna typical of northwestern chain.*

A "rat of unknown species" (King 1973: 94).

## Hawai'i

*10 458 km$^2$ (4038 sq. mi.). High volcanic, to 4214 m (13 825'), with two volcanic cones, one active.*

Cattle, goat, pig, dog, cat, Pacific rat, Norway rat, ship rat, mouse, mongoose. Indian myna (Lever 1987).

Also: Donkey, sheep, mouflon, (formerly horse).

### Kaua'i

*1432 km² (533 sq. mi.). High volcanic, 1598 m (5243').*

Cattle, goat, pig, dog, cat, Pacific rat, Norway rat, ship rat, mouse. Indian myna (Lever 1987).

Also: Mule deer, (formerly horse and donkey).

### Maui

*1888 km² (729 sq. mi.). High volcanic, to 3055 m (10 023'), with crater-like summit.*

Goat, pig, dog, cat, Pacific rat, Norway rat, ship rat, mouse, mongoose. Indian myna (Lever 1987).

Also: Axis deer (formerly cattle and horse).

### Moloka'i

*676 km² (261 sq. mi.). High volcanic, to 1515 m (4970').*

Cattle, goat, pig, dog, cat, Pacific rat, Norway rat, ship rat, mouse, mongoose. Indian myna (Lever 1987).

Also: Axis deer (formerly donkey and water buffalo).

### O'ahu

*1575 km² (608 sq. mi.). High volcanic, range rising to over 914 m (3000'). Intensive population/development including Honolulu, the state's capital and tourist centre.*

Goat, pig, dog, cat, Pacific rat, Norway rat, ship rat, mouse, mongoose. Indian myna, red-vented bulbul (Lever 1987).

Also: Wallaby, axis deer (formerly cattle).

Red-vented bulbul - introduced (?deliberately released) in 1965–66. Now widely distributed on Oahu, but may be confined to residential areas (Lever 1987: 316).

### *Case studies of significant invasives*

**Cattle** (Tomich 1986: 140–150)
Feral cattle historically abundant on Kaua'i, O'ahu, Moloka'i, Maui, and Hawai'i, also ranging freely on Lana'i. Now present only on Kaua'i, Moloka'i, and Hawai'i, "in generally inaccessible forest or lava regions".

Cattle first brought to Hawaii in 1793, by Captain George Vancouver, who "was greatly dedicated to Cook's cause of stocking the islands with various domestic animals".

Wild-type cattle intentionally re-released into the wild as late as 1969, for the purpose of photography and hunting for "safari type expeditions" on the slopes of Mauna Loa – have "thrived" and are still present in mid-eighties.

"It is most unfortunate that sample areas of native flora could not have been protected by fences, from the earliest times."

"Few studies have been made on the process of change in flora and lands under the pressure of cattle…"

**Goat** (Tomich 1986: 150–156)
"Goats are now present and at least sparsely distributed on all main islands except Ni'ihau and Lana'i. Populations not under satisfactory control exist on limited areas of Kaua'i, Maui, Hawai'i, Kaho'olawe, and perhaps Moloka'i."

Goats first reached Hawai'i in 1778 on Cook's first voyage, though these were killed in a later dispute. It is thought that further goats were left in Hawai [i on Cook's second voyage in 1778–79 (when Cook himself was killed), for by 1793 goats were well known in Hawai'i. By 1850 goats were abundant and widely distributed in the wild.

Goats "were, and are, significant as a factor in forest and range deterioration [and] the extinction of some specialized plant forms" and "may be an important factor in the ecology of the Hawaiian goose …:

Fencing of "manageable units of land" has been a key element in its control, as well as "drives and final clearing of stragglers with the aid of especially schooled dogs", imported with a trainer from New Zealand. "Radio-collared goats" can be used to join others and reveal their location. In parks where firearms are forbidden, "substantial reductions" in goat numbers have been made "after initiation of bow hunting".

**Pig** (Tomich 1986: 120–126)
Feral pigs formerly present on probably all eight major islands, and briefly also on Laysan. They are found now only on Ni'ihau, Kaua'i, O'ahu, Moloka'i, Maui, and Hawai'i.

Pigs of Asian ancestry were introduced to Hawai'i by Polynesians. Cook remarked that a small form of pig was in abundance on Kaua'i in 1778. Cook also brought English pigs to Hawai'i on his first voyage and this has been followed by many other importations.

"Feral pigs have long been distributed in the upland forests and pastures of the six larger islands … except on Maui" where they were more localised. Hawaii has "the largest, most widely distributed populations". "The old Polynesian type … has been absorbed or replaced by stocks of European origin".

Feral pigs continue to provide a "substantial source of food" and are regularly hunted.

"Watersheds, forests, and range are damaged when pigs root excessively …." On Hawai'i, with the control of feral goats and the elimination of feral sheep from certain habitats, the feral pig "has emerged as the most prominent agent of ecological perturbation, of wet forests in particular".

"…research on control and management of pigs is at an exciting level. Programs appear now to be limited only by available funds and manpower".

**Dog** (Tomich 1986: 88–93)
"Dogs in Hawaii have two histories, the first dealing with stocks that accompanied Polynesian culture to the islands, and the second resulting from introduction of mixed or selected breeds of dogs from over the world.… In Hawaii dogs were kept as pets, for food, as items of barter, and for sacrifice, and were prominent in sorcery and folklore."

Feral dogs were able to establish following the establishment of feral herds of sheep and other domestic animals. "Feral dogs attack not only sheep and cattle, but also wild pigs, feral goats, the axis deer, and flightless geese.… [The dog is] a negative factor in management of the Hawaiian goose." Feral dogs are "identified increasingly as predators" of colonial sea birds.

There have been no specific studies of local feral dog populations.

**Cat** (Tomich 1986: 101–105)
"…generally agreed to have been present in Hawaii since the early days of European contact…" There are reports of cats being "common" in Lana‘i and O‘ahu forests in 1892.

"Feral cats are most common at the lower and middle elevations, but also go high into the rugged mountains."

"Feral cats are notorious for their actual or alleged predation on birds". The cat has excellently adapted to living in the wild.

"The feral cat remains the same enigma it was 15 years ago. I know of no major publications on its presence in Hawaii. More than ever, this species demands attention if we are to understand its place in local ecosystems. It is increasingly suspect as an important predator of Newell's shearwater … a threatened bird … and may have destroyed up to 80 percent of one colony nesting there..."

"We are fortunate that researchers have taken the feral cat seriously in several sectors of the world …"

**Pacific rat** (Tomich 1986: 42–45)
"Found on Kaua‘i, O‘ahu, Moloka‘i, Lana‘i, Maui, Kaho‘olawe, and Hawai‘i. May occur on Ni‘ihau, but is not specifically reported from there. Inhabits also Kure Atoll (at the northwestern end of the chain); Popoi‘a and Mokumanu (near O‘ahu), and Kau‘ula (off Ni‘ihau)."

"… is presumed to have come to Hawaii with early [Polynesian] colonizers … the islands have been occupied from possibly as early as the second century".

"… is characteristically a lowland rodent … becomes most numerous in sugar cane fields and abandoned pineapple fields, but does well in adjacent wooded or grassy gulch and waste areas. It is usually uncommon in native or planted forests, and is often absent from them at elevations above 2,500 feet".

Pacific rats are known to prey on the Laysan albatross: "the rats literally eat the birds alive as they sit impassively on their nests". Also described as a "serious predator" on burrow-nesting species of seabird.

"Studies of the Polynesian rat after 1969 have been numerous …"

**Ship rat** (Tomich 1986: 37–40)
"Found on each of the eight main islands, also on Ford, Kaohikaipu, Mokuolo‘e, Mokoli‘i, and Moku‘auia (all near O‘ahu), and Sand and Eastern islands at Midway; may be the rat of Lehua, and possibly occurs on other small islands and islets."

Probably reached Hawaii in the 1870–1890 period.

"… is adapted especially to wooded gulches, sugar cane fields, and dry, wet, or even extremely wet forests. … is locally common at lower and middle elevations, and is found sparsely distributed at higher altitudes …"

"… has been noted specifically as a predator on native birds" … Is held responsible for the extinction of the Laysan rail, and the extirpation of a population of the Laysan finch. Many reports of bird predation.

**Norway rat** (Tomich 1986: 40–41)
"Recorded from Kaua‘i, O‘ahu, Moloka‘i, Lana‘i, Maui, and Hawai‘i. May occur on the few smaller islands where permanent human settlements are present; known also from Ford Island in Pearl Harbor."

"… sometimes locally common in and about lowland sugar cane fields… also middle elevation planted forests … Extreme known elevation is 5,800 feet …"

**Mouse** (Tomich 1986: 45–50)
"Found on all major islands, except that specific record is lacking for Ni‘ihau. Known also from Midway islands and Ka‘ula, Mokuolo‘e, Manana, Kekepa, and Kapapa (islets near O‘ahu)."

"The house mouse is now ubiquitous in Hawaii and may occupy in numbers even more ecological niches than does *Rattus rattus*.… it exists not only as a commensal, but also as a highly adapted wild species. Dense populations occur regularly in sugar cane and pineapple fields and are found also in lower elevation wet forests. Extremely wet forests and upland swamps, however, may be shunned entirely." Has been seen live at up to 12 400 feet.

"Populations of mice reaching plague proportions irrupt sporadically during late summer and fall …"

**Rabbit** (Tomich 1986: 30–37)
There is evidence that rabbits were brought in soon after European settlement. The pattern of early rabbit management in Hawaii, was "to turn the animals out on small islands to fend for themselves".

Presently surviving only on Manana and Lehua.

"Eradication of feral rabbits … has been advocated by ornithologists and others interested in the welfare of nesting sea birds…"

**Mongoose** (Tomich 1986: 93–101)
"Occurs on O'ahu, Moloka'i, Maui, and Hawai'i; widespread and firmly established throughout these four islands." Also on Ford Island in Pearl Harbour.

Mongooses live from sea level, to the upper limit of vegetation near 10 000 feet on Hawai'i.

"Greatest concentrations are in beach and lowland areas…"

"A central question for Hawaii is whether the mongoose is a negative factor in relation to birds, both native and introduced, and whether it is of positive value in rodent control. This animal is thoroughly omnivorous … Specific cases of bird predation are reported …"

"Local control … by poisoning and trapping … is a relatively simple matter … Eradication … would be a formidable task …"

**Indian myna** (notes from Lever 1987: 497–498)
Indian myna "reported to be abundant in Honolulu in 1879 .. was introduced to (or colonized) the other main islands around 1883". Colonised Kure and Midway Atolls in 1974.

Is "... most common ... in the vicinity of human habitation ... [but occurs] up to at least 8,000 feet (2,400 m)..."

There is debate over whether Indian myna has a significant effect on native birds. May be a significant predator of the eggs of the wedge-tailed shearwater (Byrd 1979), as 23 per cent of eggs were destroyed by mynas in a study area. Has been the cause of rapid spread of introduced *Lantana* species, by seed, until this has become an agricultural nuisance.

### *Opportunities for island restoration*

Consider rabbit eradication from islands on which rabbits are still present. We believe rabbits may have been recently eliminated from Lehua and Manana (rabbits were present on these islands according to Tomich 1986). Tomich suggests that removal of rabbits from the larger island, Lehua, may be "advisable" due to remnants of significant native vegetation. However, he comments that this "is likely to be impossible with means that can be reasonably found to do it".

Consider eradication of feral cattle: "A strong program should be activated for eliminating these animals from public lands, and cattlemen should support any reasonable program proposed for the elimination of their own feral herds" (Tomich 1986: 148–150).

## Line/Equatorial Islands (Kiribati and USA)

(c. 11 islands in group)

*Kingman Reef, Palmyra, and Jarvis, remain US territories, and are not part of Kiribati.*

*All but one island in group discovered between 1777 and 1825 (Krauss 1970).*

### *Significant invasive land vertebrates*

Pig, dog, cat, Pacific rat, ship rat, mouse. (Formerly goat.) Indian myna (Lever 1987: 499, following Holyoak and Thibault 1984).

#### Caroline

*3.8 km$^2$ (1.45 sq. mi.). Atoll with 24 reef islets. Once inhabited by Polynesians – small settlement in 19$^{th}$ century. Phosphate workings in 1872–95. Coconut plantations – abandoned in 1943, after prolonged drought (King 1973: 96).*

Pacific rat. King (1973: 96) suggests that "Polynesian rats are uncommon and may be restricted to one islet in the atoll".

#### Christmas

*Discovered by Cook on 24 December 1777. WWII garrison from NZ and USA. Nuclear weapons tests by British and Americans 1956–62. Garrison departed in 1967. Gilbertese population. No indigenous population.*

*321.37 km$^2$ (124.08 sq. mi.). Atoll with large flat island and almost landlocked lagoon. Fringing reef. Semi-arid. Coconut plantations.*

?Pig, ?dog, cat, Pacific rat, mouse.

"Large numbers of feral cats" (King 1973: 95). "The Lesser Frigatebird (*Fregata ariel*) population on Christmas has declined as a direct result of cat predation, and may be eliminated entirely in the next few years" (King 1973: 96).

Only *R. exulans* present (J. Clark, pers. comm. c. 1988). It would appear that King (1973) and Nelson 1922: 239) were mistaken in suggesting that ship rats were present on Christmas island.

Rougier (1925: 869) mentions tame birds. It is not clear whether he refers to boobies or birds in general: "You can touch with your own hands any bird on Christmas Island." Also comments that: "Eggs are spread all over the ground, as these birds [*Sterna pulginosa*] do not make nests." He states that as a visitor "You have not seen … rats … although you have seen legions of mice" (Rougier 1925: 870).

Two land birds now extinct? (Nelson 1922: 237).

### Fanning

*Polynesian remains (Emory 1934). Discovered by Captain Fanning of the* Betsy *(USA) in 1798.*

*32 km² (12.4 sq. mi.). Atoll with almost enclosed lagoon encircled by almost continuous islands, fringing reef. Gilbertese population (King 1973: 96). Coconut plantations.*

Pig, dog, cat, ship rat (introduced pre-1924) (Williams, letter 1982).

"Dogs, cats, and pigs are present under domestication" (King 1973: 95).

Chandler (1931) "In Fanning Island …. [a] great deal of damage is done by rats which seldom or never come to ground and no satisfactory method of dealing with them has yet been found."

The Christmas Island warbler appears to have been extirpated (King 1973: 95).

### Jarvis

*No Polynesian remains (Emory 1934). Said to have been discovered by captain of the* Eliza Francis *in 1821 (Bryan 1942). Guano mined in 19th/early 20th century.*

*4.5 km² (1.75 sq. mi.). Atoll with one island, no lagoon, narrow reef. Arid, "desert-like climate" (Rauzon 1985: 3). No trees. Uninhabited (Kirpatrick and Rauzon 1986: 72).*

Cat, rats formerly present (species unknown), ?no rats now, mouse (pre-1924) (Bryan 1942).

Cats introduced as early as 1885, but may not have survived. Cats re-introduced c. 1938, with settlers (King 1973, Rauzon 1982). Predation on seabirds reduced avifauna to 4 breeding species. Sooty terns (*Sterna fuscata*) and boobies have been the major food source (Rauzon 1982) (see Kirkpatrick and Rauzon 1986 for more detail). One bird eaten per cat per day, total of 24 000 birds killed per year (Rauzon 1983). Efforts to eliminate cats in 1982–83 successful (Kirkpatrick and Rauzon 1986).

No rats observed in 1979 by Kirkpatrick and Rauzon (1986: 73). However, house mice present (Kirkpatrick and Rauzon 1986).

### Malden

*Pre-European Polynesian population. Used for nuclear weapons testing in 1962.*

*29 km² (11.25 sq. mi.). Atoll with central enclosed saline lagoon with evaporites, fringing reef. Rainfall very variable. Unused and unoccupied since guano working ceased in 1927.*

Feral pigs, cats and goats (Douglas 1969) [goats now gone?]. Pacific rat.

Goats introduced in 1860s (Emory 1934). Cats still present in 1986 (Kirkpatrick and Rauzon 1986).

Rats (presumably *R. exulans*) "more than sufficiently numerous" in 1866–69 (Dixon 1878). Reports that cats have exterminated *R. exulans* (Emory 1934, Bryan 1942).

"POBSP killed a herd of five pigs in 1964, and one last pig died in 1967 or 1968. Five cats were seen in 1967, indicative of a very small population. The pigs were evidently responsible for the moderate numbers of most species of seabirds" (King 1973: 96).

### Palmyra

*No Polynesian remains (Emory 1934).*

*1.3 km² (0.5 sq. mi.). Atoll with 50 islets around lagoon complex on platform reef. Plantations. In US airforce use until 1961. "Uninhabited and privately owned" (King 1973: 95).*

Ship rat. Indian myna (Lever 1987: 499).

"As of 1966 it had no dogs or cats, but black rats were fairly common". … "Black rats have been observed in the Sooty Tern colony preying on eggs" (King 1973: 95, 98).

Bryan (1942) visited Palmyra in 1938 and makes no mention of rats, but comments "It is to be hoped that the construction of a naval air base will not destroy the natural beauty and scientific values of this, one of the most interesting atolls under the American flag".

### Starbuck

*No Polynesian remains. Frequent shipwrecks due to strong current and inconspicuous nature of island.*

*21 km² (8.1 sq. mi.). Atoll with one island, enclosed shallow lagoons, fringing reef. Uninhabited since 1920. Coconuts failed. Guano workings in late 19th century.*

Cat, Pacific rat (King 1973, Kirkpatrick and Rauzon 1986).

"Cats … in large numbers … prey heavily on the large Sooty Tern colony (estimated at 2,500,000 birds); about 1,000 adult birds per night were killed by cats during POBSP visits." In 1968, "scattered wings and bodies, and piles of bodies were frequently noted" around the edges of the sooty tern colony. Petrels were evidently present once but are no longer (King 1973: 96). Cats still present (Kirkpatrick and Rauzon 1986).

#### Vostok

*Discovered by a Russian expedition in 1820.*

*0.3 km² (0.1 sq. mi.). Atoll with one reef islet. Total flora of 3 species, including magnificent forest of* Pisonia grandis. *Undisturbed since 1943. Worked for guano and copra in late 19th century.*

Pacific rat – "abundant" King (1973: 97).

#### Washington

*Discovered by Captain Fanning of the* Betsy *(USA) in 1798. Polynesian remains. Settled by Europeans since 1860–70 (Emory 1934).*

*7.5 km² (2.9 sq. mi.). Atoll with one island and central freshwater lake, fringing reef. Wet, with two important bogs. Coconut plantations. Some canals cut through bog areas, though protection of bogs recommended (Douglas 1969). Gilbertese population (King 1973: 95).*

Pig, dog, cat, ship rat (introduced pre-1938) (Bryan 1942).

"Cats, dogs and pigs are kept by the Gilbertese, and feral cats are abundant" (King 1973: 95).

### *Opportunities for island restoration*

"Elimination of the remaining cats would make Jarvis among the most important seabird islands of the Central Pacific" (King 1973: 96, see also Rauzon 1985).

Consider removing *R. rattus* from Palmyra "one of the most intersting atolls under the American flag" (Bryan 1942), which apparently has never been colonised by *R. exulans*.

Vostok - "a relatively unaltered, but simple island ecosystem" (King 1973).

## Loyalty Islands (France)

(13 islands in group)

*Situated 100 km northeast of New Caledonia. Coral atolls. Tropical, tempered by trade winds.*

### *Significant invasive land vertebrates*

Pacific rat, ship rat, Norway rat (Revilliod 1913), mouse (Robinet et al. 1998: 229).

#### Lifou

*1150 km² (444 sq. mi.). Dense, mainly undisturbed rainforest (Robinet et al. 1998: 229).*

?Pig, ?dog, ?cat, Pacific rat, Norway rat, ship rat (Alicata (1963) trapped all three rats in 1962), mouse (Robinet et al. 1998: 229).

Norway rats "present in Lifou but apparently do not occur in the forest" (Robinet et al. 1998: 229).

#### Mare

*622 km² (240 sq. mi.). Elevated atoll, old reef.*

Pacific rat (R.H. Taylor, letter 1982), ship rat (Revilliod 1913).

#### Ouvea

*130 km² (50.2 sq. mi.). Coconut plantations, remnants of native forest (Robinet et al. 1998: 229).*

?Pig, ?dog, ?cat, Pacific rat (Alicata (1963) trapped *R. exulans*), mouse (Robinet et al. 1998: 229).

Pacific rat predation on eggs and nestlings of endangered Ouvea parakeet (*Eunymphicus cornutus*), "an endemic subspecies already threatened with extinction by habitat loss and capture by local peoples for the pet market" (Robinet et al. 1998: 223).

### *Opportunities for island restoration*

Islands too large to consider eradication of rats as a possibility in the next decade, but "even a low intensity" rat control programme on Ouvea "may markedly assist the parakeets (Robinet et al. 1998: 231). (No parakeets on Lifou.)

## Marquesas Islands (French Polynesia)

(14 islands in group)

*High volcanic islands without barrier reefs, three altitudinal vegetation zones, the highest (1500'–2000') 'moss forest'. These islands "share with Hawaii a dry tradewind landscape of arid lower slopes and moist high interiors…" But the islands are subject to severe droughts – lasting 3-5 years (Decker 1992: 1–2).*

### *Significant invasive land vertebrates*

Cattle, goat, pig, ?dog, cat, Pacific rat, Norway rat, ship rat. Indian myna (Lever 1987).

Also: Donkey, horse, sheep.

No dogs were present in pre-European times (Heyerdahl 1952).

Five introduced bird species, at least nine native bird species extinct (Case 1996: 71).

#### Eiao

*52 km² (20 sq. mi.). High volcanic.*

Goat, pig, cat, sheep (C. Blanvillain, pers. comm. 1999).

"Feral sheep, pigs … have apparently devastated island vegetation" (Douglas 1969).

"…Eiao, with its several springs, is a barren gullied desert of rock and orange clay. Only scraps of the former Eiao forest remain, inaccessible to the feral sheep that run freely over the island … starving, and preyed upon by feral swine" (Decker 1975).

#### Fatu Hiva

*77.7 km² (30 sq. mi.). High, 3670' (1118 m), volcanic, wet.*

Cattle, dog, Pacific rat, ship rat (C. Blanvillain, pers. comm. 1999).

### Hiva Oa

*240.9 km² (93 sq. mi.). High, 4130', volcanic, wet, rugged.*

Cattle, dog, Pacific rat, ship rat (C. Blanvillain, pers. comm. 1999). Indian myna (Lever 1987).

Also: Great horned owl (*Bubo virginianus*) - "fairly abundant" (Lever 1987: 291).

16 Indian mynas were introduced around 1918, and "had increased within 3 years to an estimated 1,000; the species is today very common in coastal regions and occurs in lesser numbers at higher altitudes." They have not reached Tahuata, only 3 km away (Lever 1987: 499-500).

### Motane/Mohotani

*15.5 km² (6 sq. mi.). High, dry, with an "interesting flora".*

Goat, cat, sheep (C. Blanvillain, pers. comm. 1999).

Has been reduced to "barren waste through overgrazing by feral sheep" (Douglas 1969).

### Nuku Hiva

*336.7 km² (130 sq. mi.). High, 3890' (1185 m), volcanic, wet.*

Cattle, dog, Pacific rat, ship rat (C. Blanvillain, pers. comm. 1999).

### Ua Huka

*77.7 km² (30 sq. mi.). High volcanic. Fossil studies by Steadman and Zousmer (1988) suggest that "at least 15 bird species had been hunted to extinction by the time Europeans arrived 200 years ago".*

Sheep (C. Blanvillain, pers. comm. 1999).

### Uapou

*103.6 km² (40 sq. mi.). High volcanic.*

Feral donkeys present (Douglas 1969).

### *Opportunities for island restoration*

Consider eradication programmes for islands with large browsing mammals – sheep, pigs, donkeys, etc…

"Three seldom-visited, but extremely interesting, islands in the northwestern Marquesas group … are among several uninhabited French Polynesian islands that were assigned protection status in 1971 … The islands are remarkable for the contrasts between them. Eiao, the largest, is severely damaged by feral livestock and erosion. Ile de Sable is a tiny sand cay upon the only extensive coral-reef formation in the Marquesas. Hatutaa (Hatutu on many charts) is a pristine terrestrial ecosystem – the only sizeable one left undisturbed in the central Pacific dry zone.... Protected from livestock introduction by its lack of perennial water, Hatutaa teems with bird life and is richly vegetated.… The rarity of type and biological significance of Hatutaa cannot be overemphasised. It is an intact ecosystem productively functioning in the harsh central Pacific climate…" (Decker 1975).

Eiao – consider removal of sheep and pigs (if still present). Some replenishment of species may be possible from the nearby Hatutaa.

"Scientifically, the Marquesan biota is the most neglected in Polynesia … every biological collecting expedition to this archipelago yields important novelties …" (Decker 1975).

"Mohotani, once cleared of sheep and possibly cats, would be an excellent site for introduction of most Marquesas endemics" (Seitre and Seitre 1992: 221).

## Marshall Islands

(34 islands in group)

*Eight islands uninhabited (King 1973: 100). The Marshall Islands are in two chains: the Ralik chain to the west and the Ratak chain to the east. Almost all the uninhabited islands are devoted to coconut culture. Taongi (Pokak) and Bikar are too dry to sustain the harvest of coconuts. Both are important seabird islands (King 1973). Nuclear weapons tests conducted on Eniwetok and Bikini.*

### *Significant invasive land vertebrates*

Pig, dog, cat, Pacific rat, ship rat, Norway rat (Spenneman 1997), mouse.

Also: Monitor lizards (*Varanus indicus*) (Spennemann 1997), Brahminy blind snake (*Ramhotyphlos brahmina*) (Spennemann 1997: 8).

Amerson (1969) states: "On some islands [in the Marshall and Gilbert groups] feral dogs and cats exist."

See Spennemann (1997: 7) for table of: "The occurrence of *Varanus indicus* and the distribution of rodent species on the atolls of the Marshall Islands."

In summary: *Rattus exulans* is present on the great majority of islands. *R. rattus* is present on nine islands (Arno, Eneen-Kio, Enewetak, Jaluit, Kwajalein, Majuro, Maloelap, Mili, Wotje). *R. norvegicus* is present on two islands (Jaluit, Majuro), and mice on three islands (Enewetak, Jaluit, Majuro).

"The data in hand suggest that the pre-World War II rat population of the Marshall Islands comprised neither *R. rattus* or *R. norvegicus*, with the possible exception of Jaluit and Majuro Atolls…" (Spennemann 1997: 5).

"In the Marshall Islands rats were eaten mainly by women" (Spennemann 1997: 4).

"The rat problem on some bases reached such proportions that *Varanus indicus* [monitor lizards] were introduced to prey upon the rats. Instead, according to local Marshallese informants, the reptiles predated on the chickens as well as other birdlife" (Spennemann 1997: 9).

### Antore

Pacific rat (R. H. Taylor, letter 1982).

### Arno

*13 km² (5 sq. mi.). Atoll with 100 islets, coconut plantations.*

Pacific rat, ship rat (introduced 1942–45).

Marshall (1955) found *R. rattus* only in certain sites, and reported that "Only in these three spots are green coconuts eaten by rats, and the Arnnese stated that large rats and opened coconuts had been found there only since the period of Japanese control of the atoll. …The species was evidently just gaining a foothold on the atoll in 1950." Discussing *R. exulans*, he says "Fresh ripe coconut meat from fallen nuts seems to be the favourite food of this rat". Mice were not present on the island.

### Bikar

*0.5 km² (0.2 sq. mi.). Atoll with 3 reef islets, dry, visited for fishing and birds).*

Pacific rat (R. H. Taylor, letter 1982).

### Bikini

*7.3 km² (2.82 sq. mi.). Now reduced in area by nuclear weapons tests? Atoll with numerous islets. Population moved to Rogerik, then to Kili, atomic testing, radiation damage. ). "Cultural deposits" on Bikini atoll have been radiocarbon dated "to perhaps greater than 3000 years B.P…. " (Streck 1990).*

Pacific rat (R. H. Taylor, letter 1982).

### Eniwetok/Enewetak

*5.8 km² (2.25 sq. mi.). Atoll with 30 islets, population moved to Ujelang in 1947, used for nuclear weapons testing.*

Cat (King 1973: 101), Pacific rat, ship rat (introduced c. 1951) (Jackson 1969), mouse "reputedly present" (Spenneman 1997: 2).

Also: Monitor lizard (*Varanus indicus*, introduced to prey on rats, is known to prey on birdlife – Amerson 1969, Spennemann 1997: 9), Brahminy blind snake (*Ramhotyphlos brahmina*), "secretive, nocturnal and earthburrowing" and said to be "harmless" (Spennemann 1997: 8).

Pacific rats may have been exterminated by the thermonuclear explosions. Extensive trapping on the islet shows that only *R. rattus* is now present (Jackson 1969).

### Jaluit

*3.6 km² (1.4 sq. mi.). Atoll with 80 reef islets, almost continuous land rim.*

Pacific rat, Norway rat (Spennemann 1997: 7), ship rat (introduced pre-1932), mouse (introduced pre-1932) (Koroia 1934).

### Majuro

*9 km² (3.5 sq. mi.). Atoll with 60 islets, coconut plantations.*

Pacific rat, Norway rat (Spennemann 1997: 7), ship rat (pre-1932), mouse (Marshall 1962, Johnson 1962).

Also: Monitor lizard (Spennemann 1997: 9).

### Odia

Pacific rat (Waite 1897b).

### Taka

Pacific rat (R. H. Taylor, letter 1982).

### Taongi (Pokak)

*3.2 km² (1.25 sq. mi.). Atoll with 13–14 islets, dry, stony, uninhabited, landing difficult.*

Pacific rat (Spennemann 1997: 7).

### Wotze (Wotje)

*8.2 km² (3.16 sq. mi.). Atoll with 56 islets, much destructive bombing. "... possible remnant population of large Micronesian pigeon" (Douglas 1969).*

Cat, Pacific rat (Spenneman 1997: 5), ship rat (introduced pre-1932) (Koroia 1934).

Cats released "to act as vermin control" prior to 1830 (Spennemann 1997:5).

### Zatobach

Pacific rat (R. H. Taylor, letter 1982).

### *Opportunities for island restoration*

Marshallese "have traditionally considered Taongi, Bikar, Jemo, and islets of Taka and Jaluit as bird sanctuaries, on which the taking of birds and eggs for food is restricted but not prohibited" (King 1973: 100).

## Nauru

*22 km² (8.5 sq. mi.). Raised limestone, 65 m (213'), with narrow coastal terrace and fringing reef. Most of island's surface mined for phosphate deposits. Much of labour force Gilbertese or Chinese. Military operations 1942–45.*

### *Significant invasive land vertebrates*

?Pigs, ?dogs, ?cats, Pacific rat, ship rat (pre-1979), mouse.

Williams (1979) visited the island in 1979: "Two species of rat, the ship or roof rat (*Rattus rattus*) and the Polynesian rat (*Rattus exulans*) were trapped. A third species (the Norway or common rat) that is also found on some Pacific islands does not appear to be on Nauru, however the house mouse (*Mus musculus*) was trapped…"

Island was originally vegetated. "Because of the considerable destruction by guano diggers and by military operations during the years 1942–1945, a reed warbler (*Acrocephalus luscinia rehsei*) has been thought to be in danger. Much vegetation remains on Nauru, however, and although it is a very small bird population, it has apparently survived" (Greenway 1967).

*R. rattus* "is the most commmon [rat] on Nauru and causing the most damage" (Williams 1979).

### *Opportunities for island restoration*

This island has been greatly depleted by phosphate mining. We do not know what opportunities remain for restoring island habitats.

A Nauru Rehabilitation Corporation has been set up at Aiwo recently, but it is not yet known what plans it has to restore native vegetation and bird life (G. Gregory, pers. comm. 2000).

## New Caledonia (France)

(One main island and c. 26 small islets)

*Total area: 16 912 km² (Case 1996: 71). Two parallel ridges, to 1676 m (5500'), sedimentary, continental rocks, metamorphosed. Barrier reef. "The main island is 400 kilometres long and forty to fifty kilometres wide.... rugged ranges, ... uninhabited except along some river valleys. Most people live on the lowland coastal plain, much of which has been cleared for grazing or altered by plantations" (Stokes 1980: 81).*

*"New Caledonia may harbour the most neglected island avifauna close to Australia. Its landbirds included eighteen endemic species, of which four are in monotypic genera ... and one is in a monotypic family ..." (Stokes 1980: 86).*

### *Significant invasive land vertebrates*

Cattle, goat, pig, dog, cat, Pacific rat, ship rat (introduced pre-1913), Norway rat (introduced pre-1944), mouse (pre-1913) (Revilliod 1913, Marshall 1962, Alicata 1963). Indian myna (Lever 1987).

Also: Donkey, house sparrow (Stokes 1980).

Barrau (1981) discusses the role of cattle in the creation of the extensive present-day savanna. He comments: "... since its inception, the cattle industry of New Caledonia had been based on a myth: that of *natural* pasture. The gardened savanna landscape of the Melanesians gave the settlers the false impression of a lush and nutritious resource ... Very quickly, due to selective grazing by the cattle, the savanna ecosystem became more biotically specialized."

Of the c. 26 small islets, most have *R. exulans*, some are rat-free, and one has *R. rattus* (B. D. Bell, pers. comm. 1999).

No pre-European dogs (Heyerdahl 1952).

Six introduced bird species, and at least 14 extinct bird species (Case 1996: 71). The New Caledonian rail (*Tricholimnas silvestris*) became extinct during the last 100 years (1845–1945) (Mayr 1945a). A giant megapode (*Sylviornis neocaledoniae*) extinct for at least 3000 years (may have disappeared shortly after human colonisation) (Green c. 1985).

### *Predation on native birds*

Warner (1948) mentions several introduced species as predators of a native bird called the kagu (*Rhynochetos jubatus*). "Escaped pigs and the introduced rats are … causing heavy damage to the kagu at the present time. They not only kill the birds but also destroy its food supply of land snails and large earthworms.... I often found snail shells in rat runways and burrow entrances and scattered about in other odd places. Many of these had been gnawed in typical rat fashion.… The pig and rat may also take young birds and eggs … Cats and dogs roam the mountains and undoubtedly take a heavy toll of the adults and young and of the single eggs.… I spoke with some people who had eaten birds [kagu] killed by their dogs on deer and pig hunting trips.…The Sambar deer (introduced) may have an increasingly detrimental effect on the kagu by the destruction of cover, but during 1945 it was not common enough in the mountain forests of southern New Caledonia to be of importance. Cattle grazing has had no appreciable effect to date."

"*Rattus norvegicus* was not common in most of the habitat of the kagu but was taken occasionally far from human habitation. Where lumbering and mining camps were in use, it was present, however, often in considerable numbers.… The three subspecies of the black rat, found to be common to abundant around the abandoned camps, along forest streams, steep banks and in rotting logs and hollow trees" (Warner 1948).

"Thus these factors: (1) decimation by man through trapping and hunting (now prohibited); (2) predation by rats, cats, dogs and pigs; and (3) destruction of natural habitat of both the kagu and its food supply by pigs, and by mining, lumbering and burning, are all hastening the extermination of this endemic species" (Warner 1948).

Extinct avifauna includes: New Caledonian lorikeet (extinct 1860), New Caledonian owlet frogmouth (extinct 1880), New Caledonian wood rail (extinct 1904), Isle of Pines solitaire (extinct 1934) (King 1981).

### *Opportunities for island restoration*

Investigate the c. 26 small islets (see comment on rat distribution by B. D. Bell, pers. comm. 1999).

## Niue (NZ)

*Discovered by Cook in 1774.*

*259 km$^2$ (100 sq. mi.). 67 m (220') raised coral plateau with terraced margins, deeply weathered. Much wooded with thickets of secondary growth. No surface water. Settlement mainly on coast, interior uninhabited (see Douglas 1969 for details). Banana, copra, etc. cultivated.*

### *Significant invasive land vertebrates*

?Pig, ?dog, ?cat, Pacific rat, ship rat (intro. 1900-1925), Norway rat (R. Hay, pers. comm. 1999).

Mice have reached the island but have not been able to establish (K. A. Wodzicki, pers. comm. 1975).

"The introduction of the roof or ship rat (*Rattus rattus*) to Niue during the first quarter of the present century and its successful spread to practically all habitats could have had a profound effect, particularly on all tree-nesting birds" (Wodzicki 1971).

"Fourteen species of birds, including an extinct species each of *Gallirallus* and *Nycticorax*, and an extirpated megapode (*Megapodius pritchardii*) were found. This increases the number of taxa known for the Niue fauna to 15 resident species, but faunas from surrounding islands indicate this is almost certainly an underestimate of original diversity (Worthy et al. 1998: 177).

### *Opportunities for island restoration*

Possibility of protection of native vegetation in rougher areas not suitable for cultivation (Douglas 1969).

## Northern Mariana Is

(14 islands in group)

*The Northern Mariana Islands are a "Commonwealth and Political Union" of the United States. Saipan is the administrative centre.*

### *Significant invasive land vertebrates*

Cattle, goat, pig, dog, cat, Pacific rat, Norway rat, ship rat, mouse, musk shrew, brown tree snake (probably present on Saipan), cane toad.

Also: sambar deer, Micronesian deer (*Rusa mariana*) [?same as rusa deer *Cervus timorensis* (G. Nugent, pers. comm. 2000)] (Johnson 1962: 37, Flannery 1995), *Rattus tanezumi* (Flannery 1995).

"When the Japanese took over the islands, a period of extreme exploitation began. On Saipan and Tinian, for example, most of the indigenous forest was cut down to make place for sugar plantations and with it went the native bird life.… the Marianas cardinal honeyeaters had already been badly decimated when William Coultas visited the islands in 1931. Most of the larger pigeons of the Marianas and of the Palau Islands were on the verge of extinction at that time, as were the Micronesian incubator bird, the Marianas nightingale reed warbler, the Marianas mallard and the Palau gray duck" (Mayr 1945a).

Baker (1946) describes in detail the impact of war on the Mariana Is.

#### Aguijan

*7.3 km$^2$ (2.8 sq. mi.). Steep cliffs to north.*

Goat, pig (both feral) (Douglas 1969). Uninhabited, but supports c. 1500 feral goats, and is occasionally visited by goat hunters, and pig hunters. Australian pine introduced as windbreaks and massive pineapple and sugarcane plantations – by Japanese. Goats exterminated much of the original vegetation in early 1940s (DiSalvatore 1981).

#### Anatahan

*32.4 km$^2$ (12.5 sq. mi.). Extinct dissected cone, 788 m (2585'). Has had military use.*

Goat. The number of goats on this uninhabited island is "staggering" (Sablan 1976).

#### Pagan

*48 km$^2$ (18.7 sq. mi.). Cluster of active volcanoes, 570 m (1869'), linked by lava and ash. Some coconut plantations.*

?Cat, ship rat, Norway rat (Corwin et al. 1957).

"The two varieties of rat are especially abundant in the vicinity of farms and settlements" (Corwin et al. 1957: 109).

#### Rota

*85 km$^2$ (33 sq. mi.). Raised limestone terraces on extinct volcano, 1612'. Some market gardening.*

?Pig, ?cat, Pacific rat, ship rat (introduced pre-1932) (Marshall 1962). Musk shrew (established by 1966) (Barbehenn 1974). Cane toad (Steadman 1992).

Also: *Rattus tanezumi* (Flannery 1995).

#### Saipan

*121 km$^2$ (47 sq. mi.). High volcanic, 474 m (1554'), with raised limestone terraces. Some coconuts.*

?Pig, ?dog, ?cat, Pacific rat, Norway rat (has occurred on Saipan since the late 1800s, Kuroda 1938 in Wiles et al. 1990: 174), ship rat (introduced pre-1931), mouse (introduced pre-1931) (all recorded by Marshall 1962). Musk shrew (discovered on Saipan in 1962, probably introduced mid-1960 ) (Barbehenn 1974). Cane toad (McCoid 1993). Brown tree snake? McCoid (1993) considered that Saipan had an "incipient population" of brown tree snakes.

Also: *Rattus tanezumi* (Flannery 1995).

Baker (1946: 210) suggests the "large amount of Japanese shipping in the prewar days" is probably the reason for the presence of the Norway rat on Saipan.

Enders (1949 in Wiles et al. 1990: 173) found the Pacific rat to be the least common of the three rat species.

### Sariguan

*4.9 km² (1.9 sq. mi.). Extinct volcanic cone, 549 m (1800'). Lower slopes cultivated, and coconuts planted.*

Goat, rat (species unknown).

Large populations of rats and wild goats – described as a poor candidate for preservation status, because many native species and habitats have been disturbed or destroyed (Anon. 1985).

### Tinian

*102 km² (39.25 sq. mi.). Raised limestone, 170 m (557'), small central lake. Disused and overgrown plantations of sugarcane, vegetables and pineapples. Some market gardening, and farming of beef cattle.*

Cattle, goat, pig, dog, cat, Pacific rat, ship rat (introduced pre-1932), mouse (Marshall 1962). Musk shrew (probably arrived on Tinian in mid-1960s, not reported until 1974) (Wiles et al. 1990: 170). Cane toad (McCoid 1993).

Also: Horse (Wiles et al. 1990: 175), *Rattus tanezumi* (Flannery 1995). (Formerly Philippine deer, *Cervus marianus*) (Wiles et al. 1990: 175).

See Wiles et al. (1990) for a comprehensive account of the history and present status (including distribution and habitat) of mammals on Tinian:

Tinian has experienced "…extensive grazing by introduced ungulates during the last 300–400 years…" (Wiles et al. 1990: 167).

**Cattle** "were introduced to Tinian early in the period of Spanish colonial rule, and were left to roam the island freely in a feral state. [Anson, in 1742, estimated that] several thousand to at least 10,000 animals were present…" By the early 20th century numbers had declined to between several hundred and several thousand, and in 1952 the last feral cow on Tinian was killed. However, Wiles et al. (1990: 176) report that domestic cattle are "common throughout Tinian and probably number about 4,000–5,000 animals … [These are] routinely pastured in a variety of habitats … particularly open fields, tangantangan forest, and secondary vegetation. They also fed and rested in native forest and strand vegetation…"

"Heavy grazing, browsing, and trampling by cattle have probably eliminated or lowered the abundance of some species of indigenous plants, reduced understory vegetation, lowered plant diversity in native forests, and increased soil erosion and compaction.… Cattle have probably also enhanced the spread of certain introduced plants around the island … habitat degradation has probably resulted in population declines of fruit bats and frugivorous birds, such as Mariana fruit doves (*Ptilinopus roseicapilla*), and white-throated ground-doves (*Gallicolumba xanthonura*). The reproductive success of Micronesian megapodes (*Megapodius laperouse*) may have declined in areas where nesting sites were trampled and soils were compacted by cattle …(Wiles et al. 1990: 177).

"Feral **goats** inhabited the slopes and cliffs along the southeastern coast of Tinian in the early 1900s, with the population estimated at a few hundred to 500 animals … a feral herd of unknown size still occurs in the extensive tract of coastal forest at Kastiyu" (Wiles et al. 1990: 177).

"Tinian held a large population of feral **pigs** between the 1700s and early 1900s … During the early 1900s … an estimated population of several thousand animals. The approximate date that feral pigs were extirpated from the island is unknown". Wiles et al. (1990: 175) found "no indications of feral pigs".

The "presence of feral and domestic **dogs** on Tinian was noted by many authors between the mid-1700s and early 1900s…" Domestic dogs common, free-ranging dogs present (Wiles et al. 1990: 174).

**Cats** were first mentioned on Tinian in the mid-1800s. "Small numbers of domestic and free-ranging cats occurred on the island in 1900…" Present sightings indicate "that a feral population still occurs on the island" (Wiles et al. 1990: 174).

The **Pacific rat** was "presumably … introduced to the Mariana Islands by the Chamorros, who have inhabited the archipelago for at least 3,500 years…" Trapped in the past by Marshall in 1945, no Pacific rats were found by Wiles et al. (1990: 172).

**Ship rats** "likely reached Tinian aboard European shipping traffic sometime between the 1600s and 1800s. [They] appear to be distributed throughout the island … in all types of habitats except native forest…" (Wiles et al. 1990: 173).

The **Norway rat** was "not captured" by Wiles et al. (1990: 174). It may not be present.

**House mice** "seem to be uncommon on Tinian …" Only one was trapped by Wiles et al. (1990: 173).

**Musk shrews** were "observed islandwide … common in most habitats" (Wiles et al. 1990: 170).

### *Opportunities for island restoration*

Consider removal of goats (if still present) from Aguijan and Anatahan.

The vegetation of some islands (e.g. Guam and Saipan) is so altered that only a skilled botanist can tell which plants are indigenous and which are introduced.

Anon. (1985) states that in November 1985, four uninhabited islands in the Commonwealth of the Northern Mariana Islands (Uracas (Farallon de Pajaros), Asuncion, Guguan, Maug) were set aside for purposes of conservation and preservation.

## Ocean/Banaba Island (Kiribati)

*Discovered by an American, Captain Jered Gardner, in 1801.*

*6.5 km² (2.5 sq. mi.). Raised limestone, 81 m (265'), with fringing reef. Most of island mined for phosphate.*

### *Significant invasive land vertebrates*

Ship rat (introduced pre-1970).

"La présence du rat noir se confirme également sur L'île Ocean, ou se trouvent les mines de phosphate…" (Smith 1970).

Rats "appeared at dusk in swarms, so that by morning the sand was laced with their tracks" (Wetmore 1925).

### *Opportunities for island restoration*

This island has been extensively modified by phosphate mining. We do not know what opportunities remain for restoring island habitats.

## Palau (Belau) Islands

(11 islands in group)

*Discovered by Spanish about 1543.*

*440 km² (170 sq. mi.) (Case 1996: 71). Large group of many close islands, volcanic and limestone. Much disturbed. Largest island Babelthuap.*

### *Significant invasive land vertebrates*

Goat, pig, dog, cat, Pacific rat, Norway rat, ship rat, mouse, musk shrew (Wiles and Conry 1990). Cane toad (McCoid 1993).

Also: *R. nitidis* (Barbehenn 1974), long-tailed macaque (*Macaca fascicularis*).

One observation of a musk shrew on Koror in 1963, but "no subsequent observations …this may have been a sterile introduction" (Barbehenn 1974).

Wiles and Conry (1990: 62) commented: "… rats were so numerous on Ulong and Euidelchol, two … limestone islands in southern Palau, that observers could see several animals within minutes of going ashore on each island".

"Pigs and goats, introduced by H.M. ships many years ago, are plentiful in most parts of the group…. Dogs and cats are found, but as the native names for them are corrupted Spanish words, they were most probably introduced by vessels from Manila which came to trade here formerly" (Robertson 1877, visited Palau islands in 1875).

Four introduced bird species, no known extinct bird species (Case 1996: 71).

By 1931 "most of the larger pigeons of the Marianas and of the Palau Islands were on the verge of extinction … [as was] the Palau gray duck. The Palau race of the Nicobar pigeon and the Palau ground dove (*Gallicolumba canifrons*) are likewise in a precarious position.... restricted to a few of the smaller islands in the southern Palau group" (Mayr 1945a).

#### Angaur

*8.4 km² (3.25 sq. mi.). Limestone, 61 m (200'), reef, no water.*

Mouse present by 1963 (Barbehenn 1974).

#### Babeldaob

*397 km² (153.3 sq. mi.). Old volcanic, 122 m (400'), reefs, fertile.*

Pacific rat, Norway rat, ship rat (introduced pre 1931) (Koroia 1934, Marshall 1962, Barbehenn 1974), cane toad (McCoid 1993).

Also: *Rattus nitidus* (introduced pre-1949) (Barbehenn 1974: 48).

Norway rats living a feral existence (Barbehenn 1974: 48).

#### Kayangel

*1.7 km² (2/3 sq. mi.). Atoll with 4 islets.*

Pacific rat, ship rat (Marshall 1962).

#### Koror

*9.3 km² (3.6 sq. mi.). Volcanic and limestone, pre-WWII Japanese town of 20 000, bombed completely in WWII, but partly rebuilt as admin. centre (Douglas 1969).*

Pacific rat, Norway rat (introduced pre-1931), ship rat (introduced pre-1931), mouse (Koroia 1934, Marshall 1962).

#### Peliliul

*12.7 km² (4.9 sq. mi.). Limestone, reefs, phosphate worked mid 20th century.*

*Rattus nitidus* (introduced pre-1945) (Barbehenn 1974: 48).

"Most of us have probably seen pictures of Peliliul Island in the Palau group, taken right after we had invaded this island. Hardly a tree was left on the island that was not torn to shreds, if one can judge from these photographs. There is a species of white-eye on Peliliul (formerly considered even a separate genus), which occurs nowhere else in the world than on Peliliul. It is doomed to world extinction, if its habitat on Peliliul is destroyed. I wonder whether it survived this ordeal" (Mayr 1945a).

### *Opportunities for island restoration*

Ngerukewid Is ('Seventy islands', 2.59 $km^2$ (1 sq. mi.), is a group of limestone islets, with undercut shores). "Uninhabited and protected formerly by ancient taboos", part of proposed national park (Douglas 1969).

Wiles and Conry (1990: 41) lament that although the Ngerukewid Islands Wildlife Preserve (NIWP) "was established in 1956 to protect a segment of Palau's rich marine and terrestrial natural resources … more than 30 years later, the preserve remains the only officially designated protected area set aside for nature conservation in the Caroline Islands". The most important role of the reserve is to restrict hunting.

Although rodents and shrews have been introduced to the Palau islands, both rodents and shrews "appear to be absent from the NIWP … with no animals captured during a combined total of 144 trap nights ... (Wiles and Conry 1990: 62).

## Papua New Guinea

(? islands in group)

*Eastern part of main island, together with numerous islands to the north and east of it. (The western part is Irian Jaya, a province of Indonesia.) The total main island is said to be the world's largest tropical island, with a total area of 808 000 $km^2$ (Case 1996: 71).*

### *Significant invasive land vertebrates*

Pig, dog, cat, Pacific rat, ship rat (Flannery 1995).

Also: *Rattus praetor* (Flannery 1995), and others - see checklist below.

Native rats include at least 3 species of *Rattus* (Dwyer 1975).

*R. exulans* "occurs in grasslands and adjoining disturbed habitats from sea level to altitudes over 2500 m" (in Dwyer 1978: 221). "To date there is no suggestion that *R. exulans* is a pest species in the New Guinea Highlands, though rats are reported as damaging cacao, coconut and root crops on Bougainville (Dwyer 1978: 246). (See Dwyer (1978: 242–243) for discussion of diet of *R. exulans* in this area.)

Dwyer (1978: 221, 246) suggests numbers of *R. exulans* "may follow a 3- or 4-year cycle linked to a culturally determined cycle in the domestic pig population". That is – as pig numbers increase, *R. exulans* decreases until pig herds are killed: "synchronously slaughtered by several neighbouring clans in connection with important ritual ceremonies". Dwyer (1978: 246–247) also suggests that "activity of pigs near and in houses presumably leads to interference with, and some predation upon, *R. exulans*. Pigs therefore may

**Faunal checklist of introduced species in Papua New Guinea by island, condensed from Flannery (1995: 409-423). (Compiled by Alexandra Szalay, 1994.)**

**Bat** – *R. exulans, R. praetor* (pi)
**Bougainville** – *Phalanger orientalis* (northern common cuscus), pig, *R. exulans, R. praetor, R. rattus*
**Buka** – *Phalanger orientalis*, pig, *R. exulans, R. praetor, R. rattus*
**Conflict group** – *R. exulans*
**Duke of York** – pig, *R. exulans*
**Fergusson** – pig, *R. exulans*
**Garove** – *R. exulans*
**Goodenough** – pig, *R. exulans*
**Karkar** – pig
**Kiriwina (Trobriand)** – pig, *R. exulans*
**Long** – *R. exulans*
**Luf** – *Spilocuscus kraemeri* (Admiralty cuscus)
**Manam** – *R. exulans*
**Manas** – *Echymipera kalubu* (common echymipera), pig, *Spilocuscus kraemeri, R. exulans, R. praetor, R. rattus*
**Marshall Bennett Islands** – *R. exulans*
**Mioko** – *Phalanger orientalis*, *R. exulans*
**Misima** – pig, *R. exulans*
**Mussau** – *Spilocuscus maculatus* (common spotted cuscus), *R. exulans*
**New Britian** – pig, *R. exulans, R. praetor* (pi), *R. rattus*
**New Ireland** – *Thylogale browni* (Northern Pademelon - a wallaby), *Phalanger orientalis, Spilocuscus maculatus,* pig, *R. exulans, R praetor*
**Ninigo** – *Spilocuscus kraemeri* (pi)
**Nissan (Green)** – pig, *Phalanger orientalis, R. exulans, R. rattus, R. praetor* (pi)
**Normanby** – pig, *R. exulans*
**Rossel (Yela)** – *R. exulans*
**Sideia** – *R. exulans, R. rattus*
**Sudest** – *R. exulans*
**Tolokiwa** – *R. exulans*
**Ulu** – *R. rattus*
**Umboi** – *Dendroiagus matschiei* (Huon tree-kangaroo), *Thylogale browni* (pi), *R. exulans*
**Woodlark** – pig, *R. exulans*

pi = prehistorically introduced

**Note:** "Some near-ubiquitous introduced species such as *Sus scrofa* (pig) or *Rattus exulans* (Pacific rat) are absent from several island listings. This absence reflects only the lack of a record for such species in the existing literature or in validated accounts to which the author had access during the writing of this book" (Szalay 1994, in Flannery 1995: 410).

reduce the impact of *R. exulans* in and around gardens and living quarters," … and cautions that as pig husbandry changes, "for reasons of health and hygiene" or due to "a growing human population, *R. exulans* could easily be released from controls formerly exercised by pigs".

Archaeological work (in Dwyer 1978) shows that *R. exulans* only appears in uppermost horizons of sites investigated. One site covered the last 1000 years – *R. exulans* only in the top level. "Certainly many authors have suggested that *R. exulans* has gained entry to New Guinea and the highlands in consequence of human impact …. I conclude that the local diversity of small terrestrial rodents in rain forests of densely populated areas of the New Guinea highlands was higher in the past than it is today and that reduction has been a consequence of habitat disturbance by men and pigs producing a smaller, less continuous area of rainforest and simplification of ground cover". Dwyer found that the short grass communities (which are created and sustained by humans) support only *R. exulans*.

#### Eastern islands

The islands off the eastern top of Papua New Guinea which have *R. exulans* are Misima, Trobriand (Kiriwina), Rossel (Yela), Tagula, Fergusson, Goodenough (R.H. Taylor, letter 1982).

#### New Ireland

In New Ireland (Bismark Archipelago), at least 50 species of birds represented by 241 bird bones from five late Pleistocene and Holocene sites (Steadman et al. 1999: 2563). "… at least 12 (petrel, hawk, megapode, quail, four rails, cockatoo, two owls, and crow) are not part of the current avifauna and have not been recorded previously from New Ireland. Larger samples of bones undoubtedly would indicate more extirpated species and refine the chronology of extinction. Humans have lived on New Ireland for ca. 35,000 years, whereas most of the identified bones are 15,000 to 6,000 years old…"

"Species of mammals brought to New Ireland by humans appear at sites only after 19,000 B.P. These are phalangers (*Phalanger orientalis*, *Spilocuscus maculatus*), wallabies (*Thylogale brunii*), rats (*Rattus praetor, Rattus exulans*), pigs... and dogs ..., of which only *Phalanger orientalis* has been recorded from the Pleistocene strata" (Steadman et al. 1999: 2564).

#### Bougainville

?Pig, ?dog, ?cat, Pacific rat, ship rat (introduced 1943) (Johnson 1946).

Also: *Rattus preator* (Johnson 1946).

Johnson (1946) observed the Pacific rat living in native villages and readily adapting to life in camps, but said it did not inhabit dense jungles far from habitations. The ship rat was introduced soon after US forces arrived on the island in 1943.

#### Nissan (Green I.)

*Coral island.*

Pig, rat (species unknown). Hartert (1926) observed that "pigs have run wild, and rats are numerous"..

### *Opportunities for island restoration*

We do not know what opportunities for restoration may remain on small islands.

## Phoenix Islands (Kiribati)

(Eight islands in group)

*"The Phoenix islands lie in the geographic center of the Pacific Ocean ..." (Fosberg and Stoddart 1994: 1). All islands are low-lying coral atolls. The islands were leased to the Pacific Islands Company in 1894 for coconut planting (Nelson 1922). "The group is at present uninhabited ... climatic conditions are marginal for human settlement" ... All the islands are dry, with great fluctuations in annual rainfall and periods of severe drought (Fosberg and Stoddart 1994: 4).*

### *Significant invasive land vertebrates*

Goat, pig, dog, cat, Pacific rat, ship rat, possibly Norway rat (introduced 1828–1840) present or formerly present on Gardner (Bryan 1942), rabbit.

Also: Sheep (Laxton 1952: 143).

#### Birnie

*Discovered and named by Emment in 1823. Never inhabited and "one of the few dry central Pacific islands not to have been mined for guano" (King 1973: 99).*

*1 km$^2$ (0.1 sq. mi.). Atoll with one island and shallow brackish lagoon. Fringing reef. Uninhabited and no signs of human settlement. Almost inaccessible, very difficult landing.*

Pacific rat (King 1973).

#### Canton

*Discovered and reported by various American whalers and British warships and named* Canton *after a New Bedford whaler which was wrecked there in 1854. (Also called Mary, Mary Balcout, and Swallow.)*

*9 km$^2$ (3.5 sq. mi.). Atoll with lagoon surrounded by broken rim of land. Worked for guano in late 19th century. Used for US military purposes during and after WWII, and as a stopover refuelling point by Pan American Airlines. Reinhabited by about 200 US Air Force personnel in 1969, "now an essential part of a new US missile testing system.... About 40 percent of the land area of the island is covered by man-made structures" (King 1973: 98).*

Feral cats and dogs (King 1973). Pacific rat (Bryan 1942).

### Enderbury

*Discovered in 1823.*

*6 km$^2$ (2.3 sq. mi.). Atoll with one large island, without lagoon except for shallow remnants in centre. No satisfactory anchorage. Guano worked in 19$^{th}$ century. Communications activity but largely uninhabited (King 1973: 98).*

Cat, ?Pacific rat – "The rat population is said to be large" (Bryan 1942).

"… a few feral cats still are present" – descendants of pets brought during an attempt at colonisation, from 1938 to 1940 (King 1973: 98).

### Gardner (Nikumaroro)

*Captain Coffin – an English captain with an American-owned ship, the* Ganges*, is credited with having found the atoll in 1828 (Bryan 1942). (Also called Kimins or Kemins Island.) There is evidence that Amelia Earhart's Lockheed Electra crashed (or ditched) beside this island in 1938. She may have got ashore but died of dehydration, being unable to contact the outside world. The island received 0.17 inches of rain in 1938 (NZ National Radio 1992).*

*4 km$^2$ (1.6 sq. mi.). Atoll with two islets almost enclosing lagoon. Fringing reef.*

*Coconut groves. Dry. Settled in 1937 from Gilbert and Ellice but settlement failed in 1955 due to drought – inhabitants were evacuated in 1963 (Douglas 1969, King 1973).*

?Dog, ?cat, Pacific rat, possibly Norway rat (introduced 1828-1840) present or formerly present (Bryan 1942).

"Possible feral domestic animals" (Douglas 1969). Gilbertese left behind cats, dogs and chickens (King 1973).

Wilkes (1845 in Bryan 1942) observed: "Birds were numerous on the island, and very tame; the tropicbirds so much so … Besides birds, a large rat …" presumably the Norway rat, but this has since disappeared" [?].

### Hull (Orona)

*3.8 km$^2$ (1.5 sq. mi.). Atoll with lagoon and 24 islets forming broken rim. Polynesian ruins. Coconut plantations, 1938 settlement from Gilbert and Ellice failed in 1955 due to drought – inhabitants evacuated in 1963. Uninhabited (Douglas 1969, King 1973).*

"Feral pigs, dogs, cats etc." left behind by Gilbertese (Douglas 1969). Pacific rat (Peale 1848, Bryan 1942).

Ellis (1936) writing about an 1887 visit, describes the "immense numbers of rats, particularly about the camp … A species of native rat, somewhat smaller in size than the common one and certainly not so repulsive, these were particularly active and could climb to places that would be inaccessible to the rat of our cities. Each night some would be at work noisily endeavouring to get at the provisions kept under our bunks, often scampering over us and making themselves generally objectionable."

### McKean

*Discovered by Wilkes in 1840.*

*0.5 km$^2$ (0.2 sq. mi.). Atoll with one islet and central landlocked lagoon, fringing reef. Guano worked in late 19$^{th}$ century.*

According to King (1973: 99) McKean "has no introduced predators" and little sign of human activity.

### Phoenix

*"One ship,* Phoenix*, under command of Captain Moore, was in this region in 1794" (Bryan 1942). "No prehistoric ruins have been found."*

*0.5 km$^2$ (0.2 sq. mi.). Atoll with one island and freshwater pools in centre, fringing reef. Worked for guano in late 19$^{th}$ century, uninhabited since (King 1973: 99).*

"No … rats were noted" (Bryan 1942). Rabbits.

"In 1924, white, yellow and brown ex-domestic rabbits were fairly numerous" (Bryan 1942). These were released at the time of guano working (1859–1871) (Douglas 1969). Rabbits (estimates vary from 100 to 1000 – "evidently kept in check by periodic harvesting, along with some seabirds, by the crews of copra boats that service the Line Islands" (King 1973: 99). The rabbits "…appeared to be sharing their burrows with the petrels and shearwaters and one had to step carefully to avoid crushing rabbits and birds wherever one went. They were in very poor condition and, although when chased they would be off like a rocket for a hundred yards or so, they soon gave a despairing squeak and lay still with their ears back, ready to be captured…. I am told that rabbits never drink, certainly those at Phoenix could not have, for though we dug six wells down to 12 feet we found nothing but salt water" (Maude and Maude 1952).

### Sydney

*Discovered by Captain Emment in 1823.*

*4.4 km$^2$ (1.7 sq. mi.). Atoll with enclosed saline lagoon, completely landlocked, one island, fringing reef. Possibly some Polynesian ruins. Worked for guano in late 19$^{th}$ century by J.T. Arundel and Co. Settled from Gilbert and Elllice in 1937–1955 but settlement abandoned due to drought.*

Feral pigs (Bryan 1942). Cat, dog, Pacific rat, ship rat (introduced 1885) (Ellis 1936, King 1973).

"One dog seen in 1968 may be the last on the island" (King 1973: 99).

Arundel (1890) writes: "On moonlight nights I have often seen hundreds of rats gathered together, and much disturbed running to and fro … We have frequently caught 100 a night in tubs made into traps in our store, and I have never visited an island however small or barren, without finding these animals living upon it."

The *Lorenzo* was wrecked in 1884/85 and ship rats got ashore (Ellis 1936).

Peale (in Poesch 1961), visiting the island in 1841 states: "… not a single land bird was seen by us, but great numbers of rats."

### *Opportunities for island restoration*

Several of these islands are bird sanctuaries (see Douglas 1969).

Enderbury – largely uninhabited – "the most important green sea turtle breeding island in the south central Pacific" (King 1973: 99).

Birnie – "the island has great value because it is nearly in an undisturbed state" (King 1973: 99).

McKean – "has no introduced predators" and little sign of human activity (King (1973: 99).

Consider removing rabbits from Phoenix, if they are still present.

## Pitcairn Group (UK)

(Four islands in group)

### *Significant invasive land vertebrates*

Goat, cat, Pacific rat, mouse. (Formerly pig and rabbit.)

#### Ducie

*0.8 km² (0.3 sq. mi.). Low coral atoll with lagoon. Partly wooded. Remote and rarely visited.*

Pacific rat (Williams 1960).

#### Henderson

*Polynesian settlement from as early as 700 AD. "…increasingly occupied for c. 500 years from 1000 AD" (Vickery 1994). "Discovered by European voyagers in 1606, at which time it had no human inhabitants" (Steadman and Olson 1985: 6191).*

*37 km² (14.3 sq. mi.) (Case 1996:71). Elevated coral atoll, 30 m. (100'), with fringing reef, undercut precipitous cliffs, flat top with deeply pitted surface, no running water. Densely wooded including many endemic tree species. Visited by Pitcairn islanders for wood. Otherwise not altered by humans. Relatively inaccessible.*

Pacific rat (Pearce 1994). ?Mouse.

" … of those introduced, only the Pacific rat … and perhaps the house mouse … survive today" (Steadman and Olson 1985: 6191).

"Goats were first taken to Henderson from Pitcairn in 1843, but through inadvertence were not landed before the vessel left … Three were, however, released during the visit of the Whitney Expedition in 1923 … but had disappeared by the time of the Mangarevan Expedition in 1934. Pigs were landed … in 1912, but of these there is no subsequent record. Mice are mentioned as being numerous at the north landing ... [in 1909] but are not otherwise recorded. The only numerous introduced mammal is the Polynesian rat. [It was] found ... there in 1819. Bank mentioned it as numerous at the north landing in 1909 …" (Fosberg et al. 1983: 18–19).

1987 excavations on Henderson Island, when combined with earlier excavations, "show that the resident avifauna of Henderson Island has lost two to five species of seabirds and three species of landbirds [pigeons] since the arrival of humans more than 800 years ago" (Schubel and Steadman 1989).

No introduced bird species (Case 1996: 71).

#### Oeno

*0.6 km² (0.25 sq. mi.). Low coral atoll with typical atoll vegetation. Some coconuts planted, visited occasionally by Pitcairn islanders. Largely undisturbed.*

Pacific rat (Williams 1960, Pearce 1994).

#### Pitcairn

*Discovered by Cartaret in 1767. Had been inhabited by Polynesians. Settled in 1780 by* Bounty *mutineers. The community moved to Norfolk I. in 1856, but some returned to Pitcairn in 1858. Pitcairn "makes a welcome pausing place for the great crowded passenger liners and for the freighters that pass on the average weekly" (Moverly 1953: 65).*

*486 hectares (1200 acres). High volcanic, 304 m (1000'). Rich deep soil. 80 in. rain p.a. Temp. 65-82°F. Luxuriant evergreen vegetation. Small farming community with cultivated areas.*

Feral goats (Douglas 1969). ?Pigs. Dogs - domesticated? (Moverly 1953), cats, fowls?

Pacific rat - currently being eradicated, though a first eradication attempt has failed. No other rats present (B. D. Bell, pers. comm. 1999). Mouse (introduced c. 1942) (Moverly 1953).

"Rats are very common... They attack citrus fruit at all stages; they eat the seeds both before and during germination, they destroy the blossoms, and they eat the fruit on the trees before it ripens. Orange trees are unpruned and grow straight up to a great height in the scrubby jungle, but only a metal collar round the trunk can discourage the rats. Mice are increasing. They came in packing materials about six years ago. Despite the very real threat of these rodents to the orange industry the inhabitants most stupidly hunt with dogs and shoot even the most domesticated of cats.... There is a large flock of goats roaming the islands … They are individually marked and owned and are the main supply of meat…. Goats and fowls are the gardener's worst enemies here, because fencing is almost unknown" (Moverly 1953: 64). Serious soil erosion follows the deforestation caused by the goats (Moverly 1953: 65)

Only one land bird present (Moverly 1953). "No extinct forms are known, though, judging from the present avifauna of Henderson, it is likely that there were once other resident land-birds on Pitcairn that have been exterminated as a result of settlement; and place-names and traditions indicate that all the petrels breeding on the other islands in the groups as well as two, perhaps even three, species of *Sula* and the greater frigate bird once bred there, but have since been eaten out of existence" (Williams 1960).

Survival of several species of petrel is "severely threatened by predation from the introduced Pacific rat" (Vickery 1994).

### *Opportunities for island restoration*

Ducie and/or Henderson? Douglas remarks that these are not adequately studied.

Pitcairn? Some reafforestation begun in 1964 (Douglas 1969). Oeno?

Henderson is described by Vickery (1994) as "the world's only raised coral atoll that is virtually intact, and supports a suite of endemic plants and animals". It has been designated a World Heritage Site. Pitcairn islanders visit Henderson to cut trees for carving, especially miro (*Thespesia populnea*). "They are unlikely to agree to any conservation measures that do not provide them some benefits and thus, one key aspect of the management plan is the development of miro as a sustainable resource" (Vickery 1994).

Petrels breed on Henderson and rats are prevalent, but eradicating rats has been considered "impractical given its size, [around] 37 square kilometres" (Pearce 1994). The next best option has been suggested to be eradicating the rats from Oeno "a nearby coral island that covers just 65 hectares … and trust that the birds have the wit to utilise it," (Pearce 1994). Others suggest that "eventually" rats may be eradicated from Henderson itself (Nuttall 1994).

In addition, "action [is] needed to ensure that [Pacific rats] were not joined by modern rats from passing cruise ships and yachts." In the opinion of Mr Hepburn, a consultant for the British Government: "The brown rat … would probably kill the island's indigenous Henderson warbler, Henderson lorikeet, Henderson rail – a wading bird – and Henderson fruit dove" (Nuttall 1994).

On Henderson: "All of the land birds are considered to be endemic … about 33% of the species of insects and gastropods thus far collected are endemic" (Steadman and Olson 1985: 6191).

With Henderson in mind, Steadman and Olson (1985: 6191) note: "Certain endangered species, such as *Ducula galeata*, might effectively be preserved by reintroduction to abandoned islands that they occupied before human intervention."

Wildlife Management International (from New Zealand) currently have a contract to eradicate the Pacific rat from Pitcairn (B. D. Bell, pers. comm. 1999).

## Rennell and Bellona (Solomon Is)

(Two islands)

#### Rennell

*825 km$^2$ (318.5 sq. mi.) (Wolff 1969). 91 m (300') raised atoll, with cliffs and central depression with lake. Honeycombed limestone surface with Pandanus scrub. Polynesian population – occupied for at least five centuries (J. Diamond, pers. comm. 1982).*

### *Significant invasive land vertebrates*

Pacific rat. No other rats or other introduced land mammals (Wolff 1969).

(Formerly goat, pig, dog.)

Said to have been no dogs, cats, or pigs present in 1929. Pigs were introduced by missionaries in 1934 but were all killed and eaten by natives. Danish expedition of 1951 found a few dogs but no pigs or cats on western end of island. British expedition in 1953 found cats, dogs (3), and a small herd of goats at Hatuna village at eastern end (Bradley 1955 in Hill 1956).

Rennell Island grey teal, extinct 1959 (King 1981).

#### Bellona

*21.6 km$^2$ (8.3 sq. mi.) (Wolff 1969). 76 m (250') raised atoll with honeycombed limestone surface.*

### *Significant invasive land vertebrates*

Pacific rat. No other rats or introduced land mammals (Wolff 1969).

***Opportunities for island restoration***

"Rennell is the world's largest raised atoll. No traders of other nations brought ship rats or house cats. The result has been that the bird fauna has not been disturbed appreciably. Of the 33 land and freshwater forms known to nest on the island, 19 (57%) are to be found nowhere else. The Australian Government has made great efforts to keep the island and its fauna inviolate. As a result of this action, as well as its good luck and freedom from predators, the birds are as nearly in their natural state as any in the world" (Hamlin 1931 in Greenway 1967).

Cliffs may have been sufficient to exclude beaching by boats … and hence protect island from predator introduction (J. Diamond, pers. comm. 1982).

Wolff (1969), visiting the islands in 1965, found *Rattus exulans* to be the only introduced land mammal.

## Rotuma (Fiji)

(One island)

*Politically part of Fiji but separated by 450 km (Zuy et al. 1988).*

*43 km$^2$ (17 sq. mi.) (Zuy et al. 1988). 256 m (840') volcanic, fringing reef. Upper slopes wooded, some swamps. 6 small islets round coast. Hot and wet. Copra, tropical fruit and cotton cultivation.*

***Significant invasive land vertebrates***

Cattle, goat, pig, dog, cat, Pacific rat, ?other rat species.

Cattle, horses, pigs, goats, dogs and cats, described as "domestic" by Zuy et al. (1988).

"The rat, *Rattus exulans*, is widespread from the houses of the coast to the gardens and plantations of the central plateau.... it is likely that *R. rattus* and/or *R. norvegicus* are also present" (Zuy et al. 1988).

One bird species introduced. None known to be extinct (Case 1996: 71).

***Opportunities for island restoration***

Unknown.

## Samoan Islands (W: Independent, E: USA)

(11 islands in group, W: 4, E: 7.)

*Discovered 1721–22 by Roggereen (Dutch), who did not land. First missionary landed on Savai'i in 1830. First description of flora and fauna from the Wilkes expedition, c. 1840.*

*Total area: 3150 km$^2$ (1216 sq. mi.) (Case 1996: 71).*

Samoa (formerly Western Samoa): Upolu (capital at Apia); Savai'i
Also: Apolima, Manono.

American Samoa: Tutuila (Pago Pago); Manua group: Tau, Ofu, Olosega, Rose
Also: Aunu'u, Swains I.

***Significant invasive land vertebrates***

Pig, dog, cat, Pacific rat, ship rat, Norway rat (King 1973: 98). Cane toad (Grant 1996), red-vented bulbul, jungle myna (Lever 1987: 504), possibly Indian myna (Lever 1987: 499, 504).

Cats "have become wild in great numbers, and prove most destructive to many kinds of birds" (Stair 1897).

Three bird species introduced, at least two bird species extinct (Case 1996: 71). See King (1973: 98) for some extinction details. Samoan wood rail, extinct 1873 (King 1981).

### Samoa

#### Aleipata Islands

Four small islands- Nu'utele, Nu'ulua, Namu'a, and Fanuatapu – at eastern end of Upolu, highly eroded remains of tuff cones (Whistler 1983: 228).

On Nu'utele "The feral pigs present..." (Whistler 1983: 230).

On Namu'a "A small herd of feral goats (possibly only five individuals)..." (Whistler 1983: 230).

On Faunuatapu, there are no goats or pigs present (Whistler 1983: 232).

#### Savai'i

*1821 km$^2$ (703 sq. mi.). Volcanic dome, 1858 m (6096'), still active. Some fringing reef. Cultivated for coconuts. Timber extraction from rainforest.*

Wild cattle, wild pigs, dog, cat, Pacific rat (K. A. Wodzicki, pers. comm.). Red-vented bulbul (Lever 1987: 318).

The Savai'i rail (*Pareudiastes pacificus* – probably flightless) became extinct during the last 100 years (1845–1945) (Mayr 1945a). "The Samoan rail is also believed to have been exterminated within a few years of rats escaping from visiting whalers" (Roots 1976).

#### Upolu

*R. L. Stevenson (in Derrick 1951) describes the effect of a hurricane which wrecked 12 out of 13 ships in Apia harbour, in 1889.*

*1114 km² (430 sq. mi.). High volcanic, 1100 m (3608'), backbone ridge with string of old volcanic cones. Some fringing reef. Banana and copra cultivation.*

Pacific rat, Norway rat (introduced 1762–1923), ship rat (introduced 1841–1923). Jungle myna (Lever 1987: 504), possibly Indian myna (Lever 1987: 499, 504), red-vented bulbul (Lever 1987: 318).

All three rat species caught in Apia in 1924–25 (Buxton and Hopkins 1927).

The Samoan wood rail (*Pareudiastes pacificus*) is thought to have been "extirpated by imported rats and cats, which are thought to have been introduced by whaling ships. …Whitmee, 1974, was of the opinion that it occurred on Upolo also" (Greenway 1967).

## American Samoa

Writing of American Samoa, King (1973: 98) stated: "The black rat is found on Tutuila, and may be present on some of the others as well. Polynesian rats have been observed on all islands of this group."

"The dense interiors of Tutuila and Tau are visited by Samoans only rarely on hunting forays after wild pigs" (King 1973: 98).

### Rose Atoll

*7000 m² (1.8 acres). Low coral atoll with two reef islets. Many seabirds.*

Pacific rat - probably (Sachet 1954).

### Swains Island

*Part of Tokelau islands until annexed by USA in 1925.*

*2.59 km² (1 sq. mi.). Atoll with freshwater lagoon. Coconut, banana and taro cultivation. Tokelau labour.*

Pig, dog, cat (King 1973: 98). Pacific rat.

"Polynesian rats (*Rattus exulans*) are plentiful and are particularly numerous in and on the piles of coconut husks left after copra-harvesting operations" (Clapp 1968).

Coulter (1941) reported that before poisoning it was estimated that 20% of the coconut crop was damaged by rats.

In the opinion of King (1973: 98), this island "would be of little value as a sanctuary".

### Tutuila

*135 km² (52 sq. mi.). Volcanic, 653 m (2141'), with chain of mountains for 25 miles, fringing reef in southeast. Densely wooded (Douglas 1969). Coconut cultivation.*

"Wild pigs" (King 1973: 98). Pacific rat, ship rat (introduced 1865–1973), Norway rat (introduced pre-1924?) (S. Anderson, letter 1978) (Flannery 1995). Mouse (Brenchley 1873). Red-vented bulbul (King 1973: 98). Possibly Indian myna, though it is uncertain whether this has established. (Lever 1987: 499).

"The black rat is found on Tutuila, and may be present on some of the others as well. Polynesian rats have been observed on all islands of this group" (i.e. all seven islands of American Samoa). … "The Mao or Giant Honeyeater (*Gymnomyza samoensis*) has been extirpated from Tutuila, although it still can be found occasionally in Western Samoa. The sooty rail (*Porzana titabuensis*) from Tau has not been seen in recent years …" (King 1973).

### *Opportunities for island restoration*

**Samoa**

The Aleipata Islands [are these close enough for rats to swim?] Uninhabited? Dense vegetation: "…distinct from the main islands (Upolu and Savai'i in both their flora and their vegetation (Whistler 1983: 241).

Douglas (1969) recommends: Protection of some parts of upper slopes of cone on Savai'i, to safeguard endemics and interesting colonisation of lava flows. Protection of upper slopes of Mt Tofua, on Upolu.

**American Samoa**

King (1973: 98) commented: "There are no legally recognised nature sanctuaries in American Samoa".

Tutuila and Tau have densely vegetated, uninhabited interiors. "A recently discovered colony of three and possibly four procellariid species [petrels and shearwaters] in the mountains of Tau, attests to the relatively unaltered nature of the interior of this island" (R. Crossin, pers. comm., King 1973: 98).

Likewise, Douglas (1969) recommends: Protection of mountain sites to safeguard endemic species, on Tutuila.

Rose atoll – is *R. exulans* the only introduced predator? …has forest, and substantial seabird populations. In the opinion of King (1973: 98), Rose "should be given legal status as a sanctuary".

## Santa Cruz Is (Solomon Is)

(14 islands total)

*The Santa Cruz group (incl. Swallow (Tuwo), Tikopia, Mitre, Cherry, Duff) is largely volcanic. Vanikoro is a recent volcano, with a fringing reef and difficult landing. Tinakula is an active volcano, 671 m (2200'), with a barren summit. Swallow (with mixed Polynesian/ Melanesian population) is made up of ten islands - fragments of a raised atoll. Tikopia (Polynesian and much studied by anthropologists) is volcanic, 1235', with crater lake and fringing reef. Cherry (Anuta) island has a reef and difficult landing. Mitre (Fatutaka) is steep and* *rocky with no vegetation. The Duff or Wilson islands (3 in total) are volcanic.*

### *Significant invasive land vertebrates*

Pig, Pacific rat, ship rat.

#### Tikopia

Colonised 2000 years ago (see Kirch and Yen 1982).

Pacific rat. (Formerly pig and dog, and also formerly *Rattus praetor*.)

"The occurrence of *R. praetor* is interesting, as it represents the easternmost penetration of this originally New Guinean species. Its remains are not present in the lowest levels of the site, and it has not been recorded from the island in historic times, suggesting that it may now be extinct there. Both pigs and dogs were rare or extinct by the early historic period, although their remains are abundant in early prehistoric levels" (Flannery 1995: 41).

### *Opportunities for island restoration*

Unknown.

## Society Islands (French Polynesia)

(14 islands in group)

*Total area: 1550 km² (599 sq. mi.) (Case 1996: 71).*

### *Significant invasive land vertebrates*

Cattle, goat, pig, dog, cat, Pacific rat, Norway rat, ship rat, mouse, Indian myna, red-vented bulbul - probably established (Lever 1987: 318).

Also: donkey, harrier (R. Hay, pers. comm. 1999).

Seitre and Seitre (1992: 215) provide a summary of the situation. All the endemic birds in French Polynesia are considered threatened or endangered (15 species and 40 subspecies). Polynesians brought with them pigs, dogs, Pacific rats and chickens. "Europeans introduced goats, sheep, cattle, horses, rabbits and domestic cats, as well as, unintentionally, roof rats *Rattus rattus*, brown rats *Rattus norvegicus* and house mice *Mus musculus*. Various birds came much later.… introductions of European pests could have been earlier than is generally believed and could partly explain why at least five native species were never seen again after Cook's passage, although they had survived 1000 years of Polynesian presence. Only one species, the Marquesas fruit dove *Ptilinopus mercierii*, has become extinct during the twentieth century, but many other bird species have suffered range reductions and their current status is very poorly known.… As well as hunting and habitat destruction, it appears that introduced predators play a major role, with the roof rat *Rattus rattus* being the most dangerous."

*Rattus rattus* is "the main danger" to *Vini* lories. "Although *Vini* and *Rattus* coexist on some islands, it is probably only a temporary phenomenon. Rats proliferate in the lowlands where birds soon disappear, the remaining population being driven to higher altitudes (as has happened in Ua Pou). While this habitat is not optimal for rats they do invade it as their numbers increase and force the birds to extinction" (Seitre and Seitre 1992: 219).

Flycatchers are abundant only where *Rattus rattus* is absent (Seitre and Seitre 1992: 220).

The Pacific rat "can be a significant predator" for the Tuamotu sandpiper *Prosobonia cancellata,* which "has an extremely limited range on a few atoll islets (motus)" (see Seitre and Seitre 1992: 219).

"Feral cats contributed to the extinction of many species and they may be the direct cause of extirpation of ground doves *Gallicolumba* spp. on many islands (Seitre and Seitre 1992: 217)

Twelve bird species introduced, at least 12 bird species extinct (Case 1996: 71).

Indian myna present on: Bellingshausen, Huahine, Moorea, Mopelia, Raiatea, Scilly (Fenuaura), Tahaa, Tahiti (details in Lever 1987: 499, from Holyoak and Thibault 1984).

#### Bora Bora (Pora-Pora)

*37.6 km² (14.5 sq. mi.). High volcanic, 579 m (1936'). Reef islands. 'Rest and recreation' centre for US armed forces in WWII.*

Pacific rat (Wallace and Rosen 1965), ship rat (introduced pre-1920) (S. Anderson, letter 1978).

#### Huahine

*Archaeological evidence of Polynesian habitation (from as early as AD 780): "…bones of… dog, chicken, and rat were present. The absence of pig bones should be noted …" (Emory 1979: 202). Visited by Cook in 1773, and called by him 'Huaheine'.*

*78 km² (30 sq. mi.). Twin islands, Huahine Nui and Huahine Iti, volcanic, to 456 m (1497'). Two lakes.*

"Feral pigs and fowl" (Douglas 1969). Pacific rat (Wallace and Rosen 1965). Indian myna (Lever 1987: 499).

#### Meetia (Mehetia)

*High volcanic to 433 m (1427'), with reef, but no lagoon.*

"Feral goats and pigs" (Douglas 1969). "Land over 500' recommended for some degree of protection" (Douglas 1969).

#### Moorea

*Visited by Cook in 1773 and called by him 'Eimeo'. Also later called Duke of York Island.*

*132 km$^2$ (51 sq. mi.). High volcanic, 1121 m (3975'). Reef.*

Pacific rat (R.H. Taylor, letter 1982), Norway rat (introduced pre-1922), ship rat (introduced pre-1922) (S. Anderson, letter 1978). Indian myna (Lever 1987: 499).

In 1841: "The woods swarmed with rats [presumably the Pacific rat], which came out many at a time when the natives commenced opening cocoa nuts for us" (Peale in Poesch 1961).

Rats may be a contributing factor in the decline of *Partula* land snails on Moorea (and other islands), although their main predator is *Euglandina*, an introduced carnivorous snail (see Tudge 1992).

#### Raiatea

*Visited by Cook in 1773 and called by him 'Uliatea'. "Source island for New Zealand Maori population" ? (Douglas 1969).*

*High volcanic to 1033 m (3389'). Reef.*

Pacific rat (Wallace and Rosen 1965). Indian myna (Lever 1987: 499).

"We also noticed that rats, which are such a bane on Otaheite [Tahiti] that at night the natives wrap up their feet to prevent them being bitten, were much scarcer here, although we could not observe that the natives took any measures to destroy them" (Sparrman 1953).

Raiatea parakeet, extinct 1774 (King 1981).

#### Scilly (Fenuaura)

*Atoll.*

Pacific rat (R.H. Taylor, letter 1982). Indian myna (Lever 1987: 499).

#### Tahaa

*98.4 km$^2$ (38 sq. mi.). High volcanic, 579 m (1936'). Within same barrier reef as Raiatea I.*

Pacific rat (Wallace and Rosen 1965). Indian myna (Lever 1987: 499).

#### Tahiti

*Visited by Cook in 1773 and called by him 'Otaheite'.*

*1000 km$^2$ (386 sq. mi.). High volcanic to 2237 m (7339'). Reef. Wet.*

"Feral cattle … goats and pigs" (Douglas 1969). Pacific rat (Peale 1848), Norway rat (introduced pre-1921), ship rat (introduced pre-1921) (S. Anderson, letter 1978). Indian myna (Lever 1987: 499), red-vented bulbul – probably established (Lever 1987: 318).

Sparrman (1953) visited Tahiti with Cook in 1773: "The pig and the dog, which are eaten as food, are the only quadrupeds, except for an unconscionable number of rats which, despite being a great pest, must nevertheless be regarded as a public benefaction, since the natives do not gather up their fruit and vegetable refuse which they strew about; the rats by devouring it thus prevent the air from becoming infected by the putrid odours emanating therefrom."

Goin (1932) suggests the Pacific rat has been driven out by the ship rat.

Tahiti parakeet, extinct 1844, Tahiti red-billed rail, extinct 1925 (King 1981).

### *Opportunities for island restoration*

"Rapid action to eradicate introduced predators, coupled with translocations, would be the most effective way to ensure the survival of the remaining bird species" (Seitre and Seitre 1992: 215).

## Solomon Islands

*The capital of the Solomons is Honiara on Guadalcanal.*

*"The longest islands (Malaita and Isabel) are about 110 miles in length, with an area of some 1,600 to 1,700 square miles [4144 to 4403 km$^2$], the largest (Guadalcanal) covers 2,500 square miles [6475 km$^2$]…" (Lever 1937).*

### *Significant invasive land vertebrates*

Pig, ?dog, cat, Pacific rat, ship rat (Friend 1971, M. Efford, pers. comm. 1978), mouse. Cane toad (Lever 1945). Indian myna (Lever 1987: 500).

Also: *Rattus preator* (Johnson 1946), *Phalanger orientalis* (northern common cuscus) (Flannery 1995).

"The value of a wife, amongst these islands, is generally estimated at about three pigs, which, when a man is able to get them, entitle him to the hand of a dusky beauty" (Markham 1872).

One bird species known to be introduced, at least two bird species extinct (Case 1996: 71).

Indian mynas present on: Guadalcanal, Russel, and the Olu Malau (Three Sisters) (Lever 1987: 500).

#### Guadalcanal

Pig, ?dog, cat, Pacific rat, ship rat (introduced pre-1920), mouse (Rowe 1967), (J. Schonewald, letter, 1979). Indian myna (Lever 1987: 500).

Also: *Phalanger orientalis* (Northern common Cuscus) (Flannery 1995).

Possibly *Rattus preator* (Rowe 1967).

(Specimens of *R. rattus* collected from Guadalcanal, in 1920 and 1921, according to J. Schonewald, letter, 1979. Thus Rowe (1967) is incorrect in his supposition that *R. rattus* arrived during WWII.)

**Malaita**

Pig, Pacific rat, ship rat (introduced 1945–59) (Rowe 1967).

Also: *Phalanger orientalis* (northern common cuscus) (Flannery 1995).

"Serious damage by rats to cocoa pods … Circumstantial evidence suggests that damage to crops followed the introduction of *R. rattus*, probably when units of the labour corps and surplus war equipment were shipped from Guadacanal after the war" (Rowe 1967).

**San Cristobal**

Pig, Pacific rat, ship rat (Flannery 1995).

Also: *Phalanger orientalis* (northern common cuscus) (Flannery 1995).

The San Cristobal rail (*Edithornis silvestris*) was still extant in 1944–45 (Mayr 1945a).

### *Opportunities for island restoration*

Unknown.

---

**Faunal checklist of introduced species in the Solomon Is by island, condensed from Flannery (1995: 409-423). (Compiled by Alexandra Szalay, 1994.)**

---

**Choiseul** – *Phalanger orientalis* (northern common cuscus), pig, *R. exulans, R. praetor*
**Florida** – *R. rattus*
**Guadalcanal** – *Phalanger orientalis*, cat, pig, *R. exulans*, *R. praetor, R. rattus*
**Malaita** – pig, *Phalanger orientalis, R. exulans, R. rattus*
**Mono** – *Phalanger orientalis*
**Nendö** – pig, *R. exulans*
**New Georgia** – *Phalanger orientalis*, pig, *R. exulans*
**Ontong** - *R. exulans*
**Russell Is** – *Phalanger orientalis, R. exulans, R. rattus*
**San Cristobal** – *Phalanger orientalis*, pig, *R. exulans, R. rattus*
**Santa Isabel** – *Phalanger orientalis*, pig, *R. exulans, R. rattus*
**Shortland Is** – *R. exulans*
**Sikopo** – *R. exulans*
**Tomotu Neo** – *R. rattus*
**Uki Ni Masi** – *R. exulans*
**Vella Lavella** – *Phalanger orientalis, R. rattus*

---

**Note:** "Some near-ubiquitous introduced species such as *Sus scrofa* (Pig) or *Rattus exulans* (Pacific Rat) are absent from several island listings. This absence reflects only the lack of a record for such species in the existing literature or in validated accounts to which the author had access during the writing of this book" (Szalay 1994, in Flannery 1995: 410).

## Tokelau Islands (NZ)

(Three islands in group)

*Total area 1012 hectares (2500 acres). Group of 3 atolls, low, with seasonal rain.*

### *Significant invasive land vertebrates*

Pig, dog, cat, Pacific rat.

"All [islands] have populations of Polynesian rats and, at times, dogs" (Kirkpatrick 1966b in King 1973: 97).

"On Atafu, like on the two other islands of Nukunonu and Fakaofo, Polynesian rats (*Rattus exulans*) damage only green coconuts on the palms … these nuts, upon being gnawed by rats fall to the ground and disintegrate" (Wodzicki 1973: 44).

**Atafu**

*223 hectares (550 acres). 42 reef islets.*

?Cat (Kirkpatrick 1966), Pacific rat (Wodzicki 1972), ?Norway rat.

An unconfirmed report (in 1982) that *R. norvegicus* had reached Atafu during the previous two or three years (K. Wodzicki, pers. comm.).

**Fakaofo**

*263 hectares (650 acres). 61 reef islets. Dense population, copra growing.*

?Cat (Kirkpatrick 1966), Pacific rat (Wodzicki 1972).

**Nukunono**

*546 hectares (1350 acres). 24 reef islets.*

?Cat (Kirkpatrick 1966), Pacific rat (Wodzicki 1972).

### *Opportunities for island restoration*

Fakaofo "is undoubtedly the most valuable islet in the group" from the point of view of breeding seabirds (King 1973: 97).

"*R. exulans* is the only rodent present on Nukunono atoll" (Wodzicki 1972).

Greenway (1967) writes: "No endemic species are to be found on them and no populations are known to have been extirpated. They [the Tokelau islands] have had little contact with European or American civilization".

## Tongan Islands

(75 islands in group)

*Discovered in 1616 by two Dutch navigators, Schouten and Lemaire, who visited Niuatoputapu and Niuafoou. Tasman visited 'Eua, Tongatapu, Nomuka (which he named Middleburgh, Amsterdam, Rotterdam respectively) in 1643. Sallis visited Niuatoputapu in 1767. Cook visited* *several islands on his second voyage (1773–74) and spent three months in the islands on his third voyage in 1777. The mutiny on the* Bounty *took place somewhere between Nomuka and Tofua (in the Ha'apai group), in 1789. Many other ships called. Mission activities from 1822 to 1890. Troops stationed during WWII.*

*Total area: 670.8 km² (259 sq. mi.). Scattered group of volcanic and limestone islands. Three main island groups:*

*Tongatapu group: e.g. Tongatapu, 'Eua*

*Ha'apai group: low-lying coral formations, e.g. Nomuka, Tofua*

*Vava'u group: high and mountainous, e.g. Uta Vava'u, Hunga*

*Outlying islands: e.g. Niuatoputapu, Tafahi, Niuafo'ou*

### *Significant invasive land vertebrates*

Pig, dog, cat, Pacific rat, ship rat, Norway rat, mouse, rabbit (on Tongatapu). Jungle myna (Rinke 1986). Red-vented bulbul (Lever 1987: 318).

Also: Horse.

Twibell (1973) trapped *R. norvegicus, R. rattus, R. exulans*, on five islands, but no mice were caught, observed or reported, contrary to other reports (e.g. Carter et al. 1945).

The arrival dates for the Norway rat, and the ship rat "are not known, but are believed to be … since the increase of regular shipping trade and the construction of wharves" (Twibell 1973).

Martin (1818: 267–71) describes hunting of rats, presumably the Pacific rat, with bows and arrows, by chiefs.

The jungle myna has "recently colonised the island of Niuafo'ou, apparently without human assistance, and may compete with the lories [*Vini australis*] for nesting sites..." (Rinke 1986).

Red-vented bulbul present on Niuafo'ou (released 1928-29), 'Eua and Tongatapu (Lever 1987: 317).

## 'Eua

*87.8 km² (33.9 sq. mi.). Volcanic, 329 m (1078').*

Pacific rat (Gill 1987). Red-vented bulbul (Lever 1987: 317).

"Protection of some sites recommended in order to safeguard some remaining native vegetation including most of interesting Tongan species" (Douglas 1969).

### Hunga

*4.8 km² (1.85 sq. mi.). 75 m (245'), sheer cliff coastline.*

Pacific rat (Martin 1818 in Waite 1897).

### Late

*15.5 km² (6 sq. mi.). High volcanic, 518 m (1700'), cliffs. Periodically visited for fishing and collecting copra.*

"Wild pigs" (Douglas 1969). Ship rat (introduced pre-1978) (W.R. Sykes, letters 1979/80).

### Tongatapu

*257 km² (99.24 sq. mi.). Raised limestone, 82 m (270'), lake complex in centre of island. Cliffbound. Reefs and islets.*

Goat, pig, dog, rabbit, Pacific rat, Norway rat, ship rat (Brenchley 1873: 134, Twibell 1973, D. R. Stoddart 1975). Red-vented bulbul (Lever 1987: 317).

Heyerdahl (1952) comments that no pre-European dogs were present, although their name was known.

Brenchley (1873: 134) comments that there are "no indigenous mammals", but that rats and rabbits had been "imported". As he considered the Pacific rat indigenous, it seems likely that one of the other rat species had reached Tongatapu by 1865.

Twibell (1973) discusses varying damage to food crops by the three rat species.

### *Opportunities for island restoration*

Unknown.

## Tuamotu Islands (French Polynesia)

(76 islands in group)

*The Tuamotu Islands together with the Society, Rapa, Austral, Gambier (Mangareva), and Marquesas Islands are administered from one centre – the town of Papeete, on Tahiti.*

*Total area: 855 km² (330 sq. mi.) (Case 1996: 72). All are low coral islands except Makatea. Hot and wet, within hurricane belt, water scarce. Thin soils. French nuclear tests on Fangataufa, Mururoa. Base for French nuclear weapons test programme in Pacific on Anaa atoll.*

### *Significant invasive land vertebrates*

?Pig, dog, cat, Pacific rat, Norway rat, ship rat, mouse (Cassin 1958). Indian myna (Lever 1987: 499).

"Introduced dogs, cats and rats, also poultry, all feral" (Douglas 1969).

No pigs in pre-European times (Heyerdahl 1952).

Two bird species introduced, none known to be extinct (Case 1996: 72).

Indian myna present on Hao and Mururoa (Lever 1987: 499).

### Ahunui, Aratika

Pacific rat (R.H. Taylor, letter 1982).

Beechey (1968: 222 (1831)), visited the island in 1826: "In their huts we found calabashes of water suspended to the roof, mats, baskets, and every thing calculated for a sea-voyage; and not far from them a plentiful store of fish, raised about four feet above the ground, out of the reach of the rats, which were very numerous".

### Disappointment Is

Pacific rat (Peale 1848, R.H. Taylor, letter 1982).

### Fakarava (Fakareva)

*Atoll with islets.*

Pacific rat, Norway rat, ship rat (Dumbleton 1955).

Dumbleton (1955) commented: "… the species responsible for the damage are said to be *Rattus rattus* …. *R. norvegicus* is present in at least some villages. It is stated that where only the Polynesia rat *Rattus exulans* is present, no damage is done to coconuts. It is believed that rats destroy 50% of the coconut crop on Fakarava, and in some localities 75%–100% of the crop is destroyed".

### Hao

*Airstrip built for use in French nuclear weapons test programme. Coconut plantations.*

Dog, ?Pacific rat (Lucett 1851: 247). Indian myna (Lever 1987: 499).

"They have no quadrupeds, save a few wretched dogs which they keep for eating, and a small species of rat which infects the islands in myriads" (Lucett 1851: 247).

### Hiti

Pacific rat (R.H. Taylor, letter 1982).

### Kakarawa

Pacific rat (R.H. Taylor, letter 1982).

### Maria and Menihi

Pacific rat (R.H. Taylor, letter 1982).

### Makatea

*Mined for phosphate in early 20th century. Is a shipping port at Temao, "where are great storage warehouses, and where launches and boats are drawn up when not in use. It is to Temao that passengers and freight come by power launches from steamers lying out in deep water" (Wilder 1934).*

*28 km$^2$ (10.8 sq. mi.). Raised atoll 111 m (230'), cliff, fringing reef. Phosphates once worked with labour force imported from Austral Is, who have since returned.*

Rat (species unknown), mouse (Wilder 1934).

Thibault and Guyot (1987) in their study of changes in the avifauna of Makatea, suggest that some extinctions between the 19th and 20th centuries may be due in part to the "introduction of a predator (e.g. *Rattus* sp.)".

### Nukutipipi

*5 km$^2$ (1.9 sq. mi.), volcanic, "one of the tiniest low-lying islands of the Tuamotu archipelago" (Salvat and Salvat 1992: 1).*

Pacific rat (R.H. Taylor, letter 1982).

"No cats, dogs, pigs or other mammals are found in the atoll and the past land-owner, Mr. Madec, was very sensitive to the natural ecosystem of the islands remaining vigilant about introductions. *Rattus exulans* is present." No introduced birds are present (Salvat and Salvat 1992: 6, 5).

### Rangiroa

*Atoll with 241 islands, reef. Coconut plantations, pearl fishery, airstrip.*

Cat, Pacific rat.

"On Rangiroa … it seems that cats are present on most of the motu, but there are some remote ones which are predator-free (except *R. exulans*) and this is where the densest populations of bristle-thighed curlew occur and where ground doves and lorikeets have hung on" (R. Hay, pers. comm. 1999).

### Raraka

Pacific rat (R.H. Taylor, letter 1982).

### Raroia

*9 km$^2$ (3.5 sq. mi.). Atoll with many islets around lagoon.*

Dog, cat, Pacific rat, ship rat (introduced c. 1855–75) (Morrison 1954).

"According to the people of Raroia, this grey rat [*R. rattus*] appeared on Raroia Atoll only after the development of the commercial copra trade about a century ago" (Morrison 1954).

Morrison (1954) characterises *R. exulans* as having "no fear of man" and living on seeds and fruit, while *R. rattus* is "larger and greyer" and "secretive, running away to hide when found at night", and feeding on the coconut both green on the tree and ripe on the ground.

The rats are most uncommon around the villages because of cats and dogs (Morrison 1954).

The ship rat has completely replaced the Pacific rat on those islets of Raroia atoll where it is present (Morrison 1954).

On islands not inhabited by rats, geckos (*Gehyra oceanica),* are apparently abundant on the tree trunks, but where rats are present they are only found high up on the underside of leaves (Morrison 1954).

#### Taenga, Tepotu, and Tureia

Pacific rat (R.H. Taylor, letter 1982).

#### Tikehau

*Inhabited.*

Cat, Pacific rat, Norway rat (Intes and Caillart 1994).

"Some domestic cats returned to the wild were seen wandering in coconut plantations and marshes" (Intes and Caillart 1994: 10).

### *Opportunities for island restoration*

"Most of the atolls are poorly known but it is apparent that, until recently at least, some such as Maturei-Vavao, Marutea-Sud, and Niau have been free of cats and European rats. However, this is mostly assumption based on the continued survival of the kingfisher and/or the Tuamotu sandpiper on those islands" (Dr. R. Hay, pers. comm. 1999).

Individual motu of Rangiroa? See comment by R. Hay about this atoll.

## Tuvalu Islands (Ellice Is) (UK)

(Nine islands in group)

*"Mendana possibly sighted the group in 1568. Captain de Peyster in the* Rebecca *is believed to be the first European to visit the largest atoll, Funafuti, … [in] 1819" (Rodgers 1985). In 1896 Funafuti became the centre of world attention because it was selected as a site on which to sink a deep bore, "in order to test Darwin's theory concerning the formation of coral islands" (Rodgers 1985).*

*Total area: 28.5 km² (11 sq. mi.). All inhabited by Polynesian population. Population suffered from 'blackbirding'* [slave trading] *in 1850–1875 with severe reduction in numbers (Douglas 1969).*

### *Significant invasive land vertebrates*

?Pig, cat, Pacific rat (all islands in group), Norway rat, ship rat (Smith 1969) (J.M. Williams, letter 1982). Mouse. (Formerly cattle, and mongoose.)

"…no assessment of the effect of the remarkable herd of cattle on Niulakita appears to have ever been made; the last of which was killed and eaten but a short time ago" (Rodgers 1985).

"In Tuvalu only three of the nine islands have *Rattus rattus*, Funafuti, Nanumea and Nukulaelae. The first two were colonised during World War II and the latter in 1922.... As in Kiribati all Tuvaluan atolls are occupied by *R. exulans* but the densities vary greatly on the different islets around atolls and between atolls. Rainfall and the nature of the substrate and ground vegetation under palms have a major effect" (J.M. Williams, letter 1982).

Only 3 islands in the group have the ship rat – Funafuti, Nanumea, and Nukulaelae. "The first two were colonised during World War II [1940–45]…" (J.M. Williams, letter 1982).

#### Funafuti

*Admin. centre for Ellice group was/is? Vaiaku on Funafuti.*

*2.8 km² (1.1 sq. mi.). Atoll with 30 islets, central swamp.*

?Dog, cat, Pacific rat, Norway rat (introduced 1850-1896), ship rat (introduced 1940-1945) (J.M. Williams, letter 1982, Smith 1968). Mouse (Hedley 1896).

Dogs at one time were domesticated, but were exterminated by orders of the 'Turimen', who used to march round the villages at night to see that everything was all right, but the barking of the dogs gave them away (Hedley 1896).

"Before the advent of Europeans and the introduction of the cat, the natives were much plagued by swarms of the Pacific rat. From time to time when the pest grew beyond endurance, it was the custom for the king to order everyone to bring in a set number e.g. 100 rats" (Hedley 1896).

"Cats have long been introduced … and have proved of service in destroying the brown rat [probably the Norway rat] formerly a great pest to the islands. The European rat [probably the ship rat] and mouse have effected an uninvited entrance to the village and have multiplied fast" (Hedley 1896).

#### Nanumea

*3.9 km² (1.5 sq. mi.). Atoll with 2 islets.*

Pacific rat, ship rat (introduced 1940–45) (J.M. Williams, letter 1982).

#### Nukulaelae

*1.8 km² (0.7 sq. mi.). Atoll with 14 islets on enclosed lagoon.*

Pacific rat, ship rat (introduced 1922) (J.M. Williams, letter 1982).

The ship rat "colonized Nukulaelae Island in the Ellice group following a 1922 ship wreck" (J.M. Williams, letter 1982). Also of interest is that mongooses were introduced about 1950 (from Fiji) in an attempt to control rats, but they died out.

### *Opportunities for island restoration*

Unknown.

## Vanuatu (including Banks and Torres Islands)

(35 islands in Vanuatu group, ten islands in Banks group, five islands in Torres group.)

*Lapita pottery site dated at 1300 ± 70 BC. Discovered by Quiros in 1606. Visited by Bougainville in 1768. Charted by Cook in 1774, who stayed in the New Hebrides, as they were known, for about six weeks.*

*Total area: 12 000 km² (4633 sq. mi.) (Case 1996: 72).*

### *Significant invasive land vertebrates*

Pig, Pacific rat, ship rat, Norway rat, mouse. Indian myna (Lever 1987: 500).

Sparrman (1953) observed "The only quadrupeds they have are a few hogs and a number of troublesome rats, against which they have to dig deep ditches round their sugar plantations".

No dogs in pre-European times (Heyerdahl 1952).

"*Rattus rattus* has not been recorded on Erromanga, currently the least densely populated by men of the six islands. Elsewhere it has been taken principally in plantations or gardens, habitats in which this rat abounds on other Pacific islands … *R. norvegicus* and *Mus musculus* are more sporadic in distribution in the New Hebrides, but equally restricted to areas of human habitation or disturbance … The occurrence of *R. norvegicus* at the high, isolated settlement of Nokovula (1100 m) on Santo was unexpected. The rat most frequently taken in our traps was *R. exulans*. It was the only rat occurring on all islands sampled, and the only rat found in all habitats, including urban housing (British compound, Luganville), gardens, plantations, secondary bush, natural sea-shore vegetation (at Ipotak, Erromanga) and climax forest far from native settlement (for instance, the kauri forest at Nuangkau, Erromanga)" (Medway and Marshall 1975).

"The pig … was probably brought to the islands by the natives when first they came to them. They are mentioned by Captain Cook … In addition to the domesticated ones, many are feral. In certain of the islands, notably Espiritu Santo and Gaua, quite a large proportion of the domesticated pigs (and of the wild ones also, according to native report) are intersexual, having external organs varying from almost the female to nearly the male condition, and more or less ill-developed male internal organs. They constitute a new type of mamalian intersexuality … Nowhere in the world is any mammalian intersex so abundant. …. These monstrosities play a large part in the social life of the natives, being of especial importance in chief-making ceremonies …" (Baker 1929).

Five bird species introduced, no known extinct birds (Case 1996: 72).

Indian myna present on some islands (Mayr 1945b, in Lever 1987: 500).

#### Aneityum/Anatom/Anaton

*103.6 km² (40 sq. mi.). Volcanic, 850 m (2788'). Fertile.*

Pacific rat, ship rat, mouse (Brenchley 1873: 199, Medway and Marshall 1975).

#### Banks Islands

(None is individually called Banks, main ones are Gaua and Vanua Lava.)

*Almost all are volcanic islands.*

Pacific rat (Tate 1935).

**Gaua** – *Eroded volcano, 700 m (2300'), crater lake, hot springs.*

Pacific rat (Baker 1929).

#### Efate

*777 km² (300 sq. mi.). Volcanic overlain with limestone, 702 m (2303').*

Pacific rat, Norway rat, ship rat (introduced pre-1923), mouse (Medway and Marshall 1975, M. Levitt, letter 1979).

#### Erromanga (Eromanga)

*854.7 km² (330 sq. mi.). Volcanic to 914 m (3000'), with raised coral terraces. Formerly noted for sandalwood.*

Pacific rat (Medway and Marshall 1975).

#### Espiritu Santo

*3885 km² (1500 sq. mi.). Limestone plateau and volcanic mountains to 1829 m (6000'). West coast precipitous. East coast, chain of coral islets.*

Pacific rat, Norway rat, ship rat (Alicata 1963, Medway and Marshall 1975).

#### Malekula

*1165.5 km² (450 sq. mi.). Recent limestone, and volcanic to 891 m (2925').*

Pacific rat, ship rat (Medway and Marshall 1975).

#### Tanna

*388.5 km² (150 sq. mi.). Active volcano, 970 m (3420'), with limestone fringe.*

Pacific rat, ship rat (introduced post-1865) (Brenchley 1873: 213, Medway and Marshall 1975).

#### Torres Islands

(None is individually called Torres, main ones are Hiu, Tegua, Lo, and Toga.)

*All islands are of raised limestone.*

Pacific rat (R.H. Taylor, letter 1982).

**Hiu** - *Three limestone terraces rising to 375 m (1230'), some reef.*

Pacific rat (Tate 1935).

### *Opportunities for island restoration*

Unknown.

## Wake Islands/Eneen-Kio (USA)

*Roughly 2000 km east of the Marianas. Visited by Japanese poachers in early 20th century. US naval and air establishment in 1939–41. Attacked during WWII.*

*7.4 km² (2.85 sq. mi.). Atoll with three islets, connected by bridges. No original vegetation remaining. Scrub (see Douglas 1969 for details). Devastated by military use and civilian occupation. Airstrip/airport terminal still used (in 1969) by Federal Aviation Agency, for stopover and refuelling. Coastguard station, cable station. "…presently about 1400 US civilian and military personnel on Wake" (King 1973: 101).*

### *Significant invasive land vertebrates*

Cat, Pacific rat, ship rat (introduced 1923–1951, King 1973). Brown tree snake? – has reached Wake, but unclear whether it has established.

"The three islets of this atoll are connected by bridges. Feral cats, black and Polynesian rats occur on all three islets. An endemic rail (*Rallus wakensis*) became extinct during World War II. There are eight breeding seabird species; seven more bred in the recent past but have been extirpated (King 1973: 101). Bryan (1942) states that the rail, which was more-or-less flightless, and stood eight or nine inches high, "was the only native land bird, and was by far the most interesting species". "Rats prey heavily on Sooty Terns" (King 1973: 101).

The ship rat was introduced to Wake "during the Japanese occupation" in WWII (Dec 1941–Sept 1945) … "with devastating effects on birdlife (Fosberg 1959, in Spennemann 1997: 8).

Several sources describe an explosion of rats: "…soon the Americans were driven near to madness by the countless hordes of rats", writes an anonymous source in 1941, describing how rat-catchers poisoned the rats, hermit crabs ate the rats and died, then seabirds ate the crabs and died.

"Following the establishment of the Pan American Airways station on Wake and the creation of open rubbish tips, Polynesian rats were to become a plague of major proportions and eventually were the focus of several eradication campaigns" (Spennemann 1997: 5).

"Following Typhoon Sarah on 15 September 1967 rat populations exploded. 'All fresh eggs disappeared within 24 hours and on two occasions I actually saw rats dragging eggs away while the adult bird stood "helplessly" watching. We watched several rats chewing on young birds'…" (R. Schreiber, Pacific Ocean Biological Survey Program unpublished fieldnotes, in King 1973: 101).

Wake Island rail, extinct 1945 (King 1981).

### *Opportunities for island restoration*

According to Douglas (1969), there is a bird sanctuary for boobies, frigate birds and terns at far end of Wilkes Island (one of the three reef islets).

## Wallis and Futuna Is (France)

(Three islands in group)

#### Alofi

*Total area 30 km² (11.4 sq. mi.). High volcanic, 366 m (1200'). Well wooded. Sporadic timber extraction. Not permanently settled?*

?Pig, ?Pacific rat only, ?Norway rat (King 1973).

#### Futuna

(Futuna and Alofi = Horn Islands.)

*65 km² (24.7 sq. mi.). High volcanic 762 m (2500'). Deeply dissected with many streams, fringing reef. Well wooded valleys, fernbreaks, some grassland, and montane forest.*

### *Significant invasive land vertebrates*

"Pigs are common…" (Burrows 1938: 216). Cat, Pacific rat, ?ship rat (King 1973). Norway rat (Flannery 1995).

#### Wallis (Uvea)

*US airbase in WWII. Considerable emigration of population to New Caledonia.*

*60 km² (23.1 sq. mi.). Low volcanic, 146 m (479'). Relatively flat with no running water. Barrier reef with 22 reef islets. Warm and humid. Coconut plantations (in 1969, infested with rhinoceros beetle). Breadfruit, bananas and tropical fruit cultivation.*

### *Significant invasive land vertebrates*

"Pigs are common…" (Burrows 1938: 216). Pacific rat, ?ship rat, ?Norway rat (King 1973). Indian myna – first reported 1999 (R. Hay, pers. comm. 1999).

### *Opportunities for island restoration*

Alofi – if still uninhabited, may be worth investigating.

# 4. Discussion

## 4.1 Human impact

The impact of introduced plants and animals on island ecosystems in the Pacific has been enormous. Why is it that the native plants and animals, particularly birds, of isolated islands appear to be more vulnerable to introduced mammals than is the case with native plants and animals of continents? The evidence available suggests that it is because island plants and animals have evolved in environments where, apart from bats, land mammals have never been present. Thus island birds have not developed behaviours which give them some protection against mammalian predators, although they may be able to evade bird predators such as hawks and owls. In a parallel manner, the plants of isolated islands have not developed mechanical deterrents, such as spines, or chemical deterrents in their leaves, that would protect them against mammalian herbivores.

However, when considering how much has been lost through our introductions of alien plants and animals, we must also acknowledge the more direct impacts of humans: overkill by hunting; burning and logging of native vegetation and other habitat destruction; and our widespread use of many substances that have polluted air, water and soils.

The impact of humans and their introduced animals and plants on islands goes back many centuries and sometimes thousands of years. Whenever fossil deposits extending into pre-human times are uncovered on an island, we find that a number of interesting animals formerly present (particularly birds) have disappeared since humans arrived. These losses were never described in writing at the time. But this is also frequently the case with losses of fauna and other changes that followed European contact. It is now often difficult to determine whether a particular native species disappeared as a direct result of human action (for example, the introduction of guns for hunting) or whether it was an effect of newly introduced animals, such as rats or pigs.

Notwithstanding the urge that many of us have to get rid of these invasive species, it is not realistic to think that everyone will share this view. Animals such as pigs will always be valued for food; others such as mongooses may still be seen as useful for rat control even though it is very doubtful that such ‘control’ is effective. Still others will be valued for ethical or religious reasons. Thus, in considering and planning control or eradication for a particular introduced animal, it is necessary to understand these various views and accommodate them in any plan that is produced.

## 4.2 Information gaps

As can be seen from this report, we know the general distribution of introduced mammals and birds across island groups, and we know something of the risks they pose to native plants and animals. *Within* an island group, however, there is often very little available information on the distribution of these mammals and birds. There is need for trained observers to visit each island within a group, beginning with islands greater than 5 hectares in area, to ascertain which introductions of mammals and birds have already happened.

A good example of this basic inventory work is the study by Buden (1996) of the introduced reptiles, birds, and mammals present on Ant Atoll in the Caroline Islands. Such work lays the basis for more comprehensive studies of whole island groups, of which the work in Fiji by Pernetta and Watling (1978) is an excellent example.

Knowing which introduced animals are present on each island is a necessary starting point. Sometimes, however, it is possible to go beyond this point and document the historical sequence in which each invader arrived, as, for example, in the study of Tinian Island, Mariana group, by Wiles et al. (1990). The great value of having such a chronology is that it may provide clearer insights into the causes of particular impacts as well as revealing information about interactions between different species of invasive animal. In passing, it should be mentioned that Wiles et al. (1990) make a useful distinction between “domestic” and “free-ranging” individuals of an invading species. Dogs and pigs, for example, can quickly change from domestic to free-ranging behaviour, to the detriment of wildlife, without necessarily establishing feral populations. One or two individual animals can have effects out of all proportion to their numbers (as, for example, the loss of kiwi to a single dog in New Zealand—see Section 2.4 on ‘Dog’).

There are areas on some islands where legal protection is given to safeguard habitats or threatened species. These need to be inventoried with respect to their legal status/ownership and the conservation values they are intended to protect. Ideally, whole island groups need to be inventoried in this way so that remaining candidates for protection can be identified.

A third major information gap is that of identifying areas of remaining habitat (with legal status), that, with some management, are likely to be suitable for protecting threatened species, be they plants or animals. “Suitability”, of course, may be dependent on the removal of certain introduced animals and this raises the question of which animals need to be controlled or eradicated if the habitat in question is to provide effective protection for particular threatened species.

## 4.3 Research needs

Most studies of the impact of invasive animals on native plants and animals have been made in countries outside the area considered here. In spite of this, there is quite sufficient information available from islands both inside and outside the SPREP region to demonstrate how damaging some of these animals can be. All three of the rat species discussed are detrimental to wildlife although little is known about their impact on seeds and seedlings of native trees in the Pacific. Nor is there any doubt about the serious impact that cats (domestic and wild), mongooses and brown tree snakes will have on the wildlife of any island they reach. Most of the information relating to the detrimental effects of pigs in the Pacific comes from Hawai‘i. Some further studies are needed on islands in the SPREP region as a basis for making island people more aware of the need for effective containment of these animals. There is also a need for more data on the incidence of domestic and wild dogs in native forests and the impact they may be having on native wildlife on islands of the region. Little appears to be known of the impact cane toads have on native animals. Two small animals where there appears to be no information from South Pacific islands are the house mouse and the musk shrew. So far as browsing animals are concerned, it is clear that goats, rabbits, and cattle, where they are present, are all extremely damaging both to plants and the structure of habitats.

The value of analytical studies of the impacts of particular invasive species cannot be over-estimated. A good example is the analysis of factors potentially responsible for the decline of the Guam bird fauna (Savidge 1987, Savidge et al. 1992), which clearly identified brown tree snakes as the primary factor. But every invasive animal that reaches an island, in addition to its primary impact, also exerts secondary effects, sometimes referred to as “indirect effects” or “flow-on effects”. McCoid’s (1991) discussion of the secondary effects of brown tree snakes in Guam. though preliminary in nature, underlines the need to understand much more about these effects if we are to achieve a comprehensive understanding of the impacts of invasive species.

We presently have very little idea of what the current impact of birds introduced to Pacific islands may be. Possible ways in which impacts can occur have been discussed under “Introduced birds” (Section 2.15). Behavioural studies of both species of myna, and bulbuls, are needed in habitats where they are likely to interact with native birds. Questions relating to their feeding, nesting and aggressive behaviour need to be answered, from which it should be possible to determine whether these birds pose any significant threat to the breeding success of native birds.

Additional questions remain. What are the effects of jungle fowl on ground-feeding birds and reptiles through food competition? Many other introduced birds appear to feed mainly in agricultural crops, but as with introduced mammals, more information is needed on the total range of foods taken by each of these birds as well as effects that may follow.

Deciding priorities for control of different invasive mammals requires knowledge of their impacts. This is not easy because the most obvious effects are not always the most serious. Furthermore, if stomach analyses are used to determine what a particular predator is eating, a low incidence of a threatened species in the stomach contents of a predator does not mean there is no problem. If the threatened species is rare, it is unlikely to contribute a large part of the predator’s diet; and ***any*** predation can be critical if the threatened species is already reduced to low numbers. Decisions on control priorities should be based on the maximum amount of impact information that can be gathered. In this connection, any archaeological or palaeo-ecological studies that are likely to extend our understanding of past impacts of humans and their introduced animals should be encouraged and supported in every way possible.

With respect to the question of how to maintain relatively unmodified islands free of invasive mammals, it is necessary to measure the distances that animals such as rats, mongooses, tree snakes or cane toads can swim. Data relating to the distances that rats may swim is given by Jackson and Strecker (1962) and Spennemann and Rapp (1989). More extensive trials, involving a wider range of sea conditions and all three rat species, are needed.

## 4.4 Priorities for control or eradication of invasive vertebrates

As indicated above, decisions on control priorities must be based on knowledge of the impacts of invasive species present. A starting point is to identify exactly what is at risk. Is it a particular native plant or animal species, a group of these species, or perhaps a whole community of plants and animals? Can it be demonstrated that introduced mammals are mainly responsible for the problem or are other factors involved such as overhunting, fires or other kinds of habitat disturbance?

If it is clear that introduced animals are the major factor, then which species is having the greatest effect? An invasive species can have a major impact on one island and be unimportant on another. Such differences can even be found on the same island. Pigs, for example, may be having a relatively minor effect on either the plants or the landbirds present in an area of forest. But in another part of the island, where there is a seabird colony, predation of the seabirds by pigs may be taking the colony to extinction. In other instances, a predator may learn to take a certain kind of prey in one part of an island but not in another. This appears to be the case in the example of ship rats preying on the eggs of the Bonin petrels on Midway Atoll (Grant et al. 1981). Furthermore, the impact of an introduced animal can be modified by the combination of other introduced animals present.

Programmes for control or eradication of any invasive species are likely to be expensive. They must be justified in terms of the expected conservation gain. Thus it must be clear that the animal to be controlled or eradicated is indeed placing particular conservation values at risk.

Eradication of some species of invasive mammal is often feasible on smaller islands even if presently impractical on large islands. Parkes (1990) has identified four conditions that must be met for a successful eradication. All individuals of the animal to be eradicated must be put at risk; there must be no chance of recolonisation from another source; the rate at which the animals are killed must exceed the rate at which the population is increasing; and those attempting the task must believe it is possible. He also concluded that short intensive campaigns concentrating on one pest animal are the most effective, and that eradication campaigns must be funded separately from those requiring sustained control. If the target animal is to be killed faster than it can replace itself, sufficient money must be available to fund the campaign on a scale that will achieve this end.

These requirements for success in eradication programmes raise the question of how to judge whether a proposed eradication attempt is possible. Managers should always attempt to measure the effort, costs and results of either eradication or control programmes so that their experience can be combined with that from programmes elsewhere and thus more reliable judgements reached. It should always be remembered that every eradication programme provides an opportunity to measure recovery of native plants and animals and thus better understand the impact of the animal eradicated.

Details of successful eradications of animals from New Zealand islands up to 1990 are given by Veitch and Bell (1990).

## 4.5 Preventing the further spread of invasive animals to islands in the SPREP region

Many island groups already have all the widespread problem mammals characteristic of Pacific islands: cattle, goats, pigs, cats, dogs, three species of rats and mice. But this is not the case on many individual islands within a group. It is essential to prevent the further spread of invasive animals within an island group as well as between groups. Islands of particularly high conservation value should be identified and, wherever possible, given extra protection. Any island that is completely free of invasive mammals should be given the highest priority for protection.

Preventing this spread depends partly on identifying the pathways by which invasive animals are most likely to reach an island. Cattle, goats, pigs, rabbits, cats, dogs and mongooses are purposely, rather than accidentally, taken to islands in boats or aircraft. Thus a checking and quarantine system, vigilantly applied at all times, could be expected to largely prevent the further spread of many of these animals to islands they have not so far reached. But such a system would not prevent further spread altogether. There is an essential educational task of explaining the environmental costs of releasing any of these animals on to islands where they are not already present.

Unless special precautions are taken, the remaining invasive animals are liable to be spread accidentally to additional islands in food supplies, building materials or other cargoes carried by boats or aircraft. These animals are rats, mice and shrews, and brown tree snakes. The boats can vary in size from large ocean-going ships to small 'run-abouts', but the greatest risk from invasive animals carried by boats is at the time the vessel is tied to a wharf or on a slipway, or is anchored close inshore. Construction of wharves capable of holding ocean-going ships is an almost certain pathway by which *Rattus rattus* and *R. norvegicus* can colonise a previously uninfested island. Atkinson (1977) gives examples of this in Hawai'i, and Spennemann (1997) demonstrates the same pathway on the atolls of the Marshall Islands.

Regular quarantine searches are already made for tree snakes at airports receiving direct flights from Guam where the snake is established. Any island within the SPREP region whose airport is visited by civil or military aircraft that have passed through Guam, and possibly those countries to which the snake is native (Australia, Papua New Guinea and the Solomon Islands), is vulnerable to invasion. Improved control of tree snakes at airports on source islands will reduce this risk. The use of dogs trained to detect snakes at airports receiving flights from Guam, or other islands with snakes, will further reduce the risk.

Precautions against rats and mice, which are applicable also to shrews, are identified and listed by Moors et al. (1992). These precautions include establishing a legal basis for excluding rodents from islands, preparing rodent contingency plans and destruction kits for dealing with invasives, rat-proofing all boxes and crates destined for rodent-vulnerable islands, packing cargoes and stores in rodent-proof containers, re-checking cargo and stores for rodent sign during unloading, and placing permanent rodent-poison stations on wharves and within a radius of about 200 m of the wharf. Poison-bait stations should also be carried by boats moving between rodent-infested and rodent-free islands.

Islands at highest risk to rodents are those importing bulk foodstuffs for humans or stock, or building supplies that are not packaged in rodent-proof containers. Nevertheless, the contents of any container imported to an island cannot be assumed to be free of rodents, shrews or injurious reptiles and insects, if precautions were not taken to exclude such animals during the loading of the container.

We must be aware at all times of the possibility that other species of rodent, snake or unrelated vertebrate, with no previous track record of negative impact, will become established with serious consequences for island plants and animals. Thus a protective strategy is needed for each island group. Such a strategy should include:

(i) a list of the ***most likely invaders*** from other island groups or from continents, particularly those that pose risks to health, commercial crops, or conservation values;

(ii) measures for ***preventing*** these potential invaders from establishing; these should include agreements with other countries concerning the importation of goods;

(iii) means for the ***early detection*** of these potential invaders;

(iv) ***contingency plans*** for the rapid elimination of these potential invaders before they have time to establish (Atkinson 1996).

Everybody knows of occasions when warnings about the need to protect certain conservation values have been passed unnoticed if not ignored. There must be a continuing effort by SPREP to assess these warnings for validity and urgency, incorporate them in protection plans when appropriate, and make people generally more aware of measures necessary to protect conservation values.

## 4.6 Island restoration

*Protection* is always essential to achieve conservation goals. But many island ecosystems are so seriously damaged, with respect to the condition of native habitats and losses of animal or plant species, that effective conservation cannot be achieved by protecting what is left. Increasingly, there is a need for island *restoration* programmes in which at least the most aggressive invasive species have to be removed. This paves the way for re-planting programmes in circumstances where natural regeneration is unlikely to repair the damage at a sufficiently fast rate. It may also open possibilities for replacing animal (or plant) species that were formerly present, as well as reinstating some physical conditions of an earlier period, e.g. water-table regimes. The aim of this kind of historical/ecological restoration is to rebuild a plant/animal community that functions more like it did before modification by humans and their introduced plants and animals.

The first need is to identify and list those islands, or parts of larger islands, where there is already some protection of the native plants and animals and the communities they form. Some islands may be uninhabited and free from all other introduced mammals. Depending on their present condition they may be worth restoring to an earlier condition or they may warrant only continuing protection. Opportunities for restoration vary greatly between island groups.

There are several island groups with large numbers of islands. These include Fiji, Caroline Is, Cook Is, Mariana Is, Marshall Is, New Caledonia, New Guinea, Solomon Is, Tonga, Tuamotu Is, and Vanuatu. A search for islands suitable as restoration sites should be undertaken within each of these island groups.

There are a number of islands scattered through the Pacific that should be assessed as possible candidates for programmes of active restoration. Baker and Howland Islands are recognised for their large seabird colonies. Both islands have been troubled by cats in the past. It is unclear whether these have been eliminated on Baker but they are still present on Howland (King 1973, Rauzon 1986). In the Cook Islands, Suwarrow Atoll is considered to be of great interest scientifically (Douglas 1969), and on Mangaia, Merlin (1991) stated that the plant life on the elevated coral is "still largely dominated by native species." In the Line Island group, Caroline Atoll (Kepler et al. 1994), and Jarvis and Vostok Islands (King 1973) have all been identified as outstanding for seabird or terrestrial habitat reasons. Permanent protection for Caroline, Vostok and Flint Islands was being negotiated in 1994 (Kepler and Kepler 1994).

In the Mariana Islands some of the uninhabited islands have been protected since 1985 and these may be candidates for restoration (Anon. 1985). In the Marquesas group, the island of Hatutaa appears to be largely unmodified and could be used as a model for restoring the neighbouring Eiao Island, severely damaged by sheep and pigs (Decker 1975). In the Palau group, the Ngerukewid Islands have been identified as of special conservation interest (Wiles and Conry 1990). In the Phoenix group, Bernie Island was described by King (1973) as "nearly in an undisturbed state", and Enderbury Island is the site of an important green turtle colony.

There are three uninhabited islands in the Pitcairn group (Henderson, Ducie and Oeno). The Pacific rat is present on all three but there is potential for some restoration if this rat can be eradicated on any one of these islands (Steadman and Olsen 1985, Vickery 1994).

In Samoa, the Aleipata Islands are considered to be substantially undisturbed although they may have *R. exulans* (A. Whistler, letter, 1984). Rose Atoll (American Samoa), where *R. exulans* is present, is another island that may have restoration potential (King 1973). In the Society Islands, Mohotani is a possible candidate for restoration (Seitre and Seitre 1992: 221), and the same appears to be the case for Rangiroa in the Tuamotu group (R. Hay, pers. comm. 1999). Alofi Island, unlike the neighbouring Wallis and Futuna Islands, seems not to be permanently inhabited and may therefore be worthy of assessment for restoration.

In the south-western Pacific, Rennell and Bellona Islands, Solomon group, have long been recognised as of very high conservation value (see Hamlin 1931 in Greenway 1967, Wolff 1969).

The islands discussed above as possible candidates for restoration have been listed on the basis of very scanty information, much of which is historical and consequently may be seriously dated. Restorative management is not necessarily always expensive but each proposal must be weighed against the conservation benefits expected. Selecting the most appropriate islands for restorative action in each island group must be based on knowledge of all the options available in each group.

The potential value to restoration projects of long-distance translocations of bird species, that have been lost from one island but survive on another, has been pointed out by Atkinson (1989). Strategies are needed that will disperse populations of vulnerable species to a greater number of islands. Long-distance translocation is also a means of restoring lost components of island ecosystems. Archaeological work by Steadman and Olson (1985), for example, revealed that Henderson Island, Pitcairn group, formerly had a species of large pigeon. This was closely allied to the 'Marquesas' pigeon (*Ducula galeata*), which now survives only on Nuku Hiva in the Marquesas Islands, 2000 km northwest of Henderson Island. It may be that Henderson is a suitable site for the translocation of the endangered Marquesas pigeon.

Franklin and Steadman (1991) provide a detailed methodology, involving habitat mapping, to facilitate such translocations on mainland America, which may have applicability to the Pacific

## 5. Recommendations

These recommendations have been written in response to the needs of SPREP member countries and territories, but apply to other islands in the Pacific. We recommend that:

1. All island governments should interact and establish an effective strategy to protect islands within their jurisdiction from further entry and establishment of invasive animals. This responsibility of governments needs to be taken up for reasons of economic interest (risks to commercial crops, human health, etc.) and conservation interest. The necessary steps in an effective protection strategy for each island group are:
   (i) listing likely invaders that can be expected;
   (ii) developing means for preventing these potential invaders from establishing, including appropriate import agreements with other countries;
   (iii) developing methods of early detection for each of these invaders by setting up a reporting system with a wide range of cooperators: commercial companies, con-

servation authorities, local NGOs and private individuals (see Westbrooks 1998);

(iv) developing plans for eliminating these invaders before they have time to establish (Atkinson 1996).

2. All reserves where legal protection is given to safeguard habitats or particular species should be listed, together with their legal status/ownership and the conservation values they are intended to protect. Island groups where the existing reserves do not include the range of habitats and native species present in the group should be identified.

3. Systematic surveys of all islands (beginning with those greater than 5 hectares in area) should be made in each island group to find out which introduced mammals and other vertebrate species are present, where this information is not adequately known.

4. A formal system of reserves in the SPREP region should be established that initially recognises three categories:

   (i) islands free of all introduced mammals,

   (ii) islands free of major mammalian predators (i.e. rats, cats, dogs, pigs and mongooses) that are of a size where it is feasible to eradicate all mammalian herbivores,

   (iii) other reserves of conservation value.

   Categories (i) and (ii) deserve special protective measures.

5. Islands or island reserves should be identified where control or removal of particular introduced animals is likely to give effective protection to particular kinds of habitat or threatened species.

6. When planning for control or eradication of introduced animals, both specific threats to conservation values and other values that may be attached to the introduced animals should be considered.

7. In each island group, islands should be identified, whether formally reserved or not, where there is real potential for restoring wildlife and vegetation to a condition more like that of earlier times.

8. Further scientific studies should be encouraged, of the ecological impacts of dogs (wild and domestic), mice, musk shrews and cane toads on the native faunas of islands.

9. Behavioural studies of interactions between introduced birds and native plants and animals (vertebrate and invertebrate) should be encouraged and supported.

10. Archaeological and palaeo-ecological studies that are likely to increase our understanding of the impact of humans and their introduced animals should be encouraged and supported.

11. Comprehensive tests should be made to ascertain the distances to which rats, mongooses, tree snakes, cane toads, and pigs can swim.

12. Additional specific research needs identified in this study include:

   (i) historical studies to ascertain the sequence and approximate dates of establishment of each invasive animal on a particular island;

   (ii) analysis of secondary effects of invasive species so that more comprehensive understanding of their impacts is achieved;

   (iii) impact studies of animals such as macaque monkeys and monitor lizards, introduced to Pacific islands, even though they may not at present be seen as serious invasive species.

## 6. Acknowledgements

We thank Dr Greg Sherley, Dr Rod Hay, Dr Dick Watling, Ms Cathleen Hodges, Mr Ed Saul, Sir Christopher Lever, and Dr Dirk Spennemann for information they have supplied to us during the preparation of this report. Susan Sutherland assisted us with obtaining some of the less accessible published information. We thank Geoff Gregory for his careful editing of the original report for publication.

## 7. References

Aitken, R.T. 1930. Ethnology of Tubuai. *Bernice P. Bishop Museum Bulletin* 70. 169 pp.

Alicata, J.E. 1963. The incidence of *Angiostrongylus cantonensis* (Chen) among rats and mollusks in New Caledonia and nearby islands and its possible relationship to eosinophilic meningitis. *South Pacific Commission Technical Paper* 139. 9 pp.

Alicata, J.E.; McCarthy, D.D. 1964. On the incidence and distribution of the rat lungworm *Angiostrongylus cantonensis* in the Cook Islands, with observations made in New Zealand and Western Samoa. *Canadian Journal of Zoology* 42: 605–611.

Amerson, A.B. 1969. Ornithology of the Marshall and Gilbert Islands. *Atoll Research Bulletin* 127: 1–348.

Anderson, A.J. 1990. Kuri. *In*: King, C.M. (ed.) *The Handbook of New Zealand Mammals*. Oxford University Press, Auckland. pp. 281–287.

Anderson, S.J.; Stone, C.P. 1993. Snaring to control feral pigs *Sus scrofa* in a remote Hawaiian rain forest. *Biological Conservation* 63: 195–201.

Anonymous. 1941. Rats – crabs – birds. How PAA unwittingly upset nature's balance at Wake Is. *Pacific Islands Monthly*. p. 68.

Anonymous. 1985. CNMI Northern Islands win preservation. *Information Bulletin (Pacific Science Association)* 7(6): 57–58.

Arundel, J.T. 1890. The Phoenix Group and other islands of the Pacific. *NZ Herald*, Auckland. pp. 5,12. July 1890.

Atkinson, I.A.E. 1977. A reassessment of factors, particularly *Rattus rattus* L., that influenced the decline of endemic forest birds in the Hawaiian Islands. *Pacific Science* 31: 109–133.

Atkinson, I.A.E. 1985. The spread of commensal species of *Rattus* to oceanic islands and their effects on island avifaunas. *In*: Moors, P.J. (ed.) *Conservation of island birds. ICBP Technical Publication No.3*. pp. 35–81.

Atkinson, I.A.E. 1989 Introduced animals and extinctions. *In*: Western, D.; Pearl, M.C. (eds) *Conservation for the Twenty–first Century.* Oxford University Press.

Atkinson, I.A.E. 1996 Introduction of wildlife as a cause of species extinctions. *Wildlife Biology* 2: 135–141.

Atkinson, I.A.E.; Bell, B.D. 1973. Offshore and outlying islands. *In*: Williams, G.R. (ed.) *The Natural History of New Zealand.* A.H. and A.W. Reed, Wellington. pp. 372–392.

Auld, B.A.; Tisdell, C.A. 1986. *In*: Groves, R.H.; Burdon, J.J. (eds.) *Ecology of Biological Invasions: An Australian Perspective.* Australian Academy of Science, Canberra.

Austin, O.L. 1961. *Birds of the World*. Paul Hamlyn, London. 317 pp.

Baker, J.R. 1929. The northern New Hebrides. *Geographic[al] Journal* 73(4): 305–325.

Baker, R.H. 1946. Some effects of the war on the wildlife of Micronesia. *Proceedings of the Eleventh North American Wildlife Conference*. pp. 205–213.

Baldwin, P.H.; Fagerlund, G.O. 1943. The effect of cattle grazing on koa reproduction in Hawaii National Park. *Ecology* 24: 118–122.

Baldwin, P.H.; Schwartz, C.W.; Schwartz, E.R. 1952. Life history and economic status of the mongoose in Hawaii. *Journal of Mammalogy 33*: 335–356.

Banko, P.C. 1982. Productivity of wild and captive nene populations. *Proceedings of the 4th Hawaii Volcanoes National Park National Science Conference*. University of Hawaii, Honolulu. pp. 12–32.

Barbehenn, K.R. 1962. The house shrew on Guam. *In*: Storer, T.I. (ed.) Pacific Island rat ecology. *Bernice P. Bishop Museum Bulletin* 225: 247–256.

Barbehenn, K.R. 1974. Recent invasions of Micronesia by small mammals. *Micronesica* 10: 41–50.

Barnett, B.D. 1982. Feral dogs of southern Isabela. *Noticias Galapagos* 35: 15–16.

Barrau, J. 1981. Indigenous and colonial land-use systems in Indo-Oceanian savannas: the case of New Caledonia. *In*: Harris, D. R. (ed.) *Human Ecology in Savanna Environments*. Academic Press, London. pp. 253–265.

Bates, M.; Abbott, D.P. 1958 *Coral Island. Portrait of an atoll.* Charles Scribner's Sons, New York.

Beaglehole, J.C. (date unknown) *The Journals of Captain James Cook III. Part 2.*

Beaglehole, E.; Beaglehole, P. 1938. Ethnology of Pukapuka. *Bernice P. Bishop Museum Bulletin* 150. 419 pp.

Bech, P. 1995. Bid to rid islands of slippery intruders. *Geo* 17: 12–13.

Beechey, F.W. 1968. *Narrative of a voyage to the Pacific and Beering's Strait.* N. Israel and Da ?Capo Press, New York (Republication of an 1831 edition).

Beichle, U.R. 1989. Common myna on Upolu: first record for the Western Samoa Islands. *Elepaio* 49: 85–86.

Bloomer, J.P.; Bester, M.N. 1992. Control of feral cats on subantarctic Marion Island, Indian Ocean. *Biological Conservation* 60: 211–219.

Bloxam, A. 1925. Diary of Andrew Bloxam, Naturalist of the "Blonde" on her trip from England to the Hawaiian Islands, 1824–25. *Bernice P. Bishop Museum Special Publication* 10: 1–96.

Boag, P.T. 1983. More extinct island birds. *Nature* 305: 274.

Brenchley, J.L. 1873. *Jottings during the Cruise of* H.M.S. Curacoa *among the South Sea Islands in 1865.* Longmans, London. 487 pp.

Brooke, M. de L. 1995. The breeding biology of the gadfly petrels *Pterodroma* spp. of the Pitcairn Islands: characteristics, population sizes and controls. *In*: Benton, T.G.; Spencer, T. The Pitcairn Islands: biogeography, ecology and prehistory. *Biological Journal of the Linnean Society* 56: 213–231.

Brown, P.E. 1949. The breeding of avocets in England, 1948. *British Birds* 42: 2–13.

Bryan, E.H. 1942. *American Polynesia and the Hawaiian Chain.* Honolulu. 253 pp.

Buck, P.H. 1938. Ethnology of Mangareva. *Bernice P. Bishop Museum Bulletin* 157.

Buden, D.W. 1996a. Reptiles, birds, and mammals of Ant Atoll, Eastern Caroline Islands. *Micronesica* 29(1): 21–36.

Buden, D.W. 1996b. Reptiles, birds, and mammals of Pakin Atoll, Eastern Caroline Islands. *Micronesica* 29(1): 37–48.

Burrows, E.G. 1938. Topography and culture on two Polynesian islands. *Geographical review* 28: 214–223.

Burrows, E.G.; Spiro, M.E. 1953. An Atoll Culture. Ethnography of Ifaluk in the central Carolines. Human Relations Area File, New Haven.

Buxton, P.A.; Hopkins, G.E.H. 1927. Researches in Polynesia and Melanesia. *?London School of Hygiene and Tropical Medicine Memoir* 1. 260 pp.

Byrd, G.V. 1979. Common myna predation on wedge-tailed shearwater eggs. *Elepaio* 39: 69–70.

Campbell, D.J.; Atkinson, I.A.E. 1999. Effects of kiore (*Rattus exulans* Peale) on recruitment of indigenous coastal trees on northern offshore islands of New Zealand. *Journal of the Royal Society of New Zealand* 29: 265–269.

Carter, T.D.; Hill, J.E.; Tate, G.H.H. 1945. *Mammals of the Pacific World.* Macmillans, New York. 227 pp.

Case, T.J. 1996. Global patterns in the establishment and distribution of exotic birds. *Biological Conservation* 78: 69–96.

Case, T.J; Bolger, D.T. 1991. The role of introduced species in shaping the distribution and abundance of island reptiles. *Evolutionary Ecology 5*: 272–290.

Cassin, J. 1858. *United States Exploring Expedition. Mammalogy and Ornithology*. Lippincott, Philadelphia. 466 pp.

Chandler, S.E. 1931. Letter to the Agricultural Journal. *Agricultural Journal* [Fiji] 4: 64–68.

Christophersen, E.; Caum, E.L. 1931. Vascular plants of the Leeward Islands, Hawaii. *Bernice P. Bishop Museum Bulletin* 81. 41 pp.

Clapp, R.B. 1968. The birds of Swain's Island, South-central Pacific. *Notornis* 15: 198–206.

Clapp, R.B. 1977. Notes on the vertebrate fauna of Tongareva Atoll. *Atoll Research Bulletin* 198: 1–8.

Clapp, R.B.; Wirtz, W.O. 1975. European rabbit (*Oryctolagus cuniculus*). *Atoll Research Bulletin* 186: 150–151.

Coblentz, B.E. 1978. The effects of feral goats (*Capra hircus*) on island ecosystems. *Biological Conservation* 13: 279–286.

Coblentz, B.E.; Coblentz, B.A 1985. Control of the Indian mongoose *Herpestes auropunctatus* on St John, US Virgin Islands. *Biological Conservation* 33: 281–288.

Cohic, F. 1959. Report on a visit to the Chesterfield Islands, September 1957. *Atoll Research Bulletin* 63.

Corwin , G.; Bohnam, L.D.; Terman, M.J.; Viele, G.W. 1957. Military Geology of Pagan, Mariana Islands. US Army Report (in Landcare Library, Lincoln, New Zealand).

Coulter, J.W. 1941. Land utilization in American Samoa. *Bernice P. Bishop Museum Bulletin* 170: 14–16, 43.

Coulter, M.C.; Cruz, F.; Cruz, J. 1985. A programme to save the dark–rumped petrel, *Pterodroma phaeopygia*, on Floreana Island, Galapagos, Ecuador. *In*: Moors, P.J. (ed.) *Conservation of Island Birds. ICBP Technical Publication No. 3*: 177–180.

Crabb, W.D.; Emik, L.O. 1946. Evaluating rat baits by field acceptance trials on Guam. *Journal of Wildlife Management* 10: 162–171.

Daniel, M.J. 1978. Draft proposals for the establishment in Ecology Division of a Cook Islands ecological survey group, initially to study the rodent problem in the Cook Islands. Unpubl. report, Ecology Division, Department of Scientific and Industrial Research (in Landcare Library, Lincoln, New Zealand).

Decker, B.G. 1975. Unique dry-island biota under official protection in northwestern Marquesas Islands (Isles Marquises). *Biological Conservation* 5(1): 66–67.

Decker, B.G. 1992. Secondary plant cover on upland slopes, Marquesas Islands, French Polynesia. *Atoll Research Bulletin* 363.

Delacour, J. 1966. *Guide des oiseaux de la Nouvelle Caledonie et de ses Dependances*. Delachaux et Niestle, Neuchatel, Switzerland.

Derrick, R.A. 1951. *The Fiji Islands.* Government Printing Department, Suva, Fiji.

Dill, H.R.; Bryan, W.A. 1912. Report of an expedition to Laysan Island in 1911. *US Department of Agriculture, Biological Survey Bulletin* 42. 30 pp.

DiSalvatore, B. 1981. The goat men of Aguijan. *Islands* 1(1): 86–92.

Dixon, W.A. 1878. Notes on the meteorology and natural history of a guano island. *Journal of the Proceedings of the Royal Society, New South Wales* 11: 165–175.

Doty, R.E. 1945. Rat control on Hawaiian sugar cane plantations. *Hawaiian Planters Record* 49(2): 71–241.

Douglas, G. 1969. Draft check list of Pacific Oceanic Islands. *Micronesica* 5(2): 332–463.

Dryden, G.L. 1965. The food and feeding habits of *Varanus indicus* on Guam. *Micronesica* 2: 73–76.

Dumbleton, L.J. 1955. Rat poisoning in French Oceania. *Quarterly Bulletin of the South Pacific Commission 5(2)*: 15–16.

Dwyer, P.D. 1975. Observations on the breeding biology of some New Guinea Murid rodents. *Australian Wildlife Research* 2: 33–45.

Dwyer, P.D. 1978. Disturbance and diversity in the New Guinea highlands. *Australian Journal of Ecology* 3: 213–232.

Ellis, A.F. 1936. *Adventuring in Coral Seas.* Angus and Robertson, Sydney. 264 pp.

Emory, K.P. 1934. Archaeology of the Pacific equatorial islands. *Bernice P. Bishop Museum Bulletin* 123.

Emory, K.P. 1979. The Societies. *In*: Jennings, J.D. *The Prehistory of Polynesia*. Harvard University Press. pp. 200–221.

Empson, R.A.; Miskelly, C.M. 1999. The risks, costs and benefits of using brodifacoum to eradicate rats from Kapiti Island, New Zealand. *New Zealand Journal of Ecology* 23: 241–254.

Feare, C.J. 1979. Ecology of Bird Island, Seychelles. *Atoll Research Bulletin* 226: 1–29.

Fisher, H.I.; Baldwin, P.H. 1946. War and the birds on Midway Atoll. *Condor* 48: 3–15.

Fitzgerald, B.M. 1990. House cat. *In*: King, C.M. (ed.) *The Handbook of New Zealand Mammals*. Oxford University Press, Auckland. pp. 330–348.

Fitzgerald, B.M.; Karl, B.J. 1986. Home range of feral cats (*Felis catus* L.) in forest of the Orongorongo Valley, Wellington, New Zealand. *New Zealand Journal of Ecology* 9: 71–81.

Fitzgerald, B.M.; Meads, M.J.; Murphy, E.C. In press. Changes in arthropod populations after the eradication of house mice (*Mus musculus*) from Allports Island, Queen Charlotte Sound, New Zealand. *Biological Conservation.*

Fitzgerald, B.M.; Veitch, C.R. 1985. The cats of Herekopare Island, New Zealand; their history, ecology and effects on wildlife. *New Zealand Journal of Zoology* 12: 319–330.

Flannery, T.F. 1995. *Mammals of the South–West Pacific and Moluccan Islands.* Cornell University Press. 464 pp.

Fleet, R.R. 1972. Nesting success of the red-tailed tropicbird on Kure Atoll. *Auk* 89: 651–659.

Flux, J.E.C. 1993. Relative effect of cats, myxomatosis, traditional control, or competitors in removing rabbits from islands. *New Zealand Journal of Zoology* 20: 13–18.

Flux, J.E.C.; Fullager, P.J. 1992. World distribution of the rabbit *Oryctolagus cuniculus* on islands. *Mammal Review* 22(3–4): 151–205.

Forsell, D.J. 1982. Recolonisation of Baker Island by seabirds. *Bulletin of the Pacific Seabird Group* 9: 75–76.

Fosberg, F.R.; Sachet, M.-H.; Stoddart, D.R. 1983. Henderson Island (Southeastern Polynesia): Summary of current knowledge. Smithsonian Institution, Washington DC.

Fosberg, F.R.; Stoddart, D.R. 1994. Flora of the Phoenix Islands, Central Pacific. *Atoll Research Bulletin* 393.

Franklin, J.; Steadman, D.W. 1991. The potential for conservation of Polynesian birds through habitat mapping and species translocation. *Conservation Biology* 5: 506–521.

Freycinet, L. de 1824. Voyage autour du monde, …. *Historique* II (I).

Friend, D. 1971. Rat damage to cocoa in the Solomons. *South Pacific Bulletin,* first quarter 21: 19–22.

Fritts, T.H. 1988. The brown tree snake, *Boiga irregularis*, a threat to the Pacific islands. *US Fish and Wildlife Service, Biological Report* 88(31). 36 pp.

Fullager, P.J. 1978. *Report on the rabbits on Philip Island, Norfolk Island*. CSIRO Division of Wildlife Research, Canberra.

Gaze, P. 1998. Tahiti monarch flycatcher. *Ornithological Society of New Zealand News* 89:1.

Gibb, J.A.; Williams, J.M. 1990. European rabbit. *In*: King, C.M. (ed.) *The Handbook of New Zealand Mammals*. Oxford University Press, Auckland. pp. 138–160.

Gill, B.J. 1987. Notes on the birds, reptiles and mammals of Tongatapu and ‘Eua (Tonga). *Notornis* 34: 217–223.

Gill, B.J. 1999. A myna increase – notes on introduced mynas (*Acridotheres*) and bulbuls (*Pycnonotus*) in Western Samoa. *Notornis* 46: 268–269.

Gill, W.W. 1876. *Life in the Southern Isles.* The Religious Tract Society, London. 360 pp.

Gill, W.W. 1885. *Jottings from the Pacific.* The Religious Tract Society, London. 248 pp.

Goin, [initial unknown]. 1932. Le problème du rat en Oceanie. 2e Conférence Internationale et Congrès Colonial du Rat et de la Peste. pp. 209–212.

Gorman, M.L. 1975a. The diet of feral *Herpestes auropunctatus* (Carnivora:Viverridae) in the Fijian Islands. *Journal of Zoology, London* 175: 273–278.

Gorman, M.L. 1975b. Habitats of the land-birds of Viti Levu, Fiji islands. *Ibis* 117: 152–161.

Grant, G.S. 1996. Prey of introduced *Bufo marinus* in American Samoa. *Herpetological Review* 27: 67–79.

Grant, S.G.; Pettit, T.N.; Whittow, G.C. 1981. Rat predation on Bonin petrel eggs on Midway Atoll. *Journal of Field Ornithology* 52: 336–8.

Green, R.C. 1979. Lapita. *In*: Jennings, J.D. (ed.) The Prehistory of Polynesia. Harvard University Press. pp. 27–60.

Green, R.C. 1988. Those mysterious mounds are for the birds. *New Zealand Archaeological Newsletter* 31(3): 153–158.

Greenway, J.C. 1967. Extinct and vanishing birds of the world. *Special Publication 13, American Committee for International Wild Life Protection*.

Griffen, C.R.; Shallenberger, R.J.; Fefer, S.I. 1989. Hawaii’s endangered waterbirds: a resource management challenge. *In*: Sharitz, R.R.; Gibbons, S.W. (eds) *Proceedings of Freshwater Wetlands and Wildlife Symposium.* Savannah River Ecology Laboratory, Aiken, South Carolina. pp. 155–169.

Griffen, J. 1977. Ecology of the feral pig on Hawaii Island. *Elepaio* 37: 140–142.

Gross, A.O. 1912. Observations on the yellow-billed tropicbird (*Phaethon americanus* Grant) at the Bermuda Islands. *Auk* 29: 49–71.

Haeberie, F.R. 1952. The D’Entrecasteaux Reef Group. *American Journal of Science* 250: 22–34.

Hague, J.D. 1862. On phosphatic guano islands of the Pacific Ocean. *American Journal of Science,* 2nd Series 34: 224–43.

Harris, M.P. 1970. The biology of an endangered species, the dark-rumped petrel (*Pterodroma phaeopygia*), in the Galapagos Islands. *Condor* 72: 76–84.

Hartert, E. 1926. The birds of Feni and Nissan Islands, east of south New Ireland. *Novitates Zoologicae* XXXIII: 33–48.

Hartmann, F.W. 1947. Further observations on leptospirosis in Micronesia. *Science* 106: 294.

Heather, B.D.; Robertson, H.A. 1996. *The Field Guide to the Birds of New Zealand.* Viking, Auckland.

Hedley, C. 1896. General account of the atoll of Funafuti. *Memoirs of the Australian Museum* 3: 3–71.

Hedley, C. 1897. The ethnology of Funafuti. *Memoirs of the Australian Museum* 3: 229–304.

Heyeradahl, T. 1952. *American Indians in the Pacific.* Allen and Unwin, London. 821 pp.

Hezel, F.F. 1979. *Foreign ships in Micronesia: A compendium of ship contacts with the Caroline and Marshall Islands 1521–1885.* Published in co-operation with Trust Territory Historic Preservation Office and the US Heritage Conservation and Recreation Service.

Hill, J.E. 1956. The Mammals of Rennell Island. *In*: *The Natural History of Rennell Island, British Solomon Islands* 1: 73–84. Danish Science Press, Copenhagen.

Hindwood, K.A. 1940. The birds of Lord Howe Island. *Emu* 40: 1–86.

Hinkley, A.D. 1962. Diet of the giant toad, *Bufo murinus* (L.), in Fiji. *Herpetologica* 18: 253–259.

Holyoak, D.T.; Thibault, J.C. 1984 Contribution a l’Étude des Oiseaux de Polynésie Orientale. *Mémoires du Muséum National d’Histoire Naturelle, n.s. Série A, Zoologie,* Tome 127. Éditions du Museum, Paris.

Hook, T.; Todd, P. 1992. Mouse eradication on Mana Island. *In*: Veitch, C.R.; Fitzgerald, M.; Innes, J.; Murphy, E. (eds) Proceedings of the national predator management workshop. *Threatened Species Occasional Publication* 3. Department of Conservation, Wellington. p. 33.

Imber, M.J. 1975. Petrels and predators. *International Council for Bird Preservation Bulletin* 12: 260–263.

Innes, J.; Hay, R.; Flux, I.; Bradfield, P.; Speed, H.; Jansen, P. 1999. Successful recovery of North Island kokako *Callaeas cinerea wilsoni* populations by adaptive management. *Biological Conservation* 87: 201–204.

Innes, J.G. 1990. Ship rat. *In*: King, C.M. (ed.) *The Handbook of New Zealand Mammals*. Oxford University Press, Auckland. pp. 206–225.

Intes, A.; Caillart, B. 1994. Environment and biota of the Tikehau Atoll (Tuamotu Archipelago, French Polynesia). *Atoll Research Bulletin* 415.

Iyengar, M.O.T.; Menon, M.A.U. 1957. Filariasis in the Cook Islands. *Quarterly Bulletin of the South Pacific Commission* 7(1): 25–7.

Jackson, W.B. 1962. Area of study. *In*: Storer, T.I. (ed.) Pacific Island rat ecology. *Bernice P. Bishop Museum Bulletin* 225: 14–20.

Jackson, W.B. 1969. Survival of rats at Eniwetok Atoll. *Pacific Science* 23: 265–275.

Jackson, W.B.; Strecker, R.L. 1962. Ecological distribution and relative numbers. *In*: Storer, T.I. (ed.) Pacific Island rat ecology. *Bernice P. Bishop Museum Bulletin* 225: 45–63.

Johnson, M.S. 1945. Rodent control on Midway Islands. *US Naval Medical Bulletin* 45: 384–398.

Johnson, D.H. 1946. The rat population of a newly established military base in the Solomon Islands. *US Naval Medical Bulletin* 46: 1628–1632.

Johnson, D.H. 1962. Rodents and other Micronesian mammals collected. *In*: Storer. T.I. (ed.) Pacific Island rat ecology. *Bernice P. Bishop Museum Bulletin* 225. pp. 21–38.

Kaiser, G.W.; Taylor, R.H.; Buck, P.D.; Elliott, J.E.; Howald, G.R.; Drever, M.C. 1997. The Langara Island Seabird Habitat Recovery Project: Eradication of Norway Rats – 1993–1997. *Technical Report Series No. 304, Canadian Wildlife Service, Pacific and Yukon Region, British Columbia*.

Kepler, C.B. 1967. Polynesian rat predation on nesting Laysan albatrosses and other Pacific seabirds. *Auk* 84: 426–430.

Kepler, A.K.; Kepler, C.B. 1994. Caroline Atoll. Part 1. History, physiography, botany, and islet descriptions. *Atoll Research Bulletin* 397.

Kepler, C.B.; Kepler, A.K.; Ellis, D.H. 1994. Caroline Atoll. Part 2. Seabirds, other terrestrial animals, and conservation. *Atoll Research Bulletin* 398.

King, W.B. 1973. Conservation status of birds of central Pacific Islands. *Wilson Bulletin* 85. pp. 89–103.

King, W.B. 1981. (comp.) *Endangered Birds of the World*. The International Council for Bird Preservation (ICBP) Red Data Book. Smithsonian Institution Press, Washington DC.

King, W.B. 1985. Island birds: will the future repeat the past? *In*: Moors, P.J. (ed.) Conservation of Island Birds. *ICBP Technical Publication* 3: 3–15.

Kirch, P.V.; Yen, D.E. 1982. Tikopia, the prehistory and ecology of a Polynesian outlier. *Bernice P. Bishop Museum Bulletin* 238.

Kirk, T. 1896. The displacement of species in New Zealand. *Transactions of the New Zealand Institute* 28: 1–27.

Kirkpatrick, R.D. 1966. Mammals of the Tokelau Islands. *Journal of Mammalogy* 47: 701–704.

Kirkpatrick, R.D.; Rauzon, M.J. 1986. Foods of feral cats *Felis catus* on Jarvis and Howland Islands, central Pacific Ocean. *Biotropica* 18(1): 72–75.

Koroia, N. 1934. Rodents of the South Sea Islands in the collection of Marquis Yamashina. *Botany and Zoology, Theoretical and Applied (Toyko)* 2: 1012–1020.

Krauss, N.L.H. 1970. Bibliography of the Line Islands, Central Pacific. Published by the author, Honolulu. 18 pp.

Lamont, E.H. 1867. *Wild Life amongst the Pacific Islanders*. Hurst and Blackett.

Lamoureux, C.H. 1963. Vegetation of Laysan. *Proceedings of the Hawaiian Academy of Science* 37 (1961–62): 22.

Lance, V.A. 1976. The land vertebrates of Hong Kong. *In*: Lofts, B. (ed.) *The Fauna of Hong Kong.* Royal Asiatic Society, Hong Kong. pp. 6–22.

Laxton, P.B. 1952. Nikumaroro. *Journal of the Polynesian Society* 60: 134–160.

Lessa, W.A. 1961. *Tales from Ulithi Atoll*. University of California Press. 493 pp.

Lever, C. 1987. *Naturalized birds of the world.* Longman Scientific and Technical, London.

Lever, R.J.A.W. 1937. The physical environment, fauna and agriculture of the British Solomon Islands. *Tropical Agriculture* XIV (10): 281–285.

Lever, R.J.A.W. 1945. The giant toad in the Solomon Islands. *Fiji Agricultural Journal* 16: 1.

Long, J.L. 1981. *Introduced Birds of the World*. David and Charles, London.

Lucett, E. 1851. *Rovings in the Pacific*. Vols I – II, London.

Marples, R.R. 1955. *Rattus exulans* in Western Samoa. *Pacific Science* 9: 171–176.

Marshall, J.T. 1955. Rats of Arno Atoll, Marshall Islands. *Journal of Mammalogy* 36: 259–263.

Marshall, J.T. 1962. Geographic distribution and colour phases of Mironesian rodents. *In*: Storer, T.I. (ed.) Pacific Island rat ecology. *Bernice P. Bishop Museum Bulletin* 225: 39–44.

Marshall, M. 1975. The natural history of Namoluk Atoll, Eastern Caroline Islands. *Atoll Research Bulletin* 189: 1–53.

Martin, J. 1818. *An account of the natives of the Tonga Islands … from the extensive communications of Mr William Mariner.* 2 vols, Murray, London.

Maude, H.C.; Maude, H.E. 1952. The colonization of the Phoenix Islands. *Journal of the Polynesian Society* 61: 62–89.

Mayr, E. 1945a. Bird conservation problems in the southwest Pacific. *Audubon Magazine*, Sept–Oct 1945: 279–282.

Mayr, E. 1945b. *Birds of the South West Pacific*. MacMillan: New York.

McCoid, M.J. 1991. Brown tree snake (*Boiga irregularis*) on Guam: a worst case scenario of an introduced predator. *Micronesica* 3: 63–69.

McCoid, M.J. 1993. The 'new' herpetofauna of Guam, Mariana Islands. *Herpetological Review* 24: 16–17.

McIlroy, J.C. 1990. Feral pig. *In*: King, C.M. (ed.) *The Handbook of New Zealand Mammals*. Oxford University Press, Auckland. pp. 358–371.

Meads, M.J.; Walker, K.J.; Elliott, G.P. 1984. Status, conservation and management of the land snails of the genus *Powelliphanta* (Mollusca: Pulmonata). *New Zealand Journal of Zoology* 11: 277–306.

Medway, L.; Marshall, A.G. 1975 Terrestrial vertebrates of the New Hebrides: origin and distribution. *Philosophical Transactions of the Royal Society, London* B 272: 423–465.

Merlin, M.D. 1991. Woody vegetation on the raised coral limestone of Mangaia, Southern Cook Is. *Pacific Science* 45(2): 131–151.

Merton, D. 1987. Eradication of rabbits from Round Island, Mauritius: a conservation success story. *Dodo, Journal of the Jersey Wildlife Preservation Trust* 24: 19–44.

Moller, H.; Craig, J.L. 1986. The population ecology of *Rattus exulans* on Tiritiri Island, and a model of comparative population dynamics in New Zealand. *New Zealand Journal of Zoology* 14: 305–328.

Moors, P.J. 1990. Norway rat. *In*: King, C.M. (ed.) *The Handbook of New Zealand Mammals.* Oxford University Press, Auckland. pp. 192–206.

Moors, P.J.; Atkinson, I.A.E. 1984. Predation on seabirds by introduced animals, and factors affecting its severity. *In*: Croxall, J.P.; Evans, P.G.H.; Schreiber, R.W. (eds) Status and Conservation of the World's Seabirds. *ICBP Technical Publication* 2: 667–690.

Moors, P.J.; Atkinson, I.A.E.; Sherley, G.H. 1992. Reducing the rat threat to island birds. *Bird Conservation International* 2: 93–114.

Morris, R.O. 1964. The birds of the Gilbert Islands. *The Sea Swallow* 16: 79–83.

Morrison, J.P.E. 1954. Animal ecology of Raroia Atoll, Tuamotus. *Atoll Research Bulletin* 34: 1–26.

Moseley, H.N. 1944 (1879). *Notes by a Naturalist ... during the Voyage of* H.M.S. Challenger. Werner, London. 540 pp.

Moverly, A.V. 1953. Pitcairn Island: an economic survey. *Transactions of the Fiji Society* 4: 61–67.

Munro, G. 1945. Tragedy in bird life. *Elepaio* 5(8): 48–51.

Murphy, E.C.; Pickard, C.R. 1990. House mouse. *In*: King, C.M. (ed.) *The Handbook of New Zealand Mammals.* Oxford University Press, Auckland. pp. 225–242.

Neale, T. 1966. *An Island to Oneself*. Collins.

Nellis, D.W.; Everard, C.O.R. 1983. The biology of the mongoose in the Caribbean. *Studies on the fauna of Curacao and other Caribbean Islands* 64: 1–162.

Nelson, E.W. 1922. The land fauna of islands in the Pacific. *The Mid-Pacific Magazine* 23: 233–40.

Niering, W.A. 1956. Bioecology of Kapingamarangi Atoll, Caroline Islands: terrestrial aspects. *Atoll Research Bulletin* 49.

Nuttall, F. 1994. Rats and tourists threaten Bounty's paradise islands. *The Times*, Friday 6 May, p.11.

Olson, S.L. 1986. An early account of some birds from Mauke, Cook Islands, and the origin of the "mysterious starling" *Aplonis mavornata* Buller. *Notornis* 33: 197–208.

Owen, R.P. 1978. Conservation is for everyone. *Micronesian Reporter* 26: 16–20.

Paine, R.W. 1934. Observations on rat damage to coconuts on Taveuni. *Agricultural Journal (Fiji*) 7(1): 26–34.

Parkes, J.P. 1990. Eradication of feral goats on islands and habitat islands. *Journal of the Royal Society of New Zealand* 20: 297–304.

Parkes, J.P. 1990. Feral goat control in New Zealand. *Biological Conservation 54*: 335–348.

Peale, T.R. 1848. *In*: *Mammalia and Ornithology*. Vol. 8 of US Exploring Expedition. Lea and Blanchard, Philadelphia. pp. 47–51.

Pearce, F. 1994. Can poison save Pitcairn petrel? *New Scientist*, 23 July, p.8.

Pernetta, J.C.; Watling, D. 1978. The introduced and native terrestrial vertebrates of Fiji. *Pacific Science* 32: 223–244.

Perry, G. 1998. Brown treesnake update. *Aliens* 8: 6–7.

Poesch, J. 1961. Titian Ramsay Peale and his journals of the Wilkes Expedition, 1799–1885. *American Philosophical Society Memoirs* 52. 214 pp.

Pye, T.; Bonner, W.N. 1980. Feral brown rats, *Rattus norvegicus*, in South Georgia (South Atlantic Ocean). *Journal of Zoology, London* 192: 237–255.

Rauzon, M.J. 1982. Feral cat eradication on Jarvis Island. *Bulletin of the Pacific Seabird Group* 9: 75.

Rauzon, M.J. 1985. Feral cats on Jarvis Island; their effects and their eradication. *Atoll Research Bulletin* 282–292 (282). 32 pp.

Recher, H.F.; Clark, S.S. 1974. A biological survey of Lord Howe Island with recommendations for conservation of the island's wildlife. *Biological Conservation* 6: 263–273.

Reichel, J.D.; Lemke, T.O. 1994. Ecology and extinction of the Mariana mallard. *Journal of Wildlife Management* 58: 199–205.

Revilliod, P. 1913. Les mammifères de la Nouvelle Calédonie et des isles Loyalty. *In*: Sarasin, F. and Rowx, J. *Nova Caledonia, A Zoologie* 1: 341–365.

Rinke, D. 1986. The status of wildlife in Tonga. *Oryx* 20: 146–151.

Rhymer, J.M.; Williams, M.J.; Braun, M.J. 1994. Mitochondrial analysis of gene flow between New Zealand mallards (*Anas platyrhynchos*) and grey ducks (*A. superciliosa*). *Auk* 111: 970–978.

Robertson, H.A.; Hay, J.R.; Saul, E.K.; McCormack, G.V. 1994. Recovery of the kakerori: an endangered forest bird of the Cook Islands. *Conservation Biology* 8: 1078–1086.

Robertson, R. 1877. The Caroline Islands. *Asiatic Society of Japan, Transactions*, 5: 41–63. [Read 1876, published 1877.]

Robinet, O., Craig, J.L., Chardonnet, L. 1998. Impact of rat species in Ouvea and Lifou (Loyalty Islands) and their consequences for conserving the endangered Ouvea Parakeet. *Biological Conservation* 86 (2).

Rodgers, K.A. 1985. An annotated bibliography of the natural history of Tuvalu (Ellice Islands). *Pacific Science* 39(1): 100–130.

Roots, C. 1976. *Animal Invaders.* David and Charles, London.

Rougier, E. 1925. Travelling around Christmas Island. *The Mid-Pacific Magazine* 29: 865–870.

Rowe, F.P. 1967. Notes on rats in the Solomon and Gilbert Islands. *Journal of Mammalogy* 48: 649–50.

Rudge, M.R. 1976. A note on the food of feral pigs (*Sus scrofa*) of Auckland Island. *Proceedings of the New Zealand Ecological Society* 23: 83–84.

Rudge, M.R. 1990. Feral goat. *In*: King, C.M. (ed.) *The Handbook of New Zealand Mammals*. pp. 406–423.

Rudge, M.R.; Smit, T. 1970. Expected rate of increase of hunted populations of feral goats (*Capra hircus* L.) in New Zealand. *New Zealand Journal of Science* 13: 256–259.

Sablan, M.C. 1976. Anatahan. *Micronesian Reporter* 23(1): 37–38.

Sachet, M.H. 1954. A summary of information on Rose Atoll. *Atoll Research Bulletin* 29: 1–25.

Salvat, F.; Salvat, B. 1992. Nukutipipi Atoll, Tuamotu archipelago: Geomorphology, land and marine flora and fauna and interrelationships. *Atoll Research Bulletin* 357.

Saul, E.K.; Robertson, H.A.; Tiraa, A. 1998. Breeding biology of the kakerori (*Pomarea dimidiata*) on Rarotonga, Cook Islands. *Notornis* 45: 255–269.

Savidge, J. A. 1984. Guam: paradise lost for wildlife. *Biological Conservation* 30: 305–317.

Savidge, J.A. 1987. Extinction of an island forest avifauna by an introduced snake. *Ecology* 68: 660–668.

Savidge, J.A.; Sileo, L.; Siegfried, L.M. 1992. Was disease involved in the decimation of Guam's avifauna? *Journal of Wildlife Diseases* 28: 206–214.

Schubel, S.E.; Steadman, D.W. 1989. More bird bones from Polynesian archaeological sites on Henderson Island, Pitcairn Group, South Pacific. *Atoll Research Bulletin* 325.

Seaman, G.A.; Randall, J.E. 1962. The mongoose as a predator in the Virgin Islands. *Journal of Mammalogy* 43: 544–546.

Seitre, R.; Seitre, J. 1992. Causes of land-bird extinctions in French Polynesia. *Oryx* 26: 215–222.

Sincock, J.L.; Swedberg, G.E. 1969. Rediscovery of the nesting grounds of Newell's Manx shearwater (*Puffinus puffinus newellii*) with initial observations. *Condor* 71: 69–71.

Small, V. 1982. Sea turtle nesting at Virgin Islands National Park and Buck Island Reef National Monument, 1980 and 1981. USDI National Park Service, Research Resources Management Report, SER–61, Virgin Islands National Park.

Smith, F.J. 1968. Rat damage to coconuts in the Gilbert and Ellice Islands. *In*: Proceedings – Rodents as factors in disease and economic loss. Institute for Technical Interchanges East-West Center, Honolulu, Hawaii. pp. 55–57.

Smith, F.J. 1969. Atoll rat research. *South Pacific Bulletin* 3: 41–45.

Smith, F.J. 1970. La recherche sur les rats dans les atolls. *Oleagineux* 25(3): 147–152.

Smith, S.P. 1889. Tongarewa, or Penrhyn Island, and its people. *Transactions of the New Zealand Institute* 22: 85.

Snowcraft, P.G. 1983. Tree cover changes in mammane (*Sophora chrysophylla*) forests grazed by sheep and cattle. *Pacific Science* 37: 109–119.

Sparrman, A. 1953. *A Voyage around the World with Captain James Cook in* HMS Resolution. Robert Hale, London.

Spennemann, D.H.R. 1997. Distribution of rat species (*Rattus* spp.) on the atolls of the Marshall Islands: Past and present dispersal. *Atoll Research Bulletin* 446.

Spennemann, D.H.R.; Rapp, G. 1989. Can rats colonise oceanic islands unaided? An assessment and review of the swimming capabilities of the genus *Rattus* (Rodentia: Muridae) with particular reference to tropical waters. *Zoologische Abhandlungen des Museums für Tierkunde Dresden* 45: 81–91.

Spoehr, A. 1957. Marianas prehistory: archaeological survey and excavations on Saipan, Tinian and Rota. *Fieldiana: Anthropology* 48: 1–185.

Stair, J.B. 1897. *Old Samoa, or Flotsam and Jetsam from the Pacific Ocean.* The Religious Tract Society, London. 296 pp.

Steadman, D.W. 1987. Two new species of rails (Aves: Rallidae) from Mangaia, Southern Cook Islands. *Pacific Science* 40(1–4).

Steadman, D.W. 1991. Extinct and extirpated birds from Aitutaki and Atiu, Southern Cook Islands. *Pacific Science* 45(4): 325–347.

Steadman, D.W. 1992. Extinct and extirpated birds from Rota, Mariana Is. *Micronesica* 25: 71–84.

Steadman, D.W.; Intoh, M. 1994. Biogeography and prehistoric exploitation of birds from Fais Island, Yap State, Federated States of Micronesia. *Pacific Science* 48(2): 116–135.

Steadman, D.W.; Olson, S.L. 1985. Bird remains from an archaeological site on Henderson Island, South Pacific: Man-caused extinctions on an "uninhabited" island. *Proceedings of the National Academy of Science, USA* 82: 6191–6195.

Steadman, D.W.; White, J.P.; Allen, J. 1999. Prehistoric birds from New Ireland, Papua New Guinea: Extinctions on a large Melanesian Island. *Proceedings of the National Academy of Science, USA* 96: 2563–2568.

Steadman, D.W.; Zousmer, S. 1988. *Galapagos. Discovery on Darwin's Islands*. Smithsonian Institution Press, Washington DC.

Stoddart, D.L. 1975. Scientific studies in the southern Cook Islands: background and bibliography. *Atoll Research Bulletin* 190: 1–30.

Stoddart, D.R. 1975. Sand cays of Tongatapu. *Atoll Research Bulletin* 181: 1–8.

Stokes, T. 1980. Notes on the landbirds of New Caledonia. *Emu* 80: 81–86.

Stone, C.P. 1984. Alien animals in Hawaii's native ecosystems: towards controlling the adverse effects of introduced vertebrates. *In*: Stone, C.P.; Scott, J.M. (eds) *Hawaii's Terrestrial Ecosystems: Preservation and Management*. Proceedings of a symposium,University of Hawaii, Honolulu, 1984. pp. 251–297.

Storer, T.I. 1962. Pacific island rat ecology: report of a study made on Ponape and adjacent islands 1955–1958. *Bernice P. Bishop Museum Bulletin* 225.

Streck, C.F. 1990. Prehistoric settlement in eastern Micronesia: archaeology on Bikini Atoll, Republic of the Marshall Islands. *Micronesia Supplement* 2: 247–260.

Sykes, W.R. 1992. Botanical observations on Atiu, Cook Islands. *New Zealand Botanical Society Newsletter* 27: 12–16.

Taborsky, M. 1988. Kiwis and dog predation: observations in Waitangi State Forest. *Notornis* 35: 197–202.

Tate, G.G.H. 1935. Rodents of the genera *Rattus* and *Mus* from the Pacific Islands. *Bulletin of American Natural History* 48: 145–178.

Taylor, R.H. 1975. What limits kiore (*Rattus exulans*) distribution in New Zealand? *New Zealand Journal of Zoology* 2: 473–477.

Taylor, R.H. 1979. How the Macquarie Island parakeet became extinct. *New Zealand Journal of Ecology* 2: 42–45.

Thibault, J.-C. 1976. L'avifaune de Tetiaroa (Archipel de la Société, Polynésie Francaise). *l'Oiseau* 46: 31–40.

Thibault, J.-C.; Guyot, I. 1987. Recent changes in the avifauna of Makatea Island (Tuamotus, Central Pacific). *Atoll Research Bulletin* 300.

Thomson, J.P. 1889. The island of Kadavu. *Scottish Geographical Magazine* 5: 638–652.

Thurston, B. 1924. The first crossing of Fiji. *Geographical Journal*, Nov. pp. 394–403.

Tomich, P.Q. 1969. *Mammals in Hawaii: a synopsis and notational bibliography*. Bishop Museum Press, Honolulu.

Tomich, P.Q. 1986. *Mammals in Hawaii.* (2nd edn) Bishop Museum Press, Honolulu.

Tomkins, R.J. 1985. Breeding success and mortality of dark–rumped petrels in the Galapagos, and control of their predators. *ICBP Technical Publication* 3: 159–175.

Towns, D.R. 1991. Response of lizard assemblages in the Mercury Islands, New Zealand, to removal of an introduced rodent: the kiore (*Rattus exulans*). *Journal of the Royal Society of New Zealand* 21: 119–136.

Tudge, C. 1992. Last stand for Society snails. *New Scientist*, 11 July.

Twibell, J. 1973. The ecology of rodents in the Tonga Islands. *Pacific Science* 27: 92–98.

Van Riper, S.G.; van Riper III, C. 1982. *A Field Guide to the Mammals in Hawaii*. Oriental Publishing Co., Honolulu.

Veitch, C.R. 1985. Methods of eradicating feral cats from offshore islands in New Zealand. *In*: Moors, P.J. (ed.) Conservation of Island Birds. *ICBP Technical Publication* 3: 125–141.

Veitch, C.R.; Bell, B.D. 1990 Eradication of introduced animals from the islands of New Zealand. *In*: Towns, D.R.; Daugherty, C.H.; Atkinson, I.A.E. (eds) Ecological Restoration of New Zealand Islands. *Conservation Sciences Publication* 2. Department of Conservation, Wellington. pp. 137–146.

Vickery, J. 1994. The Pitcairn Islands: paradise past, paradise present? *Tree* 9: 316. 9 September. Elsevier Science Ltd.

Villadolid, D.V. 1956. A study of Cotabato rats and their control. *Araneta Journal of Agriculture* 3: 1–45.

Waite, E.R. 1897a. The mammals, reptiles, and fishes of Funafuti. *Australian Museum Memoir* 3(3): 165–201.

Waite, E.R. 1897b. The mammals, reptiles, and fishes of Funafuti. *Australian Museum Memoir* 3(9): 534–546.

Wallace, G.D.; Rosen, L. 1965. Studies on eosinophilic meningitis. *American Journal of Epidemiology* 81(1): 52–62.

Walter, R.; Robins, B. 1974. *A Voyage Round the World in the Years MDCCXL, I, II, III, IV by George Anson.* Oxford University Press, London. 402 pp.

Warner, D.W. 1948. The present status of the kagu, *Rhynochetos jubatus*, on New Caledonia. *Auk* 65: 287–288.

Warshauer, F.R.; Jacobi, J.D. 1982. Distribution and status of *Vicia mensiesii* Spreng. (Leguminosae): Hawaii's first officially listed endangered plant species. *Biological Conservation* 23: 111–126.

Watson, J.S. 1961. Feral rabbit populations on Pacific Islands. *Pacific Science* 15: 591–593.

Westbrooks, R.G. 1998. Proposed national system for early detection, reporting, assessment and eradication of new invasive plants in the United States. *Aliens* 8: 16–18.

Wetmore, A. 1925. Bird life among larva rock and coral sand. *National Geographic Magazine* 48(1): 76–108.

Whistler, W.A. 1983 Vegetation and flora of the Aleipata Islands, Western Samoa. *Pacific Science* 37(3): 227–249.

Whitaker, A.H. 1973. Lizard populations on islands with and without Polynesian rats, *Rattus exulans* (Peale). *Proceedings of the New Zealand Ecological Society* 20: 121–130.

Wilder, G.P. 1934. The flora of Makatea. *Bernice P. Bishop Museum Bulletin* 120.

Wiles, G.J.; Amerson, A.B.; Beck, R.E. 1990. The mammals of Tinian, Mariana Islands. *Micronesica* 23: 167–180.

Wiles, G.J.; Conry, P.J. 1990 Terrestrial vertebrates of the Ngerukewid Islands Wildlife Preserve, Palau Islands. *Micronesica* 23(1): 41–66.

Wilkes, C. 1845. Narrative of the United States Exploring Expedition during the years 1838, 1839, 1840, 1841, 1842, under the command of Charles Wilkes.

Williams, G.R. 1960. The birds of the Pitcairn Islands. *Ibis* 102: 58–70.

Williams, J. 1839. *A Narrative of Missionary Enterprises in the South Seas.* J. Snow, London. 506 pp.

Williams, J.M. 1973. The ecology of *Rattus exulans* (Peale) reviewed. *Pacific Science* 27: 120–127.

Williams, J. M. 1974. The ecology and behaviour of *Rattus* species in relation to the yield of coconuts and cocoa in Fiji. Unpubl. PhD thesis, University of Bath.

Williams, J.M. 1979. Report on the rat situation in Nauru. Unpubl. New Zealand Ministry of Agriculture and Fisheries Report. 9 pp.

Wodzicki, K. 1971. The birds of Niue Island, South Pacific: an annotated checklist. *Notornis* 18: 291–304

Wodzicki, K. 1973. A survey of rats on Atafu Atoll, Tokelau Islands and recommendations for a scheme of control. Unpublished report, for Tokelau Islands Administration.

Wodzicki, K. 1972. Effect of rat damage on coconut production on Nukunonu Atoll, Tokelau Islands. *Oleagineux* 27(6): 309–314.

Wodzicki, K.A. 1950. Introduced mammals of New Zealand. *Department of Scientific and Industrial Research Bulletin* 98. Department of Scientific and Industrial Research, Wellington.

Wolff, T. 1969. The fauna of Rennell and Bellona, Solomon Islands. *Philosophical Transactions of the Royal Society* B255: 321–343.

Woodford, C.M. 1890. Further explorations in the Solomon Islands. *Royal Geographical Society Proceedings* 12: 393–419.

Woodford, C.M. 1895. The Gilbert Islands. *Geographical Journal* 6: 325–350.

Woodward, P.W. 1972. The natural history of Kure Atoll, north–western Hawaiian Islands. *Atoll Research Bulletin* 164: 1–318.

Worthy, T.H.; Anderson, A.J.; Molnar, R.E. 1999. Megafaunalexpression in a land without mammals – the first fossil faunas from terrestrial deposits in Fiji. *Senckenbergiana Biologica* 79: 237–242.

Worthy, T.H.; Walter, R.; Anderson, A.J. 1998. Fossil and archaeological avifauna of Niue Island, Pacific Ocean. *Notornis* 45: 177–190.

Yosida, T.H. 1980. *Cytogenetics of the Black Rat: karyotype evolution and species differentiation*. University of Tokyo Press.

Zuy, G.R.; Springer, V.G.; Williams, J.T.; Johnson, G.D. 1988. The vertebrates of Rotuma and surrounding waters. *Atoll Research Bulletin* 316: 1–25.

# Preliminary review of the invasive plants in the Pacific islands (SPREP Member Countries)

**Jean-Yves Meyer**

***Délégation à la Recherche, BP 20981 Papeete, Tahiti, French Polynesia***

## Abstract

This report lists and characterises more than 30 alien invasive plant species that are considered by local and academic experts to have become serious threats to the native habitats of the Pacific islands. SPREP member countries except for those considered to be continents or large continental islands and those for which too little information was available have been reviewed. Among the most significant invasive taxa found in most of these islands are the trees *Adenanthera pavonina*, *Leucaena leucocephala*, *Psidium* spp. (*P. cattleianum* and *P. guajava*), *Spathodea campanulata* and *Syzygium* spp. (mainly *S. cumini* and *S. jambos*); the thorny shrubs *Lantana camara*, *Mimosa invisa*, and *Rubus spp.* (mainly *R. moluccanus* and *R. rosifolius*); the ornamental shrubs *Clerodendrum* spp. and erect herbs *Hedychium* spp.; the climbing vines *Merremia peltata*, *Mikania micrantha*, and *Passiflora* spp.; the grasses *Panicum* spp. (*P. maximum* and *P. repens*), *Paspalum* spp. (especially *P. conjugatum*), and *Pennisetum* spp. (mainly *P. polystachyon* and *P. purpureum*); the creeping herb *Wedelia (Sphagneticola) trilobata*; and the aquatic plant *Eichhornia crassipes*. Special attention is given to alien plant species which are able to penetrate montane rainforests in several islands, such as the shrubs *Clidemia hirta* and *Cestrum* spp., and to very aggressive species found only in one or a few islands and which have not been introduced to the other Pacific islands yet. These include *Castilloa elastica* in the Samoas, *Cordia alliodora* in Vanuatu, *Miconia calvescens* in French Polynesia and Hawaii, *Myrica faya* in Hawaii, *Piper aduncum* in Fiji, and *Timonius timon* in Palau. Among the 30 and more potential invasive plants in the Pacific islands, sometimes locally naturalised but not widespread yet, are *Cryptostegia grandiflora*, *Chrysobalanus icaco*, *Cinchona pubescens*, *Cinnamomum* spp., *Ligustrum* spp., *Solanum mauritianum*, and *Thunbergia grandiflora*, which are known to be serious invaders in other islands (Galapagos, Mascarenes, Mayotte, New Zealand, St Helena, Seychelles) or tropical countries (Australia, Florida, South Africa, Singapore).

Manuscript received December 1999

## Résumé

Ce rapport fait la liste et caractérise plus de 30 espèces végétales introduites envahissantes qui sont considérées par des experts locaux et académiques comme étant devenues des menaces sérieuses pour les milieux naturels des îles du Pacifique. Quelques pays membres du programme régional océanien de l'environnement (PROE) ont été étudiées. Parmi les taxons envahissants les plus significatifs dans la plupart des îles étudiées figurent les arbres *Adenanthera pavonina*, *Leucaena leucocephala*, *Psidium* spp. (*P. cattleianum* et *P. guajava*), *Spathodea campanulata* et *Syzygium* spp. (principalement *S. cumini* et *S. jambos*); les arbustes épineux *Lantana camara*, *Mimosa invisa* et *Rubus* spp. (principalement *R. moluccanus* et *R. rosifolius*); les arbustes ornementaux *Clerodendrum* spp. et les grandes herbacées *Hedychium* spp.; les lianes grimpantes *Mikania micrantha*, *Merremia peltata* et *Passiflora* spp.; les graminées *Panicum* spp. (*P. maximum* et *P. repens*), *Paspalum* spp. (en particulier *P. conjugatum*) et *Pennisetum* spp. (principalement *P. polystachyon* et *P. purpureum*); l'herbacée rampante *Wedelia (Sphagneticola) trilobata*; et la plante aquatique *Eichhornia crassipes*. Une attention particulière est portée aux plantes capable de pénétrer les forêts humides de montagne dans plusieurs îles comme les arbustes *Clidemia hirta* et *Cestrum* spp., ainsi qu'aux espèces particulièrement aggressives trouvées dans une ou quelques îles et qui n'ont pas encore été introduites dans les autres îles du Pacifique. Elles inclues *Castilloa elastica* aux îles Samoas, *Cordia alliodora* au Vanuatu, *Miconia calvescens* en Polynésie française et à Hawaii, *Myrica faya* à Hawaii, *Piper aduncum* à Fidji, et *Timonius timon* à Palau. Parmi plus de 30 plantes envahissantes potentielles dans les îles du Pacifique, parfois naturalisées localement mais pas encore largement répandues, figurent *Cryptostegia grandiflora*, *Chrysobalanus icaco*, *Cinnamomum* spp., *Cinchona pubescens*, *Ligustrum* spp., *Thunbergia grandiflora*, et *Solanum mauritianum*, qui sont connues pour être des envahisseurs dans d'autres îles (Galàpagos,

Mascareignes, Mayotte, Nouvelle-Zélande, St Hélène, Seychelles) ou pays tropicaux (Afrique du Sud, Australie, Floride, Singapour).

### Foreword

With 22 SPREP member countries formed by several hundreds of islands, scattered on the largest ocean on Earth, grouped in three different ethnological and biogeographical regions (Melanesia, Micronesia and Polynesia), conducting this review was not an easy task. The difficulty of a plant-related review in the Pacific Islands is enhanced by the extraordinary diversity of types of island or group of islands (see e.g. Nunn 1994; Mueller-Dombois and Fosberg 1998): some are oceanic, others are semi-continental or continental; some are disposed in linear groups, others are clustered, or isolated; some are atolls and low limestone islands, other are raised atolls (elevated limestone islands, or makatea islands), or high volcanic islands with rugged relief and great heterogeneity of ecological conditions. Indeed, it is scientifically accepted that invasion processes and successes are not only related to the life-history traits of the invader ("its agressiveness") but also to the nature of the invaded habitat, including its native biota ("its susceptibility to invasion").

## 1. Introduction

This review is the first compiling botanical and ecological data on the current invasive plant species in the Pacific islands (SPREP member countries). The data presented here are based on existing published literature, on recent personal communications of local and academic experts, and on personal observations conducted during the last few years in some Pacific islands during field trips (especially on French Polynesia, Hawaii, Cook Islands, Pohnpei, and Fiji). Numerous reviews have been conducted on ***weeds*** in the Pacific islands (see e.g. Whistler 1983, 1995; Waterhouse 1997; Swarbrick 1997), but none of them deals with invasive plants in natural ecosystems. Although lists of invasive plants in some Pacific islands or groups of islands have been drawn up in past or present research and management studies (e.g. Stone et al. 1992 in Hawaii; Meyer 1998 in French Polynesia; Space and Falanruw 1999 in Micronesia; Owen 1997 in New Zealand), the knowledge of invasive plants in the great majority of the other islands in the region is sparse if not completely non-existent. Thus, the main aim of this review was to set up preliminary lists of the dominant, moderate and potential plant invaders in the Pacific islands supplemented by available botanical and ecological data. The voluntary collaboration of local and/or academic experts consulted for this review was essential, as it was not possible to visit each island country in the time available. Although most of these experts are not invasive plant specialists, taxonomists or botanists but rather ethnobotanists, biogeographers, foresters, conservationists or naturalists with good field experience, their contribution was highly valuable. The lists presented here are of course not exhaustive nor definitive. They may serve as a technical information document and an indispensable working tool for further research studies and management plans in Pacific island countries.

### 1.1 Definitions

This review deals with invasive plants (or plant invaders), as defined by the five following criteria in the scientific literature (see *e.g.* McDonald et al. 1989; Cronk and Fuller 1995; Pysek 1995): (1) they are ***alien*** (or non-native, or non-indigenous, or exotic) species; (2) ***introduced*** intentionally or accidentally, usually by humans (sometimes by wind, water, birds, mammals) in an area where they have never occurred (or evolved) before; (3) ***naturalised*** (or established) in that area, which means that they are able to reproduce sexually or vegetatively without human assistance (or capable to build self-sustaining populations); (4) they are ***expanding their distribution*** and/or ***increasing their abundance***; (5) they are ***occurring in natural*** (or native, or primary, or undisturbed) ***and semi-natural habitats*** (restored habitats and secondary habitats, or partially disturbed areas such as forest trails, gaps and edges); and, last but not least, (6) they are showing ***significant ecological impacts***, often irreversible.

These ecological changes could be on the composition, the structure or the ecosystem processes:

- increased dominance (formation of monotypic stands),
- decreased overall species richness,
- decreased structural diversity,
- decreased spatial heterogeneity,
- competition with native species,
- replacement (or displacement) of native plant and animal species leading to extirpation (loss of one or several populations) or even extinction (loss of all populations),
- change in the ecosystem-level processes: alteration of the water or fire regime, changes in the light quantity and quality, changes in the nutrient cycling pattern, removal of food sources.

### 1.2 Important remarks

In this review we consider that native (or indigenous) species which show an increase in their distribution and/or their abundance during primary succession or secondary succession (following natural or man-induced disturbances) are not considered as plant invaders but as aggressive ***colonisers***.

Alien species which are not naturalised (most garden ornamental, food plants and tree crops), or which are naturalised but not increasing their distribution and/or abundance (or ***sub-spontaneous plants*** such as garden escapes and some cultivated plants) are not considered to be invaders but could be potential (or incipient) invaders if they are known to be invasive in other tropical countries or islands. Indeed, if a plant species has a history of successes in invading specific areas, it is more likely to invade other suitable areas.

Although it is difficult to generalise and make predictions on the invasiveness of a plant species, the following natural history life traits (or biological characteristics) are found in many aggressive invaders:

- rapid growth rate,
- early sexual maturity,
- high reproductive capacity,
- effective dispersal (e.g. fleshy fruits dispersed by frugivorous birds, winged seeds dispersed by wind),
- large soil seed bank,
- long seed persistence in soil,
- tolerance to a wide range of ecological conditions, especially for germination and growth.

A "good invader" can display all these characteristics or only a few of them.

***Weeds*** **(**or ***ruderals*****)** which thrive only in disturbed human-made (or unnatural, or human-transformed, or anthropogenic) habitats such as roadsides, dwellings, waste places, village periphery, trails, pastures, agricultural or forested areas, are not included in this review, except when they show a tendency to invade semi-natural and natural habitats. Some invasive plants can also be weeds, and some weeds can invade natural habitats.

Popular terms such as ***plant pests, noxious plants, harmful plant species*** are not used in this review, as they can be applied to both weeds and invasive plants.

## 2. Method

Altogether 16 Pacific islands or groups of islands among the 22 SPREP member countries have been surveyed in this review. Hawaii, a State of the USA, which is one of the four developed nations that are members of SPREP (along with Australia, France, and New Zealand), has been included, as it constitutes an exemplary case for the occurrence and impact of invasive plants in an island ecosystem of the Pacific region.

Papua New Guinea, the Solomon Islands, and New Zealand, which are also SPREP members, have not been included, as they are considered as continent or large continental islands. Because of their large size and high biodiversity, they certainly deserve their own treatment.

Because of the lack of available published data and to the impossibility of contacting academic/local experts, the atolls and table reefs of Kiribati (Micronesia), the Marshall Islands (Micronesia), Tokelau (Polynesia), and Tuvalu (Melanesia) have not been considered in this review.

Political boundaries are used in this review rather than the affiliation to the three main biogeographical regions (Melanesia, Micronesia and Polynesia). The islands are cited by alphabetical order of the country/nation name: Cook Islands (Polynesia), Federated States of Micronesia (Micronesia), Fiji (Melanesia), French Polynesia (Polynesia), Guam (Micronesia), Nauru (Micronesia), New Caledonia (Melanesia), Niue (Polynesia), Northern Mariana Islands (Micronesia), Palau (Micronesia), Pitcairn (Polynesia), Samoas (American Samoa and Samoa) (Polynesia), Tonga (Polynesia), Vanuatu (Melanesia), Wallis and Futuna (Polynesia).

Three categories of invaders have been qualitatively (and subjectively) defined:

- the ***dominant, D,*** **(**or major**)** invaders are those considered to be the most important threat to biodiversity because they are very widespread and/or they form dense stands, causing severe impacts on native biota;
- the ***moderate, M,*** invaders are those considered to be of secondary importance at present, although some of them could become dominant in the future;
- the ***potential*** invaders are naturalised alien plants which are not considered as invaders yet, but are known to be highly invasive elsewhere and/or are showing signs of extension (species which are in an early stage of invasion).

Habitat (or vegetation, or plant community) type and elevation range is given when this information is available, as well as some relevant locations (a particular island or archipelago for Pacific countries composed of several islands or several archipelagos, or a specific conservation area).

Habitat description varies according to various authors and to the islands considered (see e.g. Bailey et al. 1991; Dahl 1980; Schmid 1989). The classification system commonly defines vegetation types in terms of physiognomy (structure and stature of the vegetation: grassland v. shrubland v. forest); species composition (emphasising the dominant species, e.g. a *Metrosideros* forest); topographic position (upland v. lowland, leeward v. windward, volcanic v. calcareous soils); and climatic conditions (dry v. mesic v. wet). In addition, classes can be identified by the degree of human disturbance from completely altered areas to partially disturbed natural vegetation.

The main vegetation units used in this review are based on the most recent book on the vegetation of the Pacific islands by Mueller-Dombois and Fosberg (1998):

- coastal (or strand, or littoral) vegetation,
- mangrove forest,
- lowland dry forest,
- inland mesic (or mesophytic, or moist) forest,
- upland wet (or rain) forest, and
- montane cloud forest (or mossy forest, or elfin forest) which can be viewed as biodiversity hotspots and refugia for endemic species.

The cloud forests, in addition to their biodiversity value, are the principal watersheds of Pacific high oceanic islands. For both these reasons, their protection, conservation and active management should be given a very high priority within the Pacific region (Merlin and Juvic 1995). Subalpine and alpine forests, and montane bogs have not been considered in this review, as they occur above 2500 m elevation and are found only in Hawaii and New Zealand. Fernlands and grasslands are usually found on disturbed dry or mesic slopes (human or natural disturbances).

Habit is defined when needed (aquatic plants are rooted, floating or emergent in aquatic situations – wetlands, lakes and rivers; terrestrial plants are species rooted in soil). Life (or growth) forms are:

- herbs, defined as plants with little or no woody growth; among the herbs, we have distinguished ferns (Pteridophytes) from grasses (Gramineae), and sedges (Cyperaceae) – erect or tall herbs (ferns, grasses, or sedges) are above 1 m in height;
- shrubs are woody plants with several stems, usually shorter than trees;
- trees are woody plants with generally one major trunk; small trees are less than 10 m tall and large trees above 10 m tall; we have also distinguished palms (Palmae) and tree ferns (Cyatheaceae);
- vines are woody or non woody plants which can not stand free by themselves;
- succulents are xerophytic plants with fleshy or succulent stems (Agavaceae, Crassulaceae, Cactaceae).

As the scientific name of a genus or plant species may change, the most common synonym is indicated in brackets. The genus and family names are chosen according to Mabberley (1997). For instance, the botanical genus Palmae is used rather than Arecaceae, Compositae rather than Asteraceae, Leguminosae rather than Fabaceae and Caesalpiniaceae.

The common names are the English names commonly used worldwide (see e.g. Mabberley 1997), rather than local (island) names.

# 3. Results

## Cook Islands

### *Preliminary list of invasive plants*

| Scientific name (Family name) | Common name(s) | Habit/ Life form | Habitat (and Locations) |
|---|---|---|---|
| **Dominant invaders** | | | |
| *Ardisia elliptica (humilis)* (Myrsinaceae) | Shoebutton ardisia | shrub | Lowland (Rarotonga) |
| *Cardiospermum grandiflorum* (Sapindaceae) | Balloon vine, Heartseed | vine | Inland (Rarotonga) |
| *Cecropia obtusifolia* (Cecropiaceae) | Trumpet tree | tree | Inland forest (Rarotonga) |
| *Cestrum nocturnum* (Solanaceae) | Night cestrum, Night-blooming jasmine | shrub | Lowland (Rarotonga) |
| *Hedychium coronarium* (Zingiberaceae) | White ginger | erect herb | Inland (Rarotonga) |
| *Lantana camara* (Verbenaceae) | Lantana | thorny shrub | (Rarotonga) |
| *Leucaena leucocephala* (Leguminosae) | Wild tamarind, Lead tree | small tree | (Rarotonga) |
| *Merremia peltata* (Convolvulaceae) | Merremia | vine | (Rarotonga) |

| Scientific name (Family name) | Common name(s) | Habit/ Life form | Habitat (and Locations) |
|---|---|---|---|
| **Dominant invaders** | | | |
| *Mikania micrantha* (Compositae) | Mile-a-minute | vine | (Rarotonga) |
| *Passiflora rubra* (Passifloraceae) | Red passionfruit | vine | |
| *Psidium cattleianum* (Myrtaceae) | Strawberry/Chinese guava | tree | Inland forest (Rarotonga) |
| *Spathodea campanulata* (Bignoniaceae) | African tulip tree | large tree | (Rarotonga) |
| **Moderate invaders** | | | |
| *Cinnamomum verum (zeylanicum)* (Lauraceae) | Cinnamon tree | tree | Inland forest (Rarotonga) |
| *Coffea arabica* (Rubiaceae) | Arabica coffee | small tree | (Rarotonga) |
| *Eichhornia crassipes* (Pontederiaceae) | Water hyacinth | aquatic herb | (Rarotonga) |
| *Flacourtia rukam* (Flacourtiaceae) | Indian/Governor's plum | tree | Inland forest (Rarotonga) |
| *Paraserianthes (Albizia) falcataria* (Leguminosae) | Molucca albizia | large tree | (Rarotonga) |
| *Paspalum conjugatum* (Gramineae) | T-grass, Sour paspalum | grass | (Rarotonga) |
| *Passiflora maliformis* (Passifloraceae) | Hard-shelled passionfruit | vine | (Rarotonga) |
| *Psidium guajava* (Myrtaceae) | Common guava | tree | (Rarotonga, Mangaia) |
| *Solanum mauritianum* (Solanaceae) | Wild tobacco, | shrub | (Rarotonga) |
| *Syzygium (Eugenia) cumini* (Myrtaceae) | Java plum, Jambolan | large tree | Inland forest (Rarotonga) |
| *Syzygium (Eugenia) jambos* (Myrtaceae) | Rose apple<br>Woolly nightshade | tree | (Rarotonga) |
| *Tecoma stans* (Bignoniaceae) | Yellow bells, Yellow elder | small tree | (Rarotonga) |
| **Potential invaders** | | | |
| *Acacia farnesiana* (Leguminosae) | Ellington's curse, Cassie | thorny shrub | (Rarotonga) |
| *Clerodendrum chinense (philippinum)* (Verbenaceae) | Honolulu rose, Glory bower | shrub | (Rarotonga) |
| *Eugenia uniflora* (Myrtaceae) | Surinam cherry | small tree | (Rarotonga) |
| *Hedychium flavescens* (Zingiberaceae) | Yellow ginger | erect herb | (Rarotonga) |
| *Fucraea foetida* (Agavaceae) | Mauritian hemp | succulent | Lowland (Rarotonga) |
| *Jacobinia carnea* (Acanthaceae) | Pink plume-flower | shrub | Lowland (Rarotonga) |
| *Melia azedarach* (Meliaceae) | China berry, Pride of India | tree | (Rarotonga) |
| *Odontonema tubiforme (strictum)* (Acanthaceae) | Fire spike, Cardinal flower | shrub | Lowland (Rarotonga) |
| *Passiflora quadrangularis* (Passifloraceae) | Giant granadilla | vine | (Rarotonga) |
| *Sanchezia speciosa (nobilis)* (Acanthaceae) | Sanchezia | shrub | Lowland (Rarotonga) |
| *Schefflera (Brassaia) actinophylla* (Araliaceae) | Octopus/Umbrella tree | tree | (Rarotonga) |
| **Schinus molle* (Anacardiaceae) | Pepper tree, California pepper | tree | (Rarotonga) |

* present according to literature (Wilder 1931) but not verified by local expert (pers. comm. 9 June 1999)

## *Main references*


Cheeseman, T.F. 1903. The flora of Rarotonga, the chief island of the Cook Group. *Transactions Linnaean Society London, Botanical Series* 2(6): 216–313.

McCormack, G.; Künzle, J. 1995. *Rarotonga's Mountain Tracks and Plants. A Field Guide*. Cook Island Natural Heritage Project, Rarotonga.

Merlin, M.D. 1985. Woody vegetation in the upland region of Rarotonga, Cook Islands. *Pacific Science* 39(1): 81–99.

Merlin, M.D. 1991. Woody vegetation on the raised coral limestone of Mangaia, Southern Cook Islands. *Pacific Science* 45(2): 131–151.

Philipson, W.R. 1971. Floristics of Rarotonga. *Bulletin of the Royal Society of New Zealand* 8: 49–54.

Wilder, G.P. 1931. Flora of Rarotonga. *Bernice P. Bishop Museum Bulletin 86*.


## *Academic/local experts consulted*

Gerald McCormack, Director, Cook Islands Natural Heritage Project, PO Box 781, Rarotonga, Cook Islands.

Dr Mark Merlin, Professor, Biology Program, University of Hawaii at Manoa , Dean Hall, Room 2, Honolulu, Hawaii 96822.

Edward Saul, Technical Adviser, Takitumu Conservation Area, PO Box 3036, Rarotonga, Cook Islands.

## Federated States of Micronesia

### *Preliminary list of invasive plants*

| Scientific name (Family name) | Common name(s) | Habit/ Life form | Habitat (and Locations) |
|---|---|---|---|
| **Dominant invaders** | | | |
| *Adenanthera pavonina* (Leguminosae) | Red bead tree, Red sandalwood | tree | Secondary + primary forest (Pohnpei, Kosrae, Yap) |
| *Chromolaena (Eupatorium) odorata* (Compositae) | Siam weed, triffid weed | herb | (Kosrae, Pohnpei, Yap) |
| *Clerodendrum paniculatum* (Verbenaceae) | Pagoda flower | shrub | (Pohnpei, Yap) |
| *Clerodendrum quadriloculare* (Verbenaceae) | Bronze-leaved clerodendrum | shrub | (Pohnpei) |
| *Eichhornia crassipes* (Pontederiaceae) | Water hyacinth | aquatic herb | Wetlands (Pohnpei) |
| *Elaeis guineensis* (Palmae) | African oil palm | tree | (Pohnpei) |
| *Imperata cylindrica* (Gramineae) | Cogon/Cotton grass | grass | (Yap) |
| *Ischaemum polystachyum* var. *chordatum* (Gramineae) | | grass | Grassland (Pohnpei, Yap) |
| *Lantana camara* (Verbenaceae) | Lantana | thorny shrub | (Kosrae, Pohnpei, Yap) |
| *Leucaena leucocephala* (Leguminosae) | Wild tamarind, Lead tree | small tree | (Kosrae, Pohnpei, Yap) |
| *Merremia peltata* (Convolvulaceae) | Merremia | vine | (Kosrae, Pohnpei, Yap) |
| *Mimosa invisa* (Leguminosae) | Giant sensitive plant, Spiny mimosa | thorny shrub | (Pohnpei, Yap) |
| *Paspalum conjugatum* (Gramineae) | T-grass, Sour paspalum | grass | (Kosrae, Pohnpei, Yap) |
| *Paspalum distichum* (Gramineae) | | grass | (Kosrae, Pohnpei, Yap) |
| *Paraserianthes (Albizia) falcataria* (Leguminosae) | Molucca albizia | large tree | (Pohnpei, Yap) |
| *Pennisetum purpureum* (Gramineae) | Elephant grass, Napier grass | grass | (Kosrae, Yap) |
| *Rubus moluccanus* (Rosaceae) | Wild raspberry, Molucca bramble | spiny shrub | (Kosrae) |
| *Wedelia (Sphagneticola) trilobata* (Compositae) | Wedelia, Singapore daisy | herb | (Kosrae, Pohnpei, Yap) |
| **Moderate invaders** | | | |
| *Albizia lebbeck* (Leguminosae) | Siris tree, Indian siris | large tree | (Pohnpei, Yap,) |
| *Hedychium coronarium* (Zingiberaceae) | White ginger | erect herb | (Pohnpei, Kosrae, Yap) |
| *Pangium edule* (Flacourtiaceae) | - | large tree | Secondary forest (Pohnpei, Yap) |
| *Passiflora foetida* (Passifloraceae) | Stinking passionflower | vine | Secondary forest (Pohnpei, Yap) |
| *Schefflera (Brassaia) actinophylla* (Araliaceae) | Octopus/Umbrella tree | tree | (Pohnpei) |
| *Stachytarpheta jamaicensis* (Verbenaceae) | Jamaica vervain | herb | (Pohnpei, Kosrae,Yap) |
| *Stachytarpheta urticifolia* (Verbenaceae) | Blue rat's tail, Dark blue snake weed | herb | (Yap) |
| **Potential invaders** | | | |
| *Acacia auriculiformis* (Leguminosae) | | tree | (Kosrae, Pohnpei, Yap) |
| *Acacia confusa* (Leguminosae) | | tree | (Pohnpei, Yap) |
| *Antigonon leptotus* (Polygonaceae) | Mexican creeper, Chain of love | vine | (Pohnpei, Yap) |
| *Cedrela odorata* (Meliaceae) | Mexican/West Indies cedar | tree | (Yap) |
| *Cinnamomum verum (zeylanicum)* (Lauraceae) | Cinnamon tree | tree | (Pohnpei) |
| *Clitoria ternatea* (Leguminosae) | Butterfly pea, Blue pea | vine | (Pohnpei) |
| *Coccinea grandis* (Cucurbitaceae) | Ivy gourd, Scarlet gourd | vine | (Pohnpei) |
| *Costus sericeus (speciosus)* (Zingiberaceae) | Crape ginger, Malay ginger | herb | (Kosrae, Pohnpei, Yap) |
| *Melaleuca quinquenervia (leucadendra)* (Myrtaceae) | Paperbark | tree | (Pohnpei, Yap) |
| *Psidium cattleianum* (Myrtaceae) | Strawberry/Chinese guava | small tree | (Pohnpei) |
| *Spathodea campanulata* (Bignoniaceae) | African tulip tree | large tree | (Pohnpei) |
| *Syzygium (Eugenia) jambos* (Myrtaceae) | Rose apple | tree | (Pohnpei) |
| *Tecoma stans* (Bignoniaceae) | Yellow elder, Yellow bells | small tree | (Pohnpei) |

### *Main references*


Falanruw, M.C.; Whitesell, G.D.; Cole, T.G.; McLean, C.D.; Ambacher, A.H. 1987. Vegetation survey of Yap, Federated States of Micronesia. *Pacific Southwest Forest and Range Experiment Station, Forest Service, USDA, Resource Bulletin* PSW 21.

Fosberg, F.R.; Sachet, M.-H. 1980. Flora of Micronesia, 4: Caprifoliaceae-Compositae. *Smithsonian Contributions to Botany* 46.

Glassman, S.F. 1952. The flora of Ponape. *Bernice P. Bishop Museum Bulletin* 209.

McLean, C.D.; Cole, T.G.; Whitesell, G.D.; Falanruw, M.C.; Ambacher, A.H. 1986. Vegetation survey of Pohnpei, Federated States of Micronesia. *Pacific Southwest Forest and Range Experiment Station, Forest Service, USDA, Resource Bulletin* PSW-18.

Maxwell, B.D. 1982. Floristic description of native upland forests on Kosrae, Eastern Caroline Islands. *Micronesica* 18: 110–120

Merlin, M.; Jano, D.; Raynor, W.; Keene, T.; Juvik, J.; Sebastian, B. 1992. Tuhke en Pohnpei. *Plants of Pohnpei*. East-West Center, Honolulu.

Merlin, M.; Taulung, R.; Juvik, J. 1993. Sahk Kap Ac Kain In Acn Kosrae. *Plants and Environments of Kosrae*. East-West Center, Honolulu.

Merlin, M.; Juvik, J. 1996. Ira me Neeniier non Chuuk. *Plants and their Environment in Chuk.* East-West Center/National Park Service, USDA, University of Hawaii.

Meyer, J.-Y. 1997. Non exhaustive list of present and potential (incipient) invasive plants in the island of Pohnpei (Ponape), Micronesia. Sixth South Pacific Conference on Nature Conservation and Protected Areas, Pohnpei, 1997. (Unpublished note.)

Raynor, B. 1999. Invasive plant species database for Pohnpei. *Pacific Islands Forests and Trees* 2/99: 6.

Space, J.; Falanruw, M.C. 1999. Observations on invasive plant species in Micronesia. Ms prepared for meeting of Pacific Island Committee Council of Western States Foresters, Majuro, Marshall Islands.

Whitesell, G.D.; McLean, C.D.; Falanruw, M.C.; Cole, T.G.; Ambacher, A.H. 1986. Vegetation survey of Kosrae, Federated States of Micronesia. *Pacific Southwest Forest and Range Experiment Station, Forest Service, USDA, Resource Bulletin PSW-17*.


### *Academic/local experts consulted*

Dr Jim Juvik, Professor, Social Sciences/Geography & Environmental Studies, University of Hawaii at Hilo, 200 W. Kawili Street, Hilo, Hawaii 96720-4091.

Dr Tim Flynn; Dr David H. Lorence, National Tropical Botanical Garden, 3530 Papalina Road, Kalaheo, Kaua‘i, Hawaii 96741.

Bill Raynor, The Nature Conservancy, Pohnpei Field Office, PO Box 216, Kolonia, Pohnpei, FSM 96941, Federated States of Micronesia.

Jim Space, Project Manager, Pacific Island Ecosystem at Risk Project (PIER), 11007 E. Regal Dr., Sun Lakes, Arizona 85248-7919, USA.

## Fiji

### *Preliminary list of invasive plants*

| Scientific name (Family name) | Common name(s) | Habit/ Life form | Habitat (and Locations) |
|---|---|---|---|
| **Dominant invaders** | | | |
| *Annona glabra* (Annonaceae) | Pond/Alligator apple | small tree | Mangrove |
| **Clidemia hirta* (Melastomataceae) | Koster's curse | shrub | Mesic/Wet |
| **Eichhornia crassipes* (Pontederiaceae) | Water hyacinth | aquatic herb | Wetlands |
| *Hydrilla verticillata* (Hydrocharitaceae) | | aquatic herb | Wetlands |
| **Lantana camara* (Verbenaceae) | Lantana | thorny shrub | Dry/Mesic |
| *Leucaena leucocephala* (Leguminosae) | Wild tamarind, Lead tree | small tree | Dry 0–800 m |
| *Merremia peltata* (Convolvulaceae) | Merremia | vine | Dry/Mesic |
| *Mikania micrantha* (Compositae) | Mile-a-minute | vine | Dry/Mesic 0–800 m |
| *Pennisetum polystachyon* (Gramineae) | Mission grass | grass | 0–400 m |
| *Piper aduncum* (Piperaceae) | - | shrub | 0–1000 m |
| *Rubus moluccanus* (Rosaceae) | Wild raspberry | spiny shrub | Mesic/Wet |
| *Spathodea campanulata* (Bignoniaceae) | African tulip tree | large tree | Mesic |
| *Wedelia (Sphagneticola) trilobata* (Compositae) | Wedelia, Singapore daisy | herb | Dry/Mesic |
| **Moderate invaders** | | | |
| *Albizia (Samanea) saman* (Leguminosae) | Rain tree, Monkey pod | large tree | Dry |
| *Arundo donax* (Gramineae) | Giant reed | tall grass | Dry/Mesic |
| *Chrysobalanus icaco* (Chrysobalanaceae) | Coco plum, Icaco | shrub | Mangrove |
| *Citharexylum spinosum* (Verbenaceae) | Fiddlewood | tree | |
| *Clerodendrum chinense (philippinum)* (Verbenaceae) | Honolulu rose | shrub | 0–900 m |

| Scientific name (Family name) | Common name(s) | Habit/ Life form | Habitat (and Locations) |
|---|---|---|---|
| **Moderate invaders** | | | |
| *Cyperus rotundus* (Cyperaceae) | Nut-grass, Coco grass | sedge | |
| *Hedychium coronarium* (Zingiberaceae) | White ginger | erect herb | Mesic/Wet |
| *Hedychium flavescens* (Zingiberaceae) | Yellow ginger | erect herb | Mesic/Wet |
| *Kyllinga polyphylla* (Cyperaceae) | Navua sedge | sedge | Mesic/Wet |
| *Mimosa invisa* (Leguminosae) | Giant sensitive plant, Spiny mimosa | thorny shrub | Dry/Mesic |
| **Opuntia vulgaris* (Cactaceae) | Prickly pear | succulent | Dry |
| *Passiflora foetida* (Passifloraceae) | Stinking passionflower | vine | Mesic |
| ***Psidium guajava* (Myrtaceae) | Common guava | tree | Dry/Mesic |
| **Solanum torvum* (Solanaceae) | Prickly solanum | herb | 0–900 m |
| *Stachytarpheta urticifolia* (Verbenaceae) | Blue rat's tail, Dark blue snakeweed | herb | 0–850 m |
| **Urena lobata* (Malvaceae) | Hibiscus bur | herb | Mesic/Wet |
| *Zizyphus mauritiana* (Rhamnaceae) | Indian jujube | thorny tree | Dry |
| **Potential invaders** | | | |
| *Acacia farnesiana* (Leguminosae) | Ellington's curse, Cassie | shrub | |
| *Agave sisalana* (Agavaceae) | Sisal hemp, Sisal, Bahama hemp | succulent | |
| *Allamanda cathartica* (Apocynaceae) | Allamanda | vine | |
| *Antigonon leptotus* (Polygonaceae) | Mexican creeper, Chain of love | vine | |
| *Ardisia crispa* (Myrsinaceae) | Australian holly | shrub | |
| *Calliandra surinamensis* (Leguminosae) | - | tree | |
| *Clerodendrum paniculatum* (Verbenaceae) | Pagoda flower | shrub | |
| *Coccinia grandis* (Cucurbitaceae) | Ivy gourd | vine | |
| *Costus sericeus (speciosus)* (Zingiberaceae) | Cape ginger | herb | |
| *Cryptostegia grandiflora* (Asclepiadaceae) | Rubber vine | vine | |
| *Dissotis rotundifolia* (Melastomataceae) | - | herb | |
| *Hemigraphis alternatus* (Acanthaceae) | - | herb | |
| *Lonicera japonica* (Caprifoliaceae) | Japanese honeysuckle | vine | |
| *Melia azedarach* (Meliaceae) | Pride of India, China berry, Persian lilac | tree | |
| *Merremia tuberosa* (Convolvulaceae) | - | vine | |
| *Odontonema tubiforme (strictum)* (Acanthaceae) | Fire spike, Cardinal flower | shrub | |
| *Pseuderanthemum bicolor* (Acanthaceae) | - | shrub | |
| *Psidium cattleianum* (Myrtaceae) | Strawberry/Chinese guava | tree | |
| *Thunbergia grandiflora* (Acanthaceae) | Bengal trumpet, Blue trumpet vine | vine | |
| *Sanchezia nobilis (speciosa)* (Acanthaceae) | Sanchezia | shrub | |
| *Schefflera (Brassaia) actinophylla* (Araliaceae) | Octopus/Umbrella tree | tree | |
| *Tithonia diversifolia* (Compositae) | Mexican sunflower, Tree marigold | shrub | |

* declared a noxious weed (Mune and Parham 1956)

** in the process of being taken off the list of noxious weeds, according to local expert (pers. comm. 17 June 1999)

## *Main references*

Anon. 1998. Botanical Diversity in Fiji. Contribution to the Development of a Biodiversity Strategy and Action Plan for Fiji. (Unpublished report of technical group.)

Hassal, D.C. 1980. Studies on Fijian vegetation highland forest and stream-bank formations near Wainisavulevu Creek, Viti Levu. *South Pacific Journal of Natural Science*, 1: 26–44.

Mune, T.L.; Parham, J.W. 1956. The declared noxious weeds of Fiji and their control. *Department of Agriculture, Fiji, Bulletin 48*. (Third edn)

Parham, J.W. 1958. The weeds of Fiji. *Department of Agriculture, Fiji, Bulletin 35*.

Smith, A.C. 1979–1996. Flora Vitiensis Nova. *A New Flora of Fiji*. National Tropical Garden, Lawai, Hawaii. (6 volumes.)

## *Academic/local experts consulted*

Dr Randolph R. Thaman, Professor of Pacific Islands Biogeography, Department of Geography, University of the South Pacific, PO Box 1168, Suva, Fiji.

Marika Tuiwawa, Curator, South Pacific Regional Herbarium, University of the South Pacific, PO Box 1168, Suva, Fiji.

Dr Dick Watling, Principal, Environmental Consultants Fiji, PO Box 2041, Suva, Fiji.

Dick Phillips, Gardener, Hon. Research Associate, University of the South Pacific, PO Box 1168, Suva, Fiji.

# French Polynesia

## *Preliminary list of invasive plants*

| Scientific name (Family name) | Common name(s) | Habit/ Life form | Habitat (and Locations) |
|---|---|---|---|
| **Dominant invaders** | | | |
| **Acacia farnesiana* (Leguminosae) | Ellington's curse, Cassie | thorny shrub | Dry (Marquesas islands) |
| **Ardisia elliptica (humilis)* (Myrsinaceae) | Shoebutton ardisia | shrub | Mesic 10–300 m |
| **Cecropia peltata* (Cecropiaceae) | Trumpet tree | tree | Mesic 100–600 m |
| **Lantana camara* (Verbenaceae) | Lantana | thorny shrub | Dry/Mesic 0–1500 m |
| **Leucaena leucocephala* (Leguminosae) | Wild tamarind, Lead tree | tree | Dry 0–300 m |
| **Miconia calvescens (magnifica)* (Melastomataceae) | Miconia, Velvet tree | tree | Wet 10–1300 m (Society Islands) |
| **Melinis minutiflora* (Gramineae) | Melinis, Molasses grass | grass | Dry/Mesic–Wet 0–1600 m |
| *Merremia peltata* (Convolvulaceae) | Merremia | vine | Mesic 0–500 m |
| *Mimosa invisa* (Leguminosae) | Giant sensitive plant, Spiny mimosa | shrub | Dry/Mesic 0–600 m (Society Islands) |
| *Paraserianthes (Albizia) falcataria* (Leguminosae) | Molluca albizia | tree | Mesic–Wet 0–700 m |
| **Psidium cattleianum* (Myrtaceae) | Strawberry/Chinese guava | tree | Mesic–Wet 10–900 m |
| *Psidium guajava* (Myrtaceae) | Common guava | tree | Dry/Mesic 10–500 m (Marquesas Islands) |
| **Rubus rosifolius* (Rosaceae) | Thimbleberry, Roseleaf raspberry | spiny shrub | Wet 50–2200 m |
| **Spathodea campanulata* (Bignoniaceae) | African tulip tree | tree | Mesic–Wet 100–1200 m |
| **Syzygium (Eugenia) cumini* (Myrtaceae) | Java plum, Jambolan | large tree | Mesic–Wet 0–1200 m |
| **Syzygium (Eugenia) jambos* (Myrtaceae) | Rose apple | tree | Mesic–Wet 0–1000 m |
| **Tecoma stans* (Bignoniaceae) | Yellow bells, Yellow elder | small tree | Dry/Mesic 100–1500 m |
| **Moderate invaders** | | | |
| *Annona glabra* (Annonaceae) | Pond apple, Alligator apple | small tree | Wet lowlands (Raiatea, Tahaa) |
| *Casuarina equisetifolia* (Casuarinaceae) | Ironwood tree, Australian pine | tree | Dry lowlands (Fangataufa) |
| *Cestrum nocturnum* (Solanaceae) | Night-blooming jasmine, Night cestrum | shrub | Wet (Tahiti) |
| *Chrysobalanus icaco* (Chrysobalanaceae) | Coco plum, Icaco | shrub | Dry/Mesic (Raiatea, Fatu Hiva) |
| *Coffea arabica* (Rubiaceae) | Arabica coffee | small tree | Mesic/Wet |
| *Cyperus rotundus* (Cyperaceae) | Nutgrass, Coco grass | sedge | Mesic/Wet |
| *Dissotis rotundifolia* (Melastomataceae) | - | herb | Mesic/Wet |
| *Eichhornia crassipes* (Pontederiaceae) | Water hyacinth | aquatic herb | Wetlands |
| *Ficus microcarpa* (Moraceae) | Chinese banyan, Indian laurel | tree | Dry/Mesic (Society Islands) |
| *Flemingia strobilifera* (Leguminosae) | - | shrub | Mesic (Nuku Hiva, Raiatea) |
| *Kalanchoe pinnata* (Crassulaceae) | Air plant, Mexican love plant | succulent | Mesic uplands (Rurutu) |
| *Melia azedarach* (Meliaceae) | China berry, Pride of India | tree | Mesic (Mangareva) |
| *Paspalum conjugatum* (Gramineae) | T-grass, Sour paspalum | grass | Mesic |
| *Passiflora foetida* (Passifloraceae) | Stinking passionflower, Love-in-a-mist | vine | Dry/Mesic |
| *Passiflora laurifolia* (Passifloraceae) | Yellow granadilla | vine | |
| *Pinus caribaea* (Pinaceae) | Caribbean/Bahamas pitch, Slash pine | tree | Dry/Mesic |
| *Pluchea carolinensis (symphytifolia)* (Compositae) | Sourbush | shrub | Dry (Tuamotu Islands) |
| *Rhodomyrtus tomentosa* (Myrtaceae) | Rose myrtle, Downy rose myrtle | shrub | Mesic/Wet (Raiatea) |
| *Rhizophora stylosa* (Rhyzophoraceae) | - | tree | Wetlands (Society) |
| *Stachytarpheta urticifolia* (Verbenaceae) | Blue rat's tail, Dark blue snakeweed | herb | Mesic/Wet 10–700 m |
| *Syzygium floribundum* (Myrtaceae) | - | tree | Mesic (Moorea) |
| *Triplaris weigeltiana* (Polygonaceae) | - | tree | Mesic (Tahiti) |
| *Wedelia (Sphagneticola) trilobata* (Compositae) | Wedelia, Singapore daisy | herb | 0–1300 m |

| Scientific name (Family name) | Common name(s) | Habit/ Life form | Habitat (and Locations) |
|---|---|---|---|
| **Potential invaders** | | | |
| *Agave sisalana* (Agavaceae) | Sisal hemp, Sisal, Bahama hemp | succulent | (Rurutu) |
| *Antigonon leptotus* (Polygonaceae) | Mexican creeper, Chain of love | vine | |
| *Caesalpinia decapetala (sepiaria)* (Leguminosae) | Mauritius thorn, Cat's claw, Mysore thorn | thorny shrub | |
| *Castilloa elastica* (Moraceae) | Panama rubber tree | large tree | (Moorea) |
| *Chrysophyllum oliviforme* (Sapotaceae) | Satin leaf tree | small tree | (Tahiti) |
| *Cinnamomum verum (zeylanicum)* (Lauraceae) | Cinnamon tree | tree | |
| *Cinchona pubescens (succirubra)* (Rubiaceae) | Quinine tree | tree | (Tahiti) |
| *Citharexylum spinosum* (Verbenaceae) | Fiddlewood | tree | |
| *Clerodendrum paniculatum* (Verbenaceae) | Pagoda flower | shrub | (Tahiti) |
| *Fucraea foetida* (Agavaceae) | Mauritian hemp | succulent | (Rurutu) |
| *Grevillea robusta* (Proteaceae) | Silky oak, Silver oak | tree | (Rurutu) |
| *Hedychium coronarium* (Zingiberaceae) | White ginger | erect herb | |
| *Hedychium flavescens* (Zingiberaceae) | Yellow ginger | erect herb | (Tahiti) |
| *Heterocentron subtriplinervium* (Melastomataceae) | Pearl flower | shrub | (Tahiti) |
| *Licuala grandis* (Palmae) | Fan palm, Vanuatu fan palm | palm | (Raiatea) |
| *Ochna kirkii* (Ochnaceae) | Mickey mouse plant | shrub | (Raiatea) |
| *Ochroma pyramidale (lagopus)* (Bombacaceae) | Balsa, Corkwood | tree | (Tahiti, Fatu Hiva) |
| *Odontonema tubiforme (strictum)* (Acanthaceae) | Fire spike, Cardinal flower | shrub | (Tahiti) |
| *Pueraria lobata* (Leguminosae) | Kudzu | vine | (Raiatea) |
| *Sanchezia speciosa (nobilis)* (Acanthaceae) | Sanchezia | shrub | (Tahiti) |
| *Schefflera (Brassaia) actinophylla* (Araliaceae) | Octopus/Umbrella tree | tree | (Tahiti, Raiatea) |
| *Schinus terebinthifolius* (Anacardiaceae) | Brazilian pepper tree, Christmas berry | tree | (Tahiti) |
| *Setaria palmifolia* (Gramineae) | Palmgrass | grass | (Tahiti) |
| *Sphaeropteris (Cyathea) cooperi* (Cyatheaceae) | Australian tree fern | tree fern | (Tahiti) |
| *Syncarpia glomulifera (laurifolia)* (Myrtaceae) | Turpentine wood | tree | (Tahiti) |
| *Thunbergia grandiflora* (Acanthaceae) | Bengal trumpet, Blue trumpet vine | vine | (Tahiti) |
| *Tithonia diversifolia* (Compositae) | Mexican sunflower, Tree marigold | shrub | (Nuku Hiva, Tubuai) |
| *Tradescantia (Zebrina) pendula* (Commelinaceae) | Wandering Jew | herb | Mesic (Tahiti) |

* legally declared a threat to biodiversity in French Polynesia (Meyer 1998)

### *Main references*


Florence, J.; Guérin, M.; Reboul, J.-L. 1983. Les mauvaises herbes de la Polynésie française. (Unpublished report.)

Florence, J. 1997. *Flore de la Polynésie française. Volume 1*. Editions de l'ORSTOM, Paris.

Fosberg, F.R. 1992. Vegetation of the Society Islands. *Pacific Science* 46: 232–250.

Meyer, J.-Y.; Florence, J. 1996. Tahiti's native flora endangered by the invasion of *Miconia calvescens* DC (Melastomataceae). *Journal of Biogeography* 23(6): 775–783.

Meyer, J.-Y. 1998. Mécanismes et gestion des invasions biologiques par des plantes introduites dans des forêts naturelles à Hawai'i et en Polynésie française: une étude de cas. Rapport d'étude post-doctorale. Délégation à la Recherche, Tahiti. (Unpublished report.)

Meyer, J.-Y. 1998. Managing alien plant invasions in French Polynesia, a first step. *Aliens* N°8: 11.


### *Academic/local experts consulted*

Dr Jacques Florence, Antenne IRD (ex ORSTOM), Laboratoire de Phanérogamie, Muséum national d'Histoire naturelle, 16 rue Buffon, 75005 Paris.

Dr Jean-Yves Meyer, Délégation à la Recherche, Ministère de la Santé et de la Recherche, BP 20981 Papeete, Tahiti, French Polynesia.

## Guam

### *Preliminary list of invasive plants*

| Scientific name (Family name) | Common name(s) | Habit/ Life form | Habitat |
|---|---|---|---|
| **Dominant invaders** | | | |
| *Adenanthera pavonina* (Leguminosae) | Red bead tree, Red sandalwood | tree | |
| *Antigonon leptotus* (Polygonaceae) | Mexican creeper, Chain of love | vine | |
| *Chromolaena (Eupatorium) odorata* (Compositae) | Siam weed, triffid weed | herb | |

| Scientific name (Family name) | Common name(s) | Habit/ Life form | Habitat |
|---|---|---|---|
| **Dominant invaders** | | | |
| *Coccinia grandis* (Cucurbitaceae) | Ivy/Scarlet gourd | vine | Dry/Mesic |
| *Eichhornia crassipes* (Pontederiaceae) | Water hyacinth | aquatic herb | Wetlands |
| *Ischaemum rugosum* (Gramineae) | - | grass | |
| *Lantana camara* (Verbenaceae) | Lantana | thorny shrub | |
| *Leucaena leucocephala* (Leguminosae) | Wild tamarind, Lead tree | small tree | |
| *Mikania micrantha* (Compositae) | Mile-a-minute | vine | |
| *Mimosa invisa* (Leguminosae) | Giant sensitive plant, Spiny mimosa | thorny shrub | |
| *Panicum maximum* (Gramineae) | Guinea grass | grass | |
| *Paspalum conjugatum* (Gramineae) | T-grass, Sour paspalum | grass | |
| *Passiflora foetida* (Passifloraceae) | Stinking passionflower, Love-in-a-mist | vine | |
| *Pennisetum polystachyon* (Gramineae) | Mission grass | grass | |
| *Pennisetum purpureum* (Gramineae) | Elephant grass, Napier grass | grass | |
| *Sorghum halepense* (Gramineae) | Johnson grass | grass | |
| **Moderate invaders** | | | |
| *Albizia lebbeck* (Leguminosae) | Siris tree, Indian siris | large tree | |
| *Bauhinia monandra* (Leguminosae) | Orchid tree | tree | |
| *Ceiba pentadra* (Bombacaceae) | Kapok | tree | |
| *Cestrum diurnum* (Solanaceae) | Day cestrum, China inkberry | shrub | Sec. forests |
| *Ficus microcarpa* (Moraceae) | Chinese banyan, Indian laurel | large tree | |
| *Melaleuca quinquenervia (leucadendra)* (Myrtaceae) | Paperbark | tree | |
| *Paraserianthes (Albizia) falcataria* (Leguminosae) | Molucca albizia | large tree | |
| *Spathodea campanulata* (Bignoniaceae) | African Tulip tree | large tree | |
| *Tecoma stans* (Bignoniaceae) | Yellow bells, Yellow elder | small tree | |
| *Wedelia (Sphagneticola) trilobata* (Compositae) | Wedelia, Singapore daisy | herb | |
| **Potential invaders** | | | |
| *Clerodendrum quadriloculare* (Verbenaceae) | Bronze-leaved clerodendrum | shrub | |
| *Flemingia stobilifera* (Leguminosae) | - | shrub | |
| *Melinis minutiflora* (Gramineae) | Molasses grass, Melinis | grass | |
| *Muntingia calabura* (Tiliaceae) | Jamaican cherry, Panama cherry | tree | |
| *Pennisetum setaceum* (Gramineae) | Fountain grass | grass | |

### *Main references*

Lee, M.A.B. 1974. Distribution of native and invader plant species on the island of Guam. *Biotropica* 6(3): 158–164.

McConnell, J.; Muniappan, R. 1991. Introduced ornamental plants that have become weeds on Guam. *Micronesica Suppl.* 3 : 47-49.

Moore, P.H.; McMakin, P.D. 1979. *Plants of Guam*. University of Guam, Cooperative Extension Service, College of Agriculture & Life Science. (E. L. Gomoll, ed.)

Space, J.; Falanruw, M.C. 1999. Observations on invasive plant species in Micronesia. Ms prepared for meeting of Pacific Island Committee Council of Western States Foresters, Majuro, Marshall Islands.

Wiles, G.J.; Aguon, C.F.; Davis, G.W. 1995. The status and distribution of endangered animals and plants in Northern Guam. *Micronesica* 28(1): 31–49.

### *Academic/local experts consulted*

Dr Rangaswamy N. Muniappan, Professor Emeritus, College of Agriculture & Life Science, University of Guam, 303 University Drive, Mangiloa, Guam 96923.

Jim Space, Project Manager, Pacific Island Ecosystem at Risk Project (PIER), 11007 E. Regal Dr., Sun Lakes, Arizona 85248-7919, USA.

## Hawaii

### *Preliminary list of invasive plants*

| Scientific name (Family name) | Common name(s) | Habit/ Life form | Habitat (and Locations) |
|---|---|---|---|
| **Dominant invaders** | | | |
| ***Andropogon virginicus* (Gramineae) | Broom sedge | grass | Mesic 0–1600 m |
| ***Ardisia elliptica (humilis)* (Myrsinaceae) | Shoebutton ardisia, Duck's eye | shrub | Mesic/Wet |
| ***Clidemia hirta* (Melastomataceae) | Koster's curse | shrub | Mesic/Wet |
| ***Coccinia grandis* (Cucurbitaceae) | Ivy gourd, Scarlet-fruited gourd | vine | |

| Scientific name (Family name) | Common name(s) | Habit/ Life form | Habitat (and Locations) |
|---|---|---|---|
| **Dominant invaders** | | | |
| *Hedychium coronarium* (Zingiberaceae) | White ginger | erect herb | Wet |
| *Hedychium gardnerianum* (Zingiberaceae) | Kahili ginger | erect herb | Wet |
| *Holcus lanatus* (Gramineae) | Common velvet grass | grass | Mesic/Wet 1300–2000 m |
| *Lantana camara* (Verbenaceae) | Lantana | thorny shrub | Dry/Mesic |
| *Leucaena leucocephala* (Leguminosae) | Wild tamarind, Lead tree | tree | Dry/Mesic 0–700 m |
| *Melinis minutiflora* (Gramineae) | Melinis, Molasses grass | grass | Dry/Mesic/Wet 0–1500 m |
| ***Miconia calvescens (magnifica)* (Melastomataceae) | Miconia, Velvet tree | tree | Mesic/Wet |
| ***Myrica faya* (Myricaceae) | Firetree, Fayatree | small tree | Mesic/Wet 300–1700 m |
| ***Passiflora mollissima* (Passifloraceae) | Banana passionfruit, Banana poka | vine | Mesic |
| **Pennisetum clandestinum* (Gramineae) | Kikuyu grass | grass | Dry/Mesic 500–2000 m |
| ***Pennisetum setaceum* (Gramineae) | Fountain grass | grass | Dry |
| *Pinus radiata* (Pinaceae) | Monterey pine | tree | |
| *Psidium cattleianum* (Myrtaceae) | Strawberry guava | tree | Mesic/Wet 150–1300 m |
| ***Rhodomyrtus tomentosa* (Myrtaceae) | Rose myrtle, Downy rosemyrtle | shrub | Mesic 500–600 m |
| ***Rubus argutus (penetrans)* (Rosaceae) | Florida prickly blackberry | spiny shrub | Mesic/Wet 600–2000 m |
| ***Rubus ellipticus* (Rosaceae) | Yellow Himalayan raspberry | spiny shrub | 700–1700 m |
| *Schinus terebinthifolius* (Anacardiaceae) | Brazilian pepper, Christmas berry | small tree | Mesic |
| *Schizachyrium condensatum (Andropogon glomeratus)* (Gramineae) | Bush beardgrass | grass | |
| ***Tibouchina herbacea* (Melastomataceae) | Cane tibouchina | shrub | Mesic/Wet 100–1600 m |
| **Moderate invaders** | | | |
| *Acacia farnesiana* (Leguminosae) | Ellington's curse, Cassie | shrub | Dry 0–1000 m |
| ***Acacia mearnsii* (Leguminosae) | Black wattle | large tree | Mesic 600–1700 m |
| *Acacia melanoxylon* (Leguminosae) | Blackwood acacia | tree | |
| *Agave sisalana* (Agavaceae) | Sisal hemp | succulent | |
| *Angiopteris evecta* (Marattiaceae) | King's fern | erect fern | Mesic/Wet |
| *Anthoxanthum odoratum* (Gramineae) | Sweet vernal grass, Spring grass | grass | Mesic/Dry 1500–3000 |
| ***Bocconia frutescens* (Papaveraceae) | Bocconia, Plume poppy | shrub | Dry 300–1000 m |
| *Bromus tectorum* (Gramineae) | Downy chess | grass | |
| *Carex ovalis* (Cyperaceae) | | sedge | |
| *Casuarina equisetifolia* (Casuarinaceae) | Common ironwood, Australian pine | tree | Coastal Dry 0–500 m |
| *Cecropia obtusifolia* (Cecropiaceae) | Trumpet tree | tree | |
| *Chionanthes (Linocieria) intermedia* (Oleaceae) | Russian olive | tree | |
| *Chrysophyllum oliviforme* (Sapotaceae) | Damson plum | tree | |
| *Cinnamomum burmanii* (Lauraceae) | Padang cassia | tree | |
| *Cinnamomum camphora* (Lauraceae) | Camphor tree | tree | |
| *Citharexylum caudatum* (Verbenaceae) | Juniper berry | small tree | |
| *Citharexylum, spinosum* (Verbenaceae) | Fiddlewood | tree | |
| *Clerodendrum japonicum* (Verbenaceae) | Glorybower | shrub | |
| ***Cortaderia jubata* (Gramineae) | Andean pampas grass | tall grass | |
| *Corynocarpus laevigatus* (Corynocarpaceae) | New Zealand laurel, Karaka nut | tree | |
| *Eucalyptus globosus* (Myrtaceae) | Blue gum | tree | |
| *Ficus microcarpa* (Moraceae) | Chinese banyan, Indian laurel | large tree | 0–700 m |
| *Fuchsia magellanica* (Onagraceae) | | tree | |
| *Hedychium flavescens* (Zingiberaceae) | Yellow ginger | erect herb | Wet 0–1700 m |
| *Heterocentron subtriplinervium* (Melastomataceae) | Pearl flower | shrub | |
| *Hiptage benghalensis* (Malpighiaceae) | Hiptage | vine | |
| *Holcus lanatus* (Gramineae) | Velvet grass, Creeping soft grass | grass | |
| *Glycine wightii* (Leguminosae) | - | vine | |
| ***Grevillea banksii* (Proteaceae) | Bank's grevillea | tree | |
| *Grevillea robusta* (Proteaceae) | Silver oak, Silky oak | large tree | |
| *Juncus polyanthemos* (Juncaceae) | | | |
| *Kalanchoe pinnata* (Crassulaceae) | Air plant, Mexican love plant | succulent | Dry/Mesic |
| *Kyllinga brevifolia* (Cyperaceae) | | sedge | |
| *Leptospermum scoparium* (Myrtaceae) | New Zealand tea, Manuka | tree | |
| **Melaleuca quinquenervia (leucadendra)* (Myrtaceae) | Paperbark | tree | Wet 100-1000 m |

| Scientific name (Family name) | Common name(s) | Habit/ Life form | Habitat (and Locations) |
|---|---|---|---|
| **Moderate invaders** | | | |
| **Melastoma candidum (malabathricum)* (Melastomataceae) | Indian rhododendron | shrub | Dry 0–700 m |
| *Melia azedarach* (Meliaceae) | Pride of India | large tree | Dry 0–700 m |
| *Melochia umbellata* (Sterculiaceae) | Gunpowder tree | small tree | |
| ***Montanoa hibiscifolia* (Compositae) | Tree daisy | herb | Dry/Mesic |
| *Opuntia ficus-indica* (Cactaceae) | Prickly pear cactus | succulent | |
| *Paederia foetida* (Rubiaceae) | - | vine | |
| *Panicum maximum* (Gramineae) | Guinea grass | grass | Dry 0–1200 m |
| *Paraserianthes (Albizia) falcataria* (Leguminosae) | Molucca albizia | large tree | Dry/Mesic 0–1500 m |
| *Paspalum conjugatum* (Gramineae) | T-grass, Sour paspalum | grass | Wet 0–2000 m |
| *Passiflora ligularis* (Passifloraceae) | Sweet granadilla | vine | |
| *Pennisetum purpureum* (Gramineae) | Elephant grass | grass | |
| *Phyllostachys nigra* (Gramineae) | Black bamboo | bamboo | |
| *Phormium tenax* (Phormiaceae) | New Zealand flax, Bush flax | erect herb | |
| *Pinus caribaea* (Pinaceae) | Slash pine, Caribbean/ Bahamas pitch pine | tree | |
| *Pinus patula* (Pinaceae) | Mexican weeping pine | tree | |
| *Pinus pinaster* (Pinaceae) | Cluster/Maritime pine | tree | 1600–2200 m |
| *Pithecellobium dulce* (Leguminosae) | Madras thorn, Manila tamarind | tree | Dry 0–300 m |
| *Pluchea indica* (Compositae) | Indian fleabane | shrub | |
| *Pluchea odorata* (Compositae) | Sourbush | shrub | Dry 0–1000 m |
| **Prosopis pallida* (Leguminosae) | Mesquite | tree | Dry 0–700 m |
| *Psidium guajava* (Myrtaceae) | Common guava | tree | Dry 0–500 m |
| *Pueraria lobata* (Leguminosae) | Kudzu | vine | |
| *Rhynchelytrum repens* (Gramineae) | Natal grass | grass | |
| *Rhynchospora caduca* (Cyperaceae) | | sedge | |
| *Rhizophora mangle* (Rhyzophoraceae) | Red mangrove | shrub | wetland |
| *Rubus glaucus* (Rosaceae) | Raspberry | spiny shrub | |
| ***Rubus sieboldii* (Rosaceae) | Molucca raspberry | spiny shrub | (Kaua'i) |
| ***Rubus niveus (nivalis)* (Rosaceae) | Hill/Mysore raspberry | spiny shrub | |
| *Rubus rosifolius* (Rosaceae) | Thimbleberry | spiny shrub | |
| *Sacciolepis indica* (Gramineae) | Glenwood grass | grass | |
| *Schefflera (Brassaia) actinophylla* (Araliaceae) | Octopus/Umbrella tree | tree | Wet 0–1000 m |
| *Senecio mikanioides* (Compositae) | German ivy | vine | Wet 800–2000 m |
| *Setaria palmifolia* (Gramineae) | Palmgrass | tall grass | Wet 300–2000 m |
| *Spathodea campanulata* (Bignoniaceae) | African tulip tree | large tree | Wet 0–1000 m |
| *Sphaeropteris (Cyathea) cooperi* (Cyatheaceae) | Australian tree fern | tree fern | Wet |
| *Syzygium cumini* (Myrtaceae) | Java plum, Jambolan | large tree | Dry/Mesic/Wet 0–700 m |
| *Syzygium jambos* (Myrtaceae) | Rose apple | tree | Wet 0–500 m |
| *Tagetes minuta* (Compositae) | Strinking Roger | herb | |
| *Thunbergia grandiflora* (Acanthaceae) | Bengal trumpet, Blue trumpet vine | vine | |
| ***Tibouchina urvilleana* (Melastomataceae) | Glorybush | shrub | Wet 200–1700 m |
| ***Ulex europaeus* (Leguminosae) | Gorse | thorny shrub | Mesic 200–2100 m |
| **Potential invaders** | | | |
| *Acacia confusa* (Leguminosae) | Formosan koa | tree | Dry/Mesic 0–700 m |
| *Acacia decurrens* (Leguminosae) | Blackwell | tree | |
| *Acca (Feijoa) sellowiana* (Myrtaceae) | Pineapple guava | tree | |
| *Agave americana* (Agavaceae) | Century plant | succulent | |
| *Ardisia crispa* (Myrsinaceae) | | shrub | |
| *Arthrostemma latifolia* (Melastomataceae) | | | |
| *Arundo donax* (Gramineae) | Giant reed | tall grass | |
| *Bruguiera gymnorrhiza* (Rhizophoraceae) | Oriental mangrove | tree | wetland |
| *Buddleia madagascariensis* (Buddleiaceae) | Butterfly bush, Smoke bush | shrub | |
| *Castilloa elastica* (Moraceae) | Panama/Mexican rubber tree | large tree | |
| *Casuarina glauca* (Casuarinaceae) | Swamp oak, Saltmarsh ironwood | tree | |
| *Caesalpinia decapetala (sepiaria)* (Leguminosae) | Mauritius thorn, Cat's claw, Mysore thorn | shrub | |
| *Cestrum diurnum* (Solanaceae) | Day cestrum, China inkberry | shrub | |

| Scientific name (Family name) | Common name(s) | Habit/ Life form | Habitat (and Locations) |
|---|---|---|---|
| **Potential invaders** | | | |
| *Cestrum nocturnum* (Solanaceae) | Night cestrum, Night blooming jasmine | shrub | |
| *Cinchona pubescens (succirubra)* (Rubiaceae) | Quinine tree | tree | |
| *Cinnamomum verum (zeylanicum)* (Lauraceae) | Cinnamon tree | tree | |
| *Cryptostegia grandiflora* (Asclepiadaceae) | Rubber vine | vine | |
| *Dissotis rotundifolia* (Melastomataceae) | | herb | |
| *Flemingia strobilifera* (Leguminosae) | | shrub | |
| *Fraxinus uhdei* (Oleaceae) | Mexican ash | large tree | 1000–2000 m |
| *Fucraea foetida* (Agavaceae) | Mauritian hemp | succulent | Dry/Mesic |
| *Heliocarpus popayanensis* (Tiliaceae) | | large tree | |
| *Leptospermum scoparium* (Myrtaceae) | New Zealand tea | small tree | 300–700 m |
| *Ligustrum* spp. (Oleaceae) | | small tree | |
| *Lonicera japonica* (Caprifoliaceae) | Japanese honeysuckle | vine | |
| ***Medinilla venosa* (Melastomataceae) | | | |
| *Melia azedarach* (Meliaceae) | China berry, Pride of India | tree | |
| *Merremia tuberosa* (Convolvulaceae) | Woodrose | vine | |
| *Ochna kirkii* (Ochnaceae) | Mickey mouse plant | shrub | |
| *Odontonema tubiforme (strictum)* (Acanthaceae) | Fire spike | shrub | (O'ahu) |
| *Olea europea* var. *africana* (Oleaceae) | Russian olive | | |
| ***Oxyspora paniculata* (Melastomataceae) | | shrub | (O'ahu) |
| *Passiflora laurifolia* (Passifloraceae) | Yellow granadilla | vine | |
| *Passiflora suberosa* (Passifloraceae) | | vine | Dry 0–600 m |
| ***Pittosporum undulatum* (Pittosporaceae) | Victorian box | tree | |
| *Ricinus communis* (Euphorbiaceae) | Castor bean | shrub | Dry 0–1200 m |
| **Salvinia molesta* (Salviniaceae) | Salvinia, Water fern, Kariba weed | aquatic fern | Wetlands |
| *Sporobolus africanus* (Gramineae) | Parramatta grass, Rattail grass | grass | |
| *Toona ciliata (Cedrela toona)* (Meliaceae) | Australian red cedar | large tree | 25–600 m |
| *Trema orientalis* (Ulmaceae) | Charcoal tree | tree | |
| *Wedelia (Sphagneticola) trilobata* (Compositae) | Wedelia, Singapore daisy | herb | |

* on the Federal Noxious Weed List (USA).

** Noxious Weeds for Eradication or Control purposes by the Hawaii Department of Agriculture, 1992.

## *Main references*

Lorence, D.H.; Flynn, T.W.; Wagner, W.L. 1995. Contribution to the flora of Hawaii. III. New additions, range extension, and rediscoveries of flowering plants. *Bishop Museum Occasional Papers* 41.

Loope, L.L. 1992. Preventing establishment of new alien species in Haleakala National Park and the island of Maui, Hawaii. *George Wright Forum* 9(1): 20–31.

Medeiros, A.C.; Loope, L.L.; Hobdy, R.W. 1995. Conservation of cloud forests in Maui County (Maui, Moloka'i, and Lana'i), Hawaiian islands. *In* Hamilton, L.S.; Juvik, J.O.; Scatena, F.N. (eds) *Tropical Montane Cloud Forest*. Springer Verlag.

Smith, C.W. 1985. Impact of alien plants in Hawai'i's native biota. Pp. 180–250 *in* Stone, C.P.; Scott, J.M. (eds) *Hawai'i's Terrestrial Ecosystems Preservation and Management*. University of Hawaii Cooperative National Park Resource Studies Unit, Honolulu.

Smith, C.W. 1990. Weed management in Hawaii's national parks. *Monographs in Systematic Botany Missouri Botanical Gardens* 32: 233–234.

Tunison, J.T. et al. 1992. The distribution of selected localized alien plant species in Hawaii Volcanoes National Park. *University of Hawaii Cooperative National Park Resource Studies Unit Technical Report 84*.

Tunison, J.T. 1991. Strategies and successes in controlling alien plants in an Hawaiian National Park. Pp. 353–376 *in* Center, T.D.; Doren, R.F.; Hofstetter, R.L.; Myers, R.L.; Whiteaker, L.D. (eds) Proceedings of the Symposium on Exotic Pest Plants. *Technical Report NPS/NREVER/NRTR-91/06, University of Miami*.

## *Academic/local experts consulted*

Dr David H. Lorence, Senior Botanist, National Tropical Botanical Garden, 3530 Papalina Road, Kalaheo, Kaua''i, Hawaii 96741.

Arthur C. Medeiros; Charles Chimera, USGS-BRD, Haleakala National Park Field Station, PO Box 369 Makawao, Maui, Hawaii.

Dr Clifford Smith, Professor Emeritus, Department of Botany, Cooperative National Park Research Studies Unit, University of Hawaii at Manoa, 3190 Maile Way, St John 409, Honolulu, Hawaii.

## Nauru

### *Preliminary list of invasive plants*

| Scientific name (Family name) | Common name(s) | Habit/ Life form | Habitat (and Locations) |
|---|---|---|---|
| **Dominant invaders** | | | |
| *Adenanthera pavonina* (Leguminosae) | Red bead tree, Red sandalwood | small tree | |
| *Lantana camara* (Verbenaceae) | Lantana | thorny shrub | |
| *Leucaena leucocephala* (Leguminosae) | Wild tamarind, Lead tree | small tree | |
| *Psidium guajava* (Myrtaceae) | Common guava | tree | |
| **Moderate invaders** | | | |
| *Annona muricata* (Annonaceae) | Soursop, Prickly custard apple | shrub | |
| *Annona squamosa* (Annonaceae) | Sweetsop, Custard apple | shrub | |
| *Casuarina equisetifolia* (Casuarinaceae) | Ironwood tree, Australian pine | tree | |
| *Muntingia calabura* (Tiliaceae) | Jamaican cherry, Panama cherry | tree | |
| *Pluchea* sp. (Compositae) | - | shrub | |
| *Stachytarpheta urticifolia* (Verbenaceae) | Blue rat's tail, Dark blue snakeweed | shrub | |
| *Wedelia (Sphagneticola) trilobata* (Compositae) | Wedelia, Singapore daisy | herb | |
| **Potential invaders** | | | |
| *Acacia farnesiana* (Leguminosae) | Ellington's curse, Cassie | shrub | roads |
| *Luffa acutangula* (Cucurbitaceae) | Sinqua melon | vine | |
| *Tecoma stans* (Bignoniaceae) | Yellow bells, Yellow elder | small tree | gardens |
| *Thunbergia alata* (Acanthaceae) | Black-eyed Susan | vine | gardens |
| *Turnera ulmifolia* (Turneraceae) | | herb | gardens |

### *Main references*


Manner, H.I.; Thaman, R.R.; Hassal, D.C. 1984. Phosphate-mining induced vegetation changes on Nauru Island. *Ecology* 65(5): 1454–1465 .

Manner, H.I.; Thaman, R.R. 1985. Plant succession after phosphate mining on Nauru. *Australian Geographer* 16(3): 185–195.

Thaman, R.R. 1992. Vegetation of Nauru and the Gilbert Islands: case studies of poverty, degradation, disturbance and displacement. *Pacific Science* 46(2): 128–158.


### *Academic/local experts consulted*

Dr Harley I. Manner, Professor of Geography, College of Arts and Science, University of Guam, 303

Dr Randolph R. Thaman, Professor of Pacific Islands Biogeography, Department of Geography, University of the South Pacific, PO Box 1168, Suva, Fiji.

## New Caledonia

### *Preliminary list of invasive plants*

| Scientific name (Family name) | Common name(s) | Habit/ Life form | Habitat (and Locations) |
|---|---|---|---|
| **Dominant invaders** | | | |
| *Heteropogon contortus* (Gramineae) | | grass | drylands, savannas |
| *Lantana camara* (Verbenaceae) | Lantana | thorny shrub | dry forests, savannas |
| *Leucaena leucocephala* (Leguminosae) | Wild tamarind, Lead tree | small tree | dry forests |
| *Mimosa invisa* (Leguminosae) | Giant sensitive plant, Spiny mimosa | thorny shrub | secondary |
| *Ocimum gratissimum* (Labiatae) | Wild basil | herb | coastal, wetlands |
| *Psidium guajava* (Myrtaceae) | Common guava | small tree | dry forests, savannas |
| *Salvinia molesta* (Salviniaceae) | Salvinia, Water fern, Kariba weed (Koumac) | aquatic fern | rivers and wetlands |
| **Moderate invaders** | | | |
| *Acacia farnesiana* (Leguminosae) | Ellington's curse | shrub | |
| *Acanthocereus pentagonus* (Cactaceae) | | succulent | (Boulouparis) |
| *Albizia lebbeck* (Leguminosae) | Siris tree, Indian siris | tree | |
| *Aristolochia elegans* (Aristolochiaceae) | | vine | |
| *Arundo donax* (Gramineae) | Giant reed | tall grass | |
| *Caesalpinia decapetala (sepiaria)* (Leguminosae) | Mauritius thorn, Cat's claw, Mysore thorn | shrub | degraded forest |
| *Cirsium vulgare* (Compositae) | Spear thistle, Bull thistle | herb | (Côte Ouest) |

| Scientific name (Family name) | Common name(s) | Habit/ Life form | Habitat (and Locations) |
|---|---|---|---|
| **Moderate invaders** | | | |
| *Cryptostegia grandiflora* (Asclepiadaceae) | Rubber vine | vine | (Voh, Gatope) |
| *Doxantha (MacFadyena) unguis-cati* (Bignoniaceae) | | | dry forests (Yahoué) |
| *Eichhornia crassipes* (Pontederiaceae) | Water-hyacinth | aquatic herb | |
| *Flemingia strobilifera* (Leguminosae) | | shrub | |
| *Fucraea foetida* (Amaryllidaceae) | Mauritian hemp, Sisal | rosette | |
| *Ipomoea cairica* (Convolvulaceae) | | vine | forest edges, secondary scrub |
| *Jatropha gossipifolia* (Euphorbiaceae) | | shrub | |
| *Melinis minutiflora* (Gramineae) | Melinis, Molasses grass | grass | fernlands |
| *Opuntia* spp. (Cactaceae) | Prickly pear | succulent | coastal forests |
| *Panicum maximum* (Gramineae) | Guinea grass | grass | |
| *Parthenium hysterophorus* (Compositae) | | herb | |
| *Paspalum urvillei* (Gramineae) | Vasey grass | grass | up to 1000 m elev. |
| *Passiflora foetida* (Passifloraceae) | Stinking passionflower, Love-in-a-mist | vine | dry forests, coastal |
| *Passiflora suberosa* (Passifloraceae) | | vine | dry forests |
| *Pennisetum purpureum* (Gramineae) | Elephant grass, Napier grass | grass | wetlands |
| *Pennisetum setaceum* (Gramineae) | Fountain grass | grass | |
| *Rubus rosifolius* (Rosaceae) | Thimbleberry, Roseleaf raspberry | spiny shrub | forestry trails, gaps |
| *Schinus terebinthifolius* (Anacardiaceae) | Brazilian pepper, Christmas berry | small tree | coastal (îles Loyauté) |
| *Solanum mauritianum* (Solanaceae) | Wild tobacco, Woolly nightshade | shrub | forestry trails, edges |
| *Solanum torvum* (Solanaceae) | Prickly solanum | shrub | coastal, secondary |
| *Tecoma stans* (Bignoniaceae) | Yellow bells, Yellow elder | small tree | dry forests |
| **Potential invaders** | | | |
| *Acacia nilotica* (Leguminosae) | | tree | |
| *Asclepias physocarpa* (Asclepiadaceae) | | shrub | |
| *Cedrela odorata* (Meliaceae) | West Indies cedar | tree | |
| *Clerodendrum speciosum* (Verbenaceae) | | shrub | |
| *Flemingia strobilifera* (Leguminosae) | | shrub | |
| *Hydrilla verticillata* (Hydrocharitaceae) | | aquatic herb | |
| *Miconia calvescens* (Melastomataceae) | Miconia, Velvet tree | tree | |
| *Pinus caribaea* (Pinaceae) | Slash pine Caribbean/Bahamas pitch pine, | tree | |
| *Tithonia diversifolia* (Compositae) | Mexican sunflower, Tree marigold | shrub | |
| *Turnera ulmifolia* (Turneraceae) | | herb | gardens (Thio) |

## *Main references*


Barreau, J.; Devambez, L. 1957. Quelques remarques inattendues de l'acclimatation en Nouvelle-Calédonie, *Terre et Vie* 4: 324–334.

Bouchet, P.; Jaffre, T.; Veillon, J.-M. 1995. Plant extinction in New Caledonia: protection of sclerophyll forest urgently needed. *Biodiversity and Conservation* 4: 415–428.

Gargominy, O.; Bouchet, P.; Pascal, M.; Jaffre, T.; Tourneur, J.-C. 1996. Conséquences des introductions d'espèces animales et végétales sur la biodiversité en Nouvelle-Calédonie. *Révue d'Ecologie (Terre et Vie)* 51: 375–402.

Hoff, M.; Brisse, H.; Grandjouan, G. 1983. La végétation rudérale et anthropique de la Nouvelle-Calédonie et des Iles Loyauté (Pacifique Sud). *Colloques phytosociologiques, XII, Végétations nitrophiles*. Bailleul: 179–248.

McKee, H.S. 1985. Les plantes introduites et cultivées en Nouvelle-Calédonie. *Flore de la Nouvelle-Calédonie et dépendances, vol. hors-série*: 1-159.

Morat, Ph.; Jaffre, T.; Veillon, J.-M. 1999. Menaces sur les taxons rares et endémiques de Nouvelle-Calédonie. Pp. 129–144 *in* Lesouef, J.-Y. (ed.) Les plantes menacées de France, Actes du colloque de Brest, 15-17 octobre 1997. *Bulletin Société Botanique Centre-Ouest, Nouvelle Série, Numéro Spécial 19*.


## *Academic/local experts consulted*

Dr Tanguy Jaffré, Centre IRD (ex ORSTOM) de Nouméa, BP A5 Nouméa, New Caledonia.

Dr Michel Hoff, IRD (ex ORSTOM), Service du Patriomoine Naturel, Institut d'Ecologie et de Gestion de la Biodiversité, Muséum national d'Histoire naturelle, 57 rue Cuvier, F-75231 Paris Cedex 05, France.

# Niue

### *Preliminary list of invasive plants*

| Scientific name (Family name) | Common name(s) | Habit/ Life form | Habitat (and Locations) |
|---|---|---|---|
| **Moderate invaders** | | | |
| *Adenanthera pavonina* (Leguminosae) | Red bead tree, Red sandalwood | tree | secondary forest |
| *Clerodendrum chinense (philippinum)* (Verbenaceae) | Honolulu rose | shrub | |
| *Fucraea foetida* (Agavaceae) | Mauritian hemp | succulent | |
| *Lantana camara* (Verbenaceae) | Lantana | thorny shrub | |
| *Leucaena leucocephala* (Leguminosae) | Wild tamarind, Lead tree | small tree | |
| *Mikania micrantha* (Compositae) | Mile-a-minute | herb | |
| *Mimosa invisa* (Leguminosae) | Giant sensitive plant, Spiny mimosa | thorny shrub | |
| *Pennisetum purpureum* (Gramineae) | Elephant grass | grass | |
| *Psidium guajava* (Myrtaceae) | Common guava | tree | secondary forest |
| *Sorghum halepense* (Gramineae) | Johnson grass | grass | |
| *Stachytarpheta urticifolia* (Verbenaceae) | Blue rat's tail, Dark blue snakeweed | herb | |
| **Moderate invaders** | | | |
| *Albizia (Samanea) saman* (Leguminosae) | Rain tree, Monkeypod, Saman tree | tree | |
| *Antigonon leptotus* (Polygonaceae) | Mexican creeper, Chain of love | vine | |
| *Cassia mimosoides (leschenaultiana)* (Leguminosae) | | tree | |
| *Panicum maximum* (Gramineae) | Guinea grass | grass | |
| *Spathodea campanulata* (Bignoniaceae) | African tulip tree | large tree | |
| *Thunbergia fragrans* (Acanthaceae) | | vine | |
| **Potential invaders** | | | |
| *Acacia farnesiana* (Leguminosae) | Ellington's curse, Cassie | shrub | |
| *Clidemia hirta* (Melastomataceae) | Koster's curse | shrub | |
| *Pinus caribaea* (Pinaceae) | Slash pine<br>Caribbean/Bahamas pitch pine | tree | |
| *Tecoma stans* (Bignoniaceae) | Yellow bells, Yellow elder | small tree | |
| *Wedelia (Sphagneticola) trilobata* (Compositae) | Wedelia, Singapore daisy | herb | |

### *Main references*


Sykes, W.R. 1970. Contribution to the Flora of Niue. *New Zealand Department of Scientific and Industrial Research Bulletin 200*. Government Printer, Wellington.

Waterhouse, D.F. 1997. *The major invertebrate pests and weeds of agriculture and plantation forestry in the Southern and Western Pacific*. Australian Centre for International Agriculture Research (ACIAR), Canberra.


### *Academic/local experts consulted*

-

# Northern Mariana Islands

### *Preliminary list of invasive plants*

| Scientific name (Family name) | Common name(s) | Habit/ Life form | Habitat (and Locations) |
|---|---|---|---|
| **Dominant invaders** | | | |
| *Acacia confusa* (Leguminosae) | Formosan koa | tree | (Saipan, Tinian) |
| *Albizia lebbeck* (Leguminosae) | Siris tree, Indian siris | large tree | secondary forest (Saipan) |
| *Coccinia grandis* (Cucurbitaceae) | Ivy/Scarlet gourd | vine | (Saipan) |
| *Lantana camara* (Verbenaceae) | Lantana | thorny shrub | (Saipan, Tinian) |
| *Leucaena leucocephala* (Leguminosae) | Wild tamarind, Lead tree | small tree | (Saipan) |
| *Pennisetum polystachyon* (Gramineae) | Mission grass | grass | |
| *Pennisetum purpureum* (Gramineae) | Elephant/Napier grass | grass | |
| *Stizolobium (Mucuna) pruriens* (Leguminosae) | Cow itch, velvet bean | vine | forest edges (Saipan) |

| Scientific name (Family name) | Common name(s) | Habit/ Life form | Habitat (and Locations) |
|---|---|---|---|
| **Moderate invaders** | | | |
| *Cestrum diurnum* (Solanaceae) | Day cestrum, Day-blooming jasmine | shrub | forest edges |
| *Chromolaena (Eupatorium) odorata* (Compositae) | Siam weed, triffid weed | herb | |
| *Passiflora suberosa* (Passifloraceae) | | vine | (Tinian) |
| *Psidium guajava* (Myrtaceae) | Common guava | small tree | |
| *Mimosa invisa* (Leguminosae) | Giant sensitive plant, Spiny mimosa | thorny shrub | |
| **Potential invaders** | | | |
| *Annona reticulata* (Annonaceae) | Custard/Sugar apple, Bullock's heart | tree | |
| *Imperata cylindrica* (Gramineae) | Cogon/Cotton grass | grass | (Saipan, Tinian) |
| *Melochia villossissima* (Sterculiaceae) | | shrub | forest edges |
| *Muntingia calabura* (Tiliaceae) | Jamaican cherry, Panama cherry | tree | open fields, forest edges |
| *Pithecellobium dulce* (Leguminosae) | Madras thorne, Manila tamarind | thorny tree | |
| *Spathodea campanulata* (Bignoniaceae) | African tulip tree | large tree | |
| *Triphasia trifolia* (Rutaceae) | Limeberry, Orange berry | thorny shrub | |

### *Main references*

Craig, R.J. 1993. Regeneration of native Mariana island forest in disturbed habitats. *Micronesica* 26(2): 99–108.

Raulerson, L.; Reinhart, A. 1989. Vegetation of American Memorial Park, Saipan, Mariana Islands. *University of Hawaii Cooperative National Park Resource Studies Unit Technical Report 70.*

Raulerson, L.; Reinhart, A. 1991. Trees and shrubs of the Northern Mariana Islands. Coastal Ressources Management, Office of the Governor, Commonwealth of the Northern Mariana Islands, Saipan.

Space, J.; Falanruw, M.C. 1999. Observations on invasive plant species in Micronesia. Ms prepared for meeting of Pacific Island Committee Council of Western States Foresters, Majuro, Marshall Islands.

### *Academic/local experts consulted*

Jim Space, Project Manager, Pacific Island Ecosystem at Risk Project (PIER), 11007 E. Regal Dr., Sun Lakes, Arizona 85248-7919, USA.

Estanislao C. Villagomez, Director of Agriculture, Division of Agriculture, Department of Land & Natural Resources, Caller Box 10007, Saipan, MP 96950.

## Palau

### *Preliminary list of invasive plants*

| Scientific name (Family name) | Common name(s) | Habit/ Life form | Habitat (and Locations) |
|---|---|---|---|
| **Dominant invaders** | | | |
| *Adenanthera pavonina* (Leguminosae) | Red bead tree, Red sandalwood | tree | |
| *Chromolaena (Eupatorium) odorata* (Compositae*)* | Siam weed, triffid weed | herb | |
| *Clerodendrum paniculatum* (Verbenaceae) | Pagoda flower | shrub | |
| *Lantana camara* (Verbenaceae) | Lantana | thorny shrub | |
| *Leucaena leucocephala* (Leguminosae) | Wild tamarind, Lead tree | small tree | |
| *Melinis minutiflora* (Gramineae) | Molasses grass | grass | |
| *Merremia peltata* (Convolvulaceae*)* | Merremia | vine | (Palau) |
| *Mimosa invisa* (Leguminosae) | Giant sensitive plant, Spiny mimosa | thorny shrub | |
| *Panicum repens* (Graminaeae) | Torpedo grass | grass | |
| *Paspalum conjugatum* (Gramineae) | T-grass, Sour paspalum | grass | |
| *Pennisetum polystachyon* (Gramineae) | Mission grass | grass | |
| *Pennisetum purpureum* (Gramineae) | Elephant grass | grass | |
| *Psidium cattleianum* (Myrtaceae) | Strawberry/Chinese guava | small tree | (Koror) |
| *Timonius timon* (Rubiaceae) | Liberal | tree | (Peleliu, Anguar) |

| Scientific name (Family name) | Common name(s) | Habit/ Life form | Habitat (and Locations) |
|---|---|---|---|
| **Dominant invaders** | | | |
| *Wedelia (Sphagneticola) trilobata* (Compositae) | Wedelia, Singapore daisy | herb | |
| **Moderate invaders** | | | |
| *Kalanchoe pinnata* (Crassulaceae) | Air plant, Mexican love plant | succulent | |
| *Passiflora foetida* (Passifloraceae) | Stinking passionflowwer | vine | secondary |
| *Pluchea indica* (Compositae) | Indian fleabane | shrub | (Peleliu, Anguar) |
| *Paraserianthes (Albizia) falcataria* (Leguminosae) | Molucca albizia | large tree | |
| *Psidium guajava* (Myrtaceae) | Common guava | small tree | (Palau) |
| *Stachytarpheta urticifolia* (Verbenaceae) | Blue rat's tail, Dark blue snakeweed | herb | |
| **Potential invaders** | | | |
| *Acacia auriculiformis* (Leguminosae) | | | |
| *Acacia confusa* (Leguminosae) | | | |
| *Antigonon leptotus* (Polygonaceae) | Mexican creeper, Chain of love | vine | |
| *Cinnamomum verum (zeylanicum)* (Lauraceae) | Cinnamon tree | tree | |
| *Clerodendrum quadriloculare* (Verbenaceae) | Bronze-leaved clerodendrum | shrub | |
| *Clidemia hirta* (Melastomataceae) | Koster's curse | shrub | (Babeldaob) |
| *Clitoria ternatea* (Leguminosae) | Butterfly pea, Blue pea | vine | |
| *Ficus microcarpa* (Moraceae) | Chinese banyan, Indian laurel | large tree | |
| *Hedychium coronarium* (Zingiberaceae) | White ginger | erect herb | |
| *Imperata cylindrica* (Gramineae) | Cogon/Cotton grass | grass | |
| *Syzygium (Eugenia) cumini* (Myrtaceae) | Java plum, Jambolan | large tree | |
| *Syzygium(Eugenia) jambos* (Myrtaceae) | Rose apple | tree | |

### *Main references*


Canfield, J.E. 1981. Palau: diversity and status of the native vegetation of a unique Pacific island ecosystem. *Newsletter of the Hawaiian Botanical Society* 20: 14–20.

Space, J.; Falanruw, M.C. 1999. Observations on invasive plant species in Micronesia. Ms prepared for meeting of Pacific Island Committee Council of Western States Foresters, Majuro, Marshall Islands.

Whistler, W.A. 1995. *Wayside Plants of the Pacific Islands. A guide to the lowland flora of the Pacific Islands*. Isle Botanica, Honolulu.


### *Academic/local experts consulted*

Dr Tim Flynn; Dr David H. Lorence, National Tropical Botanical Garden, 3530 Papalina Road, Kalaheo, Kaua'i, Hawaii 96741, USA.

Jim Space, Project Manager, Pacific Island Ecosystem at Risk Project (PIER), 11007 E. Regal Dr., Sun Lakes, Arizona 85248-7919, USA.

## Pitcairn Islands

### *Preliminary list of invasive plants*

| Scientific name (Family name) | Common name(s) | Habit/ Life form | Habitat (and Locations) |
|---|---|---|---|
| **Dominant invaders** | | | |
| *Canna indica* (Cannaceae) | Canna lily, Indian shot | herb | secondary forest gaps (Pitcairn) |
| *Lantana camara* (Verbenaceae) | Lantana | thorny shrub | forest, fernland (Pitcairn, Oeno) |
| *Psidium guajava* (Myrtaceae) | Common guava | tree | secondary scrub |
| *Syzygium (Eugenia) jambos* (Myrtaceae) | Rose apple | tree | forest (Pitcairn) |
| *Sorghum sudanense* (Gramineae) | Sudan grass | tall grass | grassland, fernland (Pitcairn) |
| **Moderate invaders** | | | |
| *Aleurites moluccana* (Euphorbiaceae) | Candelnut oil tree | tree | |
| *Eugenia uniflora* (Myrtaceae) | Surinam cherry | | gardens (Pitcairn) |
| *Leucaena leucocephala* (Leguminosae) | Wild tamarind, Lead tree | small tree | gardens |
| *Crinum asiaticum* (Liliaceae) | - | tall herb | cliff and steep slopes (Pitcairn) |

| Scientific name (Family name) | Common name(s) | Habit/ Life form | Habitat (and Locations) |
|---|---|---|---|
| **Moderate invaders** | | | |
| *Paspalum conjugatum* (Gramineae) | T-grass, Sour paspalum | grass | secondary scrub (Pitcairn) |
| *Passiflora maliformis* (Passifloraceae) | Hard-shelled passionfruit | vine | forest edges (Pitcairn) |
| *Psidium cattleianum* (Myrtaceae) | Strawberry/Chinese guava | small tree | (Pitcairn) |
| **Potential invaders** | | | |
| *Carpobrotus edulis* (Aizoaceae) | Pigface | succulent | cliffs (Pitcairn) |
| *Ipomoea indica* (Convolvulaceae) | - | vine | (Pitcairn) |
| **Lonicera japonica* (Caprifoliaceae) | Japanese honeysuckle | vine | gardens (Pitcairn) |
| *Persea americana* (Lauraceae) | Avocado | tree | secondary forest (Pitcairn) |
| *Lablab purpureus (Dolichos lablab)* (Leguminosae) | Lablab, Hyacinth bean | vine | (Pitcairn) |
| *Passiflora laurifolia* (Passifloraceae) | Yellow granadilla | vine | (Pitcairn) |

*** tending to escape, but not fully naturalised (Florence et al. 1995: 102)

### *Main references*

Binggeli, P.; Starmer, J. 1997. Pitcairn Islands. *Aliens* N°6:2.

Binggeli, P. 1997. Pitcairn Island. Poster presented at the 4th International Conference on Invasive Plants, Berlin.

Fosberg, F.R.; Sachet, M.-H.; Stoddart, D.R. 1983. Henderson island (Southeastern Polynesia): summary of current knowledge. *Atoll Research Bulletin* N°272. The Smithsonian Institution, Washington DC.

Florence, J.; Waldren, S.; Chepstow-Lusty, A.J. 1995. The flora of Pitcairn Islands: a review. *Biological Journal of the Linnean Society* 56: 79–119.

St John, H.; Philipson, W.R. 1962. An account of the flora of Henderson Island, South Pacific Ocean. *Transactions Royal Society of New Zealand, Botany* 1(14): 175–194.

Waldren, S.; Florence, J.; Chepstow-Lusty, A.J. 1995. Rare and endemic vascular plants of the Pitcairn Islands, South-Central Pacific Ocean: a conservation appraisal. *Biological Conservation* 74: 83–98.

### *Academic/local experts consulted*

Dr Pierre Binggeli, ABCS, University of Ulster, Coleraine BT52 1SA, Northern Ireland.

Dr Jacques Florence, Antenne IRD (ex ORSTOM), Laboratoire de Phanérogamie, Muséum national d'Histoire naturelle, 16 rue Buffon, 75005 Paris, France.

## Samoa and American Samoa

### *Preliminary list of invasive plants*

| Scientific name (Family name) | Common name(s) | Habit/ Life form | Habitat (and Locations) |
|---|---|---|---|
| **Dominant invaders** | | | |
| *Albizia chinensis* (Leguminosae) | - | large tree | |
| *Castilla elastica* (Moraceae) | Panama/Mexican rubber tree | tree | |
| *Cestrum nocturnum* (Solanaceae) | Night-blooming jasmine, Night cestrum | shrub | |
| **Clerodendrum chinense (philippinum)* (Verbenaceae) | Honolulu rose, Glory bower | shrub | |
| *Clidemia hirta* (Melastomataceae) | Koster's curse | shrub | |
| *Funtumia elastica* (Apocynaceae) | African rubber tree | tree | (Samoa) |
| *Ischaemum timorense* (Gramineae) | - | grass | |
| **Mimosa invisa* (Leguminosae) | Giant sensitive plant, Spiny mimosa | thorny shrub | |
| *Mikania micrantha* (Compositae) | Mile-a-minute | vine | |
| *Paspalum conjugatum* (Gramineae) | T-grass, Sour paspalum | grass | |
| *Passiflora laurifolia* (Passifloraceae) | Yellow granadilla | vine | |
| **Moderate invaders** | | | |
| *Adenanthera pavonina* (Leguminosae) | Red bead tree, Red sandalwood | tree | |
| *Albizia (Samanea) saman* (Leguminosae) | Rain-tree, Monkey pod, Saman tree | large tree | |
| *Cinnamomum verum (zeylanicum)* (Lauraceae) | Cinnamon tree | tree | |
| **Lantana camara* (Verbenaceae) | Lantana | thorny shrub | |
| *Leucaena leucocephala* (Leguminosae) | Wild tamarind, Lead tree | small tree | |

| Scientific name (Family name) | Common name(s) | Habit/ Life form | Habitat (and Locations) |
|---|---|---|---|
| **Moderate invaders** | | | |
| **Opuntia vulgaris* (Cactaceae) | Prickly pear | succulent | |
| *Passiflora foetida* (Passifloraceae) | Stinking passionfruit, Love-in-the mist | vine | |
| *Psidium guajava* (Myrtaceae) | Common guava | small tree | |
| *Spathodea campanulata* (Bignoniaceae) | African tulip tree | large tree | |
| *Stachytarpheta urticifolia* (Verbenaceae) | Blue rat's tail, Dark blue snakeweed | herb | |
| *Thunbergia alata* (Acanthaceae) | Black-eyed Susan | vine | |
| **Potential invaders** | | | |
| *Alpinia purpurata* (Zingiberaceae) | Red ginger | herb | |
| *Arundo donax* (Gramineae) | Giant reed | tall grass | |
| ***Bauhinia monandra* (Leguminosae) | Bauhinia | tree | |
| ***Cestrum diurnum* (Solanaceae) | Day cestrum, China inkberry | shrub | |
| *Plectranthus (Coleus) amboinicus* (Labiatae) | - | herb | |
| *Fucraea gigantea* (Agavaceae) | Cuban hemp | succulent | |
| *Hedychium flavescens* (Zingiberaceae) | Yellow ginger | erect herb | |
| *Paraserianthes (Albizia) falcataria* (Leguminosae) | Molucca albizia | large tree | |
| *Psidium cattleianum (littorale)* (Myrtaceae) | Strawberry guava | small tree | |
| *Solanum torvum* (Solanaceae) | Prickly solanum | shrub | (Samoa) |
| *Syzygium (Eugenia) jambos* (Myrtaceae) | Rose apple | tree | |

* proclaimed a noxious weed (Parham 1972)

** growing as an escape according to literature (Parham1972) but not verified by local/academic expert (pers. comm. 27 May 1999)

### *Main references*


Amerson, A.B. Jr.; Whistler, W.A.; Schwaner, T.D. 1982. *In* Banks, R.C. (ed.) Wildlife and Wildlife Habitat of American Samoa. I. Environment and Ecology. Fish and Wildlife Service, US Department of the Interior, Washington, DC.

Amerson, A.B. Jr.; Whistler, W.A.; Schwaner, T.D. 1982. *In* Banks, R.C. (ed.) Wildlife and Wildlife Habitat of American Samoa. II. Accounts of flora and fauna. Fish and Wildlife Service, US Department of the Interior, Washington, DC.

Christophersen, E. 1935 (1971). Flowering plants of Samoa. I. *Bernice P. Bishop Museum Bulletin* 128. Kraus Reprint Co., New York.

Christophersen, E. 1938 (1971). Flowering plants of Samoa. II. *Bernice P. Bishop Museum Bulletin* 154. Kraus Reprint Co., New York.

Henson, B. (ed.) 1994. Western Samoa. National Environment and Development Management Strategies. SPREP/UNDP.

Parham, B.E.V. 1972. Plants of Samoa. A guide to their local and scientific names with authorities; with notes on their uses, domestic, traditional and economic. New Zealand Department of Scientific and Industrial Research, Wellington.

Whistler, W.A. 1978. Vegetation of the montane region of Sava'i, Western Samoa. *Pacific Science* 32(1): 79–94.

Whistler, W.A. 1980. The vegetation of Eastern Samoa. *Allertonia* 2(2): 45–190.

Whistler, W.A. 1994. Botanical inventory of the proposed Tutuila and Ofu units of the National Park of American Samoa. *University of Hawaii Cooperative National Park Research Studies Unit, Technical Report* 87.

Whistler, W.A. 1998. Weeds of Samoa. *Aliens* N°7: 8–9.


### *Academic/local experts consulted*

Dr W. Arthur Whistler, Isle Botanica, Botanical Consultants and Book Publishers, 500 University Ave., #1601, Honolulu, Hawaii 96826, USA.

## Tonga

### *Preliminary list of invasive plants*

| Scientific name (Family name) | Common name(s) | Habit/ Life form | Habitat (and Locations) |
|---|---|---|---|
| **Dominant invaders** | | | |
| *Lantana camara* (Verbenaceae) | Lantana | thorny shrub | grassland |
| *Leucaena leucocephala* (Leguminosae) | Wild tamarind, Lead tree | small tree | |
| *Mikania micrantha* (Compositae) | Mile-a-minute | vine | |
| *Panicum maximum* (Gramineae) | Guinea grass | grass | (Tongatapu) |

| Scientific name (Family name) | Common name(s) | Habit/ Life form | Habitat (and Locations) |
|---|---|---|---|
| **Dominant invaders** | | | |
| *Paspalum conjugatum* (Gramineae) | T-grass, Sour paspalum | grass | secondary forest |
| *Psidium guajava* (Myrtaceae) | Common guava | tree | |
| *Tradescantia (Rhoeo) discolor (spathacea)* (Commelinaceae) | Boat lily | herb | coastal forest |
| **Moderate invaders** | | | |
| *Adenanthera pavonina* (Leguminosae) | Red beadtree, Red sandalwood | small tree | secondary + primary forest ('Eua, Vava'u, Tongatapu) |
| *Cyperus rotundus* (Cyperaceae) | Nut-grass, Coco grass | sedge | |
| *Indigofera suffruticosa* (Leguminosae) | - | shrub | |
| *Senna (Cassia) tora* (Leguminosae) | Foetid cassia, Peanut weed | shrub | |
| *Sorghum sudanense* (Gramineae) | Sudan grass | grass | |
| *Stachytarpheta urticifolia* (Verbenaceae) | Blue rat's tail, Dark blue snakeweed | herb | |
| *Tecoma stans* (Bignoniaceae) | Yellow bells, Yellow elder | small tree | |
| *Wedelia (Sphagneticola) trilobata* (Compositae) | Wedelia, Singapore daisy | herb | |
| **Potential invaders** | | | |
| *Canna indica* (Cannaceae) | Canna lily, Indian shot | herb | |
| *Clerodendrum buchananii* var. *fallax* (Verbenaceae) | Pagoda flower | shrub | |
| *Clerodendrum chinense (philippinum)* (Verbenaceae) | Honolulu rose, Glory bower | shrub | |
| *Melinis minutiflora* (Gramineae) | Molasses grass | grass | |

### *Main references*

Drake, D.R.; Whistler, W.A.; Motley, T.J.; Imada, C.T. 1996. Rain forest vegetation of 'Eua Island, Kingdom of Tonga. *New Zealand Journal of Botany* 34: 65–77.

Franklin, J.; Drake, D.R.; Bolick L.A.; Smith D.S.; Motley, T.J. 1999. Rain forest composition and patterns of secondary succession in the Vava'u island Group, Tonga. *Journal of Vegetation Science* 10: 51–64.

Sykes, W.R. 1981. The vegetation of Late, Tonga. *Allertonia* 2(6) : 323-353.

Waterhouse, D.F. 1997. The major invertebrate pests and weeds of agriculture and plantation forestry in the Southern and Western Pacific. Australian Centre for International Agriculture Research (ACIAR), Canberra.

Whistler, W.A. 1992. Vegetation of Samoa and Tonga. *Pacific Science* 46(2): 159–178.

Yuncker, T.G. 1959. Plants of Tonga. *Bulletin Bernice P. Bishop Museum* 220: 1–283.

### *Academic/local experts consulted*

Dr Donald R. Drake, School of Biological Sciences, Victoria University of Wellington, PO Box 600, Wellington, New Zealand.

Professor Janet Franklin, Department of Geography, Mail Code 4493, San Diego State University, 5500 Campanile Drive, San Diego, CA 92182-4493, USA.

Dr Randolph R. Thaman, Professor of Pacific Islands Biogeography, Department of Geography, University of the South Pacific, PO Box 1168, Suva, Fiji.

## Vanuatu

### *Preliminary list of invasive plants*

| Scientific name (Family name) | Common name(s) | Habit/ Life form | Habitat (and Locations) |
|---|---|---|---|
| **Dominant invaders** | | | |
| *Cordia alliodora* (Boraginaceae) | Ecuador laurel, Salmwood | tree | |
| *Eichhornia crassipes* (Pontederiaceae) | Water hyacinth | aquatic herb | |
| *Heteropogon contortus* (Gramineae) | | grass | |
| *Imperata cylindrica* (Gramineae) | Cogon/Cotton grass | grass | |
| *Lantana camara* (Verbenaceae) | Lantana | thorny shrub | |
| *Leucaena leucocephala* (Leguminosae) | Wild tamarind, Lead tree | small tree | |
| *Merremia peltata* (Convolvulaceae) | Merremia | vine | forest margins |
| *Mikania micrantha* (Compositae) | Mile-a-minute | vine | forest margins |
| *Panicum maximum* (Gramineae) | Guinea grass | grass | |
| *Paspalum conjugatum* (Gramineae) | T-grass, Sour paspalum | grass | |
| *Salvinia molesta* (Salviniaceae) | Salvinia, Water fern, Kariba weed | aquatic fern | |

| Scientific name (Family name) | Common name(s) | Habit/ Life form | Habitat (and Locations) |
|---|---|---|---|
| **Moderate invaders** | | | |
| *Acacia farnesiana* (Leguminosae) | Ellington's curse, Cassie | shrub | |
| *Fucraea foetida* (Agavaceae) | Mauritian hemp | succulent | dry lowlands |
| *Psidium guajava* (Myrtaceae) | Common guava | tree | |
| *Senna (Cassia) tora* (Leguminosae) | Foetid cassia, Peanut weed | tree | |
| *Spathodea campanulata* (Bignoniaceae) | African tulip tree | large tree | |
| *Tithonia diversifolia* (Compositae) | Mexican sunflower, Tree marigold | herb | |
| **Potential invaders** | | | |
| *Clidemia hirta* (Melastomataceae) | Koster's curse | shrub | |

### *Main references*


Schmid, M. 1978. The Melanesia forest ecosystems (New Caledonia, New Hebrides, Fiji islands and Solomon islands). Pp. 654–683 *in Tropical Forest Ecosystems*. UNESCO, Paris.

Terry, P.J. 1982. Appraisal of weed problems in the Republic ofVanuatu 28 February–14 March, 1982. ARC Weed Research Organization, Internal Report n°149.

Tolfts, A. 1997. *Cordia alliodora*: the best laid plans... *Aliens* 6: 12–13.

Waterhouse, D.F.; Norris, K.R. 1997. *Biological Control Pacific Prospects*. Australian Centre for International Agricultural Research, Inkata Press, Melbourne.

Whitmore, T.C. 1969. The vegetation of the Solomon Islands. *Philosophical Transactions of the Royal Society of London, Series B, 255*: 259–270.


### *Academic/local experts consulted*

Sam Chanel, Herbarium curator, Department of Forestry, PMB 064, Vanuatu.

Dr Matthew J. D. Cock, Weed Biological Control Programme Leader, CABI Bioscience, Silwood Park, Buckhurst Road, Ascot, Berks SL5 7TA, UK.

Dr Maurice Schmid, Laboratoire de Phanérogamie, Muséum national d'Histoire naturelle, 16 rue Buffon, 75005 Paris, France.

Dr John Terry, Head, Tropical Weeds Unit, Long Ashton Research Station, Bristol BS41 9AF, UK.

## Wallis and Futuna

### *Preliminary list of invasive plants*

| Scientific name (Family name) | Common name(s) | Habit/ Life form | Habitat (and Locations) |
|---|---|---|---|
| **Dominant invaders** | | | |
| *Clidemia hirta* (Melastomataceae) | Koster's curse | shrub | dense forest |
| *Melinis minutiflora* (Gramineae) | Molasses grass | grass | fernlands |
| *Merremia peltata* (Convolvulaceae) | Merremia | vine | forest edge |
| *Mikania micrantha* (Compositae) | Mile-a-minute | vine | secondary forest |
| **Moderate invaders** | | | |
| *Leucaena leucocephala* (Leguminosae) | Wild tamarind, Lead tree | small tree | secondary vegetation |
| *Paspalum conjugatum* (Gramineae) | T-grass, Sour paspalum | grass | wetland |
| *Passiflora foetida* (Passifloraceae) | Stinking passionflower, Love-in-a-mist | vine | secondary forest |
| *Spathodea campanulata* (Bignoniaceae) | African tulip tree | large tree | |
| **Potential invaders** | | | |
| **Cestrum nocturnum* (Solanaceae) | Night cestrum, Night-blooming jasmine | shrub | secondary forest, lowland dense forest (in Futuna only) |
| *Jatropha curcas* (Euphorbiaceae) | Purging nut | | lowland dense forest |
| *Lantana camara* (Verbenaceae) | Lantana | thorny shrub | gardens, secondary vegetation |
| *Paraserianthes (Albizia) falcataria* (Leguminosae) | Molucca albizia | tree | |
| *Paspalum orbiculare* (Gramineae) | - | grass | grasslands and wetlands |
| *Physalis angulata (minima)* (Solanaceae) | Wild cape-gooseberry | herb | gardens, secondary vegetation |
| *Psidium guajava* (Myrtaceae) | Common guava tree | small tree | lowlands |
| *Sorghum halepense* (Gramineae) | Johnson grass | grass | roadsides (in Wallis only) |
| *Stachytarpheta urticifolia* (Verbenaceae) | Blue rat's tail, Dark blue snakeweed | shrub | secondary vegetation |

* In the literature (Morat and Veillon 1985), but not verified by local experts (pers.comm. 30 June 1999).

***Main references***

Hoff, M.; Brisse, H. 1990. Contribution à l'étude des groupements végétaux des Iles Wallis et Futuna. *Document phytosociologique, N.S.*, vol. XII.

Morat, P.; Veillon, J.-M.; Hoff, M. 1983. Introduction à la végétation et à la flore du Territoire de Wallis et Futuna. Rapport de missions botaniques effectuées dans ce territoire en 1981–1982, Centre ORSTOM de Nouméa.

Morat, P.; Veillon, J.-M. 1985. Contribution à la connaissance de la végétation et de la flore de Wallis et Futuna. *Bulletin Muséum national d' Histoire naturelle, Paris, 4e sér., 7, section B, Adansonia*, n°3: 259–329.

Waterhouse, D.F. 1997. The major invertebrate pests and weeds of agriculture and plantation forestry in the Southern and Western Pacific. Australian Centre for International Agriculture Research (ACIAR), Canberra.

***Academic/local experts consulted***

Frédéric Dupuy, Enseignant, Lycée de Mata'Utu, 98600 Uvea, Wallis & Futuna.

Dr. Michel Hoff, IRD (ex ORSTOM), Service du Patriomoine Naturel, Institut d'Ecologie et de Gestion de la Biodiversité, Muséum national d'Histoire naturelle, 57 rue Cuvier, F-75231 Paris Cedex 05, France.

Atloto Malau, Service Territorial de l'Economie Rurale, B.P. 19 Mata'Utu, 98600 Uvea, Wallis & Futuna.

Paino Vanai, Service Territorial de l'Environnement, B.P. 294 Mata'Utu, 98600 Uvea, Wallis & Futuna.

# 4. DISCUSSION

## 4.1 Dominant plant invaders in most of the Pacific islands

Among the most significant dominant invasive taxa which are found in most of the islands studied (dominant in at least 3 island groups, $D \geq 3$, and dominant plus moderate in at least 7 islands, $D + M \geq 7$, shown in bold in Table 1) are the trees *Adenanthera pavonina*, *Leucaena leucocephala*, *Psidium* spp. (*P. cattleianum* and *P. guajava*), *Spathodea campanulata*, and *Syzygium* spp. (mainly *S. cumini* and *S. jambos*); the thorny shrubs *Lantana camara*, *Mimosa invisa*, and *Rubus spp*. (mainly *R. moluccanus* and *R. rosifolius*), the ornamental shrubs *Clerodendrum* spp., and the erect herbs *Hedychium* spp.; the climbing vines *Merremia peltata, Mikania micrantha* and *Passiflora* spp.; the grasses *Panicum* spp. (*P. maximum* and *P. repens*), *Paspalum* spp. (especially *P. conjugatum*), and *Pennisetum* spp. (mainly *P. polystachyon* and *P. purpureum*); the creeping herb *Wedelia (Sphagneticola) trilobata*; and the aquatic plant *Eichhornia crassipes*. Other significant aggressive species found in most of the islands studied ($D < 3$ and $D + M \geq 7$) include the trees *Albizia* spp. (especially *A. lebbeck*); the shrubs *Stachytarpheta* spp. (*S. urticifolia* and *S. jamaicensis*); and the trees *Acacia* spp. (especially *A. farnesiana*). (These species are also shown in bold in Table 1.)

Most, if not all, of these species are known to be invasive in other tropical island or countries (e.g. *Acacia farnesiana* in Australia and the West Indies; *Hedychium* spp., in the Mascarenes, New Zealand and South Africa; *Clidemia hirta* and *Syzygium jambos* in the Mascarenes and the Seychelles; *Passiflora mollissima* in New Zealand and South Africa; *Pennisetum purpureum* in Galapagos, Haiti and South Africa; *Pennisetum clandestinum* in New Zealand and South Africa; *Psidium cattleianum* in the Mascarenes and New Zealand).

Among the dominant invasive taxa which are found in some Pacific islands only (not bold in Table 1), *Clidemia hirta* is known to be highly invasive in the Mascarenes and widely naturalised in Malaysia; *Tecoma stans* is considered as a noxious plant species in South Africa; *Melinis minutiflora* is invasive in the Galapagos and the Ascension Islands; and *Ardisia elliptica* is an aggressive invader in the Mascarenes and the Seychelles.

## 4.2 Dominant plant invaders in a few Pacific islands

Special attention is drawn to very aggressive plant species found only in one or a few islands ($D + M \leq 2$) and which have not been introduced to the other Pacific islands yet (or are at least not naturalised). They include *Cardiospermum grandiflorum* in the Cook islands, *Castilloa elastica* in the Samoas, *Cordia alliodora* in Vanuatu, *Miconia calvescens* in French Polynesia and Hawaii, *Myrica faya* in Hawaii, *Piper aduncum* in Fiji, *Timonius timon* in Palau (Table 2). *Miconia calvescens*, also called the "purple plague" in Hawaii or the "green cancer" in Tahiti, a tree native to tropical America and introduced as an ornamental, is now considered to be "by far the most effective and destructive competitor of all native and established wet forest plants" in the Pacific islands (Mueller-Dombois and Fosberg 1998: 412) and "the worst of all exotic escapees" (Whittaker 1998: 244). Other island-restricted invasive species such as *Antigonon leptotus* in Guam, *Elaeis guineensis* in Pohnpei, *Kalanchoe pinnata* in Palau, or *Ocimum gratissimum* are found in other Pacific islands where they are planted as garden ornamentals or are sparingly naturalised.

***Table 1. List and classification of the 33 most significant invasive taxa in most Pacific islands studied.****

| Scientific name (Family name) | D | M | D + M |
|---|---|---|---|
| ***Lantana camara* (Verbenaceae)** | **14** | **1** | **15** |
| ***Leucaena leucocephala* (Leguminosae)** | **13** | **3** | **16** |
| ***Pennisetum* spp. *(P. clandestinum, P. polystachyon, P. purpureum, P. setaceum)* (Gramineae)** | **11** | **2** | **13** |
| ***Psidium* spp. *(P. guajava + P. cattleianum)* (Myrtaceae)** | **6 + 4** | **5 + 1** | **16** |
| ***Mikania micrantha* (Compositae)** | **8** | **0** | **8** |
| ***Paspalum* spp. *(P. conjugatum, P. distichum, P. urvillei)* (Gramineae)** | **7** | **6** | **13** |
| ***Mimosa invisa* (Leguminosae)** | **7** | **2** | **9** |
| ***Merremia peltata* (Convolvulaceae)** | **7** | **0** | **7** |
| ***Adenanthera pavonina* (Leguminosae)** | **5** | **2** | **7** |
| ***Clerodendrum* spp. *(C. chinense, C. japonicum, C. paniculatum, C. quadriloculare)* (Verbenaceae)** | **5** | **2** | **7** |
| ***Passiflora* spp. *(P. foetida, P. laurifolia, P. ligularis, P. mollissima, P. quadrangularis, P. rubra)* (Passifloraceae)** | **4** | **10** | **14** |
| ***Rubus* spp. *(R. argutus, R. ellipticus, R. glaucus, R. moluccanus, R. nivalis, R. rosifolius)* (Rosaceae)** | **4** | **6** | **10** |
| ***Syzygium* spp. *(S. cumini, S. floribundum, S. jambos)* (Myrtaceae)** | **4** | **4** | **8** |
| ***Panicum* spp. *(P. maximum + P. repens)* (Gramineae)** | **3 + 1** | **3 + 0** | **7** |
| *Eichhornia crassipes* (Pontederiaceae) | 4 | 3 | 7 |
| *Paraserianthes (Albizia) falcataria* (Leguminosae) | 4 | 2 | 6 |
| *Clidemia hirta* (Melastomataceae) | 4 | 0 | 4 |
| ***Acacia* spp. *( A. confusa, A. farnesiana, A. mearnsii, A. melanoxylon, A. spirorbis)* (Leguminosae)** | **3** | **5** | **8** |
| ***Spathodea campanulata* (Bignoniaceae)** | **3** | **5** | **8** |
| ***Hedychium* spp. *(H. coronarium, H. flavescens, H. gardnerianum)* (Zingiberaceae)** | **3** | **4** | **7** |
| ***Wedelia*** *(Sphagneticola)* ***trilobata* (Compositae)** | **3** | **4** | **7** |
| *Melinis minutiflora* (Gramineae) | 3 | 2 | 5 |
| *Sorghum* spp. *(S. halepense + S. sudanense)* (Gramineae) | 2 + 1 | 1 + 1 | 5 |
| *Chromolaena (Eupatorium) odorata* (Compositae) | 3 | 1 | 4 |
| *Ardisia elliptica (humilis)* (Myrsinaceae) | 3 | 0 | 3 |
| *Ischaemum* spp. *(I. polystachyum var. chordatum, I. timorense)* (Gramineae) | 3 | 0 | 3 |
| ***Albizia* spp. *(A. chinensis, A. lebbeck, A. saman)* (Leguminosae)** | **2** | **6** | **8** |
| *Cestrum* spp. *(C. diurnum + C. nocturnum)* (Solanaceae) | 2 + 0 | 2 + 1 | 5 |
| *Cecropia* spp. *(C. obtusifolia, C. peltata)* (Cecropiaceae) | 2 | 1 | 3 |
| *Coccinia grandis* (Cucurbitaceae) | 2 | 1 | 3 |
| *Imperata cylindrica* (Gramineae) | 2 | 0 | 2 |
| *Tecoma stans* (Bignoniaceae) | 1 | 4 | 5 |
| *Stachytarpheta* spp. *(S. urticifolia + S. jamaicensis)* | 1 + 0 | 7 + 1 | 9 |

*By order of the number of island countries where the plant is considered to be dominant, D, followed by the total number of island countries where the plant is considered to be dominant and moderate, D + M > 2.

## 4.3 Potential invasive plants in Pacific islands

Among the 30 and more potential invasive plants in the Pacific islands (i.e. known to be highly invasive elsewhere), sometimes locally naturalised but not yet perceived to be widespread and dominant (Table 3), are the rubber vine *Cryptostegia grandiflora*, the coco-plum *Chrysobalanus icaco,* the quinine tree *Cinchona pubescens*, the cinnamon tree *Cinnamomum verum (zeylanicum)*, the privets *Ligustrum* spp., the ornamental shrub *Sanchezia speciosa*, the wild tobacco *Solanum mauritianum*, and the Bengal trumpet vine *Thunbergia grandiflora*. These are known to be serious invaders in other tropical islands (Galapagos, Mascarenes, Mayotte, Seychelles, St Helena) or tropical countries (Australia, Florida, South Africa, Singapore). All of them have been introduced intentionally to many Pacific islands and should be closely watched.

***Table 2. Other significant dominant invasive plants found in some Pacific islands only (D + M ≤ 2)***

| **Scientific name (Family name)** | **SPREP island countries where species is considered to be dominant (+ moderate)** | **Other tropical countries or islands where considered to be an aggressive invader** |
|---|---|---|
| *Andropogon virginicus* (Gramineae) | Hawaii | |
| *Annona glabra* (Annonaceae) | Fiji (+French Polynesia) | Cape York (Australia) |
| *Antigonon leptotus* (Polygonaceae) | Guam | Australia, Galapagos, Mayotte (Indian Ocean) |
| *Canna indica* (Cannaceae) | Pitcairn Islands | |
| *Cardiospermum grandiflorum* (Sapindaceae) | Cook Islands | Queensland (Australia) |
| *Castilloa elastica* (Moraceae) | Samoa | |
| *Cordia alliodora* (Boraginaceae) | Vanuatu | |
| *Elaeis guineensis* (Palmae) | Pohnpei | |
| *Funtumia elastica* (Apocynaceae) | Samoa | |
| *Heteropogon contortus* (Gramineae) | New Caledonia, Vanuatu | |
| *Hydrilla verticillata* (Hydrocharitaceae) | Fiji | Florida (USA) |
| *Kalanchoe pinnata* (Crassulaceae) | Palau (+ French Polynesia, Hawaii) | Galapagos |
| *Miconia calvescens* (Melastomataceae) | French Polynesia, Hawaii | |
| *Myrica faya* (Myricaceae) | Hawaii | |
| *Ocimum gratissimum* (Labiatae) | New Caledonia (+ French Polynesia) | |
| *Piper aduncum* (Piperaceae) | Fiji | |
| *Rhodomyrtus tomentosa* (Myrtaceae) | Hawaii (+ French Polynesia) | Florida (USA) |
| *Salvinia molesta* (Salviniaceae) | New Caledonia, Vanuatu | Queensland (Australia), South Africa |
| *Schinus terebinthifolius* (Anacardiaceae) | Hawaii | Florida (USA), Mascarenes (Indian Ocean), S. Africa |
| *Tibouchina herbacea* (Melastomataceae) | Hawaii | |
| *Timonius timon* (Rubiaceae) | Palau | |
| *Tradescantia (Rhoeo) discolor* (Commelinaceae) | Tonga | Florida (USA) |

## 4.4 Types of habitats susceptible to invasion

All the vegetation types in the Pacific Islands are susceptible to invasion (Table 4). Most of the dominant invasive plants listed previously are found in secondary vegetation, mainly in the dry lowlands (e.g. *Lantana camara*, *Leucaena leucocephala*, *Psidium guajava*) and the mesic habitats (e.g. *Adenanthera pavonina*, *Spathodea campanulata*). The creeping vines *Merremia peltata* and *Mikania micrantha*, and the thorny shrub *Mimosa diplotricha* prefer disturbed habitats and openings, but they can also invade forest gaps and margins.

Less-disturbed natural habitats with high ecological importance and conservation values are also prone to invasion (e.g. the mangrove forests are threatened by *Annona glabra* in Fiji, the cloudforests of Tahiti by *Miconia calvescens* and *Rubus rosifolius*). Taxa that are able to penetrate the native montane forests, such as *Cestrum* spp., *Clidemia hirta*, *Passiflora mollissima*, *Psidium cattleianum*, *Rubus* spp., *Syzygium* spp. or the grass *Melinis minutiflora*, should be of highest concern for prevention and management plans.

Extreme environments such as alpine cold zone and coastal dry and salted zones are considered as less susceptible to invasion. However, some alien plants, such as *Casuarina* spp. or *Pluchea* spp. have been documented to colonise atolls and low corallous islands. Likewise, although exotic species generally do not have the capacity to grow on ultrabasic soils (Schmid 1989), in New Caledonia the introduced *Pinus caribaea* is one of the few species which is able to colonise these soils, even where the native vegetation has not been destroyed (Morat et al. 1999).

## 4.5 Bio-ecological characteristics of invasive plants

Most of the successful plant invaders produce fleshy fruits (berries or drupes), actively dispersed by animals, mainly frugivorous birds, pigs and rats (e.g. *Ardisia elliptica*, *Clidemia hirta*, *Lantana camara*, *Miconia calvescens*, *Passiflora mollissima* or *Psidium cattleianum*); other aggressive alien plants have spiny or sticky dry fruits (e.g. *Mimosa invisa*) dispersed by animals on hairs, on people's clothing and with vehicles, or by wind-dispersed seeds (e.g. *Spathodea campanulata*, *Tecoma stans*, *Mikania*

***Table 3. Other potential aggressive invaders in the Pacific islands***

| Scientific name (Family name) | Tropical countries where considered to be an aggressive invader | Pacific island countries where a Potential or a Moderate invasive plant |
|---|---|---|
| *Agave sisalana* (Agavaceae) | South Africa | Fiji, French Polynesia, Hawaii |
| *Arundo donax* (Gramineae) | New Zealand | Fiji, Hawaii, New Caledonia, Samoas |
| *Caesalpinia decapetala (sepiaria)* (Leguminosae) | S. Africa, East Africa, New Zealand | Fiji, French Polynesia, Hawaii, New Caledonia |
| *Casuarina glauca* (Casuarinaceae) | Florida (USA), New Zealand | Hawaii |
| *Cedrela odorata* (Meliaceae) | Galapagos | Hawaii, New Caledonia, Yap |
| *Cinnamomum camphora* (Lauraceae) | Florida, Queensland (Australia), South Africa | Hawaii |
| *Cinnamomum verum (zeylanicum)* (Lauraceae) | Mayotte (Indian Ocean), Seychelles | Cook Is, Pohnpei (FSM), Hawaii, Samoas |
| *Cortaderia jubata* (Gramineae) | California, New Zealand, South Africa | Hawaii |
| *Cryptostegia grandiflora* (Asclepiadaceae) | Cape York (Australia) | Fiji, Hawaii, New Caledonia |
| *Chrysobalanus icaco* (Chrysobalanaceae) | Seychelles | Fiji, French Polynesia |
| *Cinchona pubescens (succirubra)* (Rubiaceae) | Galapagos, St Helena | French Polynesia, Hawaii |
| *Ficus microcarpa* (Moraceae) | Florida (USA) | French Polynesia, Guam, Hawaii, Palau |
| *Fuchsia magellanica* (Oenotheraceae) | La Réunion (Mascarenes) | Hawaii |
| *Grevillea robusta* (Proteaceae) | South Africa | French Polynesia, Hawaii |
| *Hiptage benghalensis* (Malpighiaceae) | Mascarenes | Hawaii |
| *Ligustrum spp.* (Oleaceae) | Australia, Florida, Mascarenes, New Zealand, South Africa | Hawaii |
| *Lonicera japonica* (Caprifoliaceae) | Florida, Juan Fernandez Islands, New Zealand, Queensland (Australia) | Hawaii, Fiji, Pitcairn Islands |
| *Melaleuca quinquenervia* (Myrtaceae) | Florida | FSM, Guam, Hawaii |
| *Melia azedarach* (Meliaceae) | Florida, South Africa | French Polynesia, Hawaii |
| *Ochna kirkii* (Ochnaceae) | Seychelles | French Polynesia, Hawaii |
| *Paederia foetida* (Rubiaceae) | Florida, New Zealand | Hawaii |
| *Pittosporum undulatum* (Pittosporaceae) | Jamaica, New Zealand, South Africa | Hawaii |
| *Pueraria lobata* (Leguminosae) | South Africa | French Polynesia, Hawaii |
| *Sanchezia speciosa (nobilis)* (Acanthaceae) | Queensland (Australia) | Fiji, French Polynesia |
| *Schefflera actinophylla* (Araliaceae) | Florida (USA) | French Polynesia, Hawaii, Pohnpei (FSM) |
| *Senecio mikanioides* (Compositae) | Chile, New Zealand | Hawaii |
| *Setaria palmifolia* (Gramineae) | New Zealand | French Polynesia, Hawaii |
| *Solanum mauritianum* (Solanaceae) | Mascarenes, New Zealand, S. Africa | Cook Islands, New Caledonia |
| *Thunbergia grandiflora* (Acanthaceae) | Florida, Queensland, Singapore | Fiji, French Polynesia, Hawaii |
| *Tithonia diversifolia* (Compositae) | Cape York (Australia), South Africa | Fiji, French Polynesia, New Caledonia, Vanuatu |
| *Toonia ciliata (Cedrela toona)* (Meliaceae) | South Africa | Hawaii |
| *Ulex europaeus* (Leguminosae) | California, La Réunion (Mascarenes), New Zealand, South Africa | Hawaii |
| *Zizyphus mauritiana* (Rhamnaceae) | Cape York (Australia) | Fiji |

***Table 4. Classification of some significant invasive plants by habitat (or vegetation types)***

| Scientific name (Family name) | Coastal | Man-grove | Dry lowland | Mesic inland | Wet upland | Cloud forests |
|---|---|---|---|---|---|---|
| *Adenanthera pavonina* (Leguminosae) | | | x | x | | |
| *Annona glabra* (Annonaceae) | x | x | | | | |
| *Ardisia elliptica* (Myrsinaceae) | | | | x | | |
| *Casuarina equisetifolia* (Casuarinaceae) | x | | | | | |
| *Chrysobalanus icaco* (Chrysobalanaceae) | | x | | x | | |
| *Clidemia hirta* (Melastomataceae) | | | | x | x | x |
| *Fucraea foetida* (Agavaceae) | | | x | | | |
| *Hedychium gardnerianum.* (Zingiberaceae) | | | | x | x | x |
| *Kalanchoe pinnata* (Crassulaceae) | | | x | x | | |
| *Lantana camara* (Verbenaceae) | | | x | x | x | |
| *Leucaena leucocephala* (Leguminosae) | | | x | | | |
| *Melinis minutiflora* (Gramineae) | | | | x | x | x |
| *Merremia peltata* (Convolvulaceae) | | | x | x | | |
| *Miconia calvescens* (Melastomataceae) | | | | x | x | x |
| *Mikania micrantha* (Compositae) | | | | x | x | |
| *Mimosa invisa* (Leguminosae) | | | x | x | x | |
| *Paraserianthes falcataria* (Leguminosae) | | | x | x | | |
| *Passiflora mollissima* (Passifloraceae) | | | | | x | x |
| *Psidium cattleianum* (Myrtaceae) | | | | | x | x |
| *Psidium guajava* (Myrtaceae) | | | x | | | |
| *Rubus moluccanus* (Rosaceae) | | | | | x | x |
| *Rubus rosifolius* (Rosaceae) | | | | | x | x |
| *Piper aduncum* (Piperaceae) | | | | x | x | x |
| *Spathodea campanulata* (Bignoniaceae) | | | x | x | | |
| *Syzygium cumini* (Myrtaceae) | | | x | x | x | x |
| *Syzygium jambos* (Myrtaceae) | | | | x | x | x |
| *Wedelia (Sphagneticola) trilobata* (Compositae) | x | x | x | | | |

*micrantha*). Some have a large and long-lived soil seed bank (e.g. *Miconia calvescens*, *Schinus terebinthifolius*) which allows them to persist and regenerate over long periods. Other are pioneers or early successional plants with rapid growth and prolific reproduction (e.g. *Cecropia* spp., *Mimosa invisa* or *Chromolaena odorata*). Reproductive system of invasive plants could be sexual and/or vegetative: *Wedelia (Sphagneticola) trilobata* and *Clerodendrum chinense* use only asexual means to spread, and *Tibouchina* spp. can spread vegetatively from old canes layering along the ground.

## 4.6 Means of introduction

Introduction of plant invaders could be accidental or intentional. Many dominant invasive species have been introduced as garden ornamentals because of their showy flowers or leaves, such as *Antigonon leptotus* in Guam, *Miconia calvescens* in Tahiti and Hawaii, *Hedychium* spp. and *Clerodendrum quadriloculare* in many islands; others were introduced as a food source, such as *Coccinia grandis* in Hawaii and Saipan; as timber, such as *Pinus* spp.; as fodder, such as *Melinis minutiflora*; as pasture species, such as *Panicum* spp., *Paspalum* spp., *Sorghum* spp.; or as ground cover, such as *Wedelia (Sphagneticola) trilobata* or *Dissotis rotundifolia.* Legume trees such as *Leucaena leucocephala*, *Paraserianthes falcataria or Albizia lebbeck* are commonly used as shade plants, for reforestation or windbreaks.

## 4.7 Impacts of invasive plants

Most of the dominant plant invaders mentioned here form monospecific stands (dense canopy covers, thickets, or mats) which exclude nearly all other plant species by preventing or suppressing their recruitment, growth, or reproduction. Taxa such as *Grevillea robusta*, *Psidium cattleianum*, *Schinus terebinthifolius* and *Syzygium* spp. are suspected to produce allelopathic substances. *Andropogon virginicus, Melinis minutiflora* and *Pennisetum setaceum* are pyrophytic grasses, i.e. they are fire-adapted species that quickly re-establish after a fire. Their tendency to form dense mats of dead matter results in increasing runoff and accelerated erosion. *Myrica faya* is a nitrogen-fixing plant, which increases nitrogen inputs and alters the soil nutrient status, thus facilitating the spread of other alien species.

## 4.8 Role of disturbance

Most of the plant invader's success depends on disturbed environments. Cyclone or flood damage can enable exotics to gain an immediate foothold, thus accelerating invasion rates. For example, on

Rarotonga (Cook Islands), the spread of *Cardiospermum grandiflorum* was triggered by the hurricane Sally in 1986 (E. Saul, pers. comm.). Physical disturbance due to fire promotes success and extension of pyrophytic grasses (see above). In Hawaii, wild pigs (*Sus scrofa*) have been identified as being the most important influence on alien plant invasion in rainforests by disturbing the soil and dispersing seeds of alien plant species (such as *Psidium cattleianum* or *Passiflora mollissima*). However, even natural communities that are protected from large disturbances can be vulnerable to invasion. Some alien plants, such as *Schinus terebintifolius, Spathodea campanulata, Miconia calvescens* or *Psidium cattleianum,* have the ability to invade natural habitats without any apparent disturbances.

# 5. Conclusions

## 5.1 Objectivity v. subjectivity of this review

Because of the scarcity of published information on invasive plants in the Pacific islands, most of the basic data were provided by local and academic experts. Although the classification used in this review (dominant/moderate/potential) is based on personal assessments of the degree of importance of invasive plants ("invasiveness"), it nevertheless contains relevant quantitative elements. Moreover, most of the information presented in this review comes from direct and current field observations.

## 5.2 Comparison with previous studies

Whistler (1995) documented 170 weeds found on highly disturbed habitats in Hawaii, Samoa, Tonga, Tahiti, Guam and Belau (Palau). The list also included 14 introduced plant species "which penetrate into natural ecosystems" such as *Clerodendrum chinense, Clidemia hirta, Ficus microcarpa, Lantana camara, Mimosa invisa, Pithecellobium dulce, Psidium cattleianum* and *P. guajava, Rubus rosifolius, Schinus terebinthifolius, Schefflera actinophylla, Spathodea campanulata, Syzygium cumini*, all included in the present review.

Waterhouse (1997) listed for the Pacific islands: the major weeds of agriculture, which include *Cyperus rotundus, Lantana camara, Mimosa invisa, Mikania micrantha, Stachytarpheta* spp.; and the "major weeds of plantation forests", which include *Coccinia grandis, Antigonon leptotus, Leucaena leucocephala, Merremia peltata, Miconia calvescens, Mimosa diplotricha, Solanum* spp.*, Cordia alliodora, Spathodea campanulata*. All of these species are part of the present review, as they are also found in natural and semi-natural environments.

Swarbrick (1997) distinguished the "weeds in National Parks", defined as areas primarily used for the maintenance or conservation of natural vegetation: *Ardisia* spp., *Cardiospermum grandiflorum, Cestrum nocturnum, Clerodendrum philippinum, Clidemia hirta, Merremia peltata, Mikania micrantha, Paspalum conjugatum, Passiflora laurifolia, P. maliformis, P. rubra, Psidium cattleianum (littorale), Rubus moluccanus, Schinus terebinthifolius, Spathodea campanulata, Syzygium cumini*, all included in the present review. The other species cited by Swarbrick (*Elephantopus mollis, Hippobroma longiflora, Leucas decemdentata, Struchium sparganophorum, Coleus (Plectranthus) scuttellorioides* and *Begonia semperflorens cultorum)* are typical weeds.

## 5.3 Potential conflict of interests

Several invasive plants are introduced intentionally and currently used as a food source (e.g. *Coccinia grandis, Passiflora* spp.) or in forestry and agroforestry (e.g. *Adenanthera pavonina, Leucaena leucocephala, Paraserianthes falcataria, Castilloa elastica*, Thaman and Whistler 1996), thus creating conflicts of interests between users and conservationists. *Grevillea robusta* and *Pinus caribaea*, for examples, used extensively in reforestation programmes in many Pacific islands, have naturalised and show a tendency to expand.

## 5.4 Growing importance of plant invasions in Pacific islands

Except for the well-studied island cases of Hawaii and New Zealand (and more recently of French Polynesia), alien plant species were considered to be minor components of the flora and fauna and generally not an important threat to native ecosystems in other Pacific islands. With the recent and rapid increase of movement of people and transportation of goods between islands and the nearests continents, between Pacific island countries, and among archipelagos and islands in the same country in recent decades, many introduced plants have become established and naturalised in native habitats, especially ornamental and forestry plantings. New potentially invasive plants are still being introduced and cultivated. There is now a growing concern that plant invaders offer real and potential threats to survival of the remaining native plants and habitats in the Pacific islands (see e.g. Smith 1995; Mueller-Dombois and Fosberg 1998). This review has clearly shown the magnitude of invasion by alien plants in the Pacific Islands, and the necessity to build inventories of plant invaders, their status and their distribution, as an integral part of prevention, education, and management plans.

## 6. Acknowledgements

This consultancy and report would not have been possible without the generous contribution of many people including: Pierre Binggeli, Sam Chanel, Chuck Chimera, Matthew Cock, Don Drake, Frédéric Dupuy, Jacques Florence, Tim Flynn, Janet Franklin, Michel Hoff, Tanguy Jaffré, Jim Juvic, Dave Lorence, Gerald McCormack, Atloto Malau, Harley Manner, Art Medeiros, Mark Merlin, Rangaswamy Muniappan, Gustav Paulay, Dick Phillips, Bill Raynor, Ed Saul, Maurice Schmid, Cliff Smith, Jim Space, Randy Thaman, John Terry, Marika Tuiwava, Paino Vanai, Stan Villagomez, Dick Watling, Art Whistler. A special thank to Professor Clifford W. Smith (University of Hawaii at Manoa) for revising the English in an early version of this draft and for suggestions, and to botanist David H. Lorence (National Tropical Botanical Garden) for useful taxonomical comments.

## 7. References

Bailey, R. et al. 1991. *An ecosystem classification and criteria for conservation in tropical insular Pacific*. Nature Conservancy, Honolulu.

Cronk, Q.C.B.; Fuller, J.L. 1995. *Plant Invaders. The threat to natural ecosystems*. Chapman & Hall, London.

Dahl, A.L. 1980. Regional Ecosystems Survey of the South Pacific Area. *South Pacific Commission Technical Paper N°179*.

Mabberley, D.J. 1997. *The Plant Book. A portable dictionary of the vascular plants*. Cambridge University Press, London.

McDonald, I.A.W.; Loope, L.L.; Usher, M.B.; Hamann, O. 1989. Wildlife conservation and the invasion of nature reserves by introduced species: a global perspective. Pp. 215-225 *in* Drake, J.A. et al. (eds) *Biological Invasions: A global perspective*. John Wiley & Sons.

Merlin, M.D.; Juvic, J.O. 1995.Montane cloud forest in the tropical Pacific: some aspects of their floristics, biogeography, ecology, and conservation. Pp. 234–253 *in*: Hamilton, L.S.; Juvic, J.O.; Scatena, F.N. (eds) *Montane Cloud Forest. Ecological Studies 110*. Springer Verlag, New York.

Meyer, J.-Y. 1998. Mécanismes et gestion des invasions biologiques par des plantes introduites dans des forêts naturelles à Hawai'i et en Polynésie française: une étude de cas. Rapport d'étude post-doctorale. Délégation à la Recherche, Tahiti. (Unpublished report.)

Morat, Ph.; Jaffre, T.; Veillon, J.-M. 1999. Menaces sur les taxons rares et endémiques de Nouvelle-Calédonie. Pp. 129–144 *in* Lesouef, J.-Y. (ed.) Les plantes menacées de France, Actes du colloque de Brest, 15-17 octobre 1997. *Bulletin Société Botanique Centre-Ouest, Nouvelle Série, Numéro Spécial 19*.

Mueller-Dombois, D; Fosberg, F.R. 1998. *Vegetation of the Tropical Pacific Islands*. Springer Verlag, New York.

Nunn, P.D. 1994. *Oceanic Islands*. Blackwell Publishers, Oxford.

Owen, S.J. (comp.) 1997. Ecological Weeds on Conservation lands in New Zealand: a database. Department of Conservation, Wellington.

Pysek, P. 1995. On the terminology used in plant invasion studies. Pp. 71-81 *in* Pysek, P.; Prach, K.; Rejmanek, M.; Wade, M. (eds) *Plant Invasions. General Aspects and Special Problems*. SPB Academic Publishers, Amsterdam.

Schmid, M. 1989. The forests in the tropical Pacific archipelagoes. Pp. 283–301 *in* Leith, H.; Werger, M.J.A. (eds) *Tropical Rain Forest Ecosystems*. Elsevier Science Publishers, Amsterdam.

Smith, C.W.1992. Management of alien species in natural areas of Oceania. *Pacific Science* 46(3): 386–387.

Space, J.; Falanruw, M.C. 1999. Observations on invasive plant species in Micronesia. Ms prepared for meeting of Pacific Island Committee Council of Western States Foresters, Majuro, Marshall Islands.

Stone, C.P.; Smith, C.W.; Tunison, J.T. (eds) 1992. Alien Plant Invasions in Native Ecosystems of Hawaii. Management and Research. University of Hawaii Cooperative National Park Resource Studies Unit, Honolulu, Hawaii.

Swarbrick, J.T. 1997. Weeds of the Pacific Islands. *South Pacific Commission Technical Paper N°209.*

Thaman, R.; Whistler, W.A. 1996. A review of uses and status of trees and forests in land-use systems in Samoa, Tonga, Kiribati and Tuvalu with recommandations for future action. Working Paper 5, South Pacific Forestry Development Programme, UNDP/FAO, Suva.

Waterhouse, D.F. 1997. The Major Invertebrate Pests and Weeds of Agriculture and Plantation Forestry in the Southern and Western Pacific. Australian Centre for International Agricultural Research (ACIAR), Canberra.

Whistler, W.A. 1983. *Weed Handbook of Western Polynesia*. German Agency for Technical Cooperation (GTZ), Eschborn.

Whistler, W.A. 1995. *Wayside Plants of the Pacific Islands: A guide to the lowland flora of the Pacific Islands.* Isle Botanica, Honolulu.

Whittaker, R.J. 1998. *Island Biogeography. Ecology, Evolution, and Conservation.* Oxford University Press, Oxford.

### References added in proof

Thaman, R.R. 1999. *Wedelia biflora*: daisy invader of the Pacific islands. *IAS technical paper 99/2*. Institute of Applied Science, University of the South Pacific, Suva.

Wagner, W.L.; Herbst, D.R.; Sohmer, S.H. 1999. *Manual of the flowering plants of Hawaii*. Revised edition, vol. 2. University of Hawaii Press/Bishop Museum Press, Honolulu.

***Web sites***

Pacific Island Ecosystem at Risk (PIER) project, a major web site for invasive plants of Micronesia and American Samoa, updated Feb 2000 by Jim Space:
www.hear.org/pier/

Botany Dept, University of Hawaii, C.W. Smith, a major web site for plants of the Hawaiian islands:
www.botany.hawaii.edu/faculty/cw_smith/aliens.htm

Pitcairn, a minor web site on invasive plants:
http://www.members.tripod.co.uk/WoodyPlantEcology/pitcairn/invasive.htm

# Arthropod pests of conservation significance in the Pacific: A preliminary assessment of selected groups

**Gordon M. Nishida and Neal L. Evenhuis**

***Pacific Biological Survey, Bishop Museum, 1525 Bernice St, Honolulu, Hawaii 96817-2704, USA***

## Abstract

Arthropod species are by far the most numerous invasive organisms on islands, but those of conservation significance in the Pacific, except for Hawaii and the Galapagos, are not well documented. Ants may pose the greatest arthropod threat to conservation in the Pacific, by predation, direct competition, and creating favourable conditions for other invasive biota. Information is given on some of the potentially most damaging: bigheaded ant *Pheidole megacephala*, long-legged or crazy ant *Anoplolepis longipes*, Argentine ant *Linepithema humile*, little fire ant *Wasmannia auropunctata*, and others. Vespid wasps pose another critical threat; an outline is given of the yellowjacket wasp *Vespula pensylvanica*, recorded only from Hawaii in the Pacific, but with serious potential for invading other Pacific island groups. The other significant pests discussed here are the black twig borer beetle *Xylosandrus compactus*, the coconut rhinoceros beetle *Oryctes rhinoceros*, and the avian malaria mosquito, *Culex quinquefasciatus*. A preliminary bibliography for ants in the Pacific is appended.

## 1. Overview

The invasion of oceanic islands by non-native arthropods has most likely been an ongoing phenomenon since the first human travelled from one place to settle another. The damage done to natural environments by cattle, pigs, goats and other large mammals is on a scale easily apparent to the human eye. Perhaps for this reason, the effects of their introductions are well documented. The effects of the introduction of non-native arthropods are less obvious and have generally been poorly understood and poorly documented. Nonetheless, the impacts of arthropods on the natural environment are great and deserve the same scale of investigation as exists for their larger cousins.

Given the amount of non-commercial and commercial traffic among Pacific islands, these former oceanic havens have become easy targets for invasive pest organisms in the last half of this century. Arthropods are by far the largest group (in numbers) of organisms that invade islands each year, e.g. an estimated 20 per year in Hawaii—of which four are considered pests (Beardsley 1979). Therefore, a review of existing knowledge of arthropod pests in the Pacific is a necessary preliminary to larger, more comprehensive surveys and detailed reviews of the fauna. This study only scratches the surface of the amount of research that will be necessary to provide adequate knowledge to deal with the alien arthropod pests that threaten native ecosystems throughout the Pacific.

Arthropods of conservation significance in the Pacific, except for Hawaii and the Galapagos, are not well documented. A critical problem is the incomplete basic knowledge of the existing flora and fauna, making impacts difficult to assess. In addition, many Pacific nations lack adequate resources to recognise the problem or potential problem, identify the culprits, and mount an intervention programmeme if necessary. There is no single compilation of the Pacific Island arthropod fauna. Very few works deal with the arthropod fauna of the region as a whole (e.g. Curran 1945); most have dealt with arthropods on: (a) a regional basis, e.g. serial works such as *Insects of Samoa* (1927–1935); *Insects of Micronesia* (1951–present); *Insects of Hawaii* (1960–1992) or single works such as Kami and Miller (1998) or Nishida (1997), or (b) a taxonomic basis (e.g. Evenhuis 1989).

Only selected groups of terrestrial arthropods are dealt with here as a first step toward a necessary and more comprehensive study. The selected groups included the ants, the avian malaria mosquito, the yellowjacket wasp, the black twig borer, and the coconut rhinoceros beetle. Each of these groups of insects does have or has had a deleterious effect on the environment in the areas in which they have invaded, has a realised or potential impact on conservation of native biota, and for the most part, active control programmemes are in progress to attempt to eradicate them from these areas. By dealing with selected groups in this way, it was felt that we could better gauge the resources needed for a more inclusive effort.

Hawaii Biological Survey Contribution No. 1999- 012
Pacific Biological Survey Contribution No. 2000-006

The literature concerning pest arthropods is voluminous and widely scattered and we can in no way do justice to a successful study of the entire group, or even subsets of it, such as the top 10 percent of major pest arthropods in the Pacific area, in this preliminary review. Much of the pest literature is for economic pests, and that body of literature must be consulted to glean conservation information, since detailed and definitive works on the direct effects on native ecosystems are few, although increasing recently.

## 1.1 Origins of the fauna

Zimmerman (1942) hypothesised the origins of the native insect fauna of the eastern Pacific, Gressitt (1982) discussed the biogeography of Pacific Coleoptera, and Evenhuis (1982) discussed the distribution and origin of Oceanic Bombyliidae, but none considered the origins of non-indigenous species. In fact, most studies of the Pacific island arthropod fauna have not dealt with origins of alien species.

As with the vast majority of studies of alien species in the Pacific, Hawaii has been the primary "research station". Beardsley (1979) summarised the study of 120 accidental insect introductions into Hawaii from 1937 to 1976 and concluded that 36% originated from the west (i.e. Asia); 52% from the east; and 12% from undetermined sources. Virtually all accidentally introduced pests to Hawaii were introduced via commercial traffic. Without reference to other island studies, it is assumed that the origins of arthropods accidentally introduced into other Pacific island faunas are most likely also correlated with shipping and air traffic into these areas.

## 1.2 Types of pest arthropods

The major groups of arthropods that are considered threats to conservation efforts include chiefly the predators and parasites, and these are the groups of organisms that we deal with in this review. The term "parasite" is used here in a broad definition (for example, boring [e.g. beetles] or piercing [e.g. sap-sucking] insects can be considered parasitic on the hosts in which they feed or bore holes for the nests of their eggs and young). Their impacts on the native biota can be disastrous. There is no telling the exact number of native species of insects and other small invertebrates that have been extirpated from lowland areas of Hawaii solely because of the effects of the big-headed ant, *Pheidole megacephala*. Perkins (1907) laments the extirpation of the native fauna of Mt Tantalus just above Honolulu in just 10 years because of the introduction of this ant.

While most arthropod pests have historically been considered as such from the standpoint of their economic impact on agriculture, some are also major threats to conservation of native elements of various ecosystems. Some agriculturally important arthropod pests will not pose any direct significant problem to native biota (for example, *Bactrocera* fruit flies that attack fruit crops and cause significant economic damage to fruits would not pose a significant threat if they were to also attack native fruits since their action does not kill or reduce the reproductive effectiveness of the host). However, other agricultural pests can and do pose a serious threat to native plants, for example *Xylosandrus compactus*, the black tree borer beetle. This has had a deleterious effect on coffee trees and other Rubiaceae in Hawaii, but apparently is not specific to just coffee trees. Surveys have shown that it can attack over 100 different species of mostly woody plants in 44 different families (Hara and Beardsley 1979), some of these being rare or endangered.

## 1.3 Characteristics of invasive species

Howarth (1985) provides a concise assessment of the features that are necessary for successful colonisation of islands by introduced species. Genetic preadaptation to exploit resources in the new land is a basic requirement. Climatic, seasonal, and other environmental cues must be present, as must proper hosts and other natural resources. The chances of both sexes of a species being present at the time of colonisation is low in most cases, so that hermaphroditic and parthenogenetic species have a better chance of colonisation than other species. However, gravid females, or nests containing individuals of both sexes can be and have been easily introduced.

## 1.4 Greatest threats

Ants may pose the greatest arthropod threat to conservation in the Pacific. The formation of large, noncompetitive, multi-queen colonies, coupled with the ability to hitchhike readily, highly aggressive predatory behaviour, protection of pests on plants, and few options for control, make ants one of the most formidable pests in the Pacific. Ants have been implicated in the elimination of lowland native invertebrates (Perkins 1913), aquatic and semiaquatic arthropods (Hardy 1979, Moore and Gagné 1982), and snails (Solem 1976), and the death or exclusion of vertebrates (Haines et al. 1994, Swaney 1994). Vespid wasps pose another critical threat. In Hawaii, yellowjacket wasps are systematically "cleansing" areas they have invaded, indiscriminately preying on many types of arthropods to feed their colonies.

Vespids and ants are critical threats, especially to native species existing in small populations occupying limited areas.

Plant-feeding species such as leafhoppers, scales, and aphids are another threat. The results of their feeding often attract ants and degrade photosynthetic capabilities of plants. Another potential threat is the indiscriminate release of parasites and predators for biocontrol purposes in commercial crops leading to unforeseen effects in native forests.

The accidental, usually unobserved, and random nature of arthropod introductions makes it difficult to predict areas of greatest threat. In general, the island groups with the greatest traffic with outside areas remain at greatest risk. Traffic in this sense includes not only commercial and military transport, but conveyances such as privately owned small planes or boats. Locations to which agricultural or horticultural plants or commodities are imported are at increased risk of introduction as are areas importing (or exporting) equipment and materials for construction. An active pet trade makes some areas more prone to introductions. Areas actively exporting agricultural products also increase the risk, as large-scale farming often is susceptible to pests and as a result more prone to use biological control agents. Most pests are associated with human disturbance, and those islands with the greatest remaining natural areas at lower elevation and adjacent to areas under cultivation are at risk.

### 1.5 Needs for the future

Loope and Medeiros (1995) provide a list of three points that are necessary for proper understanding, management, and control of invasive species and conservation of natural ecosystems. Though they are written for Hawaii, the principles are valid for most of the tropical Pacific. Continuing research is needed to:

- understand the biology and impacts of invasive species,
- provide the tools needed to manage the most destructive invasive species,
- provide tools for ecological restoration,

To this list we must add and emphasise the need for:

- foundational biosystematic research on the introduced and native arthropods,
- baseline surveys and monitoring programmes to anticipate introductions and pre-empt incipient populations.

Any systematic study is an essential first step towards any conservation programmeme. Without proper identification of organisms, attempts to control, abate, or eliminate them may prove costly and fruitless.

Additionally, enhanced quarantine should be a primary consideration for all Pacific islands, and public education should be implemented on each island to augment any control work or preventative measures being done by resource managers and quarantine staff.

As each species may have a different and often unpredictable impact on an ecosystem, and considering the ease with which species are translocated today, perhaps a useful approach may be to provide an inventory of species presently known from each island group. This will allow the tracking of new introductions. A preliminary list is available for ants, but an exhaustive search has not yet been completed and the names have not been fully verified. The foundation for this is compilation of the literature, and a preliminary list is presented in Annex 1.

## 2. Beetles (Coleoptera)

### 2.1 Black twig borer

Scientific name: *Xylosandrus compactus* (Eichhoff). Family: Scolytidae.

Distribution

SPREP area: American Samoa, Fiji, Papua New Guinea, Solomon Islands.

Other areas: Hawaiian Islands, tropical Africa, southern India, Indonesia, Japan, Malaysia, Mauritius, Seychelles, Sri Lanka, southeastern USA, Vietnam.

Discussion

The black twig borer, *Xylosandrus compactus* (Eichhoff), belongs to the tribe Xyleborini of the family Scolytidae, which contains species of beetles called ambrosia beetles. The ambrosia fungus is the primary food for the beetle's development and is the causal agent in the infection and resultant weakening or killing of the host plant that the beetle infests. Ambrosia beetles are serious pests of forest trees and, to a lesser extent, shade and fruit trees (Clausen 1978a). Most ambrosia beetles attack primarily weak or unhealthy plants; however, the black twig borer is known to attack healthy plants as well, which makes it a potentially very serious pest to native forest trees as well as other plants.

The black twig borer was first collected in 1931 on the island of O‘ahu from elderberry imported from Singapore (Samuelson 1981), but not reported in the literature until it was collected again on O‘ahu in 1961 (Davis 1963) where it was found attacking pink tecoma (*Tabebuia pentaphylla* (L.) Hemsl.). It has since spread to all the other main islands (Hawaii Dept. Agric. 1975; Samuelson 1981) and the list of hosts includes 108 species of shrubs and trees in 44 families (Hara and Beardsley 1979) including some considered rare or endangered.

***The fungus and plant symptoms***

The fungus associated with the black twig borer in Hawaii is *Fusarium solani* (Mart.) Synd. and Hans. It is the only food for *Xylosandrus compactus* throughout its life cycle and its pathogenicity on the host plants has been confirmed (Hara and Beardsley 1979). When infected, the plant exhibits necrosis of the leaves and stems extending from the entrance hole made by the beetle distally to the terminal of the branch.

***Control programmes***

Davis and Krauss (1967) list the introduction into Hawaii of three parasites [*Chaetospila frater* (Girault), *Dendrosoter enervatus* Marsh, and *Ecphylus* sp.] for control of the black twig borer; and Davis and Chong (1970) list the additional introduction of *Dendrosoter protuberans* (Nees). There have been no results on the outcomes of any of these liberations. Hill (1983) comments on the lack of success of the application of cultural methods in suppressing ambrosia beetles as a whole, but said that sprays of dieldrin, with added surfactant and sometimes with Bordeaux mixture, has given adequate levels of control in the tropics. Unsuccessful introductions for control of ambrosia beetles include the predacious clerid beetle *Thanasimus formicarius* (L.) from England into Sri Lanka in 1908 (Clausen 1978a).

## 2.2 Coconut rhinoceros beetle

Scientific name: *Oryctes rhinoceros* (Linnaeus).
Family: Scarabaeidae.

Distribution

SPREP area: American Samoa, Fiji, Palau (controlled in 1980s), Papua New Guinea, Samoa, Tokelau, Tonga, Wallis and Futuna.

Other areas: Bangladesh, Cambodia, southern China, India, Indonesia, Laos, Malaysia, Pakistan, Philippines, Taiwan, Thailand, Vietnam.

Discussion

The coconut rhinoceros beetle, *Oryctes rhinoceros* (Linnaeus), is one of the most serious pests of the coconut palm. Though, for the most part, coconut palms are considered agricultural crops, this beetle is included in this review because of its record of damage, wherever it has become established in the tropics, to native palm trees and native *Pandanus*.

It is thought to be native to southern India, Sri Lanka, Myanmar, Thailand, the Malay peninsula, southernmost China including Hong Kong, the Philippines, Taiwan, the Ryukyus, and Indonesian Archipelago as far east as Ambon Island (Leefmans, 1884). It has been introduced into Samoa, Wallis and Futuna, New Britain, New Ireland, Palau, Tonga, Guam, Cook Islands, and Fiji (Gressitt 1953; Hill 1983), primarily as a result of the increased sea traffic during World War II. Swan (1974) lists its distribution among Pacific Islands (and years of introductions in parentheses) as Western Samoa (1910); Keppel Island (1921); Wallis and Futuna (1931); Palau (1942); New Guinea (1942); Tonga (1953); Fiji (1953); and Tokelau (1963). Though there are natural factors that keep the beetle under control in its native range, its introduction into insular habitats without these natural control factors allows it to reproduce quickly and spread to become a serious pest.

***The beetle***

The larvae of this scarab beetle develop in dead palm trunks, logs, and stumps. However, the adults cause the damage by boring into the crowns of mature palms and often killing them. Gressitt (1953) reports that in introductions of the beetle into insular situations such as Palau both the adults and larvae have been reported to survive by host-shifting on to *Pandanus* after the host palm food resource had been depleted. This is evidence of the potential danger to native palms and *Pandanus* from the ravages of this pest beetle elsewhere in the Pacific. In Gressitt's (1953) report, he lists over 45 species of monocot plants (many of which are native species) that the beetle has been reported to infest, including over 30 species of palms.

***Control programmes***

After World War II, the Insect Control Committee for Micronesia (ICCM) was established through the auspices of the National Academy of Science and plans were made for control efforts of the beetle (Anon. 1947). Subsequent reports follow the progress of this control programme (Anon. 1948a, 1948b, 1949, 1950, 1951, 1952, 1953). Parasites introduced from 1947 to 1950 for control of the beetle included the wasps *Scolia ruficornis* from east Africa and *Scolia patricialis* var. *plebeja* from Malaya. By 1952, surveys failed to recover any wasps, and palms continued to be attacked by the beetle.

Swan (1974) summarises the results of control of the beetle in the Pacific using predators, parasites, and various pathogens. The most promising of the ones listed appear to be the parasite *Scolia ruficornis* (Hymenoptera: Scoliidae) and the virus *Rhabdionvirus oryctes*. Other predators or parasites in the list would have to undergo specificity trials before they could be confirmed as safe for introduction to other Pacific Islands and without the danger of damage to non-target native organisms.

Clausen (1978b) gives a summary of control attempts in Fiji, Samoa, Palau, New Guinea, New Britain, and Vanuatu. In almost all cases, *Scolia ruficornis* was released, but only up to 30 per cent parasitisation was achieved in Samoa, and other areas had significantly less success.

Hill (1983) summarises recommended methods of cultural control (planting methods, general area cleaning and burning of potential host substrata) and states that chemical control can be attained with sprays of various chemicals including diazinon or carbaryl.

# 3. Flies (Diptera)

## 3.1 Avian malaria mosquito; southern house mosquito

SCIENTIFIC NAME: *Culex quinquefasciatus* Say.
Family: Culicidae.

DISTRIBUTION

SPREP area: American Samoa, Cook Is, Federated States of Micronesia, Fiji, French Polynesia (Austral Is, Marquesas, Society Is, Tuamoto Archipelago), Guam, Hawaiian Islands, Kiribati, Marshall Islands, Nauru, New Caledonia, Niue, Northern Marianas, Palau, Papua New Guinea, Samoa, Solomon Islands, Tokelau, Tonga, Tuvalu, Vanuatu, Wallis and Futuna.

Other areas: Widespread throughout the tropics, subtropics, and warm temperate regions of the world.

DISCUSSION

Avian malaria has been postulated as one of the leading causes of the reduction and even extinction of some of Hawai‘i’s forest birds (Warner 1968; Van Riper 1991). The disease has been found in roughly 8% of the birds tested in Hawaiian experiments (e.g. Van Riper et al. 1982). Researchers have also concluded that native birds were more susceptible to acquiring the disease than introduced birds and had a significantly poorer survival rate than introduced species (Van Riper et al. 1982; Atkinson et al. 1995). This fact has serious implications for native bird faunas elsewhere in the Pacific where the mosquito and the disease parasite may occur.

***The parasite***

Several species of the filarial parasite *Plasmodium* are the causal organism for avian malaria. *Plasmodium relictum capistranoae* Russell is the parasite found in infected Hawaiian birds. Sporozoites are the infectious stage of the *Plasmodium* protozoan parasite and are transmitted to a vertebrate host through blood feeding by a mosquito. The disease to the host is caused by the parasite protozoan attacking red blood cells to continue its development. Fully developed erythrocytic schizonts cause rupturing of the red blood cells to release merozoites (to continue the blood cycle in the host) and gametocytes (capable of initiating sexual development if ingested by a mosquito). It is the merozoites with accompanying toxins that cause the chills and fever of malaria.

***The mosquito***

The transmitting agent of avian malaria is the mosquito. The most prevalent mosquito transmitting avian malaria in Hawaii is *Culex quinquefasciatus*, though a number of other mosquitoes have been found to harbour the parasite in experiments (summary of previous work in Hewitt 1940). *Culex quinquefasciatus*, native to North America, is found throughout the tropics and subtropics, including virtually all the island groups under SPREP as well as Hawaii.

Avian malaria itself has not yet been recorded from native birds on any island group in the Pacific except Hawaii, but this may only be a reflection of the fact that not many rigorous epidemiological surveys to find *Plasmodium relictum capistranoae* or other disease vectors for avian malaria have been conducted in the Pacific outside of Hawaii. The only research known that has surveyed other islands in the Pacific for avian malaria is by Savidge (1985) [Guam] and Steadman et al. (1990) [Cook Islands], and there were no findings of the parasite. Avian malaria is currently not an active threat to conservation on any other island group except Hawaii. However, it is included in this preliminary survey because of the high potential for the disease to spread to other Pacific islands through normal commercial traffic lanes (be it shipping or air traffic). One of the most prevalent methods by which the disease is spread is through the introduction of infected non-native birds.

In Hawaii, avian malaria has been reported from a variety of native bird species, with the ‘apapane (*Himatione sanguinea*) having the highest percentage of infected individuals in surveys (e.g. Van Riper et al. 1982, 1986; Van Riper and Van Riper 1985). Other native species recorded in that study as being infected with avian malaria include i‘iwi (*Vestiaria coccinea*), amakihi (*Loxops virens*), ‘elepaio (*Chasiempis sandwicensis*), oma‘o (*Myadestes obscurus*), Hawaiian creeper (*Loxops maculata*), and akiapola'au (*Hemignathus munroi*) [the last is on the US Fish and Wildlife Endangered Species List]. Scott *et al*. (1986) add a few more endangered native species to the list of Hawaiian birds found to be infected with avian malaria: Townsend's (Newell's) shearwater (*Puffinus newelli*), and the Hawaiian crow (*Corvus hawaiiensis*). Massey et al. (1996) conducted further observations on the characteristics of the Hawaiian crow after it had become infected with *Plasmodium relictum capistranoae*. Van Riper et al. (1982) showed that introduced species had a substantially better survival rate after being infected than native Hawaiian birds (100% v. 42%).

In Guam, studies were conducted in the 1980s (Savidge 1985) to determine the causes of the precipitous decline of bird populations there. Neither *Plasmodium relictum capistranoae* nor any other avian malarial parasite was found in any of the birds sampled, yet the vector, *Culex quinquefasciatus* occurs on the island. Savidge concluded that the main causes of the decline in bird populations were the brown tree snake (*Boiga irregularis*) and collisions with cars, but did not rule out the possibility that *Plasmodium* might be in the mosquito populations, although at such low levels as to not have been detected.

In the Cook Islands, Steadman et al. (1990) surveyed nine indigenous species of birds with negative results for the presence of protozoan pathogens. Nevertheless, they point out that precautions should still be taken to prohibit the introduction of potentially infected non-indigenous birds or mosquitoes into the Cooks or any other Polynesian island because of the high potential for native birds to be fatally vulnerable to the consequences of the disease should they become infected.

***Control programmes***

There are no active control programmes for the abatement of avian malaria. Attempts to control mosquitoes in general have been implemented in Hawaii, but have not met with success.

Mosquitoes that harbour the causal organism of avian malaria are container breeders (immatures can be found in both natural and artificial containers). The only effective procedure to reduce populations of mosquitoes is to reduce the number of potential water catchment containers in the area in which the mosquitoes are known to breed.

One way to reduce potential mosquito populations in Hawaiian forests and elsewhere is to reduce the number of pigs. In Hawaii, the introduction of pigs into forest areas has increased the number of potential breeding areas for mosquitoes. In foraging for soft plant food items such as roots, pigs will often fell tree ferns and eat the soft cambium, leaving trough-like depressions that fill with rainwater. Pigs also create wallows in which standing water can attract mosquitoes for long enough for them to fully develop. Mosquitoes have been found in greater abundance in these pig-infested areas than elsewhere. Thus, excluding pigs from conservation areas or eradicating them from forested areas will reduce the number of potential mosquito breeding areas and thus the number of mosquitoes that could potentially spread avian malaria or other insect-borne diseases to native animals.

# 4. Wasps (Hymenoptera: Vespidae)

## 4.1 Yellowjacket wasp

Scientific name: *Vespula pensylvanica* (Saussure). Family: Vespidae.

Distribution

SPREP area: Not yet recorded.

Other areas: Hawaiian Islands, throughout North America.

Discussion

Though not yet recorded from any Pacific island other than the Hawaiian Islands, we include a discussion of *Vespula pensylvanica* because of its notorious habits in Hawaii and potential for invading other Pacific island groups. We recommend that frequent and rigorous monitoring at all places of entry (ports and airports) be done on all islands so as to prevent the unwanted entry of this wasp.

Yellowjackets are predators, feeding on a wide range of arthropod taxa, with great potential for negative impact on the native fauna in insular habitats. This is especially troublesome in Hawaii, which compared to mainland areas where *Vespula* occur, has a high degree of endemism for arthropods that, for the most part, have evolved without anti-predator defence mechanisms selected for elsewhere (Gagné and Christensen 1985).

The yellowjacket wasp is native to North America. It and other members of the genus *Vespula* have natural distributions that are primarily north temperate. Climate is a major constraint on its reproductive behaviour; cold weather depletes normal food supplies, resulting in a reduction of colony individuals during cold winter months. However, in Hawaii with its warmer year-round climate, colonies appear to enlarge during warm winter months causing population explosions in areas it has invaded (up to 300 sorties per minute have been observed at some nests [Gambino 1991]).

*Vespula pensylvanica* was first reported from Hawaii in 1919 (on Kaua‘i) and subsequently on O‘ahu in the 1930s where all reports were primarily about it being a nuisance to humans, with concurrent reports of stinging. However, Williams (1927), misidentifying it as *V. occidentalis*, was prescient to note that “This fierce insect will probably be of no benefit to the endemic fauna”. However, it was not until an aggressive race of this species was reported from the island of Hawai‘i in 1977 (Asquith 1995) that its almost simultaneous population explosion and resultant intensive predatory habits began to have repercussions on the native invertebrate populations. Gambino and Loope (1992) provide a detailed account of surveys done over a ten-year period in Hawaii Volcanoes National Park (Hawai‘i Island) (1984–1990) and Haleakala National Park (Maui) (1981–1990) and identified 24 arthropod prey items at least to genus, of which 14 (58%) were endemic taxa (including some taxa that are currently considered as Species of Concern by the US Fish and Wildlife Service).

***Control programmes***

Almost as soon as the 1977 population was discovered, nest eradication and/or control programmes were initiated on various islands in Hawaii to attempt to control the yellowjacket. The toxicant bendiocarb, used for nest eradication, is not registered in the USA for use in agricultural situations, so its implementation had to be outside of agricultural fields. Chang (1988) discusses the use of toxic baiting in the control of yellowjackets. His results showed that the most effective combination of bait and chemical toxicant was 0.5% microencapsulated diazinon mixed with canned Figaro brand tuna cat food. Amidinohydrazone in a similar bait mix was also effective, but less so than than diazinon mix. Dispenser colour for the bait also proved critical, the preferred colour of bait dispenser being translucent white.

## 5. Ants (Hymenoptera: Formicidae)

The best-documented ant conservation problems in the Pacific are mostly from the Hawaiian Islands and the Galapagos. Most of the conservation pests listed below are exclusionary; they occupy an area, outcompete any native ants, prey on native fauna or exclude them from the area. They affect plants by harvesting seeds, pruning foliage and encouraging the increase in populations of some sap-sucking insects. Most of the beneficial aspects of alien ant species appear to occur in cultivated areas. However, Compton and Robertson (1991) point out that the presence of *Pheidole megacephala* reduces seed predation and increases the number of pollinators in figs. Documentation on effects of ants in native ecosystems in the Pacific has been slow in arriving, but recent research has revealed a number of problems and potential problems. The major potential problem ant species for conservation are discussed below.

### 5.1 Bigheaded ant

Scientific name: *Pheidole megacephala* (Fabricius). Family: Formicidae

Distribution

This ant is Afrotropical in origin and seems to be circumtropical in distribution (Wilson and Taylor 1967), although it is also found in heated greenhouses in temperate areas (Bernard 1968). In the Pacific, it has been reported from the Hawaiian Islands, Line Islands, Society Islands, Cook Islands, Austral Islands, Gambier Islands, Marquesas Islands, Fiji, Marshall Islands, and Guam, but is likely to be widely distributed throughout the Pacific. This species was first reported from Hawai‘i in 1879 (Smith 1879), but was probably established some time before that, as Blackburn and Kirby (1880) noted that it was already quite common.

Discussion

Perkins (1913) documented the loss of native species in Hawaii as a direct result of predation by the bigheaded ant. He specifically reported beetles and moths being affected, but included all arthropod groups in his assessment. Zimmerman (1948) reported the elimination of most endemic species in the bigheaded ant’s range. *P. megacephala* has also been implicated in the exclusion of native spiders (Gillespie and Reimer 1993).

In Hawaii the bigheaded ant is primarily restricted to dry and mesic lowland areas although it may occasionally be found up to 1220 m altitude (Reimer 1994, Wetterer 1998, Wetterer et al. 1998). It is the dominant ant in many areas, although other aggressive ants such as *Linepithema humile*, *Anoplolepis longipes*, *Iridomyrmex glaber*, *Solenopsis geminata*, and *Pheidole fervens* have displaced it in less suitable environments (Reimer 1994).

In addition to the negative effects of general predation on the native fauna, the big-headed ant feeds on the honeydew of scale insects and other homopterans, increasing their rates of survival by protecting them from parasites and predators (Jahn and Beardsley

1994), and possibly by removing waste material (Rohrbach et al. 1988). This behaviour may foster the depredation of native host plants by increasing the parasite load and by increasing growth of sooty moulds on leaf surfaces, disrupting photosynthesis.

Large-scale programmes to control this species in non-cultivated areas appear not to have been attempted in Hawaii. Su et al. (1980) in searching for an alternative to the mirex baits withdrawn for environmental concerns, found that AC-217,300 was effective in controlling the bigheaded ant in pineapple fields. McEwen et al. (1979) and Reimer et al. (1991) reviewed chemical controls for *P. megacephala* in Hawai'i.

## 5.2 Long-legged ant, crazy ant

Scientific name: *Anoplolepis longipes* (Jerdon). Family: Formicidae.

Long-legged ant is the common name for this species in the list of common names published by the Entomological Society of America (ESA) (Bosik 1997), but crazy ant is in wide use in the Pacific. In the ESA list, *Paratrechina longicornis* is called the crazy ant.

Distribution

After many years of interception in quarantine, *A. longipes* was discovered established in Hawaii on O'ahu in 1952. Wilson and Taylor (1967) list Africa as the source area. This ant has been spread throughout the world by human activity. Wilson and Taylor (1967) gave its distribution as the Old World tropics, and called it the dominant ant in disturbed habitats in Melanesia and Micronesia. More specifically, in the Pacific, it has been reported from Guam, Kosrae, Marshall, Kiribati, Tuvalu, Wallis and Futuna, Samoa, Fiji, Cook, Tokelau, Ellice, Austral, Tuamotu, Gambier, Marquesas, and Solomon Islands, in addition to Hawaii, and is likely to be found on other Pacific islands.

Discussion

This ant is usually found from sea level to 800 m in the Hawaiian Islands, but has been collected as high as 1220 m altitude (Reimer 1994, Wetterer 1998). Hardy (1979) first noted the effect of the long-legged ant on formerly common native insects in riparian habitats. Beardsley (1980) confirmed the threat to endemic arthropod fauna. Moore and Gagné (1982) implicated *A. longipes* as one of the causes for the depletion of the native lowland damselfly fauna. Gillespie and Reimer (1993) demonstrated that confrontations between *A. longipes* (and *P. megacephala*) and native or alien spiders resulted in the death of the native species and not the alien species. Gillespie and Reimer suggested the exclusion of native spiders in lowland areas occupied by *A. longipes*.

The long-legged ant is considered beneficial for agricultural purposes, often preying on agricultural pest species and reducing their numbers. At the same time, it can be a household nuisance (Haines et al. 1994). Haines et al. (1994) reported that, in addition to their predation of arthropods and similar to the big-headed ant, *A. longipes* affects plants by removing soil from roots and tending coccid populations and greatly enhancing their populations, increasing sooty mould growth.

The long-legged ant may also exclude vertebrates. In the Seychelles, Haines et al. (1994) noted that the ants killed newly hatched chickens and newly born domestic animals and forced older animals to leave the area. In Tonga, *A. longipes* has been shown to kill hatchlings of an endemic bird (*Megapodius pritchardii*) (Swaney 1994). This ant and similar aggressive species could potentially be a problem for native vertebrates throughout the Pacific, as even snakes and lizards were affected.

In the Solomon Islands, Greenslade (1971) noted that species diversity decreased wherever *A. longipes* populations flourished. Though Greenslade was referring to coconut plantations, the observation should also hold true for native forests.

An educational programme coupled with toxic baits were used in the Seychelles to control *A. longipes* and prevent its spread to islands of greater conservation significance, those with higher populations of native species (Haines et al. 1994). Partial success of the programme ensued, but full eradication failed for a variety of reasons. However, populations of *A. longipes* declined, perhaps as a result of natural factors associated with invasion by a new species (invasion, slow increase in numbers, explosive growth, high densities, decline in densities) (Simmonds and Greathead 1977). Lewis et al. (1976) reviewed earlier efforts using chemical controls in the Seychelles.

## 5.3 Argentine ant

Scientific name: *Linepithema humile* (Mayr). Family: Formicidae

Distribution

The Argentine ant is a tramp species that is so far reported in the Pacific only from Hawaii. This species is apparently native to Brazil and Argentina, and has a worldwide distribution, mostly in the 30°–36° latitude belts of the Northern and Southern hemispheres (Fluker and Beardsley 1970, Lieberburg et al. 1975).

Discussion

The Argentine ant was intercepted in quarantine many times before it finally became established in Hawaii in 1940 (Zimmerman 1941). At first, these ants were observed eliminating other ant species. Wilson and Taylor (1967) stated that *L. humile* excluded other larger ant species, including *Pheidole megacephala*, and Majer (1994) confirms this. However, Reimer (1994) states that *L. humile* has been displaced by other ant species, such as *P. megacephala* in Hawaii, and is now limited to the cooler higher altitudes from 900 to 2800 m. Medeiros et al. (1986) reported the Argentine ant in two slowly expanding populations at Haleakala on Maui, at altitudes of 2000–2260 m and 2740–2830 m.

Medeiros et al. (1986) suggested *L. humile* negatively affected endemic organisms, particularly ground-dwelling or ground-nesting native moths and bees. Cole et al. (1992) discussed the effects of the Argentine ant on the invertebrate fauna at higher altitudes and concluded that the ant locally reduced the abundance of many endemic species, including arthropods and snails, and could negatively affect the pollination of native plants. They also mentioned that spiders were negatively affected, although Gillespie and Reimer (1993) noted that native spiders co-existed with *L. humile* between 300 m and 1500 m altitude.

Bartlett (1961) showed that, in the absence of Argentine ants, certain parasitic species suppressed populations of scale insects, indicating that Argentine ants may also foster increases in scale insect populations to the detriment of the host plant and its surrounding environment.

Majer (1994a) suggests that the exclusivity of *L. humile* offers a potential control mechanism by giving selective advantage to competing native species. Krushelnycky and Reimer (1996) reviewed the efforts of ant control at Haleakala. Use of Maxforce baits has been effective in trials to control the Argentine ant at Haleakala (Reimer 1999).

## 5.4 Little fire ant

Scientific name: *Wasmannia auropunctata* (Roger). Family: Formicidae

Distribution

The little fire ant is a native of tropical America. It was first found in the Pacific over 35 years ago, but within the last few years has been rapidly expanding its range. *W. auropunctata* was first reported from the Galapagos in 1972 (Silberglied 1972), New Caledonia in 1972 (Fabres and Brown 1978), Wallis and Futuna (Passera 1994); and Wetterer (1998) adds the Solomon Islands. More recently, it has been found in Fiji (personal comm. J.K. Wetterer to J. Wright and G. Sherley) and Vanuatu (Rapp 1999). In addition, this ant may have just been found in Hawaii (N. Reimer, personal comm.). The sudden increase of sightings may be attributable to the work of Wetterer and others who have done much to increase the awareness of the threat of this species. Wetterer considers this ant to be “perhaps the greatest threat in the Pacific”. Much of the work documenting the problems caused by this species is from the Galapagos. Though the Galapagos is not part of SPREP, those references are included here for background information and for use by SPREP members.

Discussion

Smith (1965) indicated that *W. auropunctata* prefers cultivated areas and buildings, but this was in temperate and urban eastern USA. Silberglieb (1972) early pointed out the potential conservation problems with *W. auropunctata* as it replaced indigenous ant fauna, attacked other terrestrial insects and invertebrates, and tended a variety of honeydew secreting insects. Lubin (1984) documented the exclusionary behaviour of *Wasmannia* and found that it reduced species diversity, reduced overall abundance of flying and arboricolous insects, and eliminated populations of arachnids. *Wasmannia* is also known for its painful stings (Spencer 1941, Silberglieb 1972). Clark et al. (1982) quantified the diet of *Wasmannia* and showed that prey included eight orders of insects, chilopods, arachnids, crustaceans (mainly isopods), gastropods, annelids, and seeds and other plant parts.

In the Solomon Islands, it is considered partially beneficial because of its ability to control the coconut nutfall bug, *Amblypelta cocophaga*, in coconuts and cocoa (GPPIS 1999apr30). In New Caledonia the ant induces severe outbreaks of the coffee berry borer, *Hypothenemus hampei*, through interfering with parasitisation of the pest (GPPIS 1999apr30).

More recently, informal information suggests that *W. auropunctata* severely affects vertebrates, both domestic and native species (J.K. Wetterer to E. van Gelder in response to a query about the effects of *W. auropunctata*, April 1999). According to Wetterer, the ants attack vertebrates, including giant tortoises in the Galapagos, attacking eyes and cloacas and potentially rendering them infertile. The little fire ant also reportedly eats the hatchlings of the Galapagos tortoises (Hayashi 1999). In New Caledonia and the

Solomon Islands, local reports indicate that dogs are blinded by the ant's venom (Wetterer to van Gelder, Hayashi 1999).

Spencer (1941) reviewed control measures against *W. auropunctata* in citrus groves. Abedrabbo (1994) reviewed control efforts in the Galapagos using commercial formulations in chemical baits. Heraty (1994) offers a potential method of control, suggesting that host-specific eucharitid wasps of the genus *Orasema* might provide biological control of *Wasmannia* and *Solenopsis*.

## 5.5 Other ants

The following ant species are treated together as they were cited as conservation problems as a group, not individually.

### Fire ant

Scientific name: *Solenopsis geminata* (Fabricius). Family: Formicidae

### [Ants without common names]

Scientific name: *Monomorium floricola* (Jerdon). Family: Formicidae

Scientific name: *Tapinoma minutum* Mayr. Family: Formicidae

Scientific name: *Technomyrmex albipes* (F. Smith). Family: Formicidae

Nafus (1993) presented evidence that the ants listed above were significant factors in reducing populations of native butterflies on Guam. The most important species attacking eggs were *Monomorium floricola*, *Solenopsis geminata*, and *Tapinoma minutum*. The most commonly observed predators attacking butterfly larvae were *T. minutum*, *S. geminata*, and *Technomyrmex albipes*.

According to Wilson and Taylor (1967), *Monomorium floricola* is one of the most widespread of all pantropical ant species and probably originated from tropical Asia. It occurs virtually on all island groups in the Pacific. *Solenopsis geminata* is similarly widespread, but is native to the tropics and warmer parts of temperate New World. It prefers drier habitats. *Tapinoma minutum* is tiny, inconspicuous and often overlooked. It may be indigenous to the Southwest Pacific and has been recorded from Samoa, Micronesia, tropical Australia, New Guinea, Solomon Islands, and Fiji as well as Hawaii. *Technomyrmex albipes* is probably the most widespread member of the genus, ranging from India to eastern Australia and throughout the Pacific including Polynesia, Melanesia and Micronesia. These species are all present in Hawaii, and although recent studies on impacts of their presence (e.g. Gillespie and Reimer 1993) did not implicate them as excluding native species of spiders, their presence may have an unobserved effect, such as predation of eggs or larvae as demonstrated by Nafus (1993).

Other ants may also be problems though not documented, especially if inserted into previously antless island ecosystems or if more aggressive species invade and disrupt the ecosystem. Some ants are potential problems, but their impact is unknown. Wetterer (1998) suggests that colonisation by more cold-tolerant ants such as *Pheidole bourbonica, Cardiocondyla venustula,* and *Linepithema humile* poses a general threat to the remaining native enclaves in Hawaii. The following two species are potential threats to native ecosystems, though their actual impact has not yet been confirmed.

### [Ant without a common name]

Scientific name: *Solenopsis papuana* Emery

Gillespie and Reimer (1993) found a significant inverse relationship between the abundance of *S. papuana* and native spiders in Hawaii. Although exclusion was not shown as in the case of *Pheidole megacephala* and *Anoplolepis longipes*, they suggest this species may be the most serious threat to native Hawaiian arthropods. They suggest the present coexistence of ant and spiders is due to the recent invasion of *S. papuana* (first reported as *Solenopsis* sp. "b" by Huddleston and Fluker 1969). The basis for the threat is that this ant has successfully invaded native and disturbed wet forests, areas that retain the highest level of endemism in Hawaii.

### Glaber ant

Scientific name: *Ochetellus glaber* (Mayr)

Though not included in Gillespie and Reimer's (1993) study, another ant that may bear careful observation is *Ochetellus glaber*. This ant was first reported in 1978 in Hawaii and is aggressively invading areas formerly occupied by other species of ants.

## 5.6 Tramp species of ants

Most of the ants listed above exhibit similar characteristics that categorise them as "tramp" species (Hölldobler and Wilson 1990, Passera 1994). Tramp species are attracted to perturbed environments and thus are often associated with human activities. They are unicolonial or show the absence of aggressive behaviour to individuals of the same species from different nests. They are polygynous where nests have multiple queens and the queens do not exhibit dominant behaviour. Their colonies tend to expand by budding rather than by nuptial flights and aerial dispersal. These ants are particularly aggressive to other species of ants. Tramp species also tend to be smaller in size (<1.5 to 3.5 mm in worker length). Brandao and Paiva (1994) include opportunistic with regard to nest sites and omnivorous as additional characteristics of tramp species. Jourdan (1997) suggests the rapid spread of tramp species such as *Wasmannia auropunctata* may be partly a result of paucity of ant species and ant-filled niches in the Pacific.

Ants attracted to perturbed environments are more likely to become hitchhikers on machinery and plants associated with humans and from areas where habitat modification is commonly practised, such as farms, nurseries, greenhouses and the like. The lack of intraspecific aggression, multiple queens, and budding permit the establishment of large numbers of individuals in a single area, maximising foraging efficiency.

The traits listed for tramp species also have implications for control measures. For example, in Hawaii, Reimer (1994) states the Argentine ant occupies limited areas in Haleakala National Park and suggests it could be eliminated or contained with an appropriate bait. Colonies multiplying by budding rather than aerial dispersal could be more easily eliminated because of the restricted area of occupation. However, the budding also makes it more difficult to determine whether the entire colony has been eliminated.

## 5.7 Methods of ant control

Chemicals, particularly those used in conjunction with baits, seem to be the most effective method to control established unwanted species at this time (Lewis et al. 1976, Abedrabbo 1994, Reimer 1999).

Apart from other ant species, few biological control options exist. Predators such as antlions and ant-feeding vertebrates such as anteaters have either minimal impact on the large populations or are inappropriate to introduce. Relatively little is known about pathogenic microorganisms and fungi (Hölldobler and Wilson 1990). Parasitoids have been a major means of controlling plant pests such as scales, aphids, and caterpillars, but have not been widely used for ant control. Hölldobler and Wilson (1990) did not even include a section on ant parasitoids in their comprehensive treatment of ants. Recently, however, some effort is being made to identify and assess the impact of ant parasitoids such as eucharitid wasps (Heraty 1994) and phorid flies (Disney 1994, Morrison and Gilbert 1998).

Effective quarantine measures, continuous monitoring, and immediate response upon finding newly established ant species may be more effective than attempting to eradicate established species.

## 5.8 Summary (ants)

Many tramp species of ants are found throughout much of the Pacific. Some of these were introduced to Pacific islands very early. As many of the lowland ecosystems are quite disrupted, the damage, if any, done by these species perhaps cannot be established. For example, when first observed in Hawaii, *P. megacephala* was considered beneficial as it was found in sugar cane fields and was observed feeding on many pest species (e.g. Perkins 1907). Perkins was completing an inventory of the arthropod species of Hawaii at the time he noted the absence of native beetles, moths and other groups in areas occupied by *P. megacephala*, and began documenting the predation on native species. Other areas of the Pacific other than the Galapagos did not have the combination of baseline inventory and field observation at the time of invasion by the pest species of ants, and the effects of the invading species are probably unknown.

Perhaps one of the greatest threats to Pacific conservation is *Wasmannia auropunctata*, which is spreading rapidly. Though much of the previous evidence of their impact was anecdotal, a substantial number of reports on the negative consequences of their introduction to Pacific islands are beginning to emerge. The damage to native ecosystems from this species is likely to be considerable.

In Hawaii, except for *Linepithima humile*, which is found as high as 3000 m, most of the environmental depredations caused by ants have been at lower elevations. This would suggest that intact lowland ecosystems with high diversity of native species would be most at risk. However, Wetterer (1998) states that ants continue to spread in the Hawaiian Islands, and cites unpublished data indicating that *P. megacephala* is found as high as the saddle area between Mauna Kea and Mauna Loa, up to 2020 m in altitude. Though populations of most ant species have not deeply penetrated native forest at higher altitudes, the situations posed by *Linepithima humile* and possibly *Solenopsis papuana* should serve as warnings about the potential threats posed by ants to native flora and fauna at even the higher elevations and in wet forests. Others have pointed out that ants can exclude vertebrates. For example, Wetterer et al. (1998) suggest that ants rather than avian malaria at upper elevations on the island of Hawai‘i may be responsible for the exclusion of the endangered palila (*Loxioides bailleui*). Ants are also predators of other invertebrates including snails, and invertebrate biodiversity must be considered also when assessing ant invasions.

Particular care should be taken in introducing ants as biological control agents, and Majer (1994b) cautions against such an approach. Zenner-Polania (1994) documents the effects on the native ant fauna of introducing *Paratrechina fulva* (Mayr) into Colombia, and many authors discuss the exclusion of native species of ants by aggressive invaders.

A review of the information cited above indicates that much more information must be gathered to understand the true impact of ants on native ecosystems, especially considering the uniqueness of Pacific floras and faunas. Their actual impact may not have been observed nor fully understood, as monitoring of Pacific island ecosystems has not usually been done. Only recently have some of the negative aspects of their presence been documented and these present increasing and extremely disturbing evidence of environmental modification. Based on the information presented above, it appears that many if not most ants may have an effect on any environment they invade. Except for a few species, the size of the impact, whether positive or negative, and the extent of the impact are usually poorly known.

Current methods of eradicating ant invasions in native forests are for the most part, inadequate, ineffective, or inappropriate. Control is often obtained by the use of baits with pesticides. More research is needed in this area.

## 6. References


Abedrabbo, S. 1994. Control of the little fire ant, *Wasmannia auropunctata*, on Santa Fe Island in the Galapagos Islands. Pp. 219–227 *in*: D.F. Williams (ed.) *Exotic ants: biology, impact, and control of introduced species*. Westview Press, Boulder. 332 pp.

Anonymous. 1947. Insect Control Committee for Micronesia (ICCM). *Annual Report of the Pacific Science Board*, 1: 17–21.

Anonymous. 1948. Insect Control Committee for Micronesia (ICCM). *Annual Report of the Pacific Science Board*, 2: 16–20.

Anonymous. 1948. Insect Control Committee for Micronesia (ICCM). *Annual Report of the Pacific Science Board* (suppl. to 1947 report): 9–13.

Anonymous. 1949. Insect Control Committee for Micronesia (ICCM). *Annual Report of the Pacific Science Board*, 3: 74–79.

Anonymous. 1950. Insect Consultants Committee for Micronesia (ICCM). *Annual Report of the Pacific Science Board*, 4: 25–31.

Anonymous. 1951. Insect Consultants Committee for Micronesia (ICCM). *Annual Report of the Pacific Science Board*, 5: 30–37.

Anonymous. 1952. Insect Consultants Committee for Micronesia (ICCM). *Annual Report of the Pacific Science Board*, 6: 28–36.

Anonymous. 1953. Insect Consultants Committee for Micronesia (ICCM). *Annual Report of the Pacific Science Board*, 7: 21–28.

Asquith, A. 1995. Alien species and the extinction crisis of Hawaii's invertebrates. *Endangered Species Update* 12(6): 6–11.

Atkinson, C.T., K.L. Woods, R.J. Dusek, L.S. Sileo K.W. Iko. 1995. Wildlife disease and conservation in Hawaii: pathogenicity of avian malaria (*Plasmodium relictum*) in experimentally infected I'iwi (*Vestiaria coccinea*). *Parasitology*, 111, Suppl.: S59–S69.

Bartlett, B.R. 1961. The influence of ants upon parasites, predators, and scale insects. *Annals of the Entomological Society of America*, 54: 543-551.

Beardsley Jr, J.W. 1979. New immigrant insects in Hawaii: 1962 through 1976. *Proceedings of the Hawaiian Entomological Society*, 23: 35–44.

Beardsley, J.W. 1980. Haleakala National Park Crater District Resources Basic Inventory: Insects. *Cooperative National Park Research Study Unit Technical Report,* 31: 1-49.

Bernard, F. 1968. Les Fourmis (Hymenoptera: Formicidae) d'Europe occidentale et septentrionale. *Faune de l'Europe et du Bassin méditerranéan*. Masson et Cie, Paris. 411 pp.

Blackburn, T.; Kirby, W.F. 1880. Notes on species of aculeate Hymenoptera occurring in the Hawaiian Islands. *Entomologists Monthly Magazine*, 17: 85-89.

Bosik, J.J. (Chair). 1997. *Common names of insects and related organisms 1997*. Entomological Society of America, (Annapolis, MD). 232 pp.

Brandao, C.R.F.; Paiva, R.V.S. 1994. The Galapagos ant fauna and the attributes of colonizing ant species. Pp. 1–10 *in*: Williams, D.F. (ed.) *Exotic ants: biology, impact, and control of introduced species.* Westview Press, Boulder. 332 p.

Chang, V. 1988. Toxic baiting of the western yellowjacket (Hymenoptera: Vespidae) in Hawaii. *Journal of Economic Entomology*, 81: 228–35.

Clark, D.B.; Guayasamín, C.; Pazamiño, O.; Donoso, C.; Páez de Villacís, Y. 1982. The tramp ant *Wasmannia auropunctata*: autecology and effects on ant diversity and distribution on Santa Cruz Island, Galapagos. *Biotropica*, 14: 196–207.

Clausen, C.P. 1978a. Scarabaeidae. Pp. 277–92 *in*: Clausen, C.P. (ed.) *Introduced parasites and predators of arthropod pests and weeds: a world review*. US Department of Agriculture, Agriculture Handbook no. 480: vi + 545.

Clausen, C.P. 1978b. Scolytidae. Pp. 292–94 *in*: Clausen, C.P. (ed.) *Introduced parasites and predators of arthropod pests and weeds: a world review*. U.S. Department of Agriculture, Agriculture Handbook no. 480: vi + 545.

Cole, F.R.; Medeiros, A.C.; Loope, L.L.; Zuehlke, W.W.. 1992. Effects of the Argentine ant on arthropod fauna of Hawaiian high-elevation shrubland. *Ecology*, 73(4): 1313–1322.

Compton, S.G.; H.G. Robertson. 1991. Effects of ant-homopteran systems on fig-figwasp interactions. Pp. 120–130 *in*: Huxley C.R.; Cutler, D.E. (eds) *Ant-Plant Interactions.* Oxford University Press, Oxford. 601 pp.

Curran, C.H. 1945. *Insects of the Pacific world*. New York. 317 pp.

Davis, C.J. 1963. Notes and exhibitions. *Xyleborus morstatti* Hagedorn. *Proceedings of the Hawaiian Entomological Society*, 18: 201–207.

Davis, C.J.; Chong, M. 1970. Recent introductions for biological control in Hawaii. XIV. *Proceedings of the Hawaiian Entomological Society*, 20[1969]: 317–322.

Davis, C.J.; Krauss, N.L.H. 1967. Recent introductions for biological control in Hawaii. XI. *Proceedings of the Hawaiian Entomological Society*, 19[1966]: 201–207.

Disney, R.H.L. 1994. *Scuttle flies: the Phoridae*. Chapman and Hall, London.

Evenhuis, N.L. 1982. Preliminary considerations on the zoogeography of Oceanic Bombyliidae (Diptera: Brachycera). *Entomologia Generalis*, 8: 79–86.

Evenhuis, N.L. (ed.) 1989. *Catalog of the Diptera of the Australasian and Oceanian Regions*. Bishop Museum, Honolulu.; E.J. Brill, Leiden. 1155 pp.

Fabres, G.; Brown, W.L. Jr. 1978. The recent introduction of the pest ant *Wasmannia auropunctata* into New Caledonia. *Journal of the Australian Entomological Society*, 17: 139–142.

Fluker, S.S.; J.W. Beardsley. 1970. Sympatric associations of three ants: *Iridomyrmex humilis*, *Pheidole megacephala*, and *Anoplolepis longipes* in Hawaii. *Annals of the Entomological Society of America*, 63 (5): 1290–1296.

Gagné, W.C.; Christensen, C.C. 1985. Conservation status of native terrestrial invertebrates in Hawaii. Pp. 105–41 *in*: Stone, C.P.; Scott, J.M. (eds), *Hawai'i's terrestrial ecosystems: preservation and management. Proceedings of a symposium held June 5–6, 1984 at Hawaii Volcanoes National Park*. Cooperative National Park Resources Studies Unit, University of Hawaii, Honolulu. xxviii + 584 pp.

Gambino, P. 1991. Reproductive plasticity of *Vespula pensylvanica* (Hymenoptera: Vespidae) on Maui and Hawaii Islands, USA. *New Zealand Journal of Zoology*, 18: 139–49.

Gambino, P.; Loope, L.L. 1992. Yellowjacket *Vespula pensylvanica* biology and abatement in the National Parks of Hawaii. *Cooperative National Park Research Study Unit Technical Report*, 86: 1–41.

Gillespie, R.G..; N. Reimer. 1993. The effect of alien predatory ants (Hymenoptera: Formicidae) on Hawaiian endemic spiders (Araneae: Tetragnathidae). *Pacific Science*, 47: 21–33.

GPPIS (Global Plant.; Pest Information System). www.pppis.fao.org/ Version: 1999 April 30.

Greenslade, P.J.M. 1971. Interspecific competition and frequency changes among ants in Solomon Islands coconut plantations. *Journal of Applied Ecology*, 8: 323–352.

Gressitt, J.L. 1953. The coconut rhinoceros beetle (*Oryctes rhinoceros*) with particular reference to the Palau Islands. *Bishop Museum Bulletin no. 212*: 1–157.

Gressitt, J.L. 1982. Pacific-Asian biogeography with examples from the Coleoptera. *Entomologia Generalis*, 8: 1–11.

Haines, I.H.; Haines, J.B.; Cherrett, J.M.. 1994. The impact and control of the Crazy ant, *Anoplolepis longipes* (Jerd.), in the Seychelles. Pp. 206–218 *in*: Williams, D.F. (ed.), *Exotic ants. Biology, impact, and control of introduced species*. Westview Press, Boulder, San Francisco, Oxford. 332 pp.

Hara, A.H.; J.W. Beardsley Jr. 1979. The biology of the black twig borer, *Xylosandrus compactus* (Eichhoff), in Hawaii. *Proceedings of the Hawaiian Entomological Society*, 23: 55–70.

Hardy, D.E. 1979. An ecological survey of Puaaluu Stream. Part III. Report of a preliminary entomological survey of Puaaluu Stream, Maui. *Cooperative National Park Research Study Unit Technical Report*, 27 (3): 34–37.

Hawaii Department of Agriculture, Division of Plant Industry, Entomology Branch. 1975. Distribution of some agricultural pests in Hawaii. Memo. 28 pp.

Hayashi, A.M. 1999. Attack of the fire ants. *Scientific American*, 280 (2): 26, 28.

Heraty, J.M. 1994. Biology and importance of two eucharitid parasites of *Wasmannia* and *Solenopsis*. Pp. 104–120 *in*: Williams, D.F. (ed.) *Exotic ants. Biology, impact, and control of introduced species*. Westview Press, Boulder, San Francisco, Oxford. 332 pp.

Hewitt, R.I. 1940. Bird malaria. *American Journal of Hygiene, Monograph Series, no. 15*: xvii + 228 pp.

Hill, D.S. 1983. *Agricultural insect pests of the tropics and their control. Second edition*. Cambridge University Press, Cambridge, UK. xii + 746 pp.

Hölldobler, B.; Wilson, E.O. 1990. *The Ants*. Springer-Verlag, Berlin. 732 pp.

Howarth, F.G. 1985. Impacts of alien land arthropods and mollusks on native plants and animals in Hawaii. Pp. 149–79 *in*: Stone, C.P.; Scott, J.M. (eds) *Hawai'i's terrestrial ecosystems: preservation and management. Proceedings of a symposium held June 5–6, 1984 at Hawaii Volcanoes National Park*. Cooperative National Park Resources Studies Unit, University of Hawaii, Honolulu. xxviii + 584 pp.

Huddleston, E.W.; Fluker, S.S. 1968. Distribution of ant species in Hawaii. *Proceedings of the Hawaiian Entomological Society*, 20: 45–69.

Jahn, G.C.; Beardsley, J.W. 1994. Big-headed ants, *Pheidole megacephala*: interference with the biological control of Gray pineapple mealybugs. Pp. 199–205 *in*: Williams, D.F. (ed.) *Exotic ants. Biology, impact, and control of introduced species*. Westview Press, Boulder, San Francisco, Oxford. 332 pp.

Jourdan, H. 1997. Threats on Pacific islands: the spread of the tramp ant *Wasmannia auropunctata* (Hymenoptera: Formicidae). *Pacific Conservation Biology*, 3: 61–64.

Kami, K.; Miller, S.E. 1998. Samoan insects and related arthropods: checklist and bibliography. *Bishop Museum Technical Report, no. 13*: v + 121.

Krushelnycky, P.D.; Reimer, N.J. 1996. Efforts at control of the Argentine ant in Haleakala National Park, Maui, Hawaii. *Cooperative National Park Resources Study Unit Technical Report, no. 109*: 1–33.

Leefmans, S. 1884. *De klappertor (*Oryctes rhinoceros *L.).* Ruygrok & Co., Batavia. viii + 156 pp.

Lewis, T.; Cherrett, J.M.; Haines, I.; Haines, J.B.; Mathias, P.L. 1976. The crazy ant (*Anoplolepis longipes* (Jerd.) (Hymenoptera, Formicidae)) in Seychelles, and its chemical control. *Bulletin of Entomological Research*, 66: 97–111.

Lieberburg, I.; Kranz, P.M.; Seip, A. 1975. Bermudian ants revisited: the status and interaction of *Pheidole megacephala* and *Iridomyrmex humilis*. *Ecology,* 56: 473–478.

Loope, L.L.; Medeiros, A.C. 1995. Strategies for long-term protection of biological diversity in rainforests of Haleakaka National Park and East Maui, Hawaii. *Endangered Species Update,* 12 (6): 1–5.

Lubin, Y.D. 1984. Changes in the native fauna of the Galapagos islands following invasion by the little red fire ant, *Wasmannia auropunctata*. *Biological Journal of the Linnean Society*, 21 (1&2): 229–242.

Majer, J.D. 1994a. Spread of Argentine ants (*Linepithema humile*), with special reference to Western Australia. Pp. 163–173 *in*: Williams, D.F. (ed.) *Exotic ants. Biology, impact, and control of introduced species*. Westview Press, Boulder, San Francisco, Oxford. 332 pp.

Majer, J.D. 1994b. Introduction of ants as potential biological control agents, with particular reference to cocoa. *Harvest*, 16 (1&2): 1–4.

Massey, J.G.; Graczyk, T.K.; Cranfield, M.R. 1996. Characteristics of naturally acquired *Plasmodium relictum capistranoae* infections in naive Hawaiian crows (*Corvus hawaiiensis*) in Hawaii. *Journal of Parasitology,* 82: 182–85.

McEwen, F.L.; Beardsley, J.W. Jr.; Hapai, M.; Su, T.H. 1979. Laboratory tests with candidate insecticides for control of the big-headed ant, *Pheidole megacephala* (Fabricius). *Proceedings of the Hawaiian Entomological Society*, 23: 119–123.

Medeiros, A.C.; Loope, L.L.; Cole, F.R. 1986. Distribution of ants and their effects on endemic biota of Haleakala and Hawaii Volcanoes National Parks: a preliminary assessment. Pp. 39–52 *in*: Smith,C.W. *Proceedings Sixth Conference in Natural Sciences Hawaii Volcanoes National Park*. Cooperative National Park Resources Study Unit, University of Hawaii at Manoa. 98 pp.

Moore, N.; W.C. Gagné. 1982. *Megalagrion pacificum* (McLachlan) – a preliminary study of the conservation requirements of an endangered species. *Report of the Odonata Specialist Group, IUCN, no. 3*: 1–5.

Morrison, L.W.; Gilbert, L.E. 1998. Parasitoid-host relationships when host size varies: the case of *Pseudacteon* flies and *Solenopsis* fire ants. *Ecological Entomology* 23(4): 409–416.

Nafus, D.M. 1993. Movement of introduced biological control agents onto nontarget butterflies, *Hypolimnas* spp. (Lepidoptera: Nymphalidae). *Environmental Entomology*, 22 (2): 265–272.

Nishida, G.M. 1997. Hawaiian terrestrial arthropod checklist. Third edition. *Bishop Museum Technical Report, no. 12*: iv + 263.

Passera, L. 1994. Characteristics of tramp species. Pp. 23-43 *in*: Williams, D.F. (ed.) *Exotic ants. Biology, impact, and control of introduced species*. Westview Press, Boulder, San Francisco, Oxford. 332 pp.

Perkins, R.C.L. 1907. Insects of Tantalus. *Proceedings of the Hawaiian Entomological Society* (1906), 1: 38–51.

Perkins, R.C.L. 1913. Introduction. *Fauna Hawaiiensis*, 1, pt. 6: xv-ccxxvii.

Rapp, G. 1999. Introduction of the fire ant *Wasmannia auropunctata* into Vanuatu. *Ag Alert* 18: 1 p.

Reimer, N.J. 1994. Distribution and impact of alien ants in vulnerable Hawaiian ecosystems. Pp. 11–22 *in*: Williams, D.F. (ed.) *Exotic ants. Biology, impact, and control of introduced species*. Westview Press, Boulder, San Francisco, Oxford. 332 pp.

Reimer, N. 1999. A pictorial key to the most pestiferous ant species threatening Hawaii's native fauna and flora. www.pppis.fao.org/ Version: 1999 May 4.

Reimer, N.J.; Glancey, B.M.; Beardsley, J.W. 1991. Development of *Pheidole megacephala* (Hymenoptera: Formicidae) colonies following ingestion of fenoxycarb and pyriproxyfen. *Journal of Economic Entomology*, 84: 56–60.

Rohrbach, K.G.; Beardsley, J.W.; German, T.L.; Reimer, N.; Sanford, W.G. 1988. Mealybug wilt, mealybugs and ants on pineapple. *Plant Disease,* 72: 558–565.

Samuelson, G.A. 1981. A synopsis of Hawaiian Xyleborini (Coleoptera: Scolytidae). *Pacific Insects*, 23: 50–92.

Savidge, J.A. 1985. The role of disease and predation in the decline of Guam's avifauna. PhD dissertation, University of Illinois, Urbana. 79 pp.

Scott, J.M.; Mountainspring, S.; Ramsey, F.L.; Kepler, C.B. 1986. Forest bird communities of the Hawaiian Islands: their dynamics, ecology, and conservation. *Studies in Avian Biology*, 9, xiii + 341 p.

Silberglied, R. 1972. The 'little fire ant,' *Wasmannia auropunctata*, a serious pest in the Galapagos Islands. *Noticias Galapagos*, 19/20: 13–15.

Simmonds, F.J.; Greathead, D.J. 1977. Introductions and pest and weed problems. Pp. 109–124 *in*: Cherrett, J.M.; Sagar, G.R. (eds) *Origins of pest, parasite, disease and weed problems.* Symposium of the British Ecological Society, 18. Blackwell Scientific Publications Oxford. 413 pp.

Smith, F. 1879. Descriptions of new species of aculeate Hymenoptera collected by the Rev. T. Blackburn in the Sandwich Islands. *Journal of the Linnean Society of London, Zoology*, 14, no. 79: 674–685.

Smith, M.R. 1965. House infesting ants of the eastern United States, their recognition, biology and economic importance. *US Department of Agriculture Technical Bulletin, no. 1326*: 1–105.

Solem, [G.] A. 1976. *Endodontoid land snails from Pacific Islands (Mollusca: Pulmonata: Sigmurethra). Part I. Family Endodontidae*. Field Museum of Natural History, Chicago. xii + 508 pp.

Spencer, H. 1941. The small fire ant *Wasmannia* in citrus groves – a preliminary report. *Florida Entomologist*, 24: 6–14.

Steadman, D.W.; Geiner, E.C.; Wood, C.S. 1990. Absence of blood parasites in indigenous and introduced birds from the Cook Islands, South Pacific. *Conservation Biology*, 4: 398–404.

Su, T.H.; Beardsley, J.W.; McEwen, F.L. 1980. AC-217,300, a promising new insecticide for use in baits for control of the bigheaded ant in pineapple. *Journal of Economic Entomology*, 73 (6): 755–756.

Swan, D.I. 1974. A review of the work on predators, parasites and pathogens for the control of *Oryctes rhinoceros* (L.) (Coleoptera: Scarabaeidae) in the Pacific area. *Commonwealth Agriculture Bureaux Miscellanous Publication, no. 7*, 64 p.

Swaney, D. 1994. *Tonga. A Lonely Planet travel survival kit. 2nd Edition*. Lonely Planet Publications, Hawthorn, Australia. 198 pp.

Van Riper III, C.S. 1991. The impact of introduced vectors and avian malaria on insular passeriform bird populations in Hawaii. *Bulletin of the Society of Vector Ecologists*, 16: 59–83.

Van Riper III, C.S.; Van Riper, S.G.; Goff, M.L.; Laird, M. 1982. The impact of malaria on birds in Hawaii Volcanoes National Park. *Cooperative National Park Resources Studies Unit Technical Report, no. 47*: iii + 74.

Van Riper III, C.S.; Van Riper, S.G.; Goff, M.L.; Laird, M. 1986. The epizootiology and ecological significance of malaria in the Hawaiian land birds. *Ecological Monographs*, 56: 327–44.

Van Riper, S.G.; Van Riper III, C.S. 1985. A summary of the known parasites and diseases recorded from the avifauna of the Hawaiian Islands. Pp. 298–371 *in*: Stone, C.P.; Scott, J.M. (eds) *Hawai'i's terrestrial ecosystems: preservation and management. Proceedings of a symposium held June 5–6, 1984 at Hawaii Volcanoes National Park*. Cooperative National Park Resources Studies Unit, University of Hawaii, Honolulu. xxviii + 584 pp.

Warner, R.E. 1968. The role of introduced diseases in the extinction of the endemic Hawaiian avifauna. *Condor*, 70: 101–20.

Wetterer, J.K. 1997. Ants on *Cecropia* in Hawaii. *Biotropica*, 29: 128–132.

Wetterer, J.K. 1998. Nonindigenous ants associated with geothermal and human disturbance in Hawai'i Volcanoes National Park. *Pacific Science*, 52 (1): 40–50.

Wetterer, J.K.; Banko, P.C.; Laniawe, L.P.; Slotterback, J.W.; Brenner, G.J. 1998. Nonindigenous ants at high elevations on Mauna Kea, Hawaii. *Pacific Science*, 52 (3): 228–236.

Williams, F.X. 1927. Notes on the habits of bees and wasps of the Hawaiian Islands. *Proceedings of the Hawaiian Entomological Society*, 6: 425–64.

Wilson, E.O.; R.W. Taylor. 1967. The ants of Polynesia (Hymenoptera: Formicidae). *Pacific Insects Monographs, no. 14*: 1–109.

Zenner-Polania, I. 1994. Impact of *Paratrechina fulva* on other ant species. Pp. 121–132 *in*: Williams, D.F. (ed.) *Exotic ants. Biology, impact, and control of introduced species*. Westview Press, Boulder, San Francisco, Oxford. 332 pp.

Zimmerman, E.C. 1941. Argentine ant in Hawaii. *Proceedings of the Hawaiian Entomological Society*, 11 (1): 108.

Zimmerman, E.C. 1942. Distribution and origin of some eastern oceanic insects. *American Naturalist*, 76: 280–307.

Zimmerman, E.C. 1948. *Insects of Hawaii. Volume 1. Introduction*. University of Hawaii Press, Honolulu. 206 pp.

# Annex 1. Pacific ant references

A large body of literature exists pertaining to the ants of the Pacific. The following is not complete, and is biased towards the Hawaiian Islands, but it is a beginning towards building the reference base for the Pacific.


Abedrabbo, S. 1994. Control of the little fire ant, *Wasmannia auropunctata*, on Santa Fe Island in the Galapagos Islands. Pp. 219–227 *in*: Williams, D.F. (ed.) *Exotic ants: biology, impact, and control of introduced species*. Westview Press, Boulder. 332 pp.

Alfken, J.D. 1904. Beitrag zur Insectenfauna der hawaiischen und neu-seeländischen Inseln. (Ergebnisse einer Reise nach dem Pacific.) Schauinsland 1896-97. *Zoologische Jahrbuecher, Abteilung fuer Systematik Oekologie und Geographie der Thiere*, 19: 561–628.

Alicata, J.E. 1964. Parasitic infections of man and animals in Hawaii. *Hawaii Agricultural Experiment Station Technical Bulletin*, no. 61: 1–13.

Alicata, J.E. 1969. *Parasites of man and animals in Hawaii*. Karger, Basel, New York. 190 pp.

Allison, A.; Miller, S.E.; Nishida, G.M. 1995. Hawaii Biological Survey. P. 362 *in*: LaRoe, E.T.; Farris, G.S.; Puckett, C.E.; Doran, P.D.; Mac, M.J. (eds) *Our living resources. A report to the nation on the distribution, abundance, and health of US plants, animals, and ecosystems*. US Department of Interior, National Biological Service, Washington, DC. 530 pp.

Asquith, A. 1995. Distribution, abundance and phenology of *Scaptomyza (Bunostoma) anomala* Hardy (Diptera: Drosophilidae): a proposed representative species for monitoring protein bait sprays in Hawaii. *Proceedings of the Hawaiian Entomological Society*, 32: 69–81.

Asquith, A.; Messing, R.H. 1993. Contemporary Hawaiian insect fauna of a lowland agricultural area on Kaua‘i: implications for local and island-wide fruit fly eradication programs. *Pacific Science*, 47: 1–16.

Bach, C.E. 1991. Direct and indirect interactions between ants (*Pheidole megacephala*), scales (*Coccus viridis*) and plants (*Pluchea indica*). *Oecologia* , 87: 233–239.

Back, E.A.; Pemberton, C.E. 1917. The melon fly in Hawaii. *USDA Entomology Bulletin, no. 491*: 1–64.

Back, E.A.; C.E. Pemberton. 1918. The Mediterranean fruit fly in Hawaii. *USDA Technical Bulletin, no. 536*: 1–119.

Baker, G.L. 1976. The seasonal life cycle of *Anoplolepis longipes* (Jerdon) (Hymenoptera: Formicidae) in a cacao plantation and under brushed rain forest in the northern district of Papua New Guinea. *Insectes Sociaux*, 23: 253–261.

Banko, W.E. 1978. Some limiting factors and research needs of endangered Hawaiian forest birds. Pp. 17–25 *in*: Smith, C.W. (ed.) *Proceedings Second Conference in Natural Sciences Hawaii Volcanoes National Park*. University of Hawaii at Manoa, Honolulu. 354 pp.

Banko, W.E.; Banko, P.C. 1976. Role of food depletion by foreign organisms in historical decline of Hawaiian forest birds. Pp. 29–34 *in*: Smith, C.W. (ed.) *Proceedings First Conference in Natural Sciences Hawaii Volcanoes National Park*. University of Hawaii at Manoa, Honolulu. 243 pp.

Baroni Urbani, C. 1974. Competition et association dans les biocenoses de fourmis insulaires. *Revue Suisse de Zoologie*, 81: 103–135.

Bartlett, B.R. 1961. The influence of ants upon parasites, predators, and scale insects. *Annals of the Entomological Society of America*, 54: 543–551.

Basset, Y. 1996. Local communities of arboreal herbivores in Papua New Guinea: predictors of insect variables. *Ecology*,77: 1906–1919.

Beardsley, J.W. (ed.). 1979. New immigrant records for the year 1976. *Proceedings of the Hawaiian Entomological Society*, 23: 27.

Beardsley, J.W. 1980. Haleakala National Park Crater District Resources Basic Inventory: Insects. *Cooperative National Park Research Study Unit Technical Report*, 31: 1-49.

Beardsley, J.W. 1980. Impact of introduced arthropods on endemic terrestrial organisms in Hawai‘i. Pp. 17–18 *in*: Smith, C.W. (ed.) *Proceedings Third Conference in Natural Sciences Hawaii Volcanoes National Park*. University of Hawaii at Manoa, Honolulu. 396 pp.

Beardsley, J.W. 1991. Introduction of arthropod pests into the Hawaiian Islands. *Micronesica* Suppl. 3: 1–4.

Beardsley, J.W.; Tuthill, L.D. 1959. Additions to the known insect fauna of Niihau. *Proceedings of the Hawaiian Entomological Society*, 17: 56–61.

Beardsley, J.W., Jr.; Su, T.H.; McEwen, F.L.; Gerling, D. 1982. Field investigations on the interrelationships of the big-headed ant, the graypineapple mealybug, and pineapple mealybug wilt disease in Hawaii. *Proceedings of the Hawaiian Entomological Society*, 24: 51–67.

Bernard, F. 1968. Les Fourmis (Hymenoptera: Formicidae) d'Europe occidentale et septentrionale. *Faune de l'Europe et du Bassin méditerranéan*. Masson, Paris. 411 pp.

Bianchi, F.A. 1940. Notes on the role of the self-introduced insects in the economic entomology of Hawaii. *Proceedings of the Hawaiian Entomological Society*, 10: 377–388.

Blackburn, T. 1881. Hawaiian entomology. *Thrum's Hawaiian Almanac Annual* 1882: 58-61.

Blackburn, T.; Cameron, P. 1886. On the Hymenoptera of the Hawaiian Islands. *Proceedings of the Literary and Philosophical Society of Manchester*, 25: 134-183. [this paper also published *in Memoirs of the Manchester Literary and Philosophical Society*, ser. 3, 10: 194-245,1886].

Blackburn, T.; Cameron, P. 1887. On the Hymenoptera of the Hawaiian Islands. *Memoirs of the Manchester Literary and Philosophical Society*, ser. 3, 10: 194–245.

Blackburn, T.; Kirby, W.F. 1880. Notes on species of aculeate Hymenoptera occurring in the Hawaiian Islands. *Entomologist's Monthly Magazine*, 17: 85–89.

Bolton, B. 1979. The ant tribe Tetramoriini (Hymenoptera: Formicidae). The genus *Tetramorium* Mayr in the Malagasy region and in the New World. *Bulletin of the British Museum of Natural History, Entomology*, no. 38: 129–181.

Bolton, B. 1982. Afrotropical species of the myrmicine ant genera *Cardiocondyla*, *Leptothorax*, *Melissotarsus*, *Messor* and *Cataulacus* (Formicidae). *Bulletin of the British Museum of Natural History, Entomology*, no. 45: 307–370.

Bolton, B. 1983. The Afrotropical dacetine ants (Formicidae). *Bulletin of the British Museum of Natural History, Entomology*, no. 46: 267–416.

Bolton, B. 1987. A review of the Solenopsis genus-group and revision of afrotropical *Monomorium* Mayr (Hymenoptera: Formicidae). *Bulletin of the British Museum of Natural History, Entomology*, no. 54: 263–452.

Bonnet, D.D. 1948. Certain aspects of medical entomology in Hawaii. *Proceedings of the Hawaiian Entomological Society*, 13: 225–233.

Braekman, J.C.; Daloze, D.; Pasteels, J.M.; Van Hecke, J.P. 1987. Tetraponerine-8, an alkaloidal contact poison in a Neoguinean pseudomyrmecine ant, *Tetraponera* sp. *Zeitschrift für Naturforschung Section C Journal of Biosciences*, 42: 627–630.

Brandao, C.R.F.; Paiva, R.V.S. 1994. The Galapagos ant fauna and the attributes of colonizing ant species. Pp. 1–10 *in*: Williams, D.F. (ed.) *Exotic ants: biology, impact, and control of introduced species*. Westview Press, Boulder. 332 pp.

Brennan, B.M.; Mitchell, W.C.; Springer, D. 1981. Arthropods on reproductive organs of ‘Ohi’a-lehua trees. US-IBP (Int Biol Prog) Syn Ser 15: Pp.127–133 *in*: Mueller-Dombois, D.; Bridges, K.W.; Carson, H.L. (eds) *Island ecosystems. Biological organization in selected Hawaiian communities*. Hutchinson Ross Publishing Company, Stroudsburg, PA; Woods Hole, MA. 583 pp.

Bridwell, J.C. 1918. Entomological program. *Proceedings of the Hawaiian Entomological Society*, 3: 383–384.

Bridwell, J.C. 1918. Certain aspects of medical and sanitary entomology in Hawaii. *Transactions of the Medical Society of Hawaii*, 1916-17: 27–32.

Bridwell, J.C. 1920. Some notes on Hawaiian and other Bethylidae (Hymenoptera) with the description of a new genus and species. 2nd paper. *Proceedings of the Hawaiian Entomological Society*, 4: 291–314.

Brown, W.L. 1949. Revision of the ant tribe Dacetini. I. Fauna of Japan, China and Taiwan. *Mushi*, 20: 1–25.

Brown, W.L. 1949. Revision of the ant tribe Dacetini. III. *Epitritus* Emery and *Quadristruma* new genus (Hymenoptera: Formicidae). *Transactions of the American Entomological Society (Philadelphia)*, 75: 43–51.

Brown, W.L. 1954. The ant genus *Strumigenys* Fred. Smith in the Ethiopian and Malagasy regions. *Bulletin of the Museum of Comparative Zoology*, 112: 1-–34.

Brown, W.L. 1960. Contributions toward a reclassification of the Formicidae. III. Tribe Amblyoponini (Hymenoptera). *Bulletin of the Museum of Comparative Zoology*, 122: 145–230.

Brown, W.L. 1962. The neotropical species of the ant genus *Strumigenys* Fr. Smith: synopsis and keys to the species. *Psyche* 69: 238–267.

Brown, W.L. 1975. Contributions toward a reclassification of the Formicidae, V. Ponerinae, tribes Platythyreini, Cerapachyni, Cylindromyrmecini, Acanthostichini, and Aenictogitini. *Search: Agriculture* (Geneva N Y) 5: 1–115.

Browne, A.C. 1942. Insects taken at light at Kalawahine Place, Honolulu. *Proceedings of the Hawaiian Entomological Society*, 11: 151–152.

Bryan, E.H., Jr. 1926. Introduction. Pp. 1-16 *in*: E.H. Bryan, E.H., Jr.; Collaborators. Insects of Hawaii, Johnston Island and Wake Island. *Bulletin of the Bernice P. Bishop Museum* 31: 94 pp.

Bryan, E.H., Jr. 1933. Insects from Kaula Island. *Proceedings of the Hawaiian Entomological Society*, 8: 245–246.

Bryan, E.H., Jr. 1934. A review of the Hawaiian Diptera, with descriptions of new species. *Proceedings of the Hawaiian Entomological Society*, 8: 399–468.

Bryan, E.H., Jr. 1935. *Hawaiian nature notes*. 2nd edition. Honolulu Star-Bulletin, Honolulu. 285 pp.

Bryan, E.H., Jr. 1935. Insects from Rabbit Island. *Proceedings of the Hawaiian Entomological Society*, 9: 39–43.

Buckley, S.B. 1867. Descriptions of new species of North American Formicidae. *Proceedings of the Entomological Society of Philadelphia*, 6: 335–350.

Buckley, R.; Gullan, P. 1991. More aggressive ant species (Hymenoptera: Formicidae) provide better protection for soft scales and mealybugs (Homoptera: Coccidae, Pseudococcidae). *Biotropica*, 23: 282–286.

Butler, G.D. 1961. Insects and other arthropods from Laysan Island. *Proceedings of the Hawaiian Entomological Society*, 17: 379–387.

Butler, G.D.; Usinger, R.L. 1963. Insects and other invertebrates from Laysan Island. *Atoll Research Bulletin*, 98: 1–30.

Butler, G.D.; Usinger, R.L. 1963. Insects and other arthropods from Kure Island. *Proceedings of the Hawaiian Entomological Society*, 18: 237–244.

Cameron, P. 1886. On a new species of *Strumigenys* (*S. lewisi*) from Japan. *Proceedings of the Literary and Philosophical Society of Manchester*, 25: 229–232.

Carter, W. 1932. Studies of populations of *Pseudococcus brevipes* (Ckl.) occurring on pineapple plants. *Ecology*, 13: 296–304.

Caspers, H. 1966. Verbreitung und Farbanpassung der Strandfauna im Gebiet des schwarzen Lavasandesauf Hawaii. *Internationale Revue der Gesamten Hydrobiologie*, 51: 3–13.

Chang, V.C.S. 1985. Colony revival and notes on rearing and life history of the big-headed ant. *Proceedings of the Hawaiian Entomological Society*, 25: 53–58.

Chang, V.C.S.; Ota A.K.; Sanders, D. 1980. Parallel ridge barrier to control ant damage to orifices of drip irrigation tubes. *Journal of Economic Entomology*, 73: 403–406.

Clark, D.B.; Guayasamin, C.; Pazmino, O.; Donoso, C.; de Villacis, Y.P. 1982. The tramp ant *Wasmannia* *auropunctata*: autecology and effects on ant diversity and distribution on Santa Cruz Island, Galapagos. *Biotropica*, 14: 196–207.

Cole, F.R.; Medeiros, A.C.; Loope, L.L.; Zuehlke, W.W. 1992. Effects of the argentine ant on arthropod fauna of Hawaiian high-elevation shrubland. *Ecology,* 73: 1313–1322.

Compton, S.G.; Robertson, H.G. 1991. Effects of ant-homopteran systems on fig-figwasp interactions. *In*: Huxley, C.R.; Cutler, D.E. (eds) *Ant-Plant Interactions*. Oxford University Press, Oxford. 601 pp.

Coppois, G.; Wells, S. 1987. Threatened Galapagos snails. *Oryx*, 21: 236–241.

Cornelius, M.L.; Grace, J.K. 1994. Behavioral responses of the Formosan subterranean termite (Isoptera: Rhinotermitidae) to semiochemicals of seven ant species. *Environmental Entomology,* 23: 1524–1528.

Cornelius, M.L.; Grace, J.K. 1995. Laboratory evaluations of interactions of three ant species with the Formosan subterranean termite (Isoptera: Rhinotermitidae). *Sociobiology*, 26: 291–298.

Cornelius, M.L.; Grace, J.K. 1996. Effect of two ant species (Hymenoptera: Formicidae) on the foraging and survival of the Formosan subterranean termite (Isoptera: Rhinotermitidae). *Environmental Entomology*, 25: 85–89.

Cornelius, M.L.; Grace, J.K. 1997. Effect of termite soldiers on the foraging behavior of *Coptotermes formosanus* (Isoptera: Rhinotermitidae) in the presence of predatory ants. *Sociobiology,* 29: 247–253.

Cornelius, M.L.; Grace, J.K.; Ford, P.W.; Davidson, B.S. 1995. Toxicity and repellency of semiochemicals extracted from a dolichoderine ant (Hymenoptera: Formicidae) to the Formosan subterranean termite (Isoptera: Rhinotermitidae). *Environmental Entomology*, 24: 1263–1269.

Cornelius, M.L.; Grace, J.K.; Yates, J.R., III. 1996. Acceptability of different sugars and oils to three tropical ant species (Hymen., Formicidae). *Anzeiger für Schädlingskunde Pflanzenschutz*, 69: 41–43.

Cuddihy, L.W.; Stone, C.P. 1990. *Alteration of native Hawaiian vegetation. Effects of humans, their activities and introductions.* University of Hawaii Cooperative National Park Resources Studies Unit, Honolulu. 138 pp.

Dalla Torre, C.G. de. 1893. *Formicidae (Heterogyna). Catalogus Hymenopterorum hucusque descriptorum systematicus et synonymicus*. Sumptibus Guilelmi Engelmann, Lipsiae. 289 pp.

Delabie, J.H.C.; da Encarnação, A.M.V.; Cazorla, I.M. 1994. Relations between the little fire ant, *Wasmannia auropunctata*, and its associated mealybug, *Planococcus citri*, in Brazilian cocoa farms. Pp. 91–103 *in*: Williams, D.F. (ed.) *Exotic ants: biology, impact, and control of introduced species*. Westview Press, Boulder. 332 pp.

de la Vega, I. 1983. Behavior in the search for food by *Wasmannia auropunctata* and by native ants and competition between them. *Informe a Estacion Cientias Charles Darwin*, 1982: 99–108.

de la Vega, I. 1994. Food searching behavior and competition between *Wasmannia auropunctata* and native ants on Santa Cruz and Isabela, Galapagos Islands. Pp. 73–79 *in*: Williams, D.F. (ed.) *Exotic ants: biology, impact, and control of introduced species*. Westview Press, Boulder. 332 pp.

Desutter-Grandcolas, L. 1997. First record of ant-loving crickets (Orthoptera: Myrmecophilidae: Myrmecophilinae) in New Caledonia. *Australian Journal of Entomology*, 36: 159–163.

Disney, R.H.L. 1994. *Scuttle flies: the Phoridae*. Chapman and Hall, London. xii + 467 pp.

Dlusskiy, G.M. 1993. Ants (Hymenoptera: Formicidae) of Fiji, Tonga and Samoa and the problem of island faunas formation. 1. The problem. *Zoologicheskii Zhurnal*, 72: 66–76.

Dlusskiy, G.M. 1993. Ants (Hymenoptera, Formicidae) of Fiji, Tonga, and Samoa and the problem of island faunas formation. 2. Tribe Dacetini. *Zoologicheskii Zhurnal*, 72: 52–65

Donisthorpe, H. 1916. *Epitritus wheeleri*, n.sp., an ant new to science; with notes on the genus *Epitritus*, Emery. *Entomologist's Record and Journal of Variation*, 28: 121–122.

Early, M.; Goff, M.L. 1986. Arthropod succession patterns in exposed carrion on the island of Oahu, Hawaiian Islands, USA. *Journal of Medical Entomology*, 23: 520–531.

Ehrhorn, E.M. 1911. Board of Agriculture and Forestry. Division of Entomology [report]. *Hawaiian Forester and Agriculturalist*, 7: 330–331.

Ehrhorn, E.M. 1911. Division of Entomology. Report of the Superintendent of Entomology for 1909. *Report of the Board of Commissioners of Agriculture and Forestry of the Territory of Hawaii*, *1910*: 103–123.

Ehrhorn, E.M. 1912. Division of Entomology. *Hawaiian Forester and Agriculturalist*,8: 164–166.

Ehrhorn, E.M. 1913. Division of Entomology. *Hawaiian Forester and Agriculturalist*,9: 290–291.

Ehrhorn, E.M. 1913. Report of the Superintendent of Entomology. *Report of the Board of Commissioners of Agriculture and Forestry of the Territory of Hawaii*, *1912*: 101–151.

Ehrhorn, E.M. 1914. Division of Entomology. *Hawaiian Forester and Agriculturalist*, 10: 21–25.

Ehrhorn, E.M. 1915. Division of Entomology. *Hawaiian Forester and Agriculturalist*, 11: 36–38.

Ehrhorn, E.M. 1915. Division of Entomology. Report of the Superintendent of Entomology. *Report of the Board of Commissioners of Agriculture and Forestry of the Territory of Hawaii*, 1914: 103–142.

Ehrhorn, E.M. 1916. Division of Entomology. *Hawaiian Forester and Agriculturalist*, 12: 46–48.

Ehrhorn, E.M. 1917. Division of Entomology. *Hawaiian Forester and Agriculturalist*, 13: 43–45.

Ehrhorn, E.M. 1918. Division of Plant Inspection. *Hawaiian Forester and Agriculturalist*, 14: 8–10.

Ehrhorn, E.M. 1920. Division of Plant Inspection. *Hawaiian Forester and Agriculturalist*, 16: 13–14.

Ehrhorn, E.M. 1921. Division of Plant Inspection. Report of the Chief Plant Inspector, June, 1921. *Hawaiian Forester and Agriculturalist*, 18: 179–181.

Ehrhorn, E.M. 1922. Division of Plant Inspection. Report of the Chief Plant Inspector, September, 1922. *Hawaiian Forester and Agriculturalist*, 19: 261–262.

Ehrhorn, E.M. 1923. Division of Plant Inspection. Report of Chief Plant Inspector, February, 1923. *Hawaiian Forester and Agriculturalist*, 20: 63–65.

Ehrhorn, E.M. 1923. Division of Plant Inspection. Report of the Chief Plant Inspector. *Report of the Board of Commissioners of Agriculture and Forestry of the Territory of Hawaii*, *1922*: 69–80.

Ehrhorn, E.M. 1924. Division of Plant Inspection. Report of Chief Plant Inspector, February, 1924. *Hawaiian Forester and Agriculturalist*, 21: 71–74.

Ehrhorn, E.M. 1925. Division of Plant Inspection. Report of Chief Plant Inspector, December, 1924. *Hawaiian Forester and Agriculturalist*, 22: 18–20.

Ehrhorn, E.M. 1925. Division of Plant Inspection. Report of the Chief Plant Inspector. *Report of the Board of Commissioners of Agriculture and Forestry of the Territory of Hawaii*, *1924*: 36–44.

Ehrhorn, E.M. 1926. Division of Plant Inspection. Report of Chief Plant Inspector, February, 1926. *Hawaiian Forester and Agriculturalist*, 23: 20.

Ehrhorn, E.M.; Fullaway, D.T.; Swezey, O.H. 1913. Report of committee on common names of economic insects in Hawaii. *Proceedings of the Hawaiian Entomological Society*, 2: 295–300

Emery, C. 1869. Enumerazione dei formicidi che ringengonsi nei contorni di Napoli con descrizioni di specie nuove o meno conosciute. *Annali Accademia degli Aspirante Naturalisti Napoli*, 2: 1–26.

Emery, C. 1890. Studii sulle formiche della fauna neotropica. *Bolletino della Societa Entomologica Italiana*, 22: 38–80.

Emery, C. 1894. Viaggio di Leonardo Fea in Birmania e regioni vicine. LXIII. Formiche di Birmania del Tenasserim e dei Monti Carin raccolte da L. Fea e descritte da Carlo Emery. (Parte II*). Annali del Museo Civico di Storia Naturale Genova*, ser. 2, 14: 450–483.

Emery, C. 1894. Mission scientifique de M. Ch. Alluaud aux Îles Sechelles. 2e mémoire. Formicides. *Annales de la Societe Entomologique de France*, 63: 67–72.

Emery, C. 1895. Beiträge zur Kenntniss der nordamerikanischen Ameisenfauna. *Zoologische Jahrbuecher, Abteilung fuer Systematik Oekologie und Geographie der Thiere*, 8: 257–360.

Emery, C. 1899. Ergebnisse einer Reise nach dem Pacific (Schauinsland 1896–97), Formiciden. *Zoologische Jahrbuecher, Abteilung fuer Systematik Oekologie und Geographie der Thiere*, 12: 438–440.

Emery, C. 1900. Formicidarum species novae vel minus cognitae in collectione Musaei Nationalis Hungarici, quas in Nova-Guinea, colonia Germanica, collegit L. Biro. Publicatio secunda. *Termeszetrajzi Fuezetek*, 23: 310–338.

Evenhuis, N.L.; Polhemus, D.; Swift, S.; Arakaki, K.; Preston, D. 1995. A study of the biology of the orangeblack Hawaiian damselfly (*Megalagrion xanthomelas*), with special reference to conservation of the population at Tripler Army Medical Center, Oahu. Final Report. *Bishop Museum Technical Report*, no. 8: 1–81.

Fabres, G.; Brown, W.L., Jr. 1978. The recent introduction of the pest ant *Wasmannia auropunctata* into New Caledonia. *Journal of the Australian Entomological Society*, 17: 139–142.

Fabricius, J.C. 1793. *Entomologia systematica emendata et aucta. Secundum classes, ordines, genera, species, adjectis synonimis, locis, observationibus, descriptionibus*. Tom. II. C.G. Proft, Fil. et Soc. Hafniae. 519 pp.

Fabricius, J.C. 1804. *Systema Piezatorum secundum ordines, genera, species adiectis synonymis, locis, observationibus descriptionibus*. Carolum Reichard, Brunsvigae. 439 pp.

Fellers, J.H.; Fellers, G.M. 1982. Status and distribution of ants in the crater district of Haleakala National Park. *Pacific Science*, 36: 427–437.

Fluker, S.S.; Beardsley, J.W. 1970. Sympatric associations of three ants: *Iridomyrmex humilis*, *Pheidole megacephala*, and *Anoplolepis longipes* in Hawaii. *Annals of the Entomological Society of America*, 63: 1290–1296.

Folsom, J.W. 1932. Hawaiian Collembola. *Proceedings of the Hawaiian Entomological Society*, 8: 51–92

Forel, A.H. 1881. Die Ameisen der Antille St. Thomas. *Mitteilungen der Muenchner Entomologischen Verein*, 5: 1–16.

Forel, A.H. 1886. Études myrmecologiques en 1886. *Annales de la Societe Entomologique de Belgique*, 30: 131–215.

Forel, A.H. 1887. Indian ants of the Indian Museum, Calcutta No. 2. *Journal of the Asiatic Society of Bengal*, 55: 239–249.

Forel, A.H. 1890. *Aenictus*-*Typhlatta* découverte de M. Wroughton nouveaux genres de formicides. *Annales de la Societe Entomologique de Belgique*, 34: cii–cxiv.

Forel, A.H. 1894. Les Formicides de l'Empire des Indes et de Ceylan. Part IV. Adjonction aux genres *Camponotus*, Mayr., et *Polyrhachis*, Shuck. *Journal of the Bombay Natural History Society*, 8: 396–420.

Forel, A.H. 1899. Heterogyna (Formicidae). *Fauna Hawaiiensis or the zoology of the Sandwich (Hawaiian) Isles…* Cambridge University Press, Cambridge. 759 pp.

Forel, A.H. 1901. Formiciden aus dem Bismarck-Archipel, auf Grundlage des von Prof. Dr. F. Dahl gesammelten Materials bearbeitet. *Mitteilungen aus dem Zoologischen Museum in Berlin*, 2: 1–37.

Forel, A.H. 1907. Formicides du Musée National Hongrois. *Annales Historico-Naturales Musei Nationalis Hungarici*, 5: 1–42.

Forel, A.H. 1912. Quelques fourmis de Tokio. *Annales de la Société Entomologique de Belgique*, 56: 339–342.

Fullaway, D.T. 1914. Report of the Entomologist. *Hawaii Agricultural Experiment Station Report*, *1913*: 18–21.

Fullaway, D.T. 1914. A list of Laysan Island insects. *Proceedings of the Hawaiian Entomological Society*, 3: 20–22.

Fullaway, D.T. 1919. Division of Entomology. Report of the Entomologist. *Report of the Board of Commissioners of Agriculture and Forestry of the Territory of Hawaii, 1918*: 54–60.

Fullaway, D.T. 1931. Division of Entomology. Report of the Entomologist. January 1, 1929–December 31, 1930. *Report of the Board of Commissioners of Agriculture and Forestry of the Territory of Hawaii, 1930*: 74–97.

Fullaway, D.T. 1947. Niihau insects. *Proceedings of the Hawaiian Entomological Society*, 13: 51–53.

Fullaway, D.T.; Krauss, N.L.H. 1945. *Common insects of Hawaii*. Tongg Publishing Co., Honolulu. 228 pp.

Funasaki, G.Y.; Lai, P.-Y.; Nakahara, L.M.; Beardsley, J.W.; Ota, O.K. 1988. A review of biological control introductions in Hawaii: 1890 to 1985. *Proceedings of the Hawaiian Entomological Society*, 28: 105–160.

Gagné, W.C. 1979. Canopy-associated arthropods in *Acacia koa* and *Metrosideros* tree communities along an altitudinal transect on Hawaii Island. *Pacific Insects*, 21: 56–82.

Gagné, W.C. 1980. Altitudinal distribution and composition of arthropods in 'Ohi'a (*Metrosideros collina* subsp. *polymorpha*) canopies in Hawaii Volcanoes National Park with ecological implications for some native biota. Pp. 115–123 *in*: Smith, C.W. (ed.) *Proceedings Third Conference in Natural Sciences Hawaii Volcanoes National Park*. University of Hawaii at Manoa, Honolulu. 396 pp.

Gagné, W.C. 1981. Canopy-associated arthropods. Pp. 118–127 *in*: Mueller-Dombois, D.; Bridges, K.W.; Carson, H.L. (eds) *Island ecosystems. Biological organization in selected Hawaiian communities*. Hutchinson Ross Publishing Company, Stroudsburg, PA; Woods Hole, MA. 583 pp.

Gagné, W.C.; Christensen, C.C. 1985. Conservation status of native terrestrial invertebrates in Hawai'i. Pp. 105–126 *in*: Stone, C.P.; Scott, J.M. (eds) *Hawaii's terrestrial ecosystems: preservation and management: proceedings of a symposium held June 5-6, 1984, at Hawaii Volcanoes National Park*. University of Hawaii, Honolulu. 584 pp.

Giffard, W.M. 1922. Observations on *Xylocopa* and *Lithurgus* (Hymenoptera). *Proceedings of the Hawaiian Entomological Society*, 5: 53–54.

Gillespie, R.G. 1997. Range contraction and extinction vulnerability: what is natural? *Memoirs of the Museum of Victoria*, 56: 401-–409.

Gillespie, R.G.; Reimer, N. 1993. The effect of alien predatory ants (Hymenoptera: Formicidae) on Hawaiian endemic spiders (Araneae: Tetragnathidae). *Pacific Science*, 47: 21–33.

Goff, M.L.; Early, M.; Odom, C.B.; Tullis, K. 1986. A preliminary checklist of arthropods associated with exposed carrion in the Hawaiian Islands. *Proceedings of the Hawaiian Entomological Society*, 26: 53–57.

GPPIS (Global Plant; Pest Information System). Web database at pppis.fao.org/. Version: 1999 April 30.

Greenslade, P.J.M. 1971. Interspecific competition and frequency changes among ants in Solomon Islands coconut plantations. *Journal of Applied Ecology*, 8: 323–352.

Grace, J.K.; Yates, J.R.; Tome, C.H.M. 1995. Modification of a commercial bait station to collect large numbers of subterranean termites (Isoptera: Rhinotermitidae). *Sociobiology*, 26: 259–268.

Greenslade, P.J.M. 1972. Comparative ecology of four tropical ant species. *Insectes Sociaux*, 19: 195–212.

Greenslade, P.J.M.; Greenslade, P. 1978. Some effects of vegetation cover and disturbance on a tropical ant fauna. *Insectes Sociaux*, 24: 163–182.

Gulick, L. 1913. Synoptic list of ants reported from the Hawaiian Islands. *Proceedings of the Hawaiian Entomological Society*, 2: 306–311.

Gullan, P.J.; Buckley, R.C. 1990. Coccids in ants nests inside live plants in Australia and Papua New Guinea (Homoptera: Coccoidea: Coccidae). *Proceedings of the 6th International Symposium on Scale Insect Studies*, p. 82.

Hadden, F.C. 1941. Midway Islands. *Hawaiian Planters' Record*, 45: 179–221.

Haines, I.H.; Haines, J.B.; Cherrett, J.M. 1994. The impact and control of the crazy ant, *Anoplolepis longipes* (Jerd.), in the Seychelles. Pp. 206–218 *in*: Williams, D.F. (ed.) *Exotic ants: biology, impact, and control of introduced species*. Westview Press, Boulder. 332 pp.

Hansen, J.D.; Hara, A.H.; Chan, H.T., Jr.; Tenbrink, V.L. 1991. Efficacy of hydrogen cyanide fumigation as a treatment for pests of Hawaiian cutflowers and foliage after harvest. *Journal of Economic Entomology*, 84: 532–536.

Hardy, D.E. 1960. Diptera: Nematocera-Brachycera. Vol. 10. *Insects of Hawaii. A manual of the insects of the Hawaiian Islands…* University of Hawaii Press, Honolulu. 368 pp.

Hardy, D.E. 1979. An ecological survey of Pua'alu'u Stream. Part III. Report of preliminary entomological survey of Pua'alu'u Stream, Maui. *Cooperative National Park Resources Study Unit Technical Report*, 27: 34–37.

Hardy, D.E. 1981. Diptera: Cyclorrhapha IV, series Schizophora, section Calyptratae. Vol. 14. *In*: *Insects of Hawaii. A manual of the insects of the Hawaiian Islands…* University of Hawaii Press, Honolulu. 491 pp.

Hardy, D.E. 1992. Diptera new to the Hawaiian Islands. *Hawaiian Entomological Society Newsletter*, 2: 2.

Hardy, D.E.; Delfinado, M.D. 1974. Flightless Dolichopodidae (Diptera) in Hawaii. *Proceedings of the Hawaiian Entomological Society*, 21: 365–371.

Hardy, D.E.; Delfinado, M.D. 1980. Diptera: Cyclorrhapha III, series Schizophora, section Acalypterae, exclusive of family Drosophilidae. Vol. 13. In: *Insects of Hawaii. A manual of the insects of the Hawaiian Islands…* University of Hawaii Press, Honolulu. 451 pp.

Hata, T.Y.; Hara, A.H.; Jang, E.B.; Imaino, L.S.; Hu, B.K.S.; Tenbrink, V.L. 1992. Pest management before harvest and insecticidal dip after harvest as a systems approach to quarantine security for red ginger. *Journal of Economic Entomology*, 85: 2310–2316.

Hebard, M. 1926. Records of Hawaiian Dermaptera and Orthoptera of the family Gryllidae. *Proceedings of the Hawaiian Entomological Society*, 6: 299–303.

Heraty, J.M. 1994. Biology and importance of two eucharitid parasites of *Wasmannia* and *Solenopsis*. Pp. 104–120 *in*: Williams, D.F. (ed.) *Exotic ants: biology, impact, and control of introduced species*. Westview Press, Boulder. 332 pp.

Hewadikaram, K.A.; Goff, M.L. 1991. Effect of carcass size on rate of decomposition and arthropod succession patterns. *American Journal of Forensic Medicine and Pathology*, 12: 235–240.

Hinckley, A.D. 1960. The klu beetle, *Mimosestes sallaei* (Sharp), in Hawaii (Coleoptera: Bruchidae). *Proceedings of the Hawaiian Entomological Society*, 17: 260–269.

Holdaway, F.G. 1944. Insects of vegetable crops in Hawaii today. *Proceedings of the Hawaiian Entomological Society*, 12: 59–80.

Holdaway, F.G.; Look, W.C. 1942. Insects of the garden bean in Hawaii. *Proceedings of the Hawaiian Entomological Society*, 11: 249–260.

Hölldobler, B.; Wilson, E.O. 1990. *The Ants*. Springer-Verlag, Berlin. 732 pp.

Howarth, F.G. 1981. Community structure and niche differentiation in Hawaiian lava tubes. Pp. 318–336 *in*: Mueller-Dombois, D.; Bridges, K.W.; Carson, H.L. (eds) *Island ecosystems. Biological organization in selected Hawaiian communities*. Hutchinson Ross Publishing Company, Stroudsburg, PA; Woods Hole, MA. 583 pp.

Howarth, F.G. 1985. Impacts of alien land arthropods and mollusks on native plants and animals in Hawai'i. Pp. 149–179 *in*: Stone, C.P.; Scott, J.M. (eds) *Hawaii's terrestrial ecosystems: preservation and management: proceedings of a symposium held June 5-6, 1984, at Hawaii Volcanoes National Park*. University of Hawaii, Honolulu. 584 pp.

Howarth, F.G.; Medeiros, A.C. 1989. Non-native invertebrates. Pp. 82–87 *in*: Stone, C.P.; Stone, D.B. (eds) *Conservation biology in Hawai'i*. University of Hawaii Cooperative National Park Resources Studies Unit, Honolulu. 251 pp.

Howarth, F.G.; Nishida, G.; A. Asquith, A. 1995. Insects of Hawaii. Pp. 365–368 *in*: LaRoe, E.T.; Farris, G.S.; Puckett, C.E.; Doran, P.D.; Mac, M.J. (eds) *Our living resources. A report to the nation on the distribution, abundance, and health of US plants, animals, and ecosystems*. US Department of Interior, National Biological Service, Washington, D.C. 530 pp.

Huddleston, E.W.; S.S. Fluker, S.S. 1968. Distribution of ant species in Hawaii. *Proceedings of the Hawaiian Entomological Society*, 20: 45–69.

Huddleston, E.W.; LaPlante, A.A.; S.S. Fluker, S.S. 1968. Pictorial key of the ants of Hawaii based on the worker forms. *Proceedings of the Hawaiian Entomological Society*, 20: 71–79.

Huxley, C.R. 1978. The ant-plants *Mymecodia* and *Hydnophytum* (Rubiaceae), and the relationships between their morphology, ant occupants, physiology and ecology. *New Phytologist*, 80: 231–268.

Illingworth, J.F. 1914. Little brown ant doing good work in Hawaii. *Hawaiian Forester and Agriculturalist*, 10: 370–371.

Illingworth, J.F. 1916. Hen Fleas. *Xestopsylla gallinacea*. *Hawaiian Forester and Agriculturalist*, 12: 130–132.

Illingworth, J.F. 1917. Economic aspects of our predaceous ant (*Pheidole megacephala*). *Proceedings of the Hawaiian Entomological Society*, 3: 349–368.

Illingworth, J.F. 1923. Insect fauna of hen manure. *Proceedings of the Hawaiian Entomological Society*, 5: 270–273.

Illingworth, J.F. 1926. A study of ants in their relation to the growing of pineapples in Hawaii. *Association of Hawaiian Pineapple Canners, Experiment Station Bulletin*, 7: 1–16.

Illingworth, J.F. 1926. Pineapple insects and some related pests. *Association of Hawaiian Pineapple Canners, Experiment Station Bulletin*, 9: 1–64.

Illingworth, J.F. 1927. A report on insects and other animal organisms collected in the pineapple growing section at Mauna Loa, Molokai, June, 1926. *Proceedings of the Hawaiian Entomological Society*, 6: 390–397.

Illingworth, J.F. 1928. Insects collected in the pineapple growing section on the island of Lanai, August, 1927. *Proceedings of the Hawaiian Entomological Society*, 7: 42–46.

Illingworth, J.F. 1929. Preliminary notes on pests of agricultural crops of Kona, March 15, 1928. *Proceedings of the Hawaiian Entomological Society*, 7: 248–254.

Illingworth, J.F. 1941. Feeding habits of *Bufo marinus*. *Proceedings of the Hawaiian Entomological Society*, 11: 51.

Illingworth, J.F. 1942. An outbreak of cockroaches, *Nauphoeta cinerea* (Olivier), in Honolulu. *Proceedings of the Hawaiian Entomological Society*, 11: 169–170

Ito, K. 1940. Ants caught on wind traps in pineapple fields on Oahu. *Proceedings of the Hawaiian Entomological Society*, 10: 429–435.

Ito, K. 1942. Seasonal trend in the development of the sex forms of the fire ant, *Solenopsis geminata* (Fabr.) var. *rufa* (Jerdon), in the pineapple fields of Oahu. *Proceedings of the Hawaiian Entomological Society*, 11: 171–175.

Ito, K.; Carter, W. 1932. Notes on insects found on pineapple planting material. *Proceedings of the Hawaiian Entomological Society*, 8: 41–44.

Jahn, G.C.; Beardsley, J.W. 1994. Big-headed ants, *Pheidole megacephala*: interference with the biological control of gray pineapple mealybugs. Pp. 199–205 *in*: Williams, D.F. (ed.) *Exotic ants: biology, impact, and control of introduced species*. Westview Press, Boulder. 332 pp.

Jahn, G.C.; Beardsley, J.W. 1996. Effects of *Pheidole megacephala* (Hymenoptera: Formicidae) on survival and dispersal of *Dysmicoccus neobrevipes* (Homoptera: Pseudococcidae). *Journal of Economic Entomology*, 89: 1124–1129.

Jebb, M. 1991. Cavity structure and function in the tuberous Rubiaceae. Pp. 374–389 *in*: Huxley, C.R.; D.F.

Cutler, D.F. (eds) *Ant-Plant Interactions*. Oxford University Press, Oxford, New York; Tokyo. 601 pp.

Jerdon, T.C. 1851. A catalogue of the species of ants found in southern India. *Madras Journal of Literature and Science*, 17: 103–127

Jourdan, H. 1997. Threats on Pacific islands: the spread of the tramp ant *Wasmannia auropunctata* (Hymenoptera: Formicidae). *Pacific Conservation Biology*, 3: 61–64.

Joyce, C.R. (ed.) 1980. New immigrant records for the year 1977. *Proceedings of the Hawaiian Entomological Society*, 23: 189–190.

Kido, M.H.; Ha, P.; Kinzie, R.A., III. 1993. Insect introductions and diet changes in an endemic Hawaiian amphidromous goby, *Awaous stamineus* (Pisces: Gobiidae). *Pacific Science*, 47: 43–50.

Kirkaldy, G.W. 1904. A preliminary list of the insects of economic importance recorded from the Hawaiian Islands. Part III. Lepidoptera (Butterflies and Moths). *Hawaiian Forester and Agriculturalist*, 1: 205–210.

Kirkaldy, G.W. 1907. On some peregrine Aphidae in Oahu (Hem.). *Proceedings of the Hawaiian Entomological Society*, 1: 99–102.

Kirkaldy, G.W. 1909. Entomological notes. *Hawaiian Planters' Record*, 1: 146.

Kirkaldy, G.W. 1909. A bibliography of sugar-cane entomology. *Hawaiian Sugar Planters Association Entomology Bulletin*, 8: 1–37.

Kohout, R.J. 1988. A new species of *Polyrhachis* (*Polyrhachis*) from Papua New Guinea with a review of the New Guinean and Australian species (Hymenoptera: Formicidae: Formicinae). *Memoirs of the Queensland Museum*, no. 25: 417–427.

Kohout, R.J. 1990. A review of the *Polyrhachis viehmeyeri* species-group (Hymenoptera: Formicidae: Formicinae). *Memoirs of the Queensland Museum*, 28: 499–508.

Kotinsky, J. 1909. Report of Superintendent of Entomology for September, 1908. *Hawaiian Forester and Agriculturalist*, 5: 233–235.

Kotinsky, J. 1909. Division of Entomology. Fifth Report of Superintendent of Entomology. *Report of the Board of Commissioners of Agriculture and Forestry of the Territory of Hawaii*: 97–114.

Krauss, N.L.H. 1944. Notes on insects and other arthropods from the islands of Molokai and Maui, Hawaii. *Proceedings of the Hawaiian Entomological Society*, 12: 81–94.

Krauss, N.L.H. 1945. Notes on some Hawaiian insects. *Proceedings of the Hawaiian Entomological Society*, 12: 309–317.

Krombein, K.V.; Hurd, P.D., Jr.; Smith, D.R.; Burks, B.D. 1979. *Catalog of Hymenoptera in America north of Mexico. Volume 2. Apocrita (Aculeata)*. Pp. 1199–2209. Smithsonian Institution Press, Washington, DC.

Krushelnycky, P.D.; Reimer, N.J. 1996. Efforts at control of the Argentine ant in Haleakala National Park, Maui, Hawaii. *Cooperative National Park Resources Study Unit Technical Report*, 109: 1–33.

Kugler, J. 1983. The males of *Cardiocondyla* Emery (Hymenoptera: Formicidae) with the description of the winged male of *Cardiocondyla wroughtoni* (Forel). *Israel Journal of Entomology*, 17: 1–21.

Kuhns, D.B. 1910. Notes on Maui insects. *Proceedings of the Hawaiian Entomological Society*, 2: 93.

Lambdin, P.; Kosztarab, M. 1988. *Psoraleococcus browni*: a new species of pit scale from Papua New Guinea (Homoptera:Coccoidea: Lecanodiaspididae). *Annals of the Entomological Society of America*, 81: 724–727.

Latreille, P.A. 1802. *Histoire naturelle des Fourmis, et recueil de mémoires et d'observations sur les Abeilles, les Araignées, les Faucheurs, et autres Insectes*. Chez Theophile Barrois Père, Paris. 445 pp.

Latreille, P.A. 1805. *Histoire naturelle generale et particuliere des Crustacés et des Insectes*. Tome treizième. F. Dufart, Paris. 432 pp.

Leclerq, S.; Braekman, J.C.; Kaisin, M.; Daloze, D.; Detrain, J.C. 1997. Venom constitutents of three species of *Crematogaster* ants from Papua New Guinea. *Journal of Natural Products (Lloydia)* 60: 1143–1147.

Lewis, L.V. 1912. A few notes on *Solenopsis geminata*. *Proceedings of the Hawaiian Entomological Society*, 2: 175–178.

Lieberburg, I.; Kranz, P.M.; Seip, A. 1975. Bermudan ants revisited: the status and interaction of *Pheidole megacephala* and *Iridomyrmex humilis*. *Ecology*, 56: 473–478.

Linnaeus, C. 1758. *Systema Naturae per regna tria naturae, secundum classes, ordines, genera,species cum caracteribus, differentiis, synonymis, locis. Tomus I. Editio Decima, reformata*. Laurentii Salvii, Holmiae. 824 pp.

Loope, L. 1995. Hawaii's invasive invertebrates. *Aliens*, Mar 1995: 4.

Loope, L.L.; Medeiros, A.C. 1995. Haleakala silversword. Pp. 363–364 *in*: LaRoe, E.T.; Farris, G.S.; Puckett, C.E.; Doran, P.D.; Mac, M.J. (eds) *Our living resources. A report to the nation on the distribution, abundance, and health of US plants, animals, and ecosystems*. US Department of Interior, National Biological Service, Washington, D.C. 530 pp.

Loschiavo, S.R.; Okumura, G.T. 1979. A survey of stored product insects in Hawaii. *Proceedings of the Hawaiian Entomological Society*, 23: 95–118.

Lubin, Y.D. 1982. Programa de entomologia. *Informe Anuario Estacion Cientias Charles Darwin*, 1981: 29–33.

Lubin, Y.D. 1983. Some changes in the invertebrate fauna of the Galapagos Islands following the invasion of the little fire ant *Wasmannia auropunctata*. *Informe Anuario Estacion Cientias Charles Darwin*, 1982: 56–74.

Lubin, Y.D. 1984. Changes in the native fauna of the Galapagos Islands following invasion by the little red fire ant, *Wasmannia auropunctata*. *Biological Journal of the Linnaean Society*, 21: 229–242.

Lubin, Y.D. 1986S. Studies of the little fire ant, *Wasmannia auropunctata*, in a Niño year. *Estacion Cientias Charles Darwin Informe Anuario*, 1983: 22–24.

Mackay, W.P. 1995. New distributional records for the ant genus *Cardiocondyla* in the new world (Hymenoptera: Formicidae). *Pan-Pacific Entomologist*, 71: 169–172.

Maehler, K.L. 1962. The impact of jet transportation on plant quarantine. *Proceedings of the Hawaiian Entomological Society*, 18: 43–46.

Maeyama, T.; Terayama, M.; Matsumoto, T. 1997. Comparative studies of various symbiotic relationships between rubiacerous epiphytic mymecophytes and their inhabitant ant species (Hymenoptera: Formicidae). *Sociobiology*, 30: 169–174.

Majer, J.D. 1993. Comparison of the arboreal ant mosaic in Ghana, Brazil, Papua New Guinea and Australia - its structure and influence on arthropod diversity. Pp. 115–141 *in*: LaSalle, J.; Gauld, I.D. (eds) *Hymenoptera and biodiversity*. CAB International, Wallingford, Oxon, UK. 348 pp.

Majer, J.D. 1994. Spread of Argentine ants (*Linepithema humile*), with special reference to Western Australia. Pp. 163–173. *in*: Williams, D.F. (ed.) *Exotic ants. Biology, impact, and control of introduced species*. Westview Press, Boulder. 332 pp.

Majer, J.D. 1994. Introduction of ants as potential biological control agents, with particular reference to cocoa. *Harvest*, 16 (1&2): 1–4.

Mann, W.M. 1921. Ants of the Fiji Islands. *Bulletin of the Museum of Comparative Zoology*, 64: 403–499.

Mayr, G.L. 1855. Formicina Austriaca. Beschreibung der bisher im Österreichischen Kaiserstaate aufgefundenen Ameisen nebst Hinzufügung jener in Deutschland, in der Schweiz und in Italien vorkommenden Arten. *Verhandlungen der Zoologisch-Botanischen Gesellschaft in Wien*, 5: 273–478.

Mayr, G.L. 1862. Myrmecologische Studien. *Verhandlungen der Zoologisch-Botanischen Gesellschaft in Wien*, 12: 649–776.

Mayr, G.L. 1865. Formicidae. Pp. 1–119 *in*: *Reise der Österreichischen Fregatte Novara um die Erde in den Jahren 1857, 1858, 1859 unter den befehlen des Commodore B. von Wüllerstor-Ubair. Zoologischer theil, Zweiter Band. I. Abtheilung A. 3*. Der kaiserlich-königlichen Hof- und Staatsdruckerei, Wien. 119 pp.

Mayr, G.L. 1866. Myrmecologische Beiträge. *Sitzungsberichten der Akademie der Wissenschaften in Wien*, 53: 484–517.

Mayr, G.L. 1867. Adnotationes in monographiam formicidarum Indo-neerlandicarum. *Tijdschrift voor Entomologie*, ser. 2, 2: 33–117.

Mayr, G.L. 1868. Formicidae novae americanae collectae a Prof. P. de Strobel. *Annuario della Societa dei Naturalisti in Modena*, 3: 161–178.

Mayr, G.L. 1870. Neue Formiciden. *Verhandlungen der Zoologisch-Botanischen Gesellschaft in Wien*, 20: 939–996.

Mayr, G.L. 1872. Formicidae borneenses collectae a J. Doria et O. Beccari in territorio Sarawakannis 1865-1867. *Annali del Museo Civico di Storia Naturale Genova*, 2: 133–155.

Mayr, G.L. 1878. Beiträge zur Ameisen-fauna Asiens. *Verhandlungen der Zoologisch-Botanischen Gesellschaft in Wien*, 28: 645–686.

Mayr, G.L. 1887. Südamerikanische Formiciden. *Verhandlungen der Zoologisch-Botanischen Gesellschaft in Wien*, 37: 511–632.

McAlpine, D.K. 1988. Studies in upside-down flies (Diptera: Neurochaetidae) Part 2. Biology, adaptations and specific mating mechanisms. *Proceedings of the Linnaean Society of New South Wales*, 110: 59–82.

McEwen, F.L.; Beardsley, J.W., Jr.; Hapai, M.; Su, T.H. 1979. Laboratory tests with candidate insecticides for control of the big-headed ant, *Pheidole megacephala* (Fabricius). *Proceedings of the Hawaiian Entomological Society*, 23: 119–123.

Medeiros, A.C.; Loope, L.L.; Cole, F.R. 1986. Distribution of ants and their effects on endemic biota of Haleakala and Hawaii Volcanoes National Parks: a preliminary assessment. Pp. 39–52 *in*: Smith, C.W. (ed.) *Proceedings Sixth Conference in Natural Sciences Hawaii Volcanoes National Park*. University of Hawaii at Manoa, Honolulu. 98 pp.

Meier, R.E. 1982. Ecology and behaviour of ants on giant cacti at the Darwin Station and at Tortuga Bay (Island of Santa Cruz, Galapagos). *Informe Anuario Estacion Cientias Charles Darwin*, 1981: 90–92.

Meier, R.E. 1986. Coexisting patterns and foraging behavior of ants within the arid zone of the three Galapagos Islands. *Estacion Cientias Charles Darwin Informe Anuario*, 1983: 25–27.

Meier, R.E. 1994. Coexisting patterns and foraging behavior of introduced and native ants (Hymenoptera Formicidae) in the Galapagos Islands (Ecuador). Pp. 44–62 *in*: Williams, D.F. (ed.) *Exotic ants: biology, impact, and control of introduced species*. Westview Press, Boulder. 332 pp.

Miyagi, I. 1981. *Malaya leei* (Wharton) feeding on ants in Papua New Guinea (Diptera: Culicidae). *Japanese Journal of Sanitary Zoology*, 32: 332–333.

Montgomery, S.L. 1975. Comparative breeding site ecology and the adaptive radiation of picture-winged *Drosophila* (Diptera: Drosophilidae) in Hawaii. *Proceedings of the Hawaiian Entomological Society*, 22: 65–103.

Moore, N.W.; Gagné, W.C. 1982. *Megalagrion pacificum* (McLachlan) - a preliminary study of the conservation requirements of an endangered species. *Reports of the Odonata Specialist Group, IUCN*, 3: 1–5.

Morrison, L.W. 1996. The ants (Hymenoptera: Formicidae) of Polynesia revisited: species numbers and the importance of sampling intensity. *Ecography* 19: 73–84.

Morrison, L.W. 1996. Community organization in a recently assembled fauna: the case of Polynesian ants. *Oecologia* , 107: 243–256.

Morrison, L.W.; Gilbert, L.E. 1998. Parasitoid-host relationships when host size varies: the case of *Pseudacteon* flies and *Solenopsis* fire ants. *Ecological Entomology* 23(4): 409–416..

Mueller-Dombois, D. 1981. Spatial integration of the organisms studied along the transect. Pp. 181–210 *in*: Mueller-Dombois, D.; Bridges, K.W.; Carson, H.L. (eds) *Island ecosystems. Biological organization in selected Hawaiian communities*. Hutchinson Ross Publishing Company, Stroudsburg, PA; Woods Hole, MA. 583 pp.

Muir, F. 1916. Review of the autochthonous genera of Hawaiian Delphacidae. [2 parts: 168-197, 197-221] *Proceedings of the Hawaiian Entomological Society*, 3: 168–221.

Muir, F. 1921. The sugar cane leafhopper and its parasites in Hawaii. *Hawaiian Planters' Record*, 25: 108–123.

Muir, F.; Swezey, O.H. 1926. Entomologists' report on termite problems. *Hawaiian Planters' Record*, 30: 331–335.

Nafus, D.M. 1993. Movement of introduced biological control agents onto nontarget butterflies, *Hypolimnas* spp. (Lepidoptera: Nymphalidae). *Environmental Entomology*, 22 (2): 265–272.

Nafus, D.M.; Schreiner, I.H. 1988. Parental care in a tropical nymphalid butterfly *Hypolimnas anomala*. *Animal Behavior*, 36: 1425–1431.

Nakahara, L.M.; Burkhart, R.M.; Funasaki, G.Y. 1992. Review and status of biological control of *Clidemia* in Hawai'i. Pp. 452–465 *in*: Stone, C.P.; Smith, C.W.; Tunison, J.T. (eds) *Alien plant invasions in native ecosystems of Hawai'i: management and research*. Cooperative National Park Resources Studies Unit, Honolulu. 887 pp.

Namba, R. 1957. *Cryptophlebia illepida* (Butler) (Lepidoptera: Eucosmidae) and other insect pests of the macadamia nut in Hawaii. *Proceedings of the Hawaiian Entomological Society*, 16: 284–297.

Nechols, J.R.; Seibert, T.F. 1985. Biological control of the spherical mealybug, *Nipaecoccus vastator* (Homoptera: Pseudococcidae): assessment by ant exclusion. *Environmental Entomology*, 14: 32–37.

Nishida, G.M.; Tenorio, J.M. 1993. *What Bit Me? Identifying Hawai'i's Stinging and Biting Insects and their Kin.* University of Hawaii Press, Honolulu. 71 pp.

Nishida, T. 1957. Food plants, distribution, and variation in abundance of *Conotelus mexicanus* Murray, a recently discovered immigrant insect in Hawaii (Coleoptera: Nitidulidae). *Proceedings of the Hawaiian Entomological Society*, 16: 307–312.

Nishida, T. 1958. Extrafloral glandular secretions, a food source for certain insects. *Proceedings of the Hawaiian Entomological Society*, 16: 379–386.

Nishida, T. 1963. Ecology of the pollinators of passion fruit. *Hawaii Agricultural Experiment Station Technical Bulletin*, no. 55: 1–38.

Nishida, T. 1966. Behavior and mortality of the southern stink bug *Nezara viridula* in Hawaii. *Researches on Population Ecology*, 8: 78–88.

Nylander, W. 1847. Additamentum adnotationum in monographiam Formicarum borealium Europae. *Acta Societatis Scientiarum Fennicae*, 2: 1041–1062.

Passera, L. 1994. Characteristics of tramp species. Pp. 23–43 *in*: Williams, D.F. (ed.) *Exotic ants. Biology, impact, and control of introduced species*. Westview Press, Boulder. 332 pp.

Pemberton, C.E. 1934. Some future work for the entomologist in Hawaii. *Proceedings of the Hawaiian Entomological Society*, 8: 505–514.

Pemberton, C.E. 1943. Insects and other arthropods of medical interest in Hawaii. *Hawaii Medical Journal*, 2: 191–194.

Pemberton, C.E. 1947. Some insect pests of the mainland of the United States occurring also in Hawaii. *Hawaiian Planters' Record*, 51: 85–87.

Pemberton, C.E. 1964. Highlights in the history of entomology in Hawaii 1778–1963. *Pacific Insects*, 6: 689–729.

Pemberton, C.E.; Willard, H.F. 1918. Work and parasitism of the Mediterranean fruitfly in Hawaii during 1917. *Journal of Agricultural Research*, 14: 605–610.

Pemberton, C.E.; Willard, H.F. 1918. A contribution to the biology of fruit-fly parasites in Hawaii. *Journal of Agricultural Research*, 15: 419–465.

Perkins, R.C.L. 1903. The leaf-hopper of the sugar cane. *Bulletin Division of Entomology of the Board of Commissioner of Agriculture and Forestry of Hawaii*, 1: 1–66.

Perkins, R.C.L. 1907. The insects of Tantalus. *Proceedings of the Hawaiian Entomological Society*, 1: 38–51.

Perkins, R.C.L. 1913. Introduction being a review of the land-fauna of Hawaiia. *Fauna Hawaiiensis or the zoology of the Sandwich (Hawaiian) Islands...* Cambridge University Press, Cambridge. 1(6): xv–ccxxvii pp.

Perrault, G.H. 1988. Les fourmis de Tahiti. *Bulletin de la Societe Zoologique de France*, 112: 429–446.

Perrault, G.H. 1993. Peuplement en fourmis de l'atoll de Fangataufa. *Bulletin de la Societe Entomologique de France*, 98: 323–338.

Phillips, J.S. 1934. The biology and distribution of ants in Hawaiian pineapple fields. *Bulletin of the Experiment Station Pineapple Producers Association*, 15: 1–57.

Phillips, J.S. 1934. Fire ants in dry areas. *Proceedings of the Hawaiian Entomological Society*, 8: 515.

Phillips, J.S. 1934. The relations of ants with insects attacking certain poisonous plants in Hawaii. *Transactions of the Entomological Society of London*, 82: 1–3.

Plowman, K.P. 1981. Resource utilization by two New Guinea rainforest ants. *Journal of Animal Ecology*, 50: 903–916.

Rainwater, H.I. 1963. Agricultural insect pest hitchhikers on aircraft. *Proceedings of the Hawaiian Entomological Society*, 18: 303–309.

Reimer, N.J. 1988. Predation on *Liothrips urichi* Karny (Thysanoptera: Phlaeothripidae): a case of biotic interference. *Environmental Entomology*, 17: 132–134.

Reimer, N.J. 1994. Distribution and impact of alien ants in vulnerable Hawaiian ecosystems. Pp.11–22 *in*: Williams, D.F. (ed.) *Exotic ants: biology, impact, and control of introduced species*. Westview Press, Boulder. 332 pp.

Reimer, N. 1999. A pictorial key to the most pestiferous ant species threatening Hawaii's native fauna and flora. Web publication at www.hear.org/AlienSpeciesInHawaii/ants/#PictorialAntKey

Reimer, N.J.; Beardsley, J.W. 1990. Effectiveness of hydramethylnon and fenoxycarb for control of bigheaded ant (Hymenoptera: Formicidae), an ant associated with mealybug wilt of pineapple in Hawaii. *Journal of Economic Entomology*, 83: 74–80.

Reimer, N.J.; Glancey, B.M.; Beardsley, J.W. 1991. Development of *Pheidole megacephala* (Hymenoptera: Formicidae) colonies following ingestion of fenoxycarb and pyriproxyfen. *Journal of Economic Entomology*, 84: 56–60.

Reimer, N.J.; Cope, M.-L.; Yasuda, G. 1993. Interference of *Pheidole megacephala* (Hymenoptera: Formicidae) with biological control of *Coccus viridis* (Homoptera: Coccidae) in coffee. *Environmental Entomology*, 22: 483–488

Richards, E.N.; Goff, M.L. 1997. Arthropod succession on exposed carrion in three contrasting tropical habitats on Hawaii Island, Hawaii. *Journal of Medical Entomology*, 34: 328–339.

Roger, J. 1859. Beiträge zur Kenntniss der Ameisenfauna der Mittelmeerländer. *Berliner Entomologische Zeitschrift*, 3: 225–259.

Roger, J. Die Ponera-artigen Ameisen. *Berliner Entomologische Zeitschrift*, 5: 1-54.

Roger, J. 1863. Die neu aufgeführten Gattungen und Arten meines Formiciden-Verzeichnisses. *Berliner Entomologische Zeitschrift*, 7: 131–214.

Rohrbach, K.G.; Beardsley, J.W.; German, T.L.; Reimer, N.; Sanford, W.G. 1988. Mealybug wilt, mealybugs and ants on pineapple. *Plant Disease* 72: 558–565.

Rutkowski, F. 1996. A new larval foodplant for *Tmolus echion* (Lepidoptera: Lycaenidae). *Bishop Museum Occasional Papers*, 46: 32.

Sanburn, C. 1996. Island ants. *Honolulu Weekly* 6: 5–7.

Sanders, D.A.; Chang, V.C.S.; Ota, A.K.; Nomura, N. 1992. Food acceptability and distribution in the colony of the bigheaded ant, *Pheidole megacephala* (Fabr.) (Hymenoptera: Formicidae). *Proceedings of the Hawaiian Entomological Society*, 31: 65–72.

Say, T. 1836. Descriptions of new species of North American Hymenoptera, and observations on some already described. *Boston Journal of Natural History*, 1: 209–305.

Schwartz, C.W.; Schwartz, E.R. 1949. *A reconnaissance of the game birds in Hawaii*. [cover page differs from titlepage and reads: The game birds in Hawaii.] Board of Commissioners of Agriculture and Forestry, Territory of Hawaii, [Honolulu]. 168 pp.

Scott, J.M.; Mountainspring, S.; Ramsey, F.L.; Kepler, C.B. 1986. *Forest bird communities of the Hawaiian Islands: their dynamics, ecology, and conservation*. Cooper Onithological Society, [Lawrence, KS]. 431 pp.

Sherman, M.; Marsden, D.A. 1979. Farm and home insect pests. Cockroaches, what to do about them! *University of Hawaii Cooperative Extension Service Entomology Note*, 3: 1–3.

Silberglied, R. 1972. The little fire ant', *Wasmannia auropunctata*, a serious pest in the Galapagos Islands. *Noticias Galapagos*, 19–20: 13–15.

Simmonds, F.J.; Greathead, D.J. 1977. Introductions and pest and weed problems. Pp. 109–124 *in*: Cherrett, J.M.; Sagar, G.R. (eds) *Origins of pest, parasite, disease and weed problems.* Symposium of the British Ecological Society, 18. Blackwell Scientific Publications Oxford. 413 pp.

Simmons, J.S.; Whayne, T.F.; Anderson, G.W.; Horack, H.M. 1944. *Global epidemiology. A geography of disease and sanitation. Volume One. Part One: India and the Far East. Part Two: The Pacific Area*. J.B. Lippincott Company, Philadelphia; London; Montreal. 504 pp.

Smith, C.W. 1980. Haleakala Crater: its resources and management problems. Pp. 311–317 *in*: Smith, C.W. (ed.) *Proceedings Third Conference in Natural Sciences Hawaii Volcanoes National Park*. University of Hawaii at Manoa, Honolulu. 396 pp.

Smith, E.S.C. 1981. An integrated control scheme for cocoa pests and diseases in Papua New Guinea. *Tropical Pest Management*, 27: 351–359.

Smith, F. 1851. *List of the British animals in the collection of the British Museum. Part VI. Hymenoptera Aculeata. British Museum*, London. 134 pp.

Smith, F. 1857. Catalogue of the hymenopterous insects collected at Sarawak, Borneo; Mount Ophir, Malacca; and at Singapore by A.R. Wallace. *Journal and Proceedings of the Linnaean Society of London Zoology*, 2: 42–130.

Smith, F. 1858. Part VI. Formicidae. *Catalogue of hymenopterous insects in the collection of the British Museum.* Printed by order of the Trustees [British Museum]. London.

Smith, F. 1860. Catalogue of hymenopterous insects collected by Mr. A.R. Wallace in the islands of Bachian, Kaisaa, Amboyna, Gilolo, and at Dory in New Guinea. *Journal of the Linnaean Society of London Zoology*, 4 suppl.: 93–143.

Smith, F. 1861. Catalogue of the hymenopterous insects collected by Mr. A.R. Wallace in the islands of Ceram, Celebes, Ternate, and Gilolo. *Journal and Proceedings of the Linnaean Society of London Zoology*, 6: 36–66.

Smith, F. 1862. Descriptions of some new species of ants from the Holy Land, with a synonymic list of others previously described. *Journal and Proceedings of the Linnaean Society of London Zoology*, 6: 31–35.

Smith, F. 1874. Descriptions of new species of Tenthredinidae, Ichneumonidae, Chrysididae, Formicidae, &c. of Japan. *Transactions of the Entomological Society of London*, 1874: 373–409.

Smith, F. 1879. Descriptions of new species of aculeate Hymenoptera collected by the Rev. T. Blackburn in the Sandwich Islands. *Journal of the Linnaean Society of London Zoology*, 14: 674–685.

Smith, M.R. 1944. Ants of the genus *Cardiocondyla* Emery in the United States. *Proceedings of the Entomological Society of Washington*, 46: 30–41.

Smith, M.R. 1957. A contribution to the taxonomy, distribution and biology of the vagrant ant, *Plagiolepis alluaudi* Emery (Hymenoptera, Formicidae). *Journal of the New York Entomological Society*, 65: 195–198

Smith, M.R. 1965. House infesting ants of the eastern United States, their recognition, biology and economic importance. *US Department of Agriculture Technical Bulletin*, 1326: 1–105.

Solem, [G.] A. 1976. *Endodontoid land snails from Pacific Islands (Mollusca: Pulmonata: Sigmurethra).*

*Part I. Family Endodontidae*. Field Museum of Natural History, Chicago. xii + 508 pp.

Spencer, H. 1941. The small fire ant *Wasmannia* in citrus groves – a preliminary report. *Florida Entomologist*, 24: 6–14.

Stechmann, D.-H.; Volkl, W.; Stary, P. 1996. Ant-attendance as a critical factor in the biological control of the banana aphid *Pentalonia nigronervosa* Coq. (Hom. Aphididae) in Oceania. *Journal of Applied Entomology*, 120: 123.

Stone, C.P.; Pratt, L.W. 1994. *Hawai'i's plants and animals. Biological sketches of Hawaii Volcanoes National Park*. Hawaii Natural History Association, [Honolulu]. 399 pp.

Su, T.H.; Beardsley, J.W.; McEwen, F.L. 1980. AC-217,300 a promising new insecticide for use in baits for control of the bigheaded ant in pineapple. *Journal of Economic Entomology*, 73: 755–756.

Suehiro, A. 1959. Insects of Moku Manu Islet. *Proceedings of the Hawaiian Entomological Society*, 17: 90–91.

Suehiro, A. 1960. Insects and other arthropods from Midway Atoll. *Proceedings of the Hawaiian Entomological Society*, 17: 289–298.

Suehiro, A. 1986. Report 4. Insects of Honaunau. *In*: Bryan, E.H., Jr.; Emory, K.P. *The natural and cultural history of Honaunau, Kona, Hawaii. Part I. The natural history of Honaunau*. Bernice Pauahi Bishop Museum, Honolulu. 263 pp. [*Bishop Museum Anthropology Department Report*, 86-2: 31–61.]

Sugarman, B.B. 1979. Additions to the list of insects and other arthropods from Kwajalein Atoll (Marshall Islands). *Proceedings of the Hawaiian Entomological Society*, 23: 147–151.

Swaney, D. 1994. *Tonga. A Lonely Planet travel survival kit*. 2nd Edition. Lonely Planet Publications, Hawthorn, Australia. 198 pp.

Swezey, O.H. 1909. Notes on the bud moth of sugar cane and its lepidopterous associates. *Hawaiian Planters' Record*, 1: 119–143.

Swezey, O.H. 1909. The Hawaiian sugar cane bud moth (*Ereunetia flavistriata*) with an account of some allied species and natural enemies. *Hawaiian Sugar Planters Association Entomology Bulletin*, 6: 1–41.

Swezey, O.H. 1913. Sugar cane mealy bugs in the Hawaiian Islands. *Hawaiian Planters' Record*, 8: 200–208.

Swezey, O.H. 1915. Insects from French Frigate Shoals. *Proceedings of the Hawaiian Entomological Society*, 3: 98–99.

Swezey, O.H. 1921. Some aspects of Hawaiian entomology. Proceedings of the First Pan-Pacific Scientific Conference. *Special Publication of the Bernice P. Bishop Museum*, 7: 167–176.

Swezey, O.H. (ed.) 1925. Records of immigrant insects for 1924. *Proceedings of the Hawaiian Entomological Society*, 6: 217.

Swezey, O.H. 1925. Maui insect notes and records. *Proceedings of the Hawaiian Entomological Society*, 6: 47–48.

Swezey, O.H. (ed.) 1927. Records of immigrant insects for 1926. *Proceedings of the Hawaiian Entomological Society*, 6: 558.

Swezey, O.H. (ed.) 1931. Records of immigrant insects for 1929 and 1930. *Proceedings of the Hawaiian Entomological Society*, 7: 516

Swezey, O.H. 1934. Insects from Bermuda grass, Kawela Bay, Oahu, April 23, 1933. *Proceedings of the Hawaiian Entomological Society*, 8: 533–534

Swezey, O.H. 1935. The winter revival of insect life in the arid region at Koko Head, Oahu. *Proceedings of the Hawaiian Entomological Society*, 9: 93–96

Swezey, O.H. 1936. Biological control of the sugar cane leafhopper in Hawaii. *Hawaiian Planters' Record*, 40: 57–101

Swezey, O.H. (ed.) 1941. Records of immigrant insects for the year 1940. *Proceedings of the Hawaiian Entomological Society*, 11: 130

Swezey, O.H. 1942. Hymenoptera. Formicidae of Guam. *Bulletin of the B.P. Bishop Museum*, no. 172: 175–183.

Swezey, O.H. 1945. Insects associated with orchids. *Proceedings of the Hawaiian Entomological Society*, 12: 343–403.

Swezey, O.H. 1952. Insect fauna of a coconut tree. *Proceedings of the Hawaiian Entomological Society*, 14: 377–378.

Swezey, O.H. 1954. Forest entomology in Hawaii. An annotated check-list of the insect faunas of the various components of the Hawaiian forests. *Special Publications of the Bernice P. Bishop Museum*, 44: 1–266.

Swezey, O.H.; Bryan, E.H., Jr. 1927. Notes on some forest insects of Molokai. *Proceedings of the Hawaiian Entomological Society*, 6: 411–422.

Swezey, O.H.; Bryan, E.H., Jr. 1929. Further notes on the forest insects of Molokai. *Proceedings of the Hawaiian Entomological Society*, 7: 293–314.

Tanada, Y.; Beardsley, J.W. 1958. A biological study of the lawn armyworm, *Spodoptera mauritia* (Boisduval), in Hawaii (Lepidoptera: Phalaenidae). *Proceedings of the Hawaiian Entomological Society*, 16: 411–436.

Taylor, R.W. 1967. A monographic revision of the ant genus *Ponera* Latreille (Hymenoptera: Formicidae). *Pacific Insects Monographs* 13: 1–112.

Taylor, R.W. 1976. The ants of Rennell and Bellona islands. *Natural History of Rennell Island*, 7: 73–90.

Taylor, R.W. 1977. New ants of the Australasian genus *Orectognathus*, with a key to the known species (Hymenoptera: Formicidae). *Australian Journal of Zoology*, 25: 581–612.

Taylor, R.W. 1978. Melanesian ants of the genus *Amblyopone* (Hymenoptera: Formicidae). *Australian Journal of Zoology*, 26: 823–839.

Taylor, R.W. 1980. Australian and Melanesian ants of the genus *Eurhopalothrix* Brown and Kemp - notes and new species (Hymenoptera: Formicidae). *Journal of the Australian Entomological Society*, 19: 229–239.

Taylor, R.W. 1980. The rare Fijian ant *Myrmecina* (=*Archaeomyrmex*) *cacabau* (Mann) rediscovered (Hymenoptera: Formicidae). *New Zealand Entomologist*, 7: 122–123.

Taylor, R.W. 1985. The ants of the Papuasian genus Dacetinops (Hymenoptera: Formicidae: Myrmicinae). *Series Entomologica*, 33:41–67.

Taylor, R.W. 1987. A checklist of the ants of Australia, New Caledonia and New Zealand (Hymenoptera: Formicidae). *CSIRO Division of Entomology Report*, 41: 1–92

Taylor, R.W. 1988. The nomenclature and distribution of some Australian and New Caledonian ants of the genus *Leptogenys* Roger (=*Prionogenys* Emery, n. syn.) (Hymenoptera: Formicidae: Ponerinae). *General and Applied Entomology* 20: 33–37.

Taylor, R.W. 1992. Nomenclature and distribution of some Australian and New Guinean ants of the subfamily Formicinae (Hymenoptera: Formicidae). *Journal of the Australian Entomological Society*, 31: 57-–69.

Tennant, L.E. 1994. The ecology of *Wasmannia auropunctata* in primary tropical rainforest in Costa Rica and Panama. Pp. 80–90 *in*: Williams, D.F. (ed.) *Exotic ants: biology, impact, and control of introduced species*. Westview Press, Boulder. 332 pp.

Tenorio, J.M.; Nishida, G.M. 1995. *What's bugging me? Identifying and controlling household pests in Hawai'i*. University of Hawaii Press, Honolulu. 184 pp.

Terayama, M. 1996. Taxonomic studies on the Japanese Formicidae, part 2. Seven genera of Ponerinae, Cerapachyinae and Myrmicinae. *Nature and Human Activities* 1: 9–32

Terayama, M.; Miyano, S.; Kurozumi, T. 1994. Ant fauna (Insecta: Hymenoptera: Formicidae) of the northern Mariana Islands, Micronesia. *Natural History Research Special Issue* 1: 231–236.

Timberlake, P.H. 1926. Hymenoptera. *In*: Bryan, E.H., Jr. and collaborators. Insects of Hawaii, Johnston Island and Wake Island. *Bulletin of the B.P. Bishop Museum*, 31: 17–43.

Timberlake, P.H. 1927. Biological control of insect pests in the Hawaiian Islands. *Proceedings of the Hawaiian Entomological Society*, 6: 529–556.

Timberlake, P.H.; Ehrhorn, E.M.; Swezey, O.H. 1921. Report of committee on common names of economic insects in Hawaii. *Proceedings of the Hawaiian Entomological Society*, 4: 607–609.

Toyama, G.M.; Ikeda, J.K. 1976. An evaluation of fly predators at animal farms on leeward and central Oahu. *Proceedings of the Hawaiian Entomological Society*, 22: 369–379.

Tullis, K.; Goff, M.L. 1987. Arthropod succession in exposed carrion in a tropical rainforest on Oahu Island, Hawaii. *Journal of Medical Entomology*, 24: 332–339.

Ulloa-Chacon, P.; Cherix, D. 1994. Perspectives on control of the little fire ant (*Wasmannia auropunctata*) on the Galapagos Islands. Pp. 63–72 *in*: Williams, D.F. (ed.) *Exotic ants: biology, impact, and control of introduced species*. Westview Press, Boulder. 332 pp.

Van Riper, S.G.; Van Riper, C., III. 1985. A summary of known parasites and diseases recorded from the avifauna of the Hawaiian Islands. Pp. 298–371 *in*: Stone, C.P.; Scott, J.M. (eds) *Hawaii's terrestrial ecosystems: preservation and management: proceedings of a symposium held June 5-6, 1984, at Hawaii Volcanoes National Park*. University of Hawaii, Honolulu. 584 pp.

Van Zwaluwenburg, R.H. 1931. The soil fauna of sugar cane fields. Pp. 339–352 *in*: Williams, F.X. *Handbook of the insects and other invertebrates of Hawaiian sugar cane fields*. Hawaiian Sugar Planters' Association, Honolulu. 400 pp.

Van Zwaluwenburg, R.H. 1943. The insects of Canton Island. *Proceedings of the Hawaiian Entomological Society*, 11: 300–312.

Van Zwaluwenburg, R.H. (ed.) 1944. New insect records for the year 1943. *Proceedings of the Hawaiian Entomological Society*, 12: 212.

Van Zwaluwenburg, R.H.; Rust, E.W.; J.S. Rosa, J.S. 1928. Notes on the rice-borer, *Chilo simplex*. *Hawaiian Forester and Agriculturalist*, 25: 79–82.

Van Zwaluwenburg, R.H.; Rust, E.W.; J.S. Rosa, J.S. 1928. Notes on the rice-borer, *Chilo simplex*. *Hawaiian Planters' Record*, 32: 401–405.

Ward, P.S. 1984. A revision of the ant genus *Rhytidoponera* (Hymenoptera: Formicidae) in New Caledonia. *Australian Journal of Zoology*, 32: 131–175.

Ward, P.S. 1985. Taxonomic congruence and disparity in an insular ant fauna: *Rhytidoponera* in New Caledonia. *Systematic Zoology*, 34: 140–151.

Warren, A. 1915. A study of the food habits of the Hawaiian dragonflies. *College of Hawaii Bulletin*, 3: 1–45.

Warren, A. 1915. Dragonflies and their food. *Proceedings of the Hawaiian Entomological Society*, 3: 72–82.

Wetterer, J.K. 1997. Ants on *Cecropia* in Hawaii. *Biotropica*, 29: 128–132.

Wetterer, J.K. 1998. Nonindigenous ants associated with geothermal and human disturbance in Hawai'i Volcanoes National Park. *Pacific Science*, 52, no. 1: 40–50.

Wetterer, J.K.; Banko, P.C.; Laniawe, L.P.; Slotterback; J.W. 1998. Nonindigenous ants at high elevations on Mauna Kea, Hawai'i. *Pacific Science*, 52: 228–236

Whalen, M.A.; Mackay, D.A. 1988. Patterns of ant and herbivore activity on five understory euphorbiaceous saplings in submontane Papua New Guinea. *Biotropica*, 20: 294–300.

Wheeler, W.M. 1908. The ants of Porto Rico and the Virgin Islands. *Bulletin of the American Museum of Natural History*, 24: 117–158.

Wheeler, W.M. 1909. Ants collected by Prof. F. Silvestri in the Hawaiian Islands. *Bollettino del Laboratorio di Entomologia Agraria Portici*, 3: 269–272.

Wheeler, W.M. 1928. Ants collected by Professor F. Silvestri in China. *Bollettino del Laboratorio di Entomologia Agraria Portici*, 22: 3–38.

Wheeler, W.M. 1931. Concerning some ant gynandromorphs. *Psyche*, 38: 80–85.

Wheeler, W.M. 1933. Three obscure genera of ponerine ants. *American Museum Novitates*, 672: 1–23.

Wheeler, W.M. 1933. An ant new to the fauna of the Hawaiian Islands. *Proceedings of the Hawaiian Entomological Society*, 8: 275–278.

Wheeler, W.M. 1934. Revised list of Hawaiian ants. *Occasional Papers of the B.P. Bishop Museum*, 10: 3–21.

Wheeler, W.M. 1935. Ants from the Society Islands. *Bulletin of the B.P. Bishop Museum*, 113: 13–19.

Wheeler, W.M. 1935. Check list of the ants of Oceania. *Occasional Papers of the B.P. Bishop Museum*, 11: 3–56.

Whitney, L.A. 1923. Division of Plant Inspection. Report of Acting Chief Plant Inspector, September, 1923. *Hawaiian Forester and Agriculturalist*, 20: 159–161.

Whitney, L.A. 1926. Division of Plant Inspection. Report of Associate Plant Inspector, September, 1926. *Hawaiian Forester and Agriculturalist*, 23: 153–154.

Whitney, L.A. 1927. Division of Entomology. Report of Associate Plant Inspector, June, 1927. *Hawaiian Forester and Agriculturalist*, 24: 87–88.

Willard, H.F. 1927. Presidential address. Some observations in Hawaii on the ecology of the Mediterranean fruit fly *Ceratitis capitata* Wiedemann and its parasites. *Proceedings of the Hawaiian Entomological Society*, 6: 505–515.

Willard, H.F.; Bissell, T.L. 1926. Work and parasitism of the Mediterranean fruit fly in Hawaii in 1912. *Journal of Agricultural Research*, 33: 9–15.

Willard, H.F.; Mason, A.C. 1937. Parasitization of the Mediterranean fruitfly in Hawaii, 1914–33. *US Department of Agriculture Circular*, no. 439: 1–17.

Williams, F.X. 1927. Notes on the habits of the bees and wasps of the Hawaiian Islands. *Proceedings of the Hawaiian Entomological Society*, 6: 425–464.

Williams, F.X. 1931. *Handbook of the insects and other invertebrates of Hawaiian sugar cane fields*. Hawaiian Sugar Planters' Association, Honolulu. 400 pp.

Williams, F.X. 1936. Biological studies in Hawaiian water-loving insects. Part I. Coleoptera or beetles. Part II. Odonata or dragonflies. *Proceedings of the Hawaiian Entomological Society*, 9: 235–349.

Williams, F.X. 1944. Biological studies in Hawaiian water-loving insects. Part III. Diptera or flies.D. Culicidae, Chironomidae, and Ceratopogonidae. [149–180]. Part IV. Lepidoptera or moths and butterflies [180–185]. Part V. Hemiptera or bugs [186–196]. Addenda. *Proceedings of the Hawaiian Entomological Society*, 12: 149–197.

Williams, F.X. 1946. *Stigmatomma* (*Fulakora*) *zwaluwenburgi*, a new species of ponerine ant from Hawaii. *Proceedings of the Hawaiian Entomological Society*, 12: 639–640.

Wilson, E.O. 1957. The Tenuis and Selenophora groups of the ant genus *Ponera* (Hymenoptera; Formicidae). *Bulletin of the Museum of Comparative Zoology*, 116: 355–386.

Wilson, E.O. 1958. Studies on the ant fauna of Melanesia III. Rhytidoponera in western Melanesia and the Moluccas. IV. The tribe Ponerini. *Bulletin of the Museum of Comparative Zoology*, 119: 303–371.

Wilson, E.O. 1973. The ants of Easter Island and Juan Fernandez. *Pacific Insects*, 15: 285–287.

Wilson, E.O. 1976. Which are the most prevalent ant genera? *Studia Entomologica* 19: 187-200.

Wilson, E.O.; Taylor, R.W. 1967. The ants of Polynesia (Hymenoptera: Formicidae). *Pacific Insects Monograph*, 14: 1–109.

Wirth, W.W. 1947. A review of the genus *Telmatogeton* Schiner, with descriptions of three new Hawaiian species (Diptera: Tendipedidae). *Proceedings of the Hawaiian Entomological Society*, 13: 143–191.

Wong, M.A.; Wong, T.T.Y. 1988. Predation of the Mediterranean fruit fly and the Oriental fruit fly (Diptera: Tephritidae) by the fire ant (Hymenoptera: Formicidae) in Hawaii. *Proceedings of the Hawaiian Entomological Society*, 28: 169–177.

Wong, T.T.Y.; McInnis, D.O.; Nishimoto, J.I.; Ota, A.K.; Chang, V.C.S. 1984. Predation of the Mediterranean fruit fly (Diptera: Tephritidae) by the argentine ant (Hymenoptera: Formicidae) in Hawaii. *Journal of Economic Entomology*, 77: 1454–1458.

Young, G.R. 1996. The crazy ant, *Anoplolepis longipes* (Jerdon) (Hymenoptera: Formicidae) on coconut palms in New Guinea. *Papua New Guinea Agriculture Journal*, 39: 10–13.

Zakharov, A.A. 1994. Ant population structure on the islands of Tonga and Western Samoa. Pp. 1–253 *in*: Sokolov, V.E. [ed.] *Animal population of the islands of Southwestern Oceania*. Oecogeographic, Moscow. 253 pp.

Zimmerman, E.C. 1941. The Bostrichidae found in Hawaii (Coleoptera). *Proceedings of the Hawaiian Entomological Society*, 11: 103–108.

Zimmerman, E.C. 1941. Argentine ant in Hawaii. *Proceedings of the Hawaiian Entomological Society*, 11(1), p. 108.

Zimmerman, E.C. 1948. Introduction. *In*: *Insects of Hawaii. A manual of the insects of the Hawaiian Islands…* University of Hawaii Press, Honolulu. 206 pp.

Zimmerman, E.C. 1948. Apterygota to Thysanoptera inclusive. *In*: *Insects of Hawaii. A manual of the insects of the Hawaiian Islands…* University of Hawaii Press, Honolulu. 475 pp.

Zimmerman, E.C. 1948. Homoptera: Auchenorhyncha. *In*: *Insects of Hawaii. A manual of the insects of the Hawaiian Islands…* University of Hawaii Press, Honolulu. 268 pp.

Zimmerman, E.C. 1948. Homoptera: Sternorhyncha. *In*: *Insects of Hawaii. A manual of the insects of the Hawaiian Islands…* University of Hawaii Press, Honolulu. 464 pp.

Zimmerman, E.C. 1958. Macrolepidoptera. *In*: *Insects of Hawaii. A manual of the insects of the Hawaiian Islands…* University of Hawaii Press, Honolulu. 542 pp.

Zimmerman, E.C. 1958. Lepidoptera: Pyraloidea. *In*: *Insects of Hawaii. A manual of the insects of the Hawaiian Islands…* University of Hawaii Press, Honolulu. 456 pp.

Zimmerman, E.C. 1970. Adaptive radiation in Hawaii with special reference to insects. *Biotropica*, 2: 32–38

Zimmerman, E.C. 1978. Microlepidoptera. Part I. Monotrysia, Tineoidea, Tortricoidea, Gracillarioidea, Yponomeutoidea, and Alucitoidea. *In*: *Insects of Hawaii. A manual of the insects of the Hawaiian Islands…* University of Hawaii Press, Honolulu. 882 pp.

# Non-indigenous land and freshwater molluscs in the islands of the Pacific: conservation impacts and threats

**Robert H. Cowie**

***Department of Natural Sciences, Bishop Museum, 1525 Bernice St, Honolulu, Hawaii 96817-2704, USA***

## Abstract

The non-marine mollusc fauna of the Pacific islands is being homogenised. The once immense levels of native species diversity, with high single island or archipelago endemism, are declining dramatically, and these native/endemic faunas are being replaced by a much smaller number of widespread tropical "tramps", that is, those species that are most readily transported by humans. These introduced species include some that were distributed accidentally by Pacific islanders before European exploration of the Pacific; some of these are "cryptogenic". However, the majority are modern introductions. It is difficult to identify definitively the species presenting the greatest immediate future risk to conservation. However, notable among the terrestrial introductions are the giant African snail (*Achatina fulica*) and the predatory snails (e.g. *Euglandina rosea*, *Gonaxis kibweziensis*, *G. quadrilateralis*) that have been deliberately introduced in ill-conceived attempts to control it. The giant African snail probably modifies native habitat and enters into competition with native species; the predatory snails attack native species and have been heavily implicated in their extinction. More insidious impacts are due to the various species of Subulinidae (e.g. *Subulina octona*, *Paropeas achatinaceum*, *Allopeas gracile*) that often achieve extreme abundance in native ecosystems and probably out-compete native species. More recent introductions are often associated with the horticultural trade (e.g. the tentatively identified *Ovachlamys fulgens*) and their impacts are difficult to assess, although they may rapidly achieve high abundance. Among the freshwater species, apple snails (notably *Pomacea canaliculata*) pose serious threats to aquatic ecosystems through potential habitat modification and competition with native species. Lymnaeid freshwater snails (e.g. *Fossaria viridis*) pose a threat, not only through competition with native species, but because, as carriers of liver flukes, they tempt officials to initiate biological control programmes, often using highly non-specific predators and parasites that then threaten native species. Freshwater bivalves are not common in the Pacific, but the introduced Asian clam (*Corbicula fluminea*) poses a serious threat should it become more widely distributed. Many other non-indigenous species have been recorded in the Pacific but very little is known about their ecology and impacts. All of them have some impact on native ecosystems. Their impacts and spread are facilitated by other factors related to human activity that also have direct impacts on the native species. Because so little is known about these species and their distributions are only spottily recorded, it is difficult to make firm evaluations of which islands/archipelagos are at most risk and on which islands conservation efforts should be focused. However, a number of tentative suggestions can be made. High islands are of more concern than atolls. Major gaps in knowledge include Belau (Palau), Fiji, Tonga, and the Solomon Islands. These archipelagos deserve further survey work and/or documentation of diversity from earlier museum collections. In addition, for various reasons, cases can be made for focusing attention on parts of French Polynesia (notably the Society Islands), parts of the Samoan islands, New Caledonia, and Papua New Guinea. Eradication of already established species is probably impossible, except on a very small scale. Prevention of further spread and of new introductions (e.g. via enhanced strict quarantine measures) should be the main approach. Increased public education is essential to the success of these efforts.

## 1. Introduction

This report focuses on the alien non-marine gastropods (snails and slugs) and bivalves in the area covered by the South Pacific Regional Environment Programme (SPREP), plus the Hawaiian Islands, but excluding Australia and New Zealand. It is difficult to identify definitively the species presenting the greatest immediate future risk to conservation. However, the report focuses on a small number of prominent species, assessing their overall distribution and realised or potential environmental impacts. These

Hawaii Biological Survey Contribution No. 1999-010
Pacific Biological Survey Contribution No. 2000-005

species are likely to include the species exhibiting the greatest conservation threat. Other introduced species and details of their distributions in the region are listed in Annex 1. The report begins with an overview of the native non-marine mollusc fauna because it is this immensely diverse and unique fauna that may be most heavily impacted by predation by and competition with the alien species, and because it is only within the context of the immense native diversity in the Pacific that a sense of the potential impact of introduced species can truly be obtained. This native fauna has already declined dramatically on some islands/archipelagos and is being replaced by a relatively small number of introduced tropical "tramps" (Cowie 1998a, b; Solem 1964).

## 2. The indigenous non-marine mollusc fauna

The following statement of Clench and Turner (1962), specifically referring to the land snail species of New Guinea (Papua New Guinea and Irian Jaya), remains true both for there and for most of the island groups of the Pacific:

"Difficulties in understanding many species still exist. Many of the species were inadequately described, often without figures, and others with incorrect locality data. Confusion about certain species will naturally exist for many years to come . . ."

Many species undoubtedly await discovery and/or description, so that any compilation of numbers of species is probably an underestimate. On the other hand many also may have been described and named more than once as different species, so that any compilation will overestimate real numbers. Even the most recent and rigorous treatments (e.g. Cowie et al. 1995; Cowie 1998c) are undoubtedly inaccurate because of these two factors.

The land snail faunas of the Pacific islands are generally much more diverse than the freshwater faunas (Cowie 1996a). For instance, the Hawaiian Islands have about 750 native land snail species but only seven truly freshwater species (perhaps about 20 if brackish-water species are included) (Cowie et al. 1995; Cowie 1996b). The reasons for this are twofold. First, there is relatively little permanent freshwater habitat on Pacific islands. There are few large lakes and rivers, and many of the streams flow only intermittently after rain. Second, many of the freshwater species are diadromous; the adults live in the streams but the larvae pass out into the ocean, only returning to the streams to settle. Thus there is a great likelihood that these larvae are spread widely by currents, not only to different streams but also to different islands and archipelagos from those where they originated. In contrast, land snails are very poor dispersers. And because the terrain of many Pacific islands is often heavily dissected by ravines and gullies resulting from erosion, small populations can become readily isolated, increasing the chance of speciation and thereby leading to the extremely high diversities and high levels of single island endemism seen on many islands.

The native snail faunas of Pacific islands are derived from rare long-distance dispersal, including island-hopping, over ocean, followed by *in situ* evolutionary radiation (Cowie 1996a, 1996b). Probably wind and attachment to birds have been the primary mechanisms of dispersal, which would explain the generally smaller size of species of more remote islands, as discussed at greater length by Cowie (1996a). Only extremely rare successful establishment of a coloniser has been necessary.

There is no single compilation of overall numbers of Pacific island land and freshwater snail species. A number of lists are available for various island groups, some recent, others over 100 years old. The more recent lists are probably more comprehensive, but all suffer from the problems that there are many unknown and undescribed species and that many other species have been described and named as different species more than once.

Nevertheless, using what literature is available, it is possible to arrive at some rough estimates of diversity. Recent rigorous treatment of the Hawaiian fauna (Cowie et al. 1995) lists 763 native land snail species, of which all but four or fewer are endemic to the archipelago. A similar work (Cowie 1998c) treating the Samoan (American Samoa and what was formerly Western Samoa, now Samoa) fauna lists 94 native land snail species, with about two-thirds of them endemic. The Pitcairn group has been carefully studied (Preece 1995, 1998) and harbours about 30 native species. The numbers of species on each of the Society Islands were given by Peake (1981), and under an assumption of 90% single island endemism, lead to an estimate of the total fauna of the group of about 160 species. The tiny island of Rapa in the Austral archipelago (French Polynesia) harbours 98 native species (Solem 1983). In the Northern Mariana Islands, the fauna of Rota has been carefully surveyed and at least 39 native species recorded (Bauman 1996), and the islands north of Saipan have been investigated by Kurozumi (1994), who recorded at least 16 native species.

Other island groups, even those for which there are lists or compilations, remain less well known. For instance, the fauna of Vanuatu has been treated in detail by Solem (1959), who recorded around 130 species, but certain islands in the group remain very poorly investigated and this number is certainly a serious underestimate (Cowie 1996a). Other island groups are even less well known. About 110 species have been listed in the fauna of New Caledonia (Franc 1957; Solem 1961), but Solem et al. (1984) and Tillier and Clarke (1983) considered the real number to be 300–400. It is beyond the scope of this report to attempt an accurate compilation of numbers from the widely spread taxonomic literature. However, using these numbers above as a guide, and given the extremely high levels of endemism among Pacific island land snails, an estimate, excluding New Guinea, of around 4000 native species seems not unreasonable, although essentially a guess.

## 2.1 Papua New Guinea

Because of the rather different nature of New Guinea (Papua New Guinea and Irian Jaya), as compared to the other islands of the region, New Guinea is discussed separately. The non-marine mollusc fauna of New Guinea remains inadequately known, and it is not possible to give a precise estimate of numbers of species (Cowie 1993). As a broad generalisation, most species are probably endemic to New Guinea. Some are endemic to certain islands or island groups.

Various compilations are available, but none is comprehensive. Iredale's (1941) list for the land snails of "Papua" includes 198 species but it is not clear which of the offshore islands are included. Rensch (1934, 1937) listed 157 land snail species in the Bismarck archipelago. Van Benthem Jutting's (1963a, 1964, 1965) monographs of Irian Jaya, the most comprehensive works for New Guinea, indicate 481 species-group land molluscan taxa (mostly full species). This figure is still probably an underestimate.

During the first half of the twentieth century many new taxa were discovered in New Guinea, but many areas remain unexplored malacologically and new taxa continue to be found. Past collecting effort has probably been biased towards the larger and more colourful species and to accessible (especially coastal) areas. With this in mind, it is not unreasonable to suggest that the native land molluscan fauna numbers well over 1000 species, with perhaps close to 1000 in Papua New Guinea alone.

For the fresh- and brackish water fauna, van Benthem Jutting's (1963b) work, listing 165 species-group taxa of gastropods and bivalves, stands out as the most comprehensive treatment of the New Guinea fauna. For Papua New Guinea, Starmühlner's (1976) monograph, including 47 fresh water gastropods (including 33 from the Bismarck archipelago) is the most comprehensive work, but certainly covers the fauna incompletely. Haynes' (1988a) list, covering only the Neritidae, is similar. McMichael's (1956) statement that:

"New Guinea remains virtually an unexplored territory as far as this group of mollusks [freshwater mussels] is concerned"

remains true not only for mussels but also to a large extent for the whole freshwater molluscan fauna. It is not possible to estimate the total number of species in the fauna, nor to make any useful statements about their distributions.

## 2.2 Extinction

The unique native land snail faunas of the islands of the Pacific are disappearing rapidly (e.g. Bauman 1996; Cowie 1992; Solem 1990). Many species are now extinct or severely threatened, and often confined to high-altitude refugia. Destruction of habitat (beginning with prehistoric Polynesian colonisation; e.g. Preece 1998) for agricultural and urban development is an important cause of this decline, as is modification of habitat by the replacement of native plant species suitable for the snails with alien plants on which the native snail species cannot survive. Rats introduced by Polynesians (*Rattus exulans*) and Europeans (*Rattus rattus*, *Rattus norvegicus*) have a heavy impact on native snails (e.g. Hadfield et al. 1993).

A particularly important cause of the demise of the native snails has been the deliberate introduction of carnivorous snails, most notably *Euglandina rosea*, in ill-conceived attempts to control another introduced snail, the giant African snail, *Achatina fulica*. Populations of *A. fulica* have not been reduced by the carnivorous snails (Christensen 1984; Civeyrel and Simberloff 1996) but native snail populations have been devastated (Clarke et al. 1984; Hadfield 1986; Hadfield and Miller 1989; Hadfield et al. 1993; Hadfield and Mountain 1981; Murray et al. 1988). A newer and very serious threat is the introduction of an extremely voracious predatory flatworm, *Platydemus manokwari* (e.g. Hopper and Smith 1992). Reports that it can control *Achatina fulica* remain correlative, and the individuals promoting its use as a biological control agent either consider it harmless to native snail species (incorrect) or simply do not care about native species (Muniappan 1983, 1987, 1990; Muniappan et al. 1986). In the Pacific islands region *PP. manokwari* has been reported from Guam, and Saipan, Tinian, Rota and Aguijan in the Northern Marianas, from Koror and Ulong in Belau

(Palau), and from O‘ahu in the Hawaiian Islands (Eldredge 1994a, 1995). Much of the "evidence" that these predators can control populations of *A. fulica* is based on a poor understanding of ecological principles. That the predators will ***prey*** on *A. fulica* is not evidence that they can ***control*** its populations; other factors (e.g. food) may be limiting, even to the extent that heavy predation has no effect on numbers of the extremely fecund and rapidly reproducing *A. fulica*.

Introduction, both deliberate and not, of non-indigenous snails and slugs is continuing throughout the islands of the tropical Pacific (e.g. Cowie 1997, 1998c, 1998d; Gargominy et al. 1996; Hopper and Smith 1992) and to a greater or lesser extent throughout the world (e.g. Cowie 1999; Griffiths et al. 1993). Indigenous species are perishing primarily through predation and habitat modification, and perhaps competition, and being replaced by a relatively small number of mostly synanthropic, disturbance-tolerant species (Cowie 1998a, 1998b). The terrestrial molluscan fauna of the Pacific islands is being homogenised, just as is predicted for the entire world's biota (McKinney 1997).

Freshwater molluscan faunas are suffering similar fates. As discussed above, on Pacific islands there are generally far fewer freshwater mollusc species than terrestrial species; many of these freshwater species exhibit diadromous life-cycles; levels of endemism are much lower than in the terrestrial faunas (Cowie 1996b). Nevertheless, these freshwater faunas are threatened, and for the same reasons as the terrestrial faunas. For instance, in the Hawaiian Islands there are now more non-indigenous than indigenous freshwater species (Cowie et al. 1995; Cowie 1997); and the same carnivorous snail that has been the major scourge of the terrestrial fauna, *Euglandina rosea*, will even go under water in search of its prey (Kinzie 1992).

## 3. The faunas of high islands and atolls

Most Pacific islands arose from volcanism: either hot spot volcanism (Clague 1996) leading to chains of islands, such as the Hawaiian Islands; or island arc volcanism (Polhemus 1996), also often leading to chains (e.g. the Mariana Islands). Other islands are of continental origin (e.g. New Caledonia). Among the volcanic islands of the Pacific, a major distinction has been made between two main classes of islands: high volcanic islands such as the main Hawaiian, Samoan and Society Islands, Pitcairn and Rapa; and low coral atolls such as the Marshall Islands, Line Islands, Tuamoto archipelago, Swains in the Samoan group, etc. Raised coral limestone islands (e.g. Henderson, Makatea) have sometimes been recognised as a third category (e.g. Harry 1966). Arguably, these distinctions are false (Cowie 1996a), because the low islands are formed gradually from high islands as they erode and sink. Raised limestone islands are the result of sea level fluctuations and/or tectonic uplifting superimposed on this continuum. Nevertheless, the distinction has practical value, because the snail faunas of the high islands are characteristically very different from the faunas of atolls, with the faunas of raised limestone islands intermediate. High islands are characterised by high levels of diversity and endemism; low islands harbour few land snail species, most of which are widely distributed (in part through human activities). This is reasonable: low islands will frequently have been inundated during recent geological history as sea level rose and fell; they may also have been inundated as a result of tidal waves and hurricanes (Harry 1966). The land snail fauna would have certainly been destroyed in the first case and probably also in the second. Such islands would then only be expected to harbour those species that are most readily transported by birds or the wind, or more recently by humans—non-indigenous "tramp" species.

## 4. Overview of the non-indigenous non-marine mollusc fauna

In general, and with a number of notable exceptions, the nonindigenous snails of Pacific islands have been poorly studied. In the past, the fantastic and spectacular diversity of the native faunas attracted scientists, who tended to consider the non-native species uninteresting and therefore did not collect them, record them, or study them to any great extent. This is beginning to change as the native species disappear and concern is increasing with regard to the actual and potential impacts of non-native species. Nevertheless, there remains a very sparse and scattered literature on the alien species, with the exception of the giant African snail, *Achatina fulica*, and the predatory snail *Euglandina rosea*.

The most thorough accounts of the alien non-marine snail faunas of Pacific archipelagos are Cowie's (1997) catalogue and bibliography of the Hawaiian species, with the information therein analysed and discussed further by Cowie (1998a), and his combined native and non-native catalogue of the Samoan fauna (Cowie 1998c). Cowie (1998a) reported 81 species introduced to the Hawaiian Islands, with 33 probably established. In Samoa, he listed 23 introduced species (Cowie 1998c), 16 of which are also recorded in the Hawaiian Islands. New introductions are continuing in both Hawaii (Cowie 1998d, 1999) and Samoa (Cowie and Cook 1999). For New Caledonia, Gargominy et al. (1996), updating Solem (1964), listed 24 introduced land snail species. Of these, 13 (and probably more, given probable misidentifications) are also present in Hawaii. Preece (1995) listed the small fauna of the Pitcairn Islands, including 10 probable introduced species (but see Preece 1998). No explicit list of alien snails has been published for any other archipelago; records are scattered through the literature.

These introduced species come from all over the world (Cowie 1998a). A small number were transported inadvertently by Pacific island people as they colonised previously uninhabited archipelagos. These were mostly species originating within the Pacific and were generally small lowland species. It is often difficult to be sure whether these widely distributed Pacific island species really have been distributed by humans or whether they are in fact native; only archaeological evidence can resolve the question (e.g. Preece 1998). Such species have been termed "cryptogenic" (of hidden origin) by Carlton (1996). Following European discovery of the islands, and subsequent US involvement, more species began to be introduced, mostly from around the Pacific rim. With increasing worldwide commerce and air travel, new species began to appear from further afield, a significant number now being inadvertently distributed via the international horticultural trade (Cowie, 1999).

In addition to these accidental introductions, a significant number (mostly larger snails) have been introduced deliberately. There is a continuing desire to introduce snails as human food resources, both as an inexpensive protein source for local consumption and for the gourmet restaurant trade (including export). Terrestrial species (e.g. *Helix aspersa*—Gargominy et al. 1996) and freshwater species (e.g. *Pomacea canaliculata*—Cowie 1995a) have been introduced for these reasons. Most of these introductions result from illegal smuggling, which is extremely difficult to prevent completely. Additional aquatic species have been distributed via the aquarium trade, eventually ending up in native aquatic ecosystems. However, the most well-known examples of deliberate introduction are the introduction of *Achatina fulica* for food, medicinal, and ornamental purposes, followed by the introduction of predatory snails (most notably *Euglandina rosea*, but also a number of others) in poorly conceived and unsuccessful attempts to control it (see below for more details).

The features that characterise the successful introduced species, and especially those that become invasive, generally include the readiness with which they are accidentally transported, rapid reproduction and high fecundity, and generalist food and habitat requirements. These features mean that they are able to out-compete many of the native species, which have evolved and speciated in the absence of such vigorous competition. The native species have also frequently evolved in the absence of heavy predation. Many native species (e.g. the partulid and achatinelline tree snails) grow and reproduce extremely slowly (Cowie 1992). It will therefore take a long time for populations of such species to recover from a single predation episode that destroys a significant portion of the population. This means that these native species are especially vulnerable to predation by the introduced predatory snails (e.g. Hadfield et al. 1993).

It has been suggested (Harry 1966) that alien snails "tend to remain in an environment highly modified by man, and do not, through their own natural ability, invade the more natural surrounding areas." This statement would suggest that there is no need to be concerned about alien snails because they will not invade native ecosystems. This is simply not true. For example, the spread of *Euglandina rosea* throughout the islands to which it has been introduced is well documented (e.g. Clarke et al. 1984; Hadfield 1986; Hadfield et al. 1993; Murray et al. 1988); alien subulinids are probably the commonest land snails in almost pristine native forest in American Samoa (Cowie and Cook 1999); and the freshwater snail *Pomacea canaliculata* is spreading rapidly into non-agricultural aquatic environments in the Hawaiian Islands (Lach and Cowie 1999).

Introductions continue, and at an increasing rate. Unless they cause a serious problem to agriculture or human health, they often do not get documented. Alien species that cause less obvious environmental or conservation problems are frequently ignored. Records of the presence of introduced species usually depend to a great extent on casual or incidental collecting. For these reasons, many introductions undoubtedly remain unrecorded, especially in remote and unsurveyed archipelagos. Therefore, this report is necessarily incomplete in terms of giving a true picture of the Pacific distributions of many of the alien non-marine molluscs. Furthermore, because most of the introduced slugs and snails and their environmental impacts have been hardly studied at all, we do not know which species have become or may yet become serious conservation problems. In fact, all alien species have some environmental impact, simply because they become part of a pre-existing ecosystem and by being incorporated into this ecosystem they by definition contribute to its dynamics. Therefore, this report tends to be inclusive rather than exclusive in terms of listing the more serious problem species.

As discussed above, many of the alien snails and slugs are more or less cosmopolitan "tramps" (Solem 1964). The alien snail/slug faunas of most islands and archipelagos in the Pacific contain a subset of this suite of species. The faunas of atolls may be entirely composed of such species. The total number of alien non-marine snails and slugs established in the Pacific is probably at present only 100–200, with perhaps only a handful of non-native bivalves. Yet, in terms of biomass, they almost certainly outweigh the estimated 4000 or so native species. This balance will almost certainly continue to tip in favour of the alien species.

### 4.1 New Guinea

Following the format adopted above, New Guinea is here treated separately. Because of its size and the remoteness of much of its interior, many of New Guinea's native species are probably surviving, and there may be large areas into which no alien species (or at least very few) have penetrated. Lowland areas, however, have undoubtedly been invaded, probably by the same suite of alien species as are present elsewhere in the Pacific.

## 5. Species presenting particular threats

Because the suite of alien species present in each archipelago is likely to contain many species in common, the following basic species by island treatment is formulated around species rather than archipelagos, to avoid repetition. As suggested above, there are probably only 100–200 alien non-marine mollusc species in the Pacific region. It is not the intention of this report to give details of all of them. Instead, the report focuses on a small number of species that have received greatest publicity and/or which seem particularly abundant where they have been recorded and/or appear to have especially invasive potential. Again, as indicated above, it is not possible definitively to determine which species present the most serious conservation threats in the immediate future; the following list of species is therefore a very subjective treatment. For each species, a list is given of the islands from which it has been recorded, with the date of introduction (or first record) on that island if known. Annex 1 gives minimal details of other nonindigenous snail species recorded in the region.

The sequence of species treated here in detail arguably reflects their significance as conservation threats. The order in which archipelagos and islands are listed follows Motteler (1986), as does spelling of island names, including the use of diacriticals. The date of first introduction to an island or archipelago is given if known, with the citation from which that information was derived.

## 5.1 Terrestrial species

FAMILY ACHATINIDAE

***Achatina fulica* (Bowdich, 1822) — the giant African snail**

This species has been introduced widely, both deliberately (e.g. for food—Clarke et al. 1984) and accidentally. Characteristically, its populations may remain relatively low and more or less innocuous for some time, then explode dramatically with the snails becoming both agricultural and garden pests as well as a public nuisance. As with many invasive species, however, their populations subsequently decline to a low level (e.g. Eldredge 1988), for reasons that are not understood, although disease has been strongly suggested (Mead 1979; Waterhouse and Norris 1987; Cowie 1992).

By reaching such enormous numbers and invading native ecosystems they pose a serious conservation problem. Not only may they eat native plants, modifying habitat, but they probably also out-compete native snails (e.g. Tillier 1992).

However, the more insidious conservation problem they cause is that they tempt agricultural officials to initiate a number of putative biological control measures. The most well publicised of these measures is the introduction of predatory snails, most notably *Euglandina rosea* (see below). The first attempts at such biological control were made in Hawaii. Fifteen carnivorous species were deliberately introduced (Cowie 1998a). Of these, nine did not become established; the fate of three is unknown but they are certainly not common and do not appear to be causing serious problems. However, three have become established and are discussed below: *Euglandina rosea*, *Gonaxis kibweziensis*, *G. quadrilateralis*. There is no scientific evidence that the predatory snails are the reason for the decline in numbers of *A. fulica* (Christensen 1984).

Similar ill-conceived attempts at biological control involving *Euglandina rosea* in particular have been implemented in French Polynesia, American Samoa, Guam, and a number of other places in the Pacific and Indian Oceans (Griffiths et al. 1993) (see below under *Euglandina rosea*).

In addition to the deliberate introduction of predatory snails, the predatory flatworm *Platydemus manokwari* has also been introduced, although as yet less widely (Eldredge 1994a, 1995). It is reported that this flatworm can indeed cause populations of *Achatina fulica* to decline (Muniappan 1983, 1987, 1990; Muniappan et al. 1986; Waterhouse and Norris 1987), but the evidence is only correlative, not convincingly causative. However, the flatworm has also been implicated in the decline of native species on Guam (Hopper and Smith 1992). It has been seen in Hawai‘i (Eldredge 1994a, 1995) but as yet does not appear to be present in large numbers (M.G. Hadfield, unpublished observations).

It cannot be stressed enough that these introductions of putative biological control agents against *Achatina fulica* are extremely dangerous from the perspective of the conservation of native snail species. And in any case, there is no good evidence that they can indeed control *A. fulica* populations.

*Achatina fulica* continues to spread; for instance it was first reported on Upolu (Samoa) in 1990 and in Kosrae (Federated States of Micronesia) in 1998. Some islands remain free of it, for instance Ofu (American Samoa), yet seriously at risk. Once established on one island of an archipelago, the risk of local dispersal to other islands in the group is very high (Waterhouse and Norris 1987). Probably, people still see *A. fulica* as a potential food source. An effort has been made to promote it as a food resource on Upolu, collecting the snails for food being seen as a method of controlling them. However, promoting a pest, for whatever seemingly positive reason, seems fundamentally counterproductive as it will probably encourage the further deliberate spread of the snails around the island. It seems axiomatic that a pest species should not be promoted. In addition, *A. fulica* appears to be readily transported inadvertently from island to island.

### Hawaiian Islands
Kaua‘i - 1958 (Mead 1961); O‘ahu - 1936 (Mead 1961); Moloka‘i - 1963 (Mead 1979); Maui - 1936 (Mead 1961); Lāna‘i - 1963-1972 (Mead 1979; possibly not established); Hawai‘i - 1958 (Mead 1961).

### French Polynesia
Marquesas Islands: Nuku Hiva, Hiva Oa - before 1984 (Pointier and Blanc 1984).

Society Islands: Tahiti - 1967 (Mead 1979); Moorea, Huahine, Raiatea, Tahaa, Bora-Bora - after 1967 but before 1978 (Clarke et al. 1984; Mead 1979).

Tuamoto Archipelago: Moruroa - 1978 (Mead 1979); Hao - 1978 (Mead 1979); Apataki - (Pointier and Blanc 1984).

### Samoa
Upolu - 1990 (Cowie 1998c).

### American Samoa
Tutuila - 1977 (Cowie 1998c); Ta‘ū (Eldredge 1988, Cowie 1998c).

### Wallis and Futuna
Wallis Islands - (Anon. 1998a).

### Tuvalu
Vaitupu - 1996 (Anon. 1996a, b; eradicated).

### New Caledonia
1972 (Gargominy et al. 1996; Mead 1979).

### Vanuatu
Efate - 1967 (Mead 1979); Espiritu Santo - (Mead 1979).

### Solomon Islands
(Anon. 1999).

### Papua New Guinea
Pre-1945 (Mead 1961; Dun 1967).

Port Moresby - early 1960s (Mead 1979); Lae - 1976-1977 (Mead 1979); Madang - before 1972 (Mead 1979); Bougainville - 1970 (Mead 1979); Bismarck Archipelago (New Britain, New Ireland) - pre-1945 (Mead 1961); Manam Island - (Lambert 1974).

### Marshall Islands
Kwajelein - (Anon. 1996a, 1998a).

### Federated States of Micronesia
Kosrae: 1996 (Anon. 1998a).

Pohnpei: 1938 (Mead 1961, 1979; Smith 1993b).

Truk - (Mead 1979; Smith 1993c): Dublon - pre-1940 (Mead 1961); Moen, Romonum - pre-1945 (Mead 1961); Uman, Fefan - 1948 (Mead 1961).

### Belau (Palau)
Babeldaob - 1938 (Mead 1961; Cowie et al. 1996); Oreor (Koror) - 1939 (Mead 1961); Ngerekebesang (Arakabesan), Ngemelachel (Malakal) - pre-1950 (Lange 1950); Ulebsechel (Auluptagel), Ngeruktabel (Urukthapel) - 1949 (Mead 1961); Beliliou (Peleliu) - pre-1946 (Lange 1950); Ngeaur (Angaur) - pre-1950 (Lange 1950).

### Guam
1943 (Bauman 1996; Mead 1961; Eldredge 1988).

### Northern Mariana Islands
Rota, Tinian, Saipan - 1936-38 (Mead 1961; Bauman 1996); Aguijan - pre-1939 (Mead 1961); Pagan - 1939 (Mead 1961).

## FAMILY SPIRAXIDAE

### *Euglandina rosea* (Férussac, 1821) — the cannibal snail, the rosy wolf snail

This species is the most widely introduced of the numerous species that have been used in attempts to control populations of *Achatina fulica* (Griffiths et al. 1993; Mead 1961, 1979). According to Mead (1979), the earliest introductions of *E. rosea* in the Pacific were to Papua New Guinea, but it was the efforts of the Hawaii Department of Agriculture that spurred greatly increased interest in using this species as a biological control agent. Officials in Hawaii strenuously argued that *A. fulica* populations declined because of predation by *E. rosea* (e.g. Nishida and Napompeth 1975) and willingly advised other nations with *A. fulica* problems to follow their lead and introduce *E. rosea*. However, there is no rigorous scientific evidence that *E. rosea* effectively controls *A. fulica* populations (Christensen 1984). It is now widely recognised that the *A. fulica* populations declined for other reasons (Clarke et al. 1984; Cowie 1992; Mead 1961, 1979) but that *E. rosea* has been a major scourge of vulnerable native snail populations, perhaps to the extent of the extinction of a large number of endemic species (Cowie 1992; Hadfield 1986; Murray et al. 1988). The most widely publicised impacts have been on the slow-reproducing endemic tree snails (Partulidae and Achatinellinae). Statements that *E. rosea* is entirely ground-dwelling are not true; it is frequently seen in trees.

One crucial piece of evidence that tells us that *E. rosea* is not the cause of the decline in *A. fulica* populations comes from French Polynesia (Clarke et al. 1984). On Moorea, the decline in numbers of *A. fulica* occurred all over the island, in some areas prior to the spread of *E. rosea* into those areas. And a similar decline was seen on Huahine, to which *E. rosea* had not been introduced.

Most governments and other authorities appear to be aware of the potential threat posed to native faunas by *Euglandina rosea*. However, under pressure from voters to "do something" about *Achatina fulica*, they often at least consider the introduction of *E. rosea* (and other snail predators like *Platydemus manokwari*). Many island people are not aware of their unique native faunas, or do not understand their precarious existence, but have heard that *E. rosea* can solve the *Achatina fulica* problem. The pressure to introduce *E. rosea* may then become intense, or people may resort to introducing it unofficially. Introduction of *Euglandina rosea* to Tutuila (American Samoa) in 1980 was against the express written protests of widely respected land snail experts and others. The World Conservation Union (IUCN) has formally condemned the deliberate introduction of *E. rosea* and other carnivorous snails (Anon. 1989). So, with the continuing spread of *Achatina fulica*, the threat posed by the continued introduction of *E. rosea* is serious.

#### Hawaiian Islands
Kaua'i - 1958; O'ahu - 1955 (Cowie 1997; Mead 1961); Moloka'i - (Griffiths et al. 1993); Maui, Hawai'i - 1958 (Mead 1961).

#### Kiribati
(Waterhouse and Norris 1987).

#### French Polynesia
Society Islands: Tahiti - 1974 (Griffiths et al. 1993; Mead 1979; Tillier and Clarke 1983); Moorea - 1977 (Clarke et al. 1984; Griffiths et al. 1993).

#### American Samoa
1980 (Waterhouse and Norris 1987; Cowie 1998c).

#### New Caledonia
1974–78 (Gargominy et al. 1996; Mead 1979; Tillier and Clarke 1983).

#### Vanuatu
1973 (Mead 1979).

Efate - (Waterhouse and Norris 1987).

#### Solomon Islands
(Waterhouse and Norris 1987).

#### Papua New Guinea
1952–1961 (Dun 1967; Mead 1979; Waterhouse and Norris 1987; failed to establish).

New Britain - 1952–53 (Mead 1979; failed to establish).

#### Belau (Palau)
(Mead 1979; Waterhouse and Norris 1987; may not have established.)

#### Guam
1957 or 1958 (Hopper and Smith 1992; Mead 1979).

#### Northern Mariana Islands
Saipan - (Mead 1979).

## FAMILY STREPTAXIDAE

### *Gonaxis kibweziensis* (Smith, 1894)

This species was the first to be seriously considered as an agent for the control of *Achatina fulica* (Mead 1961). It is now the second most widely introduced of these predatory species. It rarely seems to become as abundant as *E. rosea*, and has not been so heavily implicated in causing extinctions of native species. It appears to be entirely ground-dwelling. Native ground-dwelling species, though a large proportion of the Pacific terrestrial snail fauna, have not received the attention the tree snails have, so it is unknown whether *G. kibweziensis* has had any impact on these non-arboreal species.

More recently, there is a lesser tendency to consider introduction of *G. kibweziensis* than of *Euglandina rosea* in control efforts against *Achatina fulica*. Nevertheless, whether officially or unofficially, there remains the possibility that *G. kibweziensis* will be introduced more widely. It therefore still poses a potential, though less understood threat. Its smaller size may mean that it is transported inadvertently more easily than *E. rosea*.

Hawaiian Islands
O'ahu - 1952 (Cowie 1997; Mead 1961); Maui - 1955 (Cowie 1997; Mead 1961).

American Samoa
Tutuila - 1977 (Cowie 1998c).

New Caledonia
1979 (Waterhouse and Norris 1987).

Papua New Guinea
New Britain - 1955 (Mead 1961).

Federated States of Micronesia
Truk - 1955 (Mead 1961, 1979; perhaps not established); Pohnpei - 1955 (Mead 1961, 1979; Smith 1993b; perhaps not established).

Belau (Palau)
After 1950 (Mead 1979).

Guam
1954 (Hopper and Smith 1992; Mead 1961).

Northern Mariana Islands
Rota - 1955 (Bauman 1996; Mead 1961, 1979; alive in 1969); Aguijan - 1950 (Anon. 1953; Mead 1961, 1979); Tinian, Saipan - 1955 (Mead 1961, 1979).

### *Gonaxis quadrilateralis* (Preston, 1910)

This species, larger than *G. kibweziensis*, was selected as a biological control agent against *Achatina fulica* because *G. kibweziensis* is only able to attack small *A. fulica* individuals (Mead 1961). *G. quadrilateralis* is now probably the third most widely introduced of the predatory species. As for *G. kibweziensis* (above), little is known about its impacts, but it may have had impacts on ground-dwelling native snails.

Again, as for *G. kibweziensis*, this species poses a potential, though not well understood threat.

Hawaiian Islands
Kaua'i - 1979–80 (Lai et al. 1982); O'ahu, Maui - 1957 (Cowie 1997; Mead 1961); Hawai'i - 1973 (Nakao et al. 1975).

Kiribati
(Waterhouse and Norris 1987).

Vanuatu
1973 (Mead 1979).

Papua New Guinea
1968–1972 (Mead 1979).

Bougainville - 1968–72 (Mead 1979); New Britain - 1952–53 (Mead 1979); New Ireland - 1968–1972 (Mead 1979).

Belau (Palau)
(Mead 1979).

Guam
1967 (Hopper and Smith 1992).

Northern Mariana Islands
Saipan - (Mead 1979; perhaps not established).

## FAMILY SUBULINIDAE

Subulinids pose a serious conservation threat that is not as obvious as that posed by the predatory species. Subulinids (at least *Subulina octona* and *Paropeas achatinaceum*, and perhaps formerly *Allopeas gracile*) often reach enormous abundances that suggest the possibility of competition with native litter-dwelling species. Competition with subulinids has been tentatively suggested as a cause of the decline of litter-dwelling helicinid and other land snails in American Samoa (Cowie and Cook 1999). These species probably also provide an abundance of food for the predatory species, which then might have a greater impact on the native species.

In addition, subulinids appear to be very readily transported accidentally (e.g. Kerney et al. 1979), often probably in association with horticultural and agricultural products (e.g. the introduction of *Subulina octona* to New Caledonia; Solem 1964).

Subulinids are notoriously difficult to identify. Probably, many misidentifications of species introduced to Pacific islands have been made. The following island distributions for individual species may therefore be insecure and should be treated with caution. Partly because of these difficulties, but also because the subulinid fauna as a whole could be construed as having a concerted impact, all records that have been found of other subulinids in the Pacific are also listed here.

### *Subulina octona* (Bruguière, 1789)

Cooke (1928) stated that "in Tutuila [American Samoa] this is one of the most abundant species living today occurring in great abundance from the seashore to the crest of the mountains". Recent survey work has confirmed that this remains the case

(Cowie and Cook 1999). In fact, *S. octona* is probably the most widespread and abundant subulinid in the Pacific. It may even be the most common land snail (native or alien). Undoubtedly, it is present but has not been recorded from many islands. It probably is native to the Neotropics (Kerney et al. 1979).

Hawaiian Islands
1903 or earlier but not earlier than about 1870 (Cowie 1997).

French Polynesia
Marquesas Islands: (Cooke 1928).

Society Islands: (Cooke 1928).

Austral Islands: Rapa - (Cooke 1928).

Tuamoto Archipelago: Makatea - 1930 (Cooke 1934).

Pitcairn Islands
Pitcairn - (Preece 1995).

Galapagos Islands
Santa Cruz - (Smith 1966).

Cook Islands
(Cooke 1928.)

Aitutaki - post-European (Allen 1992).

Samoa
Upolu - 1994 (Cowie 1998c; tentative record).

American Samoa
Tutuila - before 1928 (Cooke 1928).

Ta'ū, Ofu, Olosega - before 1992 (Cowie 1998c; Miller 1993).

Tonga
(Cooke 1928).

Fiji
(Cooke 1928).

Lau Group: Moce, Lakeba - (Solem 1978).

New Caledonia
1889 (Gargominy et al. 1996; Solem 1964).

Isle of Pines - (Solem 1964).

Vanuatu
(Cooke 1928).

Efate, Epi, Espiritu Santo - (Solem 1959).

Solomon Islands
(Peake 1968).

Tikopia - late nineteenth century (Christensen and Kirch 1981).

Marshall Islands
Jaluit - pre-1904 (Reigle 1964); Enewetak - (Kay and Johnson 1987).

Federated States of Micronesia
Kosrae - (Smith 1992b); Pohnpei - (Smith 1993b).

Belau (Palau)
Babeldaob - (Cowie et al. 1996).

Guam
(Bauman 1996; Smith 1993a).

Northern Mariana Islands
Rota - (Bauman 1996); Saipan - 1948 (Bauman 1996; Lange 1950).

### *Paropeas achatinaceum* (Pfeiffer, 1846)

This is a widespread species, especially in the tropical Indo-Pacific, probably distributed in large part through human activities. It probably originates from South-East Asia (Pilsbry 1906–1907), where it is widely distributed (Naggs 1994).

Hawaiian Islands
Kaua'i, O'ahu, Moloka'i, Maui - (Cowie 1997); Hawai'i - 1904 (Cowie 1997).

French Polynesia
Marquesas Islands: Nuku Hiva - (Naggs 1994).

Tuamoto Archipelago: Makatea - 1932 (Cooke 1934).

Samoa
Savai'i, Upolu - 1994 (Cowie 1998c; tentative records).

American Samoa
Tutuila - 1994 (Cowie 1998c; tentative record), 1998 (Cowie and Cook 1999; confirmed record).

Ta'ū, Ofu - 1998 (Cowie and Cook 1999).

Fiji
Lau Group: Moce, Lakeba - (Solem 1978).

Guam
(Smith 1993a).

Northern Mariana Islands
Saipan - 1948 (Lange 1950; identification uncertain).

### *Allopeas gracile* (Hutton, 1834)

This species was considered by Pilsbry (1906–1907) to be "probably the most widely distributed land snail in the world". It was transported around the Pacific initially via the Lapita culture expansion and subsequently by Polynesian voyagers (Christensen and Kirch 1981, 1986; Kirch 1993). However, it now appears to be declining. It is rarely found alive, even in localities where it was formerly common (personal observations). Although based on very limited observations, it is possible that subulinids that arrived later, transported via western exploration and commerce (notably *Subulina octona* and *Paropeas achatinaceum*—see above), have out-competed *A. gracile*. Many of the following records are based on records of junior synonyms, some of which are listed by Cowie (1997, 1998c).

Hawaiian Islands
Ni‘ihau, Kaua‘i, O‘ahu, Moloka‘i, Maui, Hawai‘i - pre-1778 (Christensen and Kirch 1986; Cowie 1997; probably on all the islands — Cowie et al. 1995).

French Polynesia
Marquesas: Tahuata - (Kirch 1993); Eiao or Ua Huka - (Pilsbry 1906–1907; could also refer to Teraina in the Line Islands, Kiribati).

Society Islands: Tahiti, Moorea, Huahine - (Pilsbry 1906–1907).

Austral Islands: Rapa - (Pilsbry 1906–1907; as the junior synonym *Opeas oparanum*).

Tuamoto Archipelago: Makatea - (Cooke 1934).

Pitcairn Islands
Pitcairn - (Preece 1995).

Galapagos Islands
Santa Cruz - (R.H. Cowie, personal observations 1999)

Cook Islands
Aitutaki - (Allen 1992).

Samoa
Upolu - (Cowie 1998c).

American Samoa
Tutuila - (Cowie 1998c); Ofu - (Kirch 1993).

Tonga
(Kirch 1993).

Tuvalu
Funafuti - (Hedley, 1899; Pilsbry 1906–1907).

Fiji
Lau Group: Karoni, Lakeba - (Solem 1978).

Rotuma - pre-1897 (Pilsbry 1906–1907).

New Caledonia
1859 (Gargominy et al. 1996; Solem 1964).

New Caledonia (Grand Terre), Art, "Ile Casy" - (Pilsbry 1906–1907); Maré - (Solem 1964).

Vanuatu
(Pilsbry 1906–1907).

Anatom, Espiritu Santo - (Solem 1959).

Solomon Islands
(Peake 1968).

Tikopia - (Christensen and Kirch 1981).

Nauru
Pre-1904 (Pilsbry 1906–1907).

Marshall Islands
(Pilsbry 1906–1907).

Rongelap, Enewetak - (Reigle 1964).

Federates States of Micronesia
Pohnpei - pre-1900 (Pilsbry 190–1907).

State of Yap: pre-1900 (Pilsbry 1906–1907); Ulithi - (Harry 1966).

Guam
(Smith 1993a; identification uncertain).

Northern Mariana Islands
Saipan - 1948 (Lange 1950).

### Other subulinids

Other subulinids, arguably all introduced, recorded in the Pacific are:

#### *Allopeas clavulinum* (and its probably synonymous "variety" *hawaiiense*)

Hawaiian Islands (Kaua‘i, O‘ahu, Moloka‘i, Maui, Hawai‘i) - Cowie 1997; French Polynesia (Tuamoto Archipelago [Makatea]) - Cooke 1934; Pitcairn Islands (Pitcairn) - Preece 1995; American Samoa (Tutuila, Ta‘ū, Ofu) - Cowie 1998c; Cowie and Cook 1999; Fiji (Lau Group [Lakeba]) - Solem 1978.

#### *Beckianum beckianum*

Hawaiian Islands (Kaua‘i) - Cowie 1997 (identification tentative, now confirmed), (O‘ahu) - Cowie et al. 1999).

#### *Lamellaxis micra*

Hawaiian Islands (Kaua‘i) - Cowie 1997 (identification uncertain); Galapagos Islands (Santa Cruz) - R.H. Cowie, personal observations 1999; American Samoa (Ofu) - Cowie and Cook 1999; New Caledonia - Gargominy et al. 1996, (Isle of Pines) (Solem 1964).

#### *Lamellaxis* sp(p).

Galapagos Islands (Santa Cruz, Floreana, Española) - Smith 1966; Federated States of Micronesia (Kosrae) - Smith 1992b, (Pohnpei) - Smith 1993b; Northern Mariana Islands (Saipan) - Lange 1950.

#### *Opeas blanchardianum*

New Caledonia - Pilsbry 1906–1907.

#### *Opeas hannense* (frequently used synonyms: *Opeas pumilum* and *Opeas goodallii*)

Hawaiian Islands (Ni‘ihau, Kaua‘i, O‘ahu, Hawai‘i) - Cowie 1997; Pitcairn Islands (Pitcairn) - Preece 1995; Samoa (Upolu) - Cowie 1998c; American Samoa (Tutuila [unconfirmed], Ofu) - Cowie 1998c; Cowie and Cook 1999; Fiji (Lau Group [Karoni]) - Solem 1978; Vanuatu (Efate, Espiritu Santo) - Solem 1959; Solomon Islands (Tikopia) - Christensen and Kirch 1981; Federated States of Micronesia (Kosrae) - Smith 1992b, (Pohnpei) - Smith 1993b; Guam - Smith 1993a.

#### *Opeas heptagyrum*

Nauru - Pilsbry 1906–1907.

### *Opeas kusaiense*

Federated States of Micronesia (Kosrae) - Pilsbry 1906–1907.

### *Opeas mauritianum*

Hawaiian Islands (O‘ahu, Maui, Hawai‘i) - Cowie 1997.

### *Opeas opella*

Hawaiian Islands (Kaua‘i, O‘ahu, Moloka‘i, Maui, Hawai‘i) - Cowie 1997.

### *Opeas pronyense*

New Caledonia - Pilsbry 1906–1907.

### *Opeas pruinosum*

Federated States of Micronesia (Pohnpei) - Pilsbry 1906–1907; Smith 1993b, (Kosrae) - Smith 1992b.

### *Prosopeas carolinum*

Federated States of Micronesia (Truk) - Pilsbry 1906–1907.

### *Pseudopeas tuckeri*

New Caledonia - Gargominy et al. 1996; Solem 1964 (only tentatively identified).

Almost certainly with further taxonomic study some of these species will be found to be synonyms of more commonly known and widely distributed species. Probably, if searched for, these common and widespread species would be found on almost all islands in the region. All of them contribute to the overall subulinid biomass and as such constitute a conservation problem. How they interact with each other is not known.

## FAMILY HELICIDAE

### *Helix aspersa* Müller, 1774 — the brown snail, the garden snail, l'escargot petit gris

This common western European species (Kerney et al. 1979) has been introduced to many parts of the world as the "escargot petit gris". It grows and reproduces in culture much more quickly and readily than *Helix pomatia*, the "escargot de Bourgogne", which is the species more traditionally available in restaurants. Frequently it has been introduced deliberately for culture (e.g. New Caledonia; Gargominy et al. 1996). *H. aspersa* has for a long time been a serious pest in many parts of the world (e.g. in citrus in California; Gammon 1943). It is a species of western Europe and the Mediterranean region. It is not a tropical species, nor a species of extremely wet habitats. It is therefore unlikely to ever become extremely widespread in the tropical rainforest habitats of many Pacific islands. Gargominy et al. (1996) imply that in New Caledonia it tends to be confined to disturbed habitats including secondary forest. However, it can thrive in the drier and perhaps cooler parts of the islands; for instance, in the Hawaiian Islands it is abundant in a number of relatively dry, mid-elevation localities (Cowie 1996c). There it has become a significant garden pest. It is possible that it could become an environmental problem in drier native habitats through vegetation modification and competition with native species. Some of these dry forest ecosystems (e.g. in the Hawaiian Islands) are currently seriously threatened.

Under suitable conditions *Helix aspersa* can achieve very high population densities. The fact that there is in many parts of the world a consistent interest in developing snail culture for profit suggests that this species is one of the more likely species to be introduced deliberately.

#### Hawaiian Islands

Kaua‘i - 1965, 1976 (Anon. 1965; Nakahara 1979; perhaps not established); O‘ahu - 1952 (Kondo 1956; Cowie 1996c, 1997); Maui - 1981 (Tamura et al. 1981); Hawai‘i - 1976 (Tamura et al. 1981).

#### French Polynesia

Society Islands: Tahiti - Solem (1964).

#### Pitcairn Islands

Barker (1999).

#### Easter Island

Barker (1999).

#### New Caledonia

1879 (Gargominy et al. 1996).

## FAMILY HELICARIONIDAE

### *Ovachlamys fulgens* (Gude, 1900)

This species has so far only been tentatively identified. However, it seems widely, although patchily, established in the National Park of American Samoa on Tutuila (Cowie and Cook 1999) and possibly occurs in the Hawaiian Islands (Cowie, unpublished observations). Described from the Ryukyu Islands of Japan, it has been transported around the world, frequently via the orchid trade, from Japan, through Thailand, and to Costa Rica, where it is now a horticultural pest (D. Robinson, personal communication). It is increasingly regularly intercepted entering the USA, mostly from Costa Rica, on a wide variety of plants. It seems likely that it will expand its distribution readily, so other islands of the Pacific are at risk. Although its impacts or likely impacts are unknown, observations on Tutuila suggest that it could become a dominant species of native forests.

Hawaiian Islands

O'ahu - 1999 (Cowie, unpublished observations; tentatively identified), Hawai'i - 1999 (Cowie, unpublished observations; tentatively identified).

American Samoa

Tutuila - 1998 (Cowie and Cook 1999).

## FAMILY VERONICELLIDAE

The veronicellid slugs are large slugs that in many cases are difficult to identify, even for experts. They appear to be fairly generalist in their feeding habits and may have significant agricultural and garden impacts. Because of their large size and because they can achieve high population densities, they may well have significant environmental impacts, both in modifying plant communities and in out-competing native snail species, although neither of these possible impacts has apparently been explicitly demonstrated. The fact that they have become so widely distributed suggests that they are readily transported, no doubt accidentally, in association with human activities.

### *Laevicaulis alte* (Férussac, 1822)

This alien slug, thought to be of African origin, is now widely distributed through Asia and the islands of the Pacific (Hoffman 1925; Cowie 1997; 1998c). It has frequently been referred to as *Vaginula leydigi*, a junior synonym.

Hawaiian Islands

1900 (Cowie 1997).

Midway - 1983 (Cowie 1997), O'ahu - about 1900 (Williams 1931), Moloka'i - (Wallace and Rosen 1969); Hawai'i - (Cowie 1997).

Samoa

Upolu - 1964 (Cowie 1998c; tentatively identified).

American Samoa

Tutuila - 1998 (Cowie and Cook 1999; tentatively identified).

New Caledonia

1911 or earlier (Gargominy et al. 1996).

New Caledonia (Grand Terre), Maré - pre-1924 (Grimpe and Hoffman 1925); Lifou - pre-1900 (Grimpe and Hoffman 1925); Ouvéa - pre-1924 (Grimpe and Hoffman 1925).

Vanuatu

Efate - pre-1900 (Grimpe and Hoffman 1925; Forcart 1969; Solem 1959).

### *Vaginulus plebeius* Fischer, 1868

This neotropical alien slug is also widely distributed on Pacific islands, and in some places (e.g. the Hawaiian Islands) may be replacing *Laevicaulis alte* (above) (Cowie 1997). It is often reported in the literature (e.g. Cowie 1997) as "*Vaginula plebeia*" but this appears to be incorrect (Cowie 1998c).

Hawaiian Islands

1978 (Cowie 1997).

French Polynesia

Society Islands: Tahiti - 1901 (Cockerell 1901; Grimpe and Hoffman 1925).

Samoa

Upolu - 1918 (Grimpe and Hoffman 1925); Savai'i - (Cowie 1998c; identification uncertain).

American Samoa

Tutuila - 1998 (Cowie and Cook 1999).

Fiji

Pre-1900 (Grimpe and Hoffman 1925).

Viti Levu, Luvuka, "Viti Cara" - pre-1900 (Grimpe and Hoffman 1925).

New Caledonia

1863 (Hoffman 1925; Gargominy et al. 1996).

New Caledonia (Grand Terre) - pre-1868 (Grimpe and Hoffman 1925); Art - pre-1871 (Grimpe and Hoffman 1925); Maré, Lifou, Ouvéa - pre-1924 (Grimpe and Hoffman 1925; "ganz Neu-Caledonien").

Vanuatu

Efate - pre-1900 (Grimpe and Hoffman 1925; Forcart 1969; Solem 1959); Malo - pre-1924 (Grimpe and Hoffman 1925; Forcart 1969; Solem 1959); Espiritu Santo - (Solem 1959).

Other introduced veronicellids

Other introduced veronicellids (perhaps misidentifications of the above two species) recorded in the Pacific are:

### *Veronicella cubensis*

Hawai'i (O'ahu) - Cowie 1997.

### Unidentified veronicellid

Solomon Islands (Guadalcanal) - Peake 1968.

Federated States of Micronesia (Yap [Ulithi]) - Harry 1966.

## 5.2 Freshwater species

### FAMILY AMPULLARIIDAE

Ampullariidae are freshwater snails predominantly distributed in humid tropical and sub-tropical habitats in Africa, South and Central America and South-East Asia. They include the largest of all freshwater snails (*Pomacea maculata* can exceed 15 cm) and frequently constitute a major portion of the native freshwater mollusc faunas of these regions. Among the seven to ten genera usually recognised, the two largest are *Pomacea*, with about 50 species, and *Pila*, with about 30. Snails in these two genera in particular are frequently known as 'apple snails', because many species bear large, round, often greenish shells. They have also become known as 'mystery snails', 'miracle snails', 'golden snails', among other common names ('kuhol' in the Philippines, 'bisocol' in the Filipino community in Hawaii). The comprehensive review of Cowie (in press) focuses on the increasing impact of ampullariids as agricultural pests, but also discusses their potential environmental impacts. Some species have been used to control aquatic plant pests such as water lettuce (Perera and Walls 1996). Many species appear to be extremely voracious and generalist in their food preferences and concern has been expressed (Simberloff and Stiling 1996) that they could seriously modify native ecosystems.

The genus *Pomacea* is centred in south and central America, extending into the Caribbean and the south-east of the USA. One or perhaps more species have been taken from their native South America to South-East Asia to be cultured for food (Mochida 1991). The market for the snails never developed. The snails were released or escaped into the wild, becoming major pests in rice paddies (Cowie in press; Naylor 1996). Other species have been developed as aquarium snails (Perera and Walls 1996) and have been moved around the world via the aquarium trade.

### *Pomacea canaliculata* (Lamarck, 1804) — golden apple snail

This South American species seems to be the major pest (although there remains considerable taxonomic confusion regarding its true identity and whether there is more than one pest species; Cowie in press). It was originally introduced from South America to South-East Asia around 1980, as a local food resource and as a potential gourmet export item. The markets never developed; the snails escaped or were released, and became a serious pest of rice throughout many countries of South-East Asia (Cowie in press; Naylor 1996). They were introduced to the Hawaiian Islands in 1989, probably from the Philippines, and for the same reasons as for their initial introduction to South-East Asia. Again, they rapidly escaped or were released and quickly became a major pest of taro (Cowie 1995a, 1997). *PP. canaliculata* reproduces extremely rapidly and appears to be a voracious and generalist feeder (Cowie in press), although experimental results suggest that it does nevertheless have some strong food preferences, particularly in not feeding on a major aquatic plant pest, water hyacinth (*Eichhornia crassipes*) (Lach et al., submitted). In the Hawaiian Islands it is spreading rapidly from taro-growing areas into native wetlands and other native freshwater systems, where it is perceived as potentially having a serious impact (Lach and Cowie 1999). These potential impacts could involve destruction of native aquatic vegetation leading to serious habitat modification, as well as competitive and even predatory interactions with the native aquatic fauna, including native snails (Cowie in press; Simberloff and Stiling 1996). Already, introduced *Pomacea* have been implicated in the decline of native species of *Pila* in South-East Asia (Halwart 1994). Also, native species of *Pila* in the Philippines are reported to have declined as a result of extensive pesticide applications against introduced *Pomacea* (Anderson 1993).

At present, *PP. canaliculata* is not widespread in the region (only the Hawaiian Islands, Guam, and Papua New Guinea). It has also probably been introduced to Belau (Palau) but was eradicated (Cowie in press). However, the lesson from South-East Asia is that people in some countries (e.g. Cambodia) have ignored the negative experiences of other countries (e.g. Vietnam, Philippines) and have persisted in trying to establish aquaculture operations, despite advice to the contrary (Cowie 1995b). They have then come to regret this course as the snails inevitably escaped or were released when the aquaculture operations did not become profitable and are now serious pests. Therefore, despite the negative experience in the Hawaiian Islands particularly, people from other islands may yet be tempted to introduce this species. *Pomacea canaliculata* should be considered a potentially serious threat and every effort should be made to prevent its further spread into the Pacific region.

#### Hawaiian Islands

Kaua'i - 1991; O'ahu - 1990; Maui - 1989; Lāna'i - 1995; Hawai'i - 1992 (Cowie 1995a, 1996c, 1997).

#### Papua New Guinea

1990 (Laup 1991; Anon. 1993; incorrectly identified as *Pomacea lineata*).

#### Guam

1989 (Eldredge 1994b; Smith 1992a).

### Other introduced ampullariids

Other introduced ampullariids recorded in the Pacific are:

#### *Pomacea bridgesii*

Hawaiian Islands (Kaua‘i, O‘ahu, Hawai‘i) - Cowie 1995a, 1997, in press.

#### *Pomacea paludosa*

Hawaiian Islands (Maui) - Cowie 1995a, 1997, in press.

#### *Pila conica*

Hawaiian Islands (O‘ahu, Moloka‘i, Maui) - Cowie 1995a, 1997, in press; Belau (Palau) (eradicated) - Eldredge 1994b; Guam - Smith 1992a.

None of these species seems to pose as serious a threat as does *Pomacea canaliculata*. However, all four are difficult to distinguish from each other, even by experts, and there are a number of other potentially voracious ampullariid species so far not recorded in the Pacific (e.g. *Marisa cornuarietis*). Therefore the best approach would be to guard against the introduction of all species of Ampullariidae.

### FAMILY LYMNAEIDAE

#### *Fossaria viridis* (Quoy and Gaimard, 1832)

This species is probably of eastern Asian origin. In the Hawaiian Islands, at least, it has frequently been identified as *Fossaria ollula* (or *Lymnaea ollula*), which may be a junior synonym, and it has frequently been placed in the genus *Galba*. It is extremely common and widespread in the Hawaiian Islands, and because it is a major host of cattle liver flukes, it has attracted intensive efforts at biological control using predators and parasites.

Its high population densities suggest the possibility of competition with native species, although at least in the Hawaiian Islands it seems to be found predominantly in disturbed agricultural settings (e.g. taro fields). However, the introduction of numerous generalist snail predators/parasites in attempts to control it may well have had an impact on other native snail species. Little attention has been paid to this issue, so there is no hard evidence of such an impact.

Hawaiian Islands

Late 19th century (Morrison 1969).

Ni‘ihau, Kaua‘i, O‘ahu, Moloka‘i, Maui, Hawai‘i - (Cowie 1997).

Papua New Guinea

Pre-1978 (Eldredge 1994b).

Guam

1826–1829 (Cowie 1997; originally described from Guam).

Northern Mariana Islands

Saipan - (Lange 1950).

### FAMILY CORBICULIDAE

#### *Corbicula fluminea* (Müller, 1774)

This Asian freshwater clam is so far only known in the Pacific from the Hawaiian Islands. It was probably imported deliberately and illegally direct from Asia (Burch 1978; Eldredge 1994b). It is now widespread in the Hawaiian Islands, not only in artificial water courses (e.g. clogging irrigation pipes) but also in many rivers and streams (Burch 1995; Eldredge 1994b).

*C. fluminea* is extremely widespread in North America, where it was first recorded in 1938 (Morton 1982). It has become a serious pest, fouling canals, pipelines, reservoirs, rivers, and power station condensers, but is also successfully outcompeting native unionid clams (Morton 1982). The clams cause increased sedimentation in water courses, and in California, certain fish have declined because of competition for bottom-living food (Eldredge 1994b). Its potential impact on Pacific island freshwater ecosystems is great, and as Eldredge (1994b) said, “all possible means to avoid introduction should be pursued”.

Morton (1982) outlined the taxonomic confusion surrounding this freshwater species, the related brackish-water species *Corbicula fluminalis*, and the junior synonym *C. manilensis*. Pacific island nations should be vigilant for any Asian clams.

Hawaiian Islands

Kaua‘i - 1982, O‘ahu - 1988, Maui - 1988 (Eldredge 1994).

## 6. Other species

Numerous other species of non-marine molluscs have been introduced to the Pacific region. Because the impacts or potential impacts of most of them are unknown, making a clear judgement of which species to include in the body of this report (above) was difficult. Many records of other species have also been gathered and are available in Annex 1.

## 7. Main reasons for introducing molluscs

Alien snails and slugs have been and continue to be introduced to Pacific islands both deliberately and inadvertently. Those that have been introduced deliberately include species introduced for food (e.g. *Helix aspersa*, *Pomacea canaliculata*). Other species are introduced deliberately but are not intended to reach natural habitats (e.g. aquarium species such as *Pomacea bridgesii* and the planorbids), although they inevitably do so. Others may be deliberately introduced (e.g. for food) in some places but inadvertently introduced elsewhere (e.g. *Achatina fulica*). The ill-conceived biological control efforts against *Achatina fulica* have involved the deliberate introduction of many predatory snail species. These various deliberate introductions have been legal in some cases but unofficial and sometimes illegal in others.

However, the majority of species, especially small species, probably have been and continue to be introduced accidentally. Some of the freshwater species were probably introduced inadvertently by the aquarium trade, attached to aquatic plants as either snails (especially juveniles) or eggs. Land snails and slugs have probably been introduced accidentally along with agricultural products, including food, such as among bananas or in packing material around produce or other foodstuffs. They have probably also been transported accidentally in household goods, on vehicles, in soil on shoes, flowerpots, etc. Evidence is increasing (e.g. Cowie 1998d, 1999) that the horticultural trade is inadvertently involved in the introduction and spread of a large number of species (e.g. *Polygyra cereolus*, *Liardetia doliolum*, *Ovachlamys fulgens*), either attached to vegetation or perhaps in soil or moss. Again, juveniles or eggs may be the most likely life stage to be transported accidentally.

## 8. Islands that are poorly documented

None of the islands of the Pacific is adequately known malacologically. Some are known better than others. But for very few has the alien non-marine mollusc fauna been more than cursorily documented. Therefore, it is very difficult to make specific statements about distributions or about impacts or potential impacts on particular islands.

Museum collections are an enormous source of information but much work will be required to extract that information. For instance, the Bishop Museum houses extensive collections from most of the archipelagos of Polynesia and Micronesia (less from Melanesia), but only a small proportion of the records these collections represent have been published. Significant survey work has been undertaken in the Solomon Islands (Peake 1968) with the material deposited in the Natural History Museum (London), but no species lists have been published.

Notable among those major islands or island groups for which relatively little information is readily available are Belau (Palau), Fiji (at least for land snails), Tonga, and the Solomon Islands. For most archipelagos there are records only from a small number of islands; this is especially the case with the archipelagos composed mostly of atolls (although as indicated above, all atolls will probably have rather similar faunas composed mostly of widespread and non-indigenous species).

## 9. Relationships with other factors impacting on native mollusc faunas

Many factors other than alien snails and slugs have impacts on the native non-marine mollusc faunas of Pacific islands. Most notable among these are: 1) predation by introduced predators; and 2) habitat destruction or modification.

Predation by rats has been shown to have a serious impact on populations of Hawaiian tree snails (Achatinellinae) (Hadfield et al. 1993), and probably has similar impacts elsewhere, especially on slow-reproducing groups such as partulids. Three species are involved; the Polynesian rat (*Rattus exulans*), introduced around the Pacific by early Pacific islanders, and the brown or Norway rat (*Rattus norvegicus*) and the black or roof or ship rat (*R. rattus*), introduced by Europeans. Probably the latter two have had more impact than *R. exulans*. Most human activities that favour rats also favour the usual suite of synanthropic alien snails and slugs.

Other predators (e.g. the flatworm *Platydemus manokwari*, mentioned above) could have devastating effects on native snail species (Hopper and Smith 1992). *PP. manokwari* has been introduced (usually unofficially) as a putative biological control agent against the giant African snail, *Achatina fulica*.

Habitat destruction (e.g. deforestation, urban expansion) clearly has a drastic impact on populations of native snails by removing available habitat. However, habitat modification involving replacement of native flora with alien flora may have as significant an effect because many native snail species seem restricted to native plants and cannot survive in association with alien plants. Additionally, replacement of the native flora with non-native plants may have subtle effects on microhabitat and microclimate that render the habitat no longer suitable for native snail species. Most of the alien snail and slug species seem to be rather generalist in their habitat and food requirements (often these are features of successful introduced species) and will thrive in the modified habitat.

Feral pigs have major impacts on native ecosystems to the extent that their eradication has become a primary goal of many conservation programmes (e.g. Stone and Loope 1996). Their destructive activities cause major habitat change that undoubtedly has impacts on native snail faunas. Possibly, alien snails are more able to survive in pig-ravaged areas. Other feral ungulates (e.g. sheep, goats) are abundant on some islands and have caused major habitat changes. Alien slugs have been suggested as attracting feral pigs, which then damage previously intact fragile ecosystems (Stone and Pratt 1994).

Almost all human activities, be it the introduction of additional non-native species or destruction or modification of native habitat, have some impact on native biotas. Frequently associated with most human activities is a high risk of inadvertent introduction of non-native snails and slugs. For instance, road construction will open up a corridor along which alien species, including snails, are transported or can more readily disperse into native habitat (e.g. Andrews 1990; Bennett 1991). Development of any kind is likely to increase the chance of introduction. Increasingly, the horticultural trade is a major culprit in these inadvertent introductions in the Pacific (Cowie 1998d, 1999).

## 10. Islands with high conservation value and high risk

Because of the lack of extensive and detailed knowledge, it is somewhat dangerous to select particular islands or island groups as of particular value or at particular risk. Nonetheless, there is a need to select because of the fact that with limited resources, conservation efforts have to be focused. A number of criteria can be used to make these selections. These might include the following.

- Does the island have a high proportion of endemic taxa?
- Are these endemic taxa of special interest?
- Does the island support a large number of native/endemic species?
- Is the island well-known faunistically?
- Has the island already been degraded by habitat destruction/modification?
- Does the island already harbour significant alien species?
- Is a high proportion of the endemic fauna already extinct?
- Are conservation efforts practical?

Bearing these criteria in mind, it is possible to make some tentative assessments regarding the focus of non-marine mollusc conservation in the Pacific region, as follows.

As a starting point, the atolls are in general of low conservation value because they harbour few endemic species; most of their non-marine mollusc fauna is alien, or at least widespread naturally, and is generally tolerant of human activities.

Islands where most of the fauna is already extinct (e.g. the Hawaiian Islands; Solem 1990) are less likely to respond readily to conservation efforts. The fauna has dwindled because of the very serious and widespread effects of habitat destruction and introduced predators. However, certain parts of such islands may yet remain in a relatively pristine condition and harbour an unimpacted native fauna.

Islands where certain taxa have been studied intensively (e.g. *Partula* spp. on Moorea; Johnson et al. 1993) might arguably be considered of greater conservation value because the knowledge gained through study allows conservation efforts to be tailored to the better understood needs of these well-known species.

In a similar vein, an island whose fauna is relatively well-known, because there has been extensive survey work, would be a higher conservation priority than an island that is relatively unknown. However, it could also be argued that the unknown islands deserve to be focused upon in terms of basic survey work (i) to find out what is there before it is too late, and (ii) in order that a better judgement can be made when selecting islands for conservation management.

However, well-known islands (at least some of them) may be better known (and better publicised; e.g. Gould 1991) exactly because they have been seriously impacted by, for instance, predators like *Euglandina rosea*. Arguably, conservation efforts should not be focused on these islands, because there is less remaining to be conserved.

Small islands may have proportionately less undisturbed habitat remaining. Compare Rapa with New Caledonia. Rapa, despite having had extremely high species richness (approx. 100) in a very small area (40 $km^2$), and an almost 100% level of endemism, has been largely destroyed by goats and very few of these species probably now remain. New Caledonia, with perhaps 400 species, but almost 500 times the area of Rapa, has large parts that are virtually pristine and probably harbour a more or less intact native fauna. Arguably, disproportionate conservation effort should be directed at islands/archipelagos such as New Caledonia rather than Rapa, despite the fact that the fauna of Rapa was once so unique and diverse.

Islands that already harbour alien predators such as *Euglandina rosea* should arguably receive lower priority than those that do not.

Thus, there are numerous considerations when attempting to prioritise conservation effort among the islands of the Pacific, but the lack of much basic knowledge makes the task almost impossible. The following list of islands/archipelagos that probably deserve to be focused upon (at least from a land snail perspective) is thus extremely ad hoc and should not be taken as a rigorous evaluation of all the islands across the Pacific.

### French Polynesia [Society Islands]

Highest diversity of partulid tree snails. Biology of partulid tree snails well understood. *Achatina fulica* and *Euglandina rosea* present, and causing extinction of unique snails. If this unique, relatively well known, and widely publicised fauna of tree snails is to survive, the captive breeding program already in place at a number of institutions around the world must continue to be supported and increased effort must be made to develop intensively managed reserves following the prototype already established on Moorea.

### American Samoa [Ofu, Olosega]

*Achatina fulica* and *Euglandina rosea* not present, but there is a high risk of them being introduced. Significant populations of partulid tree snails still living on Ofu. Every effort must be made to prevent the introduction of *A. fulica* and *E. rosea* to these two islands, which will require publicity campaigns and vigorous public education. The possibility of extending the boundaries of the Ofu unit of the National Park of American Samoa (US Department of the Interior) to include areas supporting partulids should be seriously investigated.

### American Samoa [Tutuila]

The Tutuila unit of the National Park of American Samoa is established in good quality native forest and has already been surveyed intensively for land snails. Significant numbers of native species (including partulid tree snails) appear to be surviving despite the presence of *Euglandina rosea*. The Park is managed by a tiny staff, who nevertheless are making significant progress in maintaining and enhancing the Park's natural resources (e.g. implementing a major pig control program). The thorough survey of land snails (native and alien) undertaken in 1998 (Cowie and Cook 1999) provides a rigorous baseline from which to monitor the trajectories of both the native and alien snail and slug species. The Park must guard against development and the encroachment of agriculture in the Park, both of which as well as having a direct physical impact will enhance the chances of alien snail introduction and spread.

### Tonga

Poorly known. Needs survey work. Almost no literature is available on the non-marine snails of Tonga, other than the sparse nineteenth century literature describing species then new to science. Surveys should be undertaken to obtain baseline diversity and distribution data from which to make an assessment of the conservation status of the native fauna and the impacts of alien species.

### Fiji

Rather poorly known. Needs survey work. The Lau group may be relatively unspoiled but is very poorly known. The freshwater fauna of some islands is relatively well known, but as for Tonga there is very little information available on the terrestrial fauna other than the basic nineteenth century taxonomic literature. Surveys need to be undertaken to obtain baseline diversity and distribution data, especially on the less modified islands, in order that the conservation status of the fauna can be assessed.

### New Caledonia [Grand Terre]

Much native forest, into which *Euglandina rosea* has not penetrated. High land snail diversity and endemism. Probably only about a quarter of the land snail species have been described, but survey work has been done and it is clear that a significant proportion of the fauna is surviving in areas of relatively undisturbed forest (Tillier 1992). It may be possible to identify areas of high diversity and/or endemism and to focus conservation efforts, including exclusion of alien species, on these areas. This may be possible on the basis of distributional data already available (or at least based on museum collection data), but additional survey work in likely areas of high diversity/endemism is probably also necessary.

### Papua New Guinea

Probably retains the greatest proportion of undisturbed forest. Immense land snail diversity and endemism. Papua New Guinea is extremely poorly known malacologically, yet probably harbours the most intact and diverse native fauna in the region, especially in inland montane regions where alien species have probably barely penetrated, if at all. However, because of its enormous size, compared to other islands in the region, a more selective conservation approach is necessary. The *Papua New Guinea Conservation Needs Assessment* (PNG-CNA: Alcorn 1993; Beehler 1993) provided a rigorous evaluation of knowledge of the biota and suggested such a selective approach to its conservation. The PNG-CNA offers a baseline platform on which to build a serious comprehensive conservation effort. However, the section in the PNG-CNA treating the non-marine molluscs (Cowie 1993) highlighted the serious lack of knowledge of this group of animals, but nevertheless also suggested a strategy for identifying areas on which to focus conservation efforts. Initially, distributional data must be extracted from the meagre literature and from museum collections in order to develop basic maps of species distributions. Using this baseline of information, selected areas should be assessed, following the general approach of Andrews and Little (1982), in order to identify the major biotic and abiotic determinants of molluscan diversity. With this background, localities coming within the limits of the parameters circumscribing high native molluscan diversity and least impacted by alien species could be identified for conservation.

**Solomon Islands**

Survey work has been done, but the data are not readily available. Significant native forest remains on some islands. As for New Caledonia, it may be possible to identify areas of relatively undisturbed forest that harbour high diversity and have high levels of endemism and are not yet seriously impacted by alien species. Synthesis of museum collection data should be a first step, but survey work on the less well known but relatively undisturbed islands is probably warranted.

## 11. Eradication or prevention

Once alien species have become established and a problem perceived, it is usually too late to have any chance of eradicating them. It may be possible to eradicate *Euglandina rosea* from small areas, which can then be intensively managed (Clarke and Pearce-Kelly 1997; Hadfield 1998), but this is not a large-scale solution. Baiting techniques used against *Euglandina rosea* and other predatory snails (Hadfield and Hopper 1994) may have non-target impacts, and may not be practical over large areas (M.G. Hadfield pers. comm.). Other species that have become abundant and widespread (e.g. *Subulina octona*) may be impossible to eradicate.

There is a small chance of successful eradication if this is undertaken immediately a new introduction is detected (e.g. *Achatina fulica* in Kosrae; Anon. 1998a). But even then, success may be unlikely and despite major eradication efforts the snails will continue to spread (e.g. *Achatina fulica* in (Western) Samoa; Anon. 1998b).

Since eradication is so difficult, it is crucial that further spread of these snails be minimised. Quarantine regulations need to be put in place (if they are not in place already) and applied strictly. Such measures are far more cost-effective than attempting to address the problems once the snails have invaded and become pests. But probably most important is the raising of awareness of the threat of alien species. Publicity must be directed at the general public. It is only with public co-operation and a real public understanding of the potential problems that alien species can cause that we hope to have any success in long-term conservation of the unique faunas of the Pacific islands.

## 12. Acknowledgements

Lu Eldredge, Rebecca Rundell, and Greg Sherley commented on a draft and offered useful suggestions. I thank Beatrice and Tom Burch, and Skippy Hau for information on *Corbicula fluminea*. Production of this report rested heavily on earlier work on the alien molluscs of the Hawaiian and Samoan (American and "Western") Islands, and I thank all those who helped in those endeavours.

## 13. References

Alcorn, J.B. (Ed.) 1993. *Papua New Guinea Conservation Needs Assessment. Volume 1.* The Biodiversity Support Program, Washington, DC. xxv + [i] + 216 pp.

Allen, M.S. 1992. Dynamic landscapes and human subsistence: archaeological investigations on Aitutaki Island, southern Cook Islands. PhD dissertation, University of Washington.

Anderson, B. 1993. The Philippine snail disaster. *Ecologist* 23: 70–72.

Andrews, A. 1990. Fragmentation of habitat by roads and utility corridors: a review. *Australian Zoologist* 26: 130–141.

Andrews, E.B.; Little, C. 1982. Renal structure and function in relation to habitat in some cylophorid land snails from Papua New Guinea. *Journal of Molluscan Studies* 48(2): 124–143.

Anon. 1963. *Achatina fulica* control experiments in the southern Marianas. Pacfic Science Association Information Bulletin PS/53/3&4: 9–10.

Anon. 1965. Destructive new snail found, search goes on. *The Garden Island* June 12 (section I): 8.

Anon. 1989. IUCN commission blasts *Euglandina* introductions. *Hawaiian Shell News* 37(4): 11.

Anon. 1993. Golden apple snail present in Papua New Guinea. *FAO Plant Protection Bulletin* 41(3): 35–36.

Anon. 1996a. Introduction of giant African snail to various Pacific islands. *AgAlert* 15: 1–2.

Anon. 1996b. Spread of the giant African snail of great concern to the Pacific. *Agricultural News. Newsletter of the South Pacific Commission Agriculture Programme* 5(1): 3.

Anon. 1998a. Giant African snail outbreak in Kosrae. *South Pacific Commission Agricultural News* 7(1): 12.

Anon. 1998b. Giant African snail in Samoa. *FAO Subregional Office for the Pacific Islands (SAPA) Newsletter* 1–3/98: 3–4.

Anon. 1999. Fiji fears invasion of giant snails. *Honolulu Advertiser* 17 May 1999: A2.

Baker, F.C. 1945. *The molluscan family Planorbidae*. University of Illinois Press, Urbana. xxxvi + 530 pp.

Barker, G.M. 1999. *Fauna of New Zealand. 38. Naturalised terrestrial Stylommatophora (Mollusca: Gastropoda).* Manaaki Whenua Press, Lincoln, New Zealand. 253 pp.

Bauman, S. 1996. Diversity and decline of land snails on Rota, Mariana Islands. *American Malacological Bulletin* 12: 13–27.

Beehler, B.M. (ed.) 1993. *Papua New Guinea Conservation Needs Assessment. Volume 2.* The Biodiversity Support Program, Washington, DC. v + 434 pp.

Bennett, A.F. 1991. Roads, roadsides and wildlife conservation: a review. In: *Nature Conservation: the role of corridors* (Eds. Saunders, D.A.; Hobbs, R.J.), pp. 99–118. Surrey Beatty and Sons, Melbourne.

Burch, B.L. 1978. Asian clam, *Corbicula*, threatens Hawaii. *Nautilus* 92(1): 54–55.

Burch, T.A. 1995. *Corbicula fluminea* Müller (Mollusca: Bivalvia) established on Oahu. *Bishop Museum Occasional Papers* 42: 58.

Carlton, J.T. 1996. Biological invasions and cryptogenic species. *Ecology* 77(6): 1653-1655.

Christensen, C.C. 1984. Are *Euglandina* and *Gonaxis* effective agents for biological control of the giant African snail in Hawaii?. *American Malacological Bulletin* 2: 98–99.

Christensen, C.C.; Kirch, P.V. 1981. Nonmarine mollusks from archaeological sites on Tikopia, southeastern Solomon Islands. *Pacific Science* 35(1): 75–88.

Christensen, C.C.; Kirch, P.V. 1986. Nonmarine mollusks and ecological change at Barbers Point, O‘ahu, Hawai‘i. *Bishop Museum Occasional Papers* 26: 52–80.

Civeyrel, L.; Simberloff, D. 1996. A tale of two snails: Is the cure worse than the disease? *Biodiversity and Conservation* 5: 1231–1252.

Clague, D.A. 1996. The growth and subsidence of the Hawaiian-Emperor volcanic chain. Pp. 35–50 *in*: Keast, A.; Miller, Scott E. (eds) *The origin and evolution of Pacific island biotas, New Guinea to eastern Polynesia: patterns and processes*. SPB Academic Publishing, Amsterdam.

Clarke, B.; Murray, J.; Johnson, M.S. 1984. The extinction of endemic species by a program of biological control. *Pacific Science* 38(2): 97–104.

Clarke, D.; Pearce-Kelly, PP. 1997. *Partula* update. *Tentacle. Newsletter of the IUCN Species Survival Commission Mollusc Specialist Group* 7: 20–21.

Clench, W.J.; Turner, R.D. 1962. Monographs of the genera *Papustyla*, *Forcartia* and *Meliobba* (Papuininae: Camaenidae). *Journal of the Malacological Society of Australia* 6: 3–33.

Cockerell, T.D.A. 1901. On a slug of the genus *Veronicella* from Tahiti. *Proceedings of the United States National Museum* 23(1238): 835–836.

Cooke, C.M., Jr. 1928. Notes on Pacific land snails. *Proceedings of the Third Pan-Pacific Science Congress* 2: 2276–2284.

Cooke, C.M., Jr. 1934. Land shells of Makatea. *Bernice PP. Bishop Museum Occasional Papers* 10(11): 1–11.

Cooke, C.M.; Kondo, Y. 1960. Revision of Tornatellinidae and Achatinellidae (Gastropoda, Pulmonata). *Bernice PP. Bishop Museum Bulletin* 221: 1–303.

Cowie, R.H. 1992. Evolution and extinction of Partulidae, endemic Pacific island land snails. *Philosophical Transactions of the Royal Society of London* B 335: 167–191.

Cowie, R.H. 1993. Non-marine Mollusca of Papua New Guinea. Pp. 311–320 *in*: Beehler, B.M. (ed.) *Papua New Guinea Conservation Needs Assessment. Volume 2*. Biodiversity Support Program, Washington, DC.

Cowie, R.H. 1995a. Identity, distribution and impacts of introduced Ampullariidae and Viviparidae in the Hawaiian Islands. *Journal of Medical and Applied Malacology* 5[for 1993]: 61–67.

Cowie, R.H. 1995b. Report on a visit to Cambodia to advise on apple snails as potential rice pests. *Bishop Museum Report to Cambodia–IRRI–Australia Project, Phnom Penh*. 8 + [2] pp.

Cowie, R.H. 1996a. Pacific island land snails: relationships, origins, and determinants of diversity. Pp. 347–372 *in*: Keast, A.; Miller, Scott E. (eds) *The origin and evolution of Pacific island biotas, New Guinea to eastern Polynesia: patterns and processes*. SPB Academic Publishing, Amsterdam.

Cowie, R.H. 1996b. Variation in species diversity and shell shape in Hawaiian land snails: in situ speciation and ecological relationships. *Evolution* 49(6)[1995]: 1191–1202.

Cowie, R.H. 1996c. New records of introduced land and freshwater snails in the Hawaiian Islands. *Bishop Museum Occasional Papers* 46: 25–27.

Cowie, R.H. 1997. Catalog and bibliography of the nonindigenous nonmarine snails and slugs of the Hawaiian Islands. *Bishop Museum Occasional Papers* 50: 1–66.

Cowie, R.H. 1998a. Patterns of introduction of non-indigenous non-marine snails and slugs in the Hawaiian Islands. *Biodiversity and Conservation* 7(3): 349–368.

Cowie, R.H. 1998b. Homogenization of Pacific island snails. *World Conservation; quarterly bulletin of IUCN-The World Conservation Union* 4/97–1/98: 18.

Cowie, R.H. 1998c. Catalog of the nonmarine snails and slugs of the Samoan Islands. *Bishop Museum Bulletin in Zoology 3*. Bishop Museum Press, Honolulu. viii + 122 pp.

Cowie, R.H. 1998d. New records of nonindigenous land snails and slugs in the Hawaiian Islands. *Bishop Museum Occasional Papers* 56: 60.

Cowie, R.H. 1999. New records of alien nonmarine mollusks in the Hawaiian Islands. *Bishop Museum Occasional Papers* 59: 48–50.

Cowie, R.H. in press. Apple snails as agricultural pests: their biology, impacts and management. *In*: Barker, G.M. (ed.) *Molluscs as Crop Pests*. CABI, Wallingford.

Cowie, R.H.; Allison, A.; Howarth, F.G.; Samuelson, G.A.; Evenhuis, N.L. 1996. Impacts of construction of the Palau Compact Road: survey of the non-marine fauna of the island of Babeldaob. Bishop Museum Report to Wil Chee Planning, Inc., Honolulu. 44 pp.

Cowie, R.H.; Cook, R.PP. 1999. The distribution and abundance of land snails in the National Park of American Samoa, with particular focus on Partulidae. Cooperative National Park Resources Studies Unit, University of Hawaii at Manoa, Technical Report 125: i–iii, 1–143.

Cowie, R.H.; Englund, R.; Nishida, G.M. 1999. Kamoku-Pūkele 138-kV transmission line project, Wa'ahila ridge, O'ahu: assessment of potential impacts on invertebrates (snails, insects and other arthropods). Bishop Museum report submitted to CH2MHill, Honolulu. 44 pp.

Cowie, R.H.; Evenhuis, N.L.; Christensen, C.C. 1995. *Catalog of the native land and freshwater molluscs of the Hawaiian Islands*. Backhuys Publishers, Leiden. vi + 248 pp.

Dun, G.S. 1967. The giant snail. *Papua and New Guinea Agricultural Journal* 18(4): 123–125.

Eldredge, L.G. 1988. Case studies of the impacts of introduced animal species on renewable resources in the U.S.-affiliated Pacific islands. Pp. 118–146 *in*: Smith, B.D. (ed.) *Topic reviews in insular resource development and management in the U.S.-affiliated Pacific islands. University of Guam Marine Laboratory Technical Report No. 88*. University of Guam Marine Laboratory, Mangilao.

Eldredge, L.G. 1994a. Introductions and transfers of the triclad flatworm *Platydemus manokwari*. *Tentacle. Newsletter of the IUCN Species Survival Commission Mollusc Specialist Group* 4: 8.

Eldredge, L.G. 1994b. *Perspectives in aquatic exotic species management in the Pacific islands. Volume 1. Introductions of commercially significant aquatic organisms to the Pacific islands*. South Pacific Commission, Nouméa. v + 127 pp.

Eldredge, L.G. 1995. Triclad flatworm tours the Pacific. *Aliens* 2: 11.

Forcart, L. 1969. Veronicellid land slugs from the New Hebrides, with description of *Semperula solemi*, new species. *Fieldiana Zoology* 51(12): 147–56.

Fossati, O.; Marquet, G. 1998. *Faune des eaux douces des Iles Marquises. Clé des macroinvertébrés et des poissons.* Muséum National d'Histoire Naturelle, Paris. [v] + 50 pp.

Franc, A. 1957. Mollusques terrestres et fluviatiles de l'archipel Néo-Calédonien. *Mémoires du Muséum National d'Histoire Naturelle, Nouvelle Série. Série A, Zoologie* 13[1956]: 1–200, pl. 1–24.

Gammon, E.T. 1943. Helicid snails in California. *State of California Department of Agriculture Bulletin* 32(3): 173–187.

Gargominy, O.; Bouchet, PP.; Pascal, M.; Jaffré, T.; Torneur, J.-C. 1996. Conséquences des introductions d'es-pèces animales et végétales sur la biodiversité en Nouvelle-Calédonie. *Revue d'Écologie (Terre et Vie)* 51: 375–402.

Gould, S.J. 1991. Unenchanted evening. *Natural History* 9/91: 4–14.

Griffiths, O.; Cook, A.; Wells, S.M. 1993. The diet of the carnivorous snail *Euglandina rosea* in Mauritius and its implications for threatened island gastropod faunas. *Journal of Zoology* 229: 79–89.

Grimpe, G.; Hoffmann, H. 1925. Die Nacktschnecken von Neu-Caledonien, den Loyalty-Inseln und Neuen-Hebriden. Pp. 337–476, pl. 5, 6 *in*: Sarasin, F.; Roux, J. C. (eds) *Nova Caledonia. Forschungen in Neu-Caledonien und auf den Loyalty-Inseln. A. Zoologie. Volume III*. W. Kreidel's Verlag, Berlin.

Hadfield, M.G. 1986. Extinction in Hawaiian achatinelline snails. *Malacologia* 27: 67–81.

Hadfield, M.G. 1998. Hawaiian *Achatinella*/*Partulina* tree snail update. *Tentacle. Newsletter of the IUCN Species Survival Commission Mollusc Specialist Group* 8: 15.

Hadfield, M.G.; Miller, S.E. 1989. Demographic studies on Hawaii's endangered tree snails: *Partulina proxima. Pacific Science* 43: 1–16.

Hadfield, M.G.; Mountain, B.S. 1981. A field study of a vanishing species, *Achatinella mustelina* (Gastropoda, Pulmonata), in the Waianae Mountains of Oahu. *Pacific Science* 34: 345–358.

Hadfield, M.G.; Miller, S.E.; Carwile, A.H. 1993. The decimation of endemic Hawai'ian [sic] tree snails by alien predators. *American Zoologist* 33: 610–622.

Halwart, M. 1994. The golden apple snail *Pomacea canaliculata* in Asian rice farming systems: present impact and future threat. *International Journal of Pest Management* 40: 199–206.

Harry, H.W. 1966. Land snails of Ulithi atoll, Caroline Islands: a study of snails accidentally distributed by man. *Pacific Science* 20(2): 212–223.

Haynes, A. 1985. The ecology and local distributions of non-marine aquatic gastropods in Viti Levu, Fiji. *The Veliger* 28(2): 204–210.

Haynes, A. 1988a. Notes on the stream neritids (Gastropoda; Prosobranchia) of Oceania. *Micronesica* 21: 93-102.

Haynes, A. 1988b. The gastropods in the streams and rivers of five Fiji islands: Vanua Levu, Ovalau, Gau, Kadavu, and Taveuni. *The Veliger* 30(4): 377–383.

Haynes, A. 1990. The numbers of freshwater gastropods on Pacific islands and the theory of island biogeography. *Malacologia* 31(2): 237–248.

Haynes, A. 1993. The gastropods in the streams and rivers of four islands (Guadalcanal, Makira, Malaita, and New Georgia) in the Solomon Islands. *The Veliger* 36(3): 285–290.

Haynes, A. 1994. The effects of development on Fijian island freshwater invertebrates. *Memoirs of the Queensland Museum* 36(1): 87–91.

Hedley, C. 1899. The Mollusca of Funafuti. Part I. Gastropoda. *Australian Museum Memoirs* 3: 397–488.

Hoffmann, H. 1925. Die Vaginuliden. Ein Beitrag zur Kenntnis ihrer Biologie, Anatomie, Systematik, geographischen Verbreitung und Phylogenie. (Fauna et Anatomia ceylanica, III, Nr. 1.). *Jenaische Zeitschrift für Naturwissenschaft* 61(1 and 2): 1–-374, pl. 1–11.

Hopper, D.R.; Smith, B.D. 1992. Status of tree snails (Gastropoda: Partulidae) on Guam, with a resurvey of sites studied by H.E. Crampton in 1920. *Pacific Science* 46(1): 77–85.

Iredale, T. 1941. A basic list of the land Mollusca of Papua. *Australian Zoologist* 10(1): 51–94, 2 pl.

Johnson, M.S.; Murray, J.; Clarke, B. 1993. The ecological genetics and adaptive radiation of *Partula* on Moorea. *Oxford Surveys in Evolutionary Biology* 9: 167–238.

Kay, E.A.; Johnson, S. 1987. Mollusca of Enewetak Atoll. Pp. 105–146 *in*: Devaney, D.M.; Reese, E.S.; Burch, B.L.; Helfrich, PP. (eds) *The natural history of Enewetak Atoll. II. Biogeography and systematics*. US Department of Energy, Oak Ridge, Tennessee.

Kerney, M.PP.; Cameron, R.A.D.; Riley, G. 1979. *A field guide to the land snails of Britain and north-west Europe*. Collins, London. 288 pp., 24 pl.

Kinzie, R.A., III. 1992. Predation by the introduced carnivorous snail *Euglandina rosea* (Ferussac) on endemic aquatic lymnaeid snails in Hawaii. *Biological Conservation* 60: 149–155.

Kirch, P.V. 1973. Prehistoric subsistence patterns in the northern Marquesas Islands, French Polynesia. *Archaeology and Physical Anthropology in Oceania* 8(1): 24–40.

Kirch, P.V. 1993. Non-marine molluscs from the To‘aga site sediments and their implications for environmental change. Pp. 115–121 *in*: Kirch, P.V.; Hunt, T.L. (eds) *The To‘aga site. Three millenia of Polynesian occupation in the Manu‘a Islands, American Samoa*. University of California Archaeological Research Facility, Berkeley.

Kondo, Y. 1956. First *Helix aspersa* in Hawaii. *Nautilus* 69(4): 141–142.

Kondo, Y. 1975. Status of *Lamellidea solomonensis* Dell (Stylommatophora: Achatinellidae: Lamellideinae). *Malacological Review* 8: 114.

Kurozumi, T. 1994. Land molluscs from the Northern Mariana Islands, Micronesia. *Natural History Research, Special Issue* 1: 113-119.

Lach, L.; Cowie, R.H. 1999. The spread of the introduced freshwater apple snail *Pomacea canaliculata* (Lamarck) (Gastropoda: Ampullariidae) on O‘ahu, Hawai‘i. *Bishop Museum Occasional Papers* 58:66–71.

Lach, L.; Britton, D.K.; Rundell, R.J.; Cowie, R.H. submitted. Have shell, will travel: food preference and reproductive plasticity in an invasive invertebrate. *Biological Invasions*.

Lai, PP.-Y.; Funasaki, G.Y.; Higa, S.Y. 1982. Introductions for biological control in Hawaii: 1979 and 1980. *Proceedings, Hawaiian Entomological Society* 24(1): 109–113.

Lambert, M. 1974. The African giant snail, *Achatina fulica*, in the Pacific islands. *South Pacific Bulletin* 24(4): 35–40.

Lange, W.H. 1950. Life history and feeding habits of the giant African snail on Saipan. *Pacific Science* 4(4): 332–335.

Laup, S. 1991. Golden apple snail and its eradication in Papua New Guinea. Pp. 55–62 *in*: Kumar, R. (ed.) *Proceedings of a seminar on pests and diseases of food crops - urgent problems and practical solutions*. Department of Agriculture and Livestock, Konedobu.

McKinney, M.L. 1997. Extinction vulnerability and selectivity: combining ecological and paleontological views. *Annual Review of Ecology and Systematics* 28: 495–516.

McMichael, D.F. 1956. Notes on the freshwater mussels of New Guinea. *Nautilus* 70(2): 38–48, pl. 2.

Mead, A.R. 1961. *The giant African snail: a problem in economic malacology*. University of Chicago Press, Chicago. xvii + 257 pp., 15 pl.

Mead, A.R. 1979. *Economic malacology, with particular reference to* Achatina fulica. Academic Press, New York. x + 150 pp.

Miller, Stephen E. 1993. *Final report on surveys of the arboreal and terrestrial snail fauna of American Samoa.* US Fish and Wildlife Service, Honolulu. 30 pp.

Mochida, O. 1991. Spread of freshwater *Pomacea* snails (Pilidae, Mollusca) from Argentina to Asia. *Micronesica, Supplement* 3: 51–62.

Morrison, J.P.E. [1969]. Notes on Hawaiian Lymnaeidae. *Malacological Review* 1[1968]: 31–33.

Morton, B. 1982. Some aspects of the population structure and sexual strategy of *Corbicula* cf. *fluminalis* (Bivalvia: Corbiculacea) from the Pearl River, People’s Republic of China. *Journal of Molluscan Studies* 48(1): 1–23.

Motteler, L.S. 1986. Pacific island names. A map and name guide to the New Pacific *Bishop Museum Miscellaneous Publication* 34, [vi] + 91 pp.

Muniappan, R. 1983. Biological control of the giant African snail. PP. 172 *in*: *15th Pacific Science Association Congress–programme, abstracts and congress information, vol. 1*. Pacific Science Association, Dunedin.

Muniappan, R. 1987. Biological control of the giant African snail, *Achatina fulica* Bowdich, in the Maldives. *FAO Plant Protection Bulletin* 35(4): 127–133.

Muniappan, R. 1990. Use of the planarian, *Platydemus manokwari*, and other natural enemies to control the giant African snail. Pp. 179–183 *in*: *The use of natural enemies to control agricultural pests*. Food and Fertilizer Technology Center for the Asian and Pacific region, Taipei.

Muniappan, R.; Duhamel, G.; Santiago, R.M.; Acay, D.R. 1986. Giant African snail control in Bugsuk island, Philippines, by *Platydemus manokwari*. *Oléagineux* 41(4): 183–186.

Murray, J.; Murray, E.; Johnson, M.S.; Clarke, B. 1988. The extinction of *Partula* on Moorea. *Pacific Science* 42: 150–153.

Naggs, F. 1994. The reproductive anatomy of *Paropeas achatinaceum* and a new concept of *Paropeas* (Pulmonata: Achatinoidea: Subulinidae). *Journal of Molluscan Studies* 60(2): 175–91.

Nakahara, L. 1979. *Helix aspersa* Muller [sic]. *Proceedings of the Hawaiian Entomological Society* 23(1): 11.

Nakao, H.K.; Funasaki G.Y.; Davis, C.J. 1975. Introductions for biological control in Hawaii, 1973. *Proceedings, Hawaiian Entomological Society* 22(1): 109–112.

Naylor, R. 1996. Invasions in agriculture: assessing the cost of the golden apple snail in Asia. *Ambio* 25: 443–448.

Nishida, T.; Napompeth, B. 1975. Effect of age-specific predation on age distribution and survival of the giant African snail, *Achatina fulica*. *Proceedings, Hawaiian Entomological Society* 22(1): 119–123.

Peake, J.F. 1968. Habitat distribution of Solomon Island land Mollusca. *Symposia of the Zoological Society of London* 22: 319–346.

Perera, G.; Walls, J.G. 1996. *Apple snails in the aquarium*. T.F.H. Publications, Neptune City, New Jersey. 121 pp.

Peake, J.F. 1968. Habitat distribution of Solomon Island land Mollusca. *Symposium of the Zoological Society of London* 22: 319–346.

Peake, J.F. 1981. The land snails of islands—a dispersalist's viewpoint. Pp. 247–263 *in*: Forey, P.L.(ed.) *The evolving biosphere*. British Museum (Natural History) and Cambridge University Press, London and Cambridge.

Pilsbry, H.A. 1906–1907. *Manual of Conchology. Second series: Pulmonata. Vol. XVIII Achatinidae: Stenogyrinae and Coeliaxinae*. Academy of Natural Sciences, Philadelphia. xii + 357 pp., 51 pl.

Pointier, J.PP.; Blanc, C. 1984. *Achatina fulica* en Polynésie française après l'introduction des escargots géants en 1967. Unpubl. report [Muséum National d'Histoire Naturelle, BP Moorea, French Polynesia]. 42 pp.

Polhemus, D.A. 1996. Island arcs and their influence on Indo-Pacific biogeography. Pp. 51–66 *in*: Keast, A.; Miller, Scott E. (eds) *The origin and evolution of Pacific island biotas, New Guinea to eastern Polynesia: patterns and processes*. SPB Academic Publishing, Amsterdam.

Preece, R.C. 1995. Systematic review of the land snails of the Pitcairn Islands. *Biological Journal of the Linnean Society* 56: 273–307.

Preece, R.C. 1998. Impact of early Polynesian occupation on the land snail fauna of Henderson Island, Pitcairn group (South Pacific). *Philosophical Transactions of the Royal Society of London* B 353: 347–368.

Reigle, N.J. 1964. Nonmarine mollusks of Rongelap Atoll, Marshall Islands. *Pacific Science* 18(2): 126–129.

Rensch, I. 1934. Systematische und tiergeographische Untersuchungen über die Landschneckenfauna des Bismarck-Archipels. I. *Archiv für Naturgeschichte N.F.* 3(3): 445–488

Rensch, I. 1937. Systematische und tiergeographische Untersuchungen über die Landschneckenfauna des Bismarck-Archipels. II. *Archiv für Naturgeschichte N.F.* 6(4): 526–644.

Simberloff, D.; Stiling, PP. 1996. How risky is biological control? *Ecology* 77: 1965–1974.

Smith A.G. 1966. Land snails of the Galápagos. Pp. 240–251 *in*: Bowman, R.I. (ed.) *The Galápagos. Proceedings of the Symposia of the Galápagos International Scientific Project*. University of California Press, Berkeley and Los Angeles.

Smith, B.D. 1992a. Introduction and dispersal of apple snails (Ampullariidae) on Guam. *Pacific Science Association Information Bulletin* 44(1-2): 12–14.

Smith, B.D. 1992b. Working list of the terrestrial gastropods of Kosrae, Caroline Islands. Working list no. 6. Unpubl. manuscript [Marine Laboratory, University of Guam, Mangilao, Guam]. 4 pp.

Smith, B.D. 1993a. Working list of the pulmonate gastropods of Guam. Working list no. 3. Unpubl. manuscript [Marine Laboratory, University of Guam, Mangilao, Guam]. 4 pp.

Smith, B.D. 1993b. Working list of the terrestrial gastropods of Pohnpei, Caroline Islands. Working list no. 5. Unpubl. manuscript [Marine Laboratory, University of Guam, Mangilao, Guam]. 5 pp.

Smith, B.D. 1993c. Working list of the terrestrial gastropods of Chuuk, Caroline Islands. Working list no. 7. Unpubl. manuscript [Marine Laboratory, University of Guam, Mangilao, Guam]. 4 pp.

Smith, B.D. 1995. A new land snail introduction on Guam. *Tentacle. Newsletter of the IUCN Species Survival Commission Mollusc Specialist Group* 5: 15.

Solem, A. 1959. Systematics and zoogeography of the land and fresh-water Mollusca of the New Hebrides. *Fieldiana. Zoology* 43(1): 1–359.

Solem, A. 1961. New Caledonian land and fresh-water snails. An annotated check list. *Fieldiana. Zoology* 43: 415–501.

Solem, A. 1964. New records of New Caledonian nonmarine mollusks and an analysis of the introduced mollusks. *Pacific Science* 18(2): 130–137.

Solem, A. 1978. Land snails from Mothe, Lakemba, and Karoni Islands, Lau Archipelago, Fiji. *Pacific Science* 32(1): 39-45.

Solem, A. 1983. *Endodontoid land snails from Pacific islands (Mollusca: Pulmonata: Sigmurethra). Part II. Families Punctidae and Charopidae, Zoogeography*. Field Museum of Natural History, Chicago. ix + 336 pp.

Solem, A. 1990. How many Hawaiian land snail species are left? and what we can do for them. *Bishop Museum Occasional Papers* 30: 27–40.

Solem, A.; Tillier, S.; Mordan, PP. 1984. Pseudo-operculate pulmonate land snails from New Caledonia. *The Veliger* 27: 193–199.

Starmühlner, F. 1976. Beiträge zur Kenntnis der Süsswasser-Gastropoden Pazifischer Inseln. *Annalen des Naturhistorischen Museums in Wien* 80: 473–656.

Stone, C.PP.; Loope, L.L. 1996. Alien species in Hawaiian national parks. Pp. 132–158 *in*: Halvorson, W.L.; Davis, G.E. (eds) *Science and ecosystem management in the national parks*. University of Arizona Press, Tucson.

Stone, C.PP.; Pratt, L.W. 1994. *Hawai'i's plants and animals*. Hawaii Natural History Association, Honolulu. xxiii + 399 pp.

Tamura, E.; Higa, S.Y.; Kami, R.S.; Watanabe, T.M. 1981. European brown snail, *Helix aspersa* Muller [sic]. *Hawaii Pest Reports* 1(4): 2.

Tillier, S. 1992. Introduced land snails in New Caledonia: a limited impact in the past, a potential disaster in the future. *Pacific Science* 46(3): 396–397.

Tillier, S.; Clarke, B.C. 1983. Lutte biologique et destruction du patromoine génétique: le cas des mollusques gastéropodes pulmonés dans les territoires français du Pacifique. *Génétique, Sélection, Évolution* 15: 559–566.

van Benthem Jutting, W.S.S. 1963a. Non-marine Mollusca of west New Guinea. Part 1, Mollusca from fresh and brackish waters. *Nova Guinea (Zoology)* 20: 409–521, 2 pl.

van Benthem Jutting, W.S.S. 1963b. Non-marine Mollusca of west New Guinea. Part 2, operculate land shells. *Nova Guinea (Zoology)* 23: 653–726, 4 pl.

van Benthem Jutting, W.S.S. 1964. Non-marine Mollusca of west New Guinea. Part 3, Pulmonata, 1. *Nova Guinea (Zoology)* 26: 1–74, 2 pl.

van Benthem Jutting, W.S.S. 1965. Non-marine Mollusca of west New Guinea. Part 4, Pulmonata 2. *Nova Guinea (Zoology)* 32: 205–304, 4 pl.

Vaught, K.C. 1989. *A classification of the living Mollusca*. American Malacologists, Inc., Melbourne, Florida. xii + 195 pp.

Wallace, G.D.; Rosen, L. 1969. Experimental infection of Pacific island mollusks with *Angiostrongylus cantonensis*. *American Journal of Tropical Medicine and Hygiene* 18(1): 13–19.

Waterhouse, D.F.; Norris, K.R. 1987. *Biological control. Pacific prospects*. Melbourne, Inkata Press. viii + 454 pp.

Williams, F.X. 1931. *Handbook of the insects and other invertebrates of Hawaiian sugar cane fields*. Experiment Station of the Hawaiian Sugar Planters' Association, Honolulu. 400 pp.

# Annex 1
# Records of other species

This list is presented as an additional source of information on species other than those dealt with in the main body of the report. It is not based on an exhaustive review of the literature on these additional species, but nevertheless is probably a fairly accurate record at least of the presence of these species on the various islands of the Pacific, as far as has been recorded. Undoubtedly many of these species are more widely distributed on other islands or archipelagos but have not yet been recorded from them.

Some widespread Pacific species may have been introduced to islands other than their island of origin by Polynesian voyagers, but others may be widely distributed naturally. This list probably does not include a number of species that could be considered introduced. Equally, it probably includes species that might have been widely dispersed by natural means. Species for which there exists this kind of uncertainty have been termed "cryptogenic" by Carlton (1996); they are indicated with an asterisk (*****) in the list below. The list generally excludes species that were introduced but appear not to have become established, but includes others for which it is unknown whether they became established or for which it is too soon to say because they have only recently been introduced (see Cowie 1998a, 1999). A significant number of the records are likely to be based on misidentifications. The sequence of families in the list follows Vaught (1989).

## Terrestrial species

### FAMILY ACHATINELLIDAE

The following widespread achatinellids, contrasting with the majority of the family, which is composed of mostly narrow endemics, may have been distributed at least in part by native Pacific islanders prior to European exploration of the Pacific. They are native somewhere in the Pacific, but it is for the most part not possible to identify their origins. They are all very small species, readily transported accidentally, and generally found at low elevations.

#### *Elasmias apertum**

(includes *Elasmias* sp(p).)

**French Polynesia** (Marquesas Islands [Ua Huka]) — Kirch 1973, (Marquesas Islands [several islands], Society Islands [several islands], Austral Islands [Tubuai], Gambier Islands [Mangareva], Tuamoto Archipelago [Makatea]) — Cooke and Kondo 1960; **Pitcairn Islands** (Henderson, Pitcairn, Oeno) — Preece 1995; but see Preece 1998; **Samoa** (Upolu) — Cowie 1998c; **American Samoa** (Tutuila, Ta‘ū, Ofu) — Cowie 1998c; Cowie and Cook 1999; **Tonga** (Tongatapu) — Cooke and Kondo 1960; **Fiji** (Rotuma) — Cooke and Kondo 1960; **New Caledonia —** Gargominy et al. 1996, (Maré) — Solem 1964; **Marshall Islands** (Rongelap) — Reigle 1964; **Guam** — Smith 1992b.

#### *Lamellidea oblonga**

**Hawaiian Islands** (Kaua‘i, O‘ahu, Moloka‘i, Maui, Hawai‘i) — Cowie 1997; **Line Islands (USA)** (Palmyra) — Cooke and Kondo 1960; **Kiribati** (Teraina, Flint) — Cooke and Kondo 1960; **French Polynesia** (Marquesas Islands [Ua Huka]) — Kirch 1973, (Marquesas Islands [many islands], Society Islands [many islands], Austral Islands [many islands], Gambier Islands [many islands], Tuamoto Archipelago [many islands]) — Cooke and Kondo 1960; **Pitcairn Islands** (Henderson, Pitcairn, Oeno) — Preece 1995; **Cook Islands** (Mangaia, Rarotonga, Mauke, Atiu, Aitutaki, Pukapuka) — Cooke and Kondo 1960; **American Samoa** (Tutuila, Olosega, Ta‘ū) — Cowie 1998c; **Tonga** (Tongatapu) — Cooke and Kondo 1960; **Wallis and Futuna** (Futuna) — Cooke and Kondo 1960; **Tuvalu** (Funafuti) — Cooke and Kondo 1960.

#### *Lamellidea pusilla**

**Kiribati** (Tarawa), **French Polynesia** (Marquesas Islands, Society Islands [most islands], Austral Islands [Rurutu], Gambier Islands [Mangareva], Tuamoto Archipelago [many islands]), **Cook Islands** (many islands) — Cooke and Kondo 1960; **Samoa** (Upolu), **American Samoa** (Tutuila, Ofu, Olosega, Ta‘ū, Swains) (Cowie 1998c); **Niue**, **Tonga** (Niuafo‘ou, Ha‘apai, Vava‘u), **Tuvalu** (most islands), **Fiji** (many islands, Lau Group) — Cooke and Kondo 1960; **Vanuatu** (Espiritu Santo) (Solem 1959; "most of Polynesia, Micronesia, and Melanesia"), **Solomon Islands** (New Georgia) — Kondo 1975, (Tikopia) — Christensen and Kirch 1981; **Papua New Guinea** (New Britain) — Kondo 1975; unverified record; **Marshall Islands** (Ebon) — Cooke and Kondo 1960, (Rongelap) — Reigle 1964, (Enewetak) — Kay and Johnson 1987; **Federated States of Micronesia** (Pohnpei), (Truk [Moen, Fefan, Parem, "Falo", "Atoda"]), (Kosrae) — Cooke and Kondo 1960.

#### *Pacificella variabilis**

**Line Islands (USA)** (Palmyra) — Cooke and Kondo 1960; **French Polynesia** (Marquesas Islands, Society Islands, Austral Islands [Rapa], Tuamoto Archipelago) — Cooke and Kondo 1960, [Makatea] — Cooke 1934; **Pitcairn Islands** (Henderson, Pitcairn, Oeno, Ducie) — Preece 1995; but see Preece 1998; **Easter Island (Chile) —** Cooke and Kondo 1960; **Cook Islands** — Cooke and Kondo 1960, (Aitutaki) — Allen 1992; **American Samoa** (Tutuila) (Cowie 1998c; tentative record), **Federated States of Micronesia** (Truk) — Cooke and Kondo 1960; Smith 1993b; **Guam** — Bauman 1996; tentative identification; **Northern Mariana Islands** (Rota, Saipan) — Bauman 1996.

### *Tornatellides oblongus**

**French Polynesia** (Marquesas Islands [Nuku Hiva, Ua Huka, Hiva Oa], Society Islands [many islands], Austral Islands [Rimatara, Rurutu, Tubuai, Raivavae], Gambier Islands [many islands]) — Cooke and Kondo 1960; **Pitcairn Islands** (Pitcairn, Henderson) — Cooke and Kondo 1960; Preece 1995; **Cook Islands** (Mangaia, Rarotonga, Mauke, Mitiaro, Atiu) — Cooke and Kondo 1960, (Aitutaki) — Allen 1992; **Tuvalu** (Funafuti) — Hedley, 1899.

## FAMILY PUPILLIDAE

Some of these species may have been dispersed by native Pacific islanders prior to European exploration of the Pacific. Others are more recent arrivals. They are all very small species, readily transported accidentally.

### *Gastrocopta pediculus**

**Hawaiian Islands** (Oʻahu, Hawaiʻi) — Cowie 1997, 1998a; **French Polynesia** (Tuamoto Archipelago [Makatea]) — Cooke 1934, (Marquesas [Ua Huka]) — Kirch 1973; **Cook Islands** (Aitutaki) — Allen 1992; **Samoa** (Upolu) — Cowie 1998c; **American Samoa** (Tutuila) — Cowie 1998c, (Ofu) — Kirch 1993; **Tuvalu** (Funafuti) — Hedley, 1899; **Fiji** (Lau Group [Karoni]) — Solem 1978; **New Caledonia** — Gargominy et al. 1996; Solem 1964; **Vanuatu** (Espiritu Santo) — Solem 1959 ("all of Polynesia and Micronesia and Hawaiʻi"); **Solomon Islands** (Tikopia) — Christensen and Kirch 1981; **Marshall Islands** (Rongelap) — Reigle 1964, (Enewetak) — Kay and Johnson 1987; **Federated States of Micronesia** (Pohnpei) — Smith 1993b, (Kosrae) — Smith 1992b; (Yap [Ulithi]) — Harry 1966.

### *Gastrocopta servilis*
(and its junior synonym *lyonsiana*)

**Hawaiian Islands** (Midway, Pearl and Hermes, Laysan, Kauaʻi, Oʻahu, Molokaʻi, Maui, Hawaiʻi) — Cowie 1997, 1998a; **French Polynesia** (Tuamoto Archipelago: Makatea) — Cooke 1934; **Fiji** (Lau Group [Karoni]) — Solem 1978; **New Caledonia** — Gargominy et al. 1996; Solem 1964, (Maré) — Solem 1964; **Marshall Islands** (Enewetak) — Kay and Johnson 1987; **Federated States of Micronesia** (Saipan) — Lange 1950.

### *Gastrocopta* sp(p).*

**Guam** — Bauman 1996; **Northern Mariana Islands** (Rota, Saipan) — Bauman 1996.

### *Nesopupa* sp(p).*

**Guam** — Bauman 1996; **Northern Mariana Islands** (Rota, Saipan) — Bauman 1996.

### *Pupisoma orcula*

**Hawaiian Islands** (Kauaʻi, Oʻahu, Molokaʻi, Maui, Hawaiʻi) — Cowie 1997, 1998a; **French Polynesia** (Tuamoto Archipelago [Makatea]) — Cooke 1934; **Pitcairn Islands** (Henderson, Pitcairn) — Preece 1995; **American Samoa** (Tutuila) — Cowie 1998c (tentative record); **Federated States of Micronesia** (Pohnpei) — Smith 1993b; (Kosrae) — Smith 1992b.

### *Pupisoma dioscoricola*
(possibly a synonym of *P. orcula*)*

**New Caledonia** — Gargominy et al. 1996; Solem 1964.

## FAMILY ENIDAE

### *Rhachistia histrio*

**New Caledonia** — Gargominy et al. 1996; Solem 1964, (Maré) — Solem 1964; **Vanuatu** (Efate) (Solem 1959).

## FAMILY ORTHALICIDAE

### *Drymaeus multilineatus*

**Guam** — Smith 1995.

## FAMILY FERUSSACIIDAE

### *Cecilioides aperta*

(including *Cecilioides* sp., and *Cecilioides baldwini*, which is probably a junior synonym [cf. Cowie 1998a])

**Hawaiian Islands** (Kauaʻi, Oʻahu, Molokaʻi, Hawaiʻi) — Cowie 1997; **Cook Islands** (Aitutaki) — Allen 1992; **Galapagos Islands** (Floreana) — Smith 1966; **New Caledonia** — Gargominy et al. 1996, (New Caledonia [Grand Terre], Loyalty Islands) — Solem 1959; **Guam** — Smith 1992b.

## FAMILY OLEACINIDAE

### *Varicella* sp.

**New Caledonia** — Gargominy et al. 1996; Solem 1964.

## FAMILY STREPTAXIDAE

These small predatory species have probably been introduced both accidentally and deliberately as biological control agents against other alien snails.

### *Gulella bicolor*

**American Samoa** (Tutuila) — Cowie 1998c, (Ofu) — Cowie and Cook 1999; **Federated States of Micronesia** (Yap [Fais, Ulithi]) — Harry 1966, (Pohnpei) — Smith 1993b; **Belau** (Palau) (Babeldaob) — Cowie et al. 1996; **Northern Mariana Islands** (Saipan) — Harry 1966.

### *Streptostele musaecola*

**American Samoa** (Tutuila, Taʻū, Ofu) — Cowie 1998c, Cowie and Cook 1999.

## FAMILY SAGDIDAE

### *Lacteoluna* sp.

**New Caledonia** — Gargominy et al. 1996; Solem 1964.

## FAMILY HELICARIONIDAE

The origins of some of these species are unclear. Others, however, appear to be strongly associated with movement of horticultural products.

### *Coneuplecta calculosa*

**French Polynesia** (Marquesas Islands, Society Islands) — Solem 1964; **Cook Islands** — Solem 1964; **New Caledonia** — Gargominy et al. 1996, (New Caledonia [Grand Terre], Isle of Pines, Maré) — Solem 1964.

### *Coneuplecta microconus**

**American Samoa** (Tutuila) — Cowie 1998c; **Fiji** (Lau Group [Karoni, Moce, Lakeba]) — Solem 1978; **Solomon Islands** (Tikopia) — Christensen and Kirch 1981; **Vanuatu** (Anatom, Efate, Espiritu Santo, Vanua Lava) — Solem 1959; **Fiji** — Solem 1959; **Federated States of Micronesia** (Kosrae) — Smith 1992b (tentative identification).

### *Diastole conula*

**French Polynesia** (Society Islands, Austral Islands [Rurutu]) — Solem 1964; **Cook Islands** — Solem 1964; **New Caledonia** — Gargominy et al. 1996, (Maré) — Solem 1964.

### *Liardetia samoensis**

**French Polynesia** (Marquesas Islands, Society Islands) — Solem 1959; **Cook Islands** — Solem 1959; **Samoa** (Upolu), **American Samoa** (Tutuila, Ofu) — Cowie 1998c); **Tuvalu** — Solem 1959; **Fiji** — Solem 1959, (Lau Group [Karoni, Moce]) — Solem 1978; **New Caledonia** — Gargominy et al. 1996, (Ouen, Isle of Pines, Maré) — Solem 1964; **Vanuatu** (Anatom, Erromango, Espiritu Santo) — Solem 1959; **Solomon Islands** — Solem 1959, (Tikopia) — Christensen and Kirch 1981; **Papua New Guinea** (Bismarck Archipelago) — Solem 1959; **Marshall Islands** — Solem 1959, (Rongelap) — Reigle 1964.

### *Liardetia doliolum*

**Hawaiian Islands** (O‘ahu, Hawai‘i) — Cowie, in press (possibly not established); **Federated States of Micronesia** (Pohnpei, Truk) — Smith 1993b, (Kosrae) — Smith 1992b; **Guam** — Smith 1992b; Bauman 1996; **Northern Mariana Islands** (Rota, Tinian) — Bauman 1996.

### *Liardetia discordiae*

**Cook Islands** (Aitutaki) — Allen 1992 (tentative identification).

### *Wilhelminaia mathildae*

**Vanuatu** (Espiritu Santo) — Solem 1959 (tentative identification); **Solomon Islands** (Tikopia) — Christensen and Kirch 1981, (Nggela Sule) — Solem 1959; **Federated States of Micronesia** (Caroline Islands) — Solem 1959.

## FAMILY ARIOPHANTIDAE

### *Parmarion martensi*

**Hawaiian Islands** (O‘ahu) — Cowie 1997, 1998c; **Samoa** (Upolu), **American Samoa** (Tutuila) — Cowie 1998c (tentative identification).

## FAMILY ZONITIDAE

### *Hawaiia minuscula*

**Hawaiian Islands** (Midway, Kaua‘i, O‘ahu, Moloka‘i, Lāna‘i, Maui, Hawai‘i) — Cowie 1997, 1998a; **French Polynesia** (Tahiti) — Solem 1964; **Pitcairn Islands** (Pitcairn, Oeno) — Preece 1995; **New Caledonia** — Gargominy et al. 1996, (Isle of Pines) — Solem 1964.

### *Oxychilus alliarius*

**Hawaiian Islands** (Kaua‘i, O‘ahu, Moloka‘i, Hawai‘i) — Cowie 1997, 1998a; **Juan Fernandez Islands** — Barker 1999.

### *Striatura* sp.*

**Hawaiian Islands** (Hawai‘i) — Cowie 1997, 1998a.

### *Zonitoides arboreus*

**Hawaiian Islands** (O‘ahu, Maui, Hawai‘i) — Cowie 1997, 1998a; **Pitcairn Islands** (Pitcairn) — Preece 1995.

## FAMILY MILACIDAE

### *Milax gagates*

**Hawaiian Islands** (Maui, Hawai‘i) — Cowie 1997, 1998a; **Juan Fernandez Islands** — Barker 1999.

## FAMILY LIMACIDAE

### *Deroceras laeve*

**Hawaiian Islands** (Kaua‘i, O‘ahu, Maui, Hawai‘i) — Cowie 1997, 1998a; **Fiji** (Viti Levu) — Barker 1999; **New Caledonia** — Gargominy et al. 1996; Solem 1964.

### *Deroceras reticulatum*

**Hawaiian Islands** (Kaua‘i, Hawai‘i) — Cowie 1997.

### *Deroceras* sp(p).

**Pitcairn Islands** (Pitcairn) — Preece 1995; **Galapagos Islands** (Santa Cruz) — Smith 1966.

### *Limax flavus*

**Cook Islands** (Rarotonga) — Barker 1999; **Vanuatu** — Barker 1999.

### *Limax maximus*

**Hawaiian Islands** (O‘ahu, Maui, Hawai‘i) — Cowie 1997, 1998a.

### FAMILY POLYGYRIDAE

Probably introduced via horticultural activities.

#### *Polygyra cereolus*

**Hawaiian Islands** (Kaua‘i, O‘ahu, Hawai‘i) — Cowie 1997, 1998a, d.

### FAMILY BRADYBAENIDAE

#### *Bradybaena similaris*

**Hawaiian Islands** (Midway, Kaua‘i, O‘ahu, Moloka‘i, Maui, Lāna‘i, Hawai‘i) — Cowie 1997, 1998a; **French Polynesia** (Society Islands) — Solem 1964; **Samoa** (Savai‘i, Upolu), **American Samoa** (Tutuila, Ofu) — Cowie 1998c; **Fiji** — Solem 1964, (Lau Group [Lakeba]) — Solem 1978; **New Caledonia** — Gargominy et al. 1996, (Ile of Pines, Maré) — Solem 1964; **Vanuatu** (Efate, Espiritu Santo) — Solem 1959; **Federated States of Micronesia** (Pohnpei) — Smith 1993b; **Guam** — L.G. Eldredge, unpublished; **Northern Mariana Islands** (Saipan) — Lange 1950.

### FAMILY ARIONIDAE

#### *Arion intermedius* (and *Arion* sp.)

**Hawaiian Islands** (Hawai‘i) — Cowie 1997, 1998a, 1999.

### FAMILY PHILOMYCIDAE

#### *Meghimatium striatum*

**Hawaiian Islands** (Kaua‘i, O‘ahu) — Cowie 1997, 1998a.

## Aquatic species

### FAMILY THIARIDAE

Numerous species of Thiaridae, some or many of which are probably introduced (notably the two commonest species, *Melanoides tuberculata*, *Tarebia granifera*), have been recorded from the Pacific region. Others may be native, but the group is so poorly understood that it is difficult to be sure of this. Thiarid taxonomy is confused and there are probably numerous synonyms.

#### *Melanoides aspirans**

**Samoa** — Starmühlner 1976, (Savai‘i, Upolu) — Cowie 1998c; **Fiji** — Starmühlner 1976, (Vanua Balavu, Beqa) — Haynes 1990, (Viti Levu) — Haynes 1985, (Vanua Levu, Ovalau, Gau, Taveuni) — Haynes 1988b; **New Caledonia**, **Vanuatu**, **Solomon Islands** — Starmühlner 1976, (New Georgia, Guadalcanal, San Cristobal [=Makira]) — Haynes 1990; **Papua New Guinea** — Starmühlner 1976.

#### *Melanoides brenchleyi**

**Samoa** (Upolu), **American Samoa** (Tutuila), **Tonga** (Tongatapu) — Cowie 1998c.

#### *Melanoides costata**

**New Caledonia**, **Vanuatu**, **Solomon Islands**, **Papua New Guinea** — Starmühlner 1976.

#### *Melanoides funiculus**

**Samoa** (Upolu) — Cowie 1998c.

#### *Melanoides laxa**

**Samoa** (Upolu) — Cowie 1998c.

#### *Melanoides luctuosa**

**Samoa** (Upolu), **Fiji** — Cowie 1998c.

#### *Melanoides lutosa**

**Samoa** (Upolu), **American Samoa** (Tutuila, Ofu) — Cowie 1998c; **Fiji** (Viti Levu) — Haynes 1985, (Vanua Levu, Ovalau) — Haynes 1988b.

#### *Melanoides pallens**

**Solomon Islands** (Guadalcanal, San Cristobal [=Makira], Malaita) — Haynes 1993; **Papua New Guinea** — Starmühlner 1976.

#### *Melanoides peregrina**

**Samoa** (Upolu) — Cowie 1998c.

#### *Melanoides persulcata**

(including the junior synonym *M. arthurii*)

**French Polynesia** (Society Islands [Tahiti]) — Starmühlner 1976; **Samoa** — Starmühlner 1976, (Upolu) — Cowie 1998c; **Fiji** — Starmühlner 1976, (Viti Levu) — Haynes 1985, (Yasawa Group: Waya) — Haynes 1990, (Kadavu, Taveuni) — Haynes 1988b; **New Caledonia** — Starmühlner 1976; **Solomon Islands** — Starmühlner 1976, (Guadalcanal, Malaita) — Haynes 1993; **Papua New Guinea** — Starmühlner 1976.

#### *Melanoides plicaria**

**Samoa** (Savai‘i, Upolu) — Cowie 1998c; **Fiji** — Starmühlner 1976, (Viti Levu) — Haynes 1985, (Vanua Levu, Ovalau) — Haynes 1988b; **New Caledonia**, **Vanuatu**, **Solomon Islands** — Starmühlner 1976, (San Cristobal [=Makira]) — Haynes 1993; **Papua New Guinea** — Starmühlner 1976.

#### *Melanoides punctata**

**Samoa** (Upolu) — Cowie 1998c (tentative record); **Vanuatu**, **Solomon Islands** — Starmühlner 1976, (New Georgia, Guadalcanal, San Cristobal [Makira], Malaita) — Haynes 1993; **Papua New Guinea** — Starmühlner 1976.

#### *Melanoides tuberculata**

**Hawaiian Islands** (Kaua‘i; “probably on all the main islands”) — Cowie 1997; **French Polynesia** (Marquesas Islands) — Fossati and Marquet 1998, (Society Islands [Tahiti]) — Starmühlner 1976; **Cook Islands** (Rarotonga) — Haynes 1990; **Samoa** (Savai‘i, Upolu), **American Samoa** (Tutuila, ?‘Aunu‘u, ?Ta‘ū) — Cowie 1998c; **Tonga** (Vava‘u, Tongatapu) — Haynes 1990; **Fiji** — Starmühlner 1976, (Viti Levu) — Haynes 1994, (Beqa, Rotuma) — Haynes 1990, (Vanua Levu, Ovalau, Kadavu, Taveuni) — Haynes 1988b; **New Caledonia**, **Vanuatu**, **Solomon**

**Islands** — Starmühlner 1976, (New Georgia, Guadalcanal, Malaita) — Haynes 1993; **Papua New Guinea** — Starmühlner 1976; **Federated States of Micronesia** (western Caroline Islands), **Guam** — Starmühlner 1976, (Pohnpei, Truk) — Haynes 1990.

### *Melanoides waigiensis**

**New Caledonia**, **Vanuatu**, **New Guinea** (Papua New Guinea or Irian Jaya not indicated) — Starmühlner 1976.

### *Tarebia granifera**

**Hawaiian Islands** (Kaua‘i, O‘ahu, Moloka‘i, Maui, Hawai‘i) — Cowie 1997; **French Polynesia** (Society Islands [Tahiti]) — Starmühlner 1976, **Vanuatu**, **Solomon Islands** — Starmühlner 1976, (Guadalcanal, San Cristobal [=Makira], Malaita) — Haynes 1993; **Papua New Guinea** — Starmühlner 1976; **Guam** — Haynes 1990; **Northern Mariana Islands** — Starmühlner 1976.

### *Thiara amarula**

**Samoan archipelago** (American or "Western" Samoa not indicated) — Cowie 1998c; **Fiji** — Starmühlner 1976, (Yasawa Group: Waya) — Haynes 1990, (Ovalau) — Haynes 1988b; **New Caledonia**, **Vanuatu**, **Solomon Islands** — Starmühlner 1976, (Guadalcanal, Malaita) — Haynes 1993; **Papua New Guinea** — Starmühlner 1976.

### *Thiara bellicosa**

**Fiji** — Starmühlner 1976, (Viti Levu) — Haynes 1990, (Vanua Levu) — Haynes 1988b; **Solomon Islands** — Starmühlner 1976, (Guadalcanal) — Haynes 1993; **Papua New Guinea** — Starmühlner 1976.

### *Thiara cancellata**

**Solomon Islands** — Starmühlner 1976, (New Georgia) — Haynes 1990; **Papua New Guinea** — Starmühlner 1976.

### *Thiara macrospira**

**Samoan archipelago** (American or "Western" Samoa not indicated) — Cowie 1998c.

### *Thiara scabra**

**Samoan archipelago** (American or "Western" Samoa not indicated) — Starmühlner 1976; **Fiji** — Starmühlner 1976, (Viti Levu) — Haynes 1985; **New Caledonia**, **Vanuatu** — Starmühlner 1976; **Solomon Islands** — Starmühlner 1976, (Guadalcanal, Malaita) — Haynes 1993; **Papua New Guinea** — Starmühlner 1976; **Federated States of Micronesia** (Pohnpei), **Guam** — Haynes 1990.

### *Thiara scitula**

**Samoa** (Upolu) — Cowie 1998c.

### *Thiara terpsichore**

**Samoan archipelago** (American or "Western" Samoa not indicated) — Cowie 1998c; **Fiji** — Starmühlner 1976, (Viti Levu) — Haynes 1985, (Vanua Levu) — Haynes 1988b.

## FAMILY VIVIPARIDAE

Introduced as food items.

### *Cipangopaludina chinensis*

**Hawaiian Islands** (Kaua‘i, O‘ahu, Moloka‘i, Maui, Hawai‘i) — Cowie 1995a.

### *Viviparus japonicus*

**Fiji** — Haynes 1994.

## FAMILY ANCYLIDAE

The Ancylidae in the Pacific are poorly studied and understood. There may only be a single species, which is cryptogenic.

### *Ferrissia noumeensis**

(including *Ferrissia* sp(p).)

**French Polynesia** (Society Islands [Tahiti]) — Starmühlner 1976, **American Samoa** (Tutuila) — Cowie 1998c; **Fiji** (Viti Levu) — Haynes 1994; **New Caledonia** — Cowie 1998c (citing the original description); **Papua New Guinea** — Starmühlner 1976.

### *Ferrissia sharpi**

**Hawaiian Islands** (Kaua‘i, O‘ahu, Hawai‘i) — Cowie 1997.

## FAMILY PHYSIDAE

Probably introduced on aquatic plants, perhaps via the aquarium trade. Many uncertain identifications.

### *Physa acuta*

**French Polynesia** (Marquesas Islands) — Fossati and Marquet 1998.

### *Physa compacta*

**Hawaiian Islands** (Kaua‘i, O‘ahu, Hawai‘i) — Cowie 1997.

### *Physa elliptica*

**Hawaiian Islands** (O‘ahu) — Cowie 1997.

### *Physa virgata*

**Hawaiian Islands** (Kaua‘i) — Cowie 1997.

### *Physa* sp.

**French Polynesia** (Society Islands [Tahiti]) — Starmühlner 1976; **Papua New Guinea** — Starmühlner 1976.

## FAMILY PLANORBIDAE

Probably introduced via the aquarium trade.

### *Gyraulus montrouzieri**

**New Caledonia** — Baker 1945.

### *Gyraulus rossiteri**

**New Caledonia** — Baker 1945.

### *Gyraulus singularis**

**Fiji** — Baker 1945.

### *Indoplanorbis exustus**

**Hawaiian Islands**, **French Polynesia** (Society Islands [Tahiti]), **Papua New Guinea** — Starmühlner 1976;

### *Planorbarius corneus*

**Fiji** (Viti Levu) — Haynes 1985.

### *Planorbella duryi*

**Hawaiian Islands** (Kaua'i) — Cowie 1997.

### *Physastra nasuta*

**Cook Islands** (Rarotonga) — Haynes 1990; **American Samoa** (Tutuila) — Cowie 1998c; **Tonga** — Starmühlner 1976 (probable record), (Tongatapu) — Haynes 1990; **Fiji** (Viti Levu) — Haynes 1994, (Vanua Levu) — Haynes 1988b; **New Caledonia**, **Vanuatu** — Starmühlner 1976.

## FAMILY LYMNAEIDAE

Probably introduced on aquatic plants, perhaps via the aquarium trade.

### *Lymnaea* sp.

**French Polynesia** (Society Islands [Tahiti]) — Starmühlner 1976.

### *Pseudosuccinea columella*

Hawaiian Islands (O'ahu) — Cowie 1997.

# Non-indigenous freshwater fishes, amphibians, and crustaceans of the Pacific and Hawaiian islands

Lucius G. Eldredge

***Department of Natural Sciences, Bishop Museum, 1525 Bernice St, Honolulu, Hawaii 96817-2704, USA***

## Abstract

Freshwater fishes, amphibians and crustaceans have been introduced to Pacific islands for aquaculture, sport, improvement of wild stock, the aquarium trade, and biological control. Many have been accidental escapes. Unintended impacts have been alterations to the habitat as well as direct competition for food and living space, introduction of pathogens, hybridisation, and environmental and socio-economic effects. Mozambique tilapia *Tilapia mossambica* is the most widely introduced freshwater fish species in the Pacific. Used to control mosquitos and aquatic weeds, it is now considered to be a pest, competing for food with other fish and native birds. Poeciliids such as guppies *Poecilia reticulata* have been introduced for biological control or aquaria or accidentally, but there have been more negative effects than positive ones, as they compete with or predate on native species and have introduced unwanted parasites. The escape of aquarium fish species has never resulted in a beneficial introduction. Among amphibians, the marine (or cane) toad *Bufo marinus*, introduced widely in the Pacific for biological control of insects and subsequently colonising other islands, is now considered to have been more disastrous than beneficial. Several crustaceans have been introduced for aquaculture or aquaria, and some now constitute threats to native species. This paper lists types of freshwater system occurring on Pacific islands; the lack of pertinent literature shows the need for further investigations on island freshwater ecosystems and their maintenance.

## 1. Introduction

Documentation of animals introduced to Pacific islands prior to European contact is for the most part anecdotal. Long-term, quantitative studies have not been conducted in the aquatic environment. The purpose of this review is to record the intentional and accidental introduction of freshwater fish, amphibians, and invertebrates (excluding molluscs) to Pacific islands. Six periods of introduction have been proposed (Eldredge 1992 1994).

1. Introduction by prehistoric voyagers. During the early periods of settlement and discovery of islands by prehistoric voyagers, traditional life styles were often maintained and interpreted as "transported landscapes" (Kirch 1982a 1982b).
2. The western exploration period. Beginning in the early 1500s with the Spanish and extending until nearly the end of the nineteenth century.
3. Expansion of western influence. During the late 1800s western influence and political colonisation expanded throughout the Pacific and continued well into the mid-1900s.
4. Post-World War II. After World War II and subsequent political changes, numerous development projects (especially in agriculture) and environmental restoration were encouraged.
5. Forms of agriculture and aquaculture. During the past 20 years great emphasis has been placed on the development and expansion of terrestrial agriculture and freshwater and marine aquaculture.
6. Impact of aquarium trade. The past decade, when greater westernisation and more affluence allowed for the development of the aquarium-ornamental aquatic plant and animal industry.

### 1.1 Motives for introducing species

Freshwater fishes and other inland aquatic species have been introduced into the Pacific and Hawaiian Islands for a variety of reasons. In his review of the introduction of inland aquatic species, primarily fishes but also amphibians and crustaceans, Welcomme (1992) analysed 1673 records of 291 species in 148 countries (very few of these records include information on Pacific islands). Nearly 50% of these took place between 1950 and 1989. The purposes for introduction proposed by Welcomme (1992) have been adopted by Lever (1996):

***Aquaculture***. Introduced species have played an important role in the development of aquaculture around

Hawaii Biological Survey Contribution No. 1999-011
Pacific Biological Survey Contribution No. 2000-007

the world. Many of these species have escaped or been intentionally released into natural waters and have become established (naturalised).

***Sport***. These introductions include: large species having fighting qualities sought by sports fishers; and species in support of sports fisheries.

***Improvement of wild stocks***. The purpose of these introductions is the development of a new food industry or subsistence fishery. These introductions have taken place, primarily, in faunistically poor regions. Introductions have also been into artificially developed habitats, such as reservoirs, canals, and the like.

***Ornament (aquarium trade)***. This category includes both introductions into ornamental fish ponds outside the natural range of a fish, and the many small, tropical species which abound in the aquarium trade.

***Biological control***. Biological control includes the control and regulation of vegetation, mosquitoes, snails, phytoplankton, and other fish.

***Accident***. Escapes or unplanned releases of species in culture; accidental releases may arise with the introduction of fry along with an intentionally introduced fish, the escape or release of bait fish, and the transport of eggs, juveniles, or adult fish in ballast water.

For aquaculture proposes the common carp [*Cyprinus carpio*] has been introduced to 50 countries worldwide; rainbow trout [*Oncorhynchus mykiss*] into 48, grass carp [*Ctenopharyngodon idella*] into 39, and Mozambique tilapia [*Tilapia mossambica*] into 34 (all of these have been introduced into Pacific island territories). Nine other species have been taken to ten or more countries. The percentages of introductions are given for the following purposes (Welcomme 1992):

| | |
|---|---|
| **Aquaculture** | **36.1%** |
| Sport | 11.8% |
| Improvement of wild stock | 10.8% |
| Accident | 9.0% |
| Ornament (aquarium trade) | 8.4% |
| Biological control | 5.4% |
| Unknown | 18.5% |

## 1.2 Ecological impacts

The ecological impacts of naturalised fish have been summarised by Taylor et al. (1984) and modified by Lever (1996):

***Habitat alterations***. These involve principally the displacement of aquatic vegetation and the degradation of water quality. Modification of aquatic plant communities can significantly affect native fishes and other animals. Reduction of macrophytes may promote increased turbidity.

Increased turbidity may disrupt the reproduction process of native fishes and other aquatic organisms and result in physiological stresses.

***Introduction of parasites, pathogens, and diseases***. Some pathogens such as infectious pancreatic necrosis and bacterial kidney disease, can be transmitted via gametes, therefore unfertilised ova, sperm, eggs, and embryos, as well as adults, are potential vectors. For the Pacific islands, Humphries (1995) has reviewed disease threats and provided a summary and checklist of diseases of aquatic aniimals to the Pacific and Hawaiian Islands.

***Trophic alterations***. The presence of introduced fishes may significantly increase the amount of prey available to natives. The feeding habits of introduced fishes can reduce the amount of forage available to native fish. Naturalised predatory fishes can affect the population dynamics of native prey species (Taylor et al. 1984).

***Hybridisation***. Hybridisation may lead to the deterioration of native genetic stocks. Hybridisation among introduced species (tilapia and poeciliids) remains a problem for those trying to identify introduced species. Maciolek (1984) noted hybridisation between largemouth bass and bluegills in the Hawaiian Islands.

***Spatial alterations***. Interaction between native and introduced species may be of significance to distribution, density, and existence of native species. Overcrowding may inhibit breeding of native species.

***Environmental effects***. The environment can be of significance to introduced species even when hydrological and climatic conditions appear suitable.

***Socio-economic effects***. Naturalised species may not be favoured for human consumption. In some areas introduced species have significantly contributed to the development of freshwater fisheries.

## 1.3 Criteria for success

Ehrlich (1986) listed eight ecological, genetic, and physiological characteristics that might lead to successful introduction:

1. Abundant in original range
2. Polyphagous
3. Short generation time
4. High genetic variability
5. Fertilised females able to colonise alone
6. Larger than most relatives

7. Closely associated with humans
8. Able to function in a wide range of physical conditions

After a cursory review of the characteristics, it should be noted that the majority of successful introduced species possess them with the exception of “larger size”, since most species introduced to islands are relatively small.

## 2. Freshwater fishes

A total of 86 species of fish have been introduced into fresh (some brackish) waters in the Pacific and Hawaiian Islands; not all of these introductions have been successful (see Systematic list below). A total of 72 fish species have been introduced into the Hawaiian Islands, and 59 have been observed or established since 1982. Twenty of the 59 are aquarium species. Papua New Guinea has received 30 species with 19 being considered established. Werry (1998) reported four species recently (between 1993 and 1997) introduced to Papua New Guinea for stock enhancing [*Colosoma bidens*, *Tor putitora*, *Acrossothedus hexagonocheilus*, and *Schizothorax richardsonii*]; they are not yet established. Guam and Fiji each have 24 species introduced, 12 species established on Fiji and 17 species established on Guam. New Caledonia has 8 established species; three previously reported are no longer found.

Nine species have been introduced into four or more territories:

| Species | No. of Territories |
|---|---|
| **Mozambique tilapia** | **19** |
| Mosquitofish | 14 |
| Guppy | 10 |
| Common carp | 6 |
| Mexican molly | 5 |
| Green swordfish | 5 |
| Goldfish | 4 |
| Largemouth bass | 4 |
| Redbelly tilapia | 4 |

Several species of the families Cichlidae (tilapia) and Poeciliidae (livebearers) have been introduced and many have become naturalised. Comments pertaining to these families are separated below, since many of the above-listed ecological impacts have been reported for these species.

### FAMILY CICHLIDAE [the tilapias]

Of the 18 species of the family Cichlidae listed below, Mozambique tilapia [*Tilapia mossambica*] is the most widely introduced species, having been taken to 19 Pacific island territories. Its native range is Lower Zambezi and associated East African rivers (Welcomme 1988). The species is very hardy and tolerates the high salinities of atoll lagoons, such as that at Fanning Atoll (Lobel 1980). Thought to be ideal pond fish, they readily produce stunted stocks when overcrowded, as the author has observed on Pagan in the Northern Mariana Islands.

Two taxonomic systems for tilapia (Family Cichilidae), one by Thys Van Den Audenearde, the other by Trewavas, differ in their generic and subgeneric designations. The American Fisheries Society Names of Fishes Committee recommended the Thys system exclusively through 1991. The current Committee gives equal weight to the Trewavas system; either may be used in American Fisheries Society publications (Kendall 1997). The Thys system is used herein [with the Trewavas name in brackets].

“The introduction of tilapia was a disaster on nearly all Pacific islands” (Baird 1976). Tilapia are now generally considered to be pests. Eradication has been suggested on Tarawa (Teroroko 1982) and Nauru (Ranoemihardjo 1981).

In Hawaii, tilapia were introduced for mosquito control, for aquatic weed control, and for potential baitfish. Tilapia are suspected of competing aggressively with the striped mullet (Eldredge 1994). At Fanning Atoll, tilapia disturb the benthic communities, and local fishermen reported fewer mullet, bonefish, and milkfish following the introduction of the Mozambique tilapia (Lobel 1980).

Mozambique tilapia held in floating tanks in Kaneohe Bay, Oahu, Hawaii, were found heavily infected with a marine monogean helminth ectoparasite (*Neobenedenia melleni*). The only other Pacific record of this helminth was from Chile and was not recorded in Hawaii by Yamaguti (1968), leading one to believe that this parasite was introduced sometime after 1968 (Kaneko et al. 1988). The significance of this finding is unknown.

At Saipan, the decline of the common moorhen [*Gallinula chloropus guami*] is thought to be caused, in part, by competition with Mozambique tilapia in Lake Susupe (Stinson et al. 1991). At Rennell Island, Solomon Islands, the extinction of two duck species [*Anas superciliosa* and *A. gibberifrons*] is speculatively attributed to the introduction of tilapia; however, the osprey [*Pandion haliaetus melvillensis*] which was always found along the seashore began to be seen at Lake Tegano after the introduction of tilapia (Diamond 1984). The originally algal-coloured green crater at Niuafo’ou Crater Lake, Tonga, lost its colour after the introduction of tilapia, and the duck population decreased markedly during the five years following the introduction (Scott 1993). In Hawaii tilapia are reported to have a significant impact on native birds through competition for food. On Maui, 20 native coots, ducks, and stilts were counted three years after the wetland was improved as nesting grounds; after the introduction of tilapia, the number of birds decreased by more than 50% (Kubota 1996).

*Tilapia mossambica*

[*Oreochromis mossambicus* (Peters, 1852)]

Hawaii—from Singapore 1951; 60 individuals, 14 survived for stocking, well established on all islands (Maciolek 1984)

Kiribati (Fanning Atoll)—from Hawaii 1958; released from research vessel, suspected negative impact on local fish (Lobel 1980); (Washington Island)—from Hawaii 1958; no apparent purpose, impact unknown (Lobel 1980); (Tarawa)—probably from Fiji 1963; to establish subsistence aquaculture, impact unknown (Villaluz 1972)

French Polynesia (Tahiti)—unknown source 1950s; impact unkown (Uwate et al. 1984)

Cook Islands—from Fiji 1955; for culture, impact unknown (Chimits 1957; Devambez 1964)

Samoa—from Fiji 1955; for small-scale culture (vanPel 1961)

American Samoa—from Samoa 1950s; to enhance stocks, fished at Aunu'u (vanPel 1959)

Niue—unkown source, date, and reason; impact unknown (Uwate et al. 1984)

Tonga (Tongatapu)—from Fiji 1955; for mosquito control, impedes aquaculture development (Chimits 1957; Devambez 1964, Fa'anunu, pers. comm.); (Nomuka Island)—from Tongatapu, 1970s; for mosquito control, fished, reduced milkfish population (Fa'anunu, pers. comm.); (Niuafo'ou Island)—probably from Tongatapu 1982; to enhance subsistence fishery (Fa'anunu, pers. comm.), duck population decreased (Scott 1993); (Vava'u Island)—probably from Tongatapu, unknown date; subsistence fishery (Fa'anunu, pers. comm.)

Wallis and Futuna (Wallis)—unknown source 1966; impact unknown (Hinds 1969)

Tuvalu (Funafuti Atoll)—unknown source, date, reason; impedes aquaculture development (Uwate et al. 1984); (Nanumanga Island and Niutao Atoll)—unknown source, date, reason; impact unknown (Uwate et al. 1984)

Fiji (Viti Levu)—from Malaysia 1954; for culture, subsistence culture (Holmes 1954; Andrews 1985), well established (Adams, pers. comm.); (Vanua Levu)—from Viti Levu, unknown date; for culture; well established (Adams, pers. comm.)

New Caledonia—from Philippines 1955; for culture (vanPel 1956), well established (Adams, pers. comm.)

Vanuatu (Efate Island and Tanna Island)—from New Caledonia 1950s; to enhance stocks, impact unknown (Uwate et al. 1984)

Solomon Islands (Guadalcanal)—unknown source 1957; for culture, impact unknown (Nichols, pers. comm.); (Malaita and Santa Anna)—probably from Guadalcanal, after 1957; impact unknown (Nichols, pers. comm.); (Rennel)—from Guadalcanal, after 1957; to enhance stocks, subsistence fishery (Wolff 1969)

Papua New Guinea—from Malaysia 1954; for culture, fishery established (Devambez 1964; Glucksman et al. 1976; Allen 1991)

Nauru—unknown source 1960s; for mosquito control, impedes traditional aquaculture (Ranoemihardjo 1981)

Federated States of Micronesia (Yap)—unknown source 1970s; for culture, impact unknown (Nelson 1987; Nelson and Hopper 1989)

Guam—from the Philippines 1954; for culture in fresh and brackish water and for aquatic weed control (DeLeon and Liming 1956; Brock and Takata 1956)

Northern Mariana Islands (Saipan)—from the Philippines 1955; to enhance stocks, impact unknown (Anon. 1955); (Pagan)—from Saipan 1955; to enhance freshwater lakes (Brown 1955)

*Tilapia niloticus*

[*Oreochromis niloticus* (Linnaeus, 1758)]

Cook Islands (Rarotonga)—from Fiji 1993; two shipments, no survival during first shipment (Adams, pers. comm.)

Samoa—unknown source, 1991 for aquaculture (Zann 1991)

Fiji (Viti Levu)—from Israel 1968; for culture, subsistence fishery (Adams, pers. comm.); (Vanua Levu)—from Viti Levu 1988-1989; for culture, subsistence fishery (Adams, pers. comm.)

*Tilapia aurea*

[*Oreochromis aureus* (Steinbachner, 1864)]

Fiji (Viti Levu)—unknown source 1974; for research, not established (Andrews 1985)

*Tilapia urolepis*

[*Oreochromis urolepis* (Norman, 1923)]

Fiji (Viti Levu)—from Taiwan 1985; for research, not established (Nelson and Eldredge 1991)

*Tilapia macrochir*

[*Oreochromis macrochir* (Boulenger, 1912)]

Hawaii—from Congo 1957; Maui and Oahu established (Brock 1960)

*Tilapia rendalli*

[*Tilapia rendalli* (Boulenger, 1896)]

Wallis and Futuna (Wallis, Lake Kikila)—unknown source 1967–1970; as *T. melanopleura*, spread to other freshwater areas (Tahimili, pers. comm.)

Papua New Guinea—from UK 1991; to enhance stock, rapidly spreading (Coates, pers. comm.)

*Tilapia zilli* [*Tilapia zillii* (Gervais, 1848)]

Hawaii—from West Indies 1955; 1500 released in Maui plantation reservoir 1957; established on Oahu, Maui, Hawaii (Brock 1960); from Congo 1957 (as *T. melanopleura*), established on Oahu, Maui, Kauai (Brock 1960)

Fiji—from Hawaii 1957; for culture, distribution and impact unknown (vanPel 1959; Adams, pers. comm.)

Guam—probably from Hawaii 1956; for aquatic weed control, small recreational fishery (Brock and Yamaguchi 1955; Brock and Takata 1956)

*Tilapia melanotheron*
[*Sarotherodon melanotheron* (Ruppell, 1852)]

Hawaii—unkown source 1970s; established on Oahu

*Tilapia occidentalis*
[*Sarotherodon occidentalis* (Daget, 1862)]

New Caledonia—probably from the Philippines, for fishery (Gargominy et al. 1996; Seret 1997)

### FAMILY POECILIIDAE [livebearers, mollies]

Poeciliids have been intentionally introduced for biological control, mostly mosquitos, and aquatic weeds; to protect species from extinction; and to dispose of unwanted pet or experimental fishes, and many have escaped or have been released through the ornamental fish culture industry. Through biological control and species conservation, introductions were intended to have positive effects; however, there are more negative effects than positive ones (Courtenay and Meffe 1989).

Negative effects include predation on larvae, juveniles, and small adult native fishes. Hybridisation, behavioral interactions, and introduction of parasites and diseases may pose further threats. Hybrids between *Poecilia reticulata* and *P. mexicana* and between *P. reticulata* and *Xiphophorus helleri* have been shown to have caused threats to native fish species in the western USA (Courtenay and Meffe 1989).

The guppy [*Poecilia reticulata*] has been introduced into ten Pacific island territories. It is a native of Venezuela, Barbados, Trinidad, northern Brazil, and the Guyanas (Welcomme 1988). It is very prolific and spreads rapidly through ditches, swamps, and ponds into areas where it becomes established. Its rapid maturity and high fecundity have earned it its alternative name "million fish". Individuals are very popular with the aquarium industry because of its brilliantly coloured varieties (Lever 1996). Guppies eat the eggs of other fish and have been blamed for the decline of a number of fish species.

Guppies (along with tilapia) have been implicated in the decrease of the native atyid shrimp *Halocaridina rubra* and with native amphipods in the unique anchialine pools of the island of Hawai'i. In a study conducted in 1994, Brock and Kam (1997) found shrimp present in pond No. 19, but five months later, following colonisation by guppies, all the shrimp had disappeared. In a June 1997 survey, the shrimp and amphipods were still absent. Another series of pools that were considered the "best example of anchialine pools" were colonised by guppies probably between late fall 1995 and January 1996, but by July 1996 the shrimp and most of the amphipods were absent (Brock and Kam 1997).

Introduced poeciliids (*P. reticulata*, *P. mexicana*, *X. helleri*, and *G. affinis*) present threats to native ecosystems throughout Hawaii. The endemic *Megalagrion* damselflies are "now absent from virtually all lowland areas where early collections occurred prior to poeciliid introductions" (Englund, 1999). Introduced odonates (dragonflies and damselflies) were found living sympatrically with native damselflies in areas lacking poeciliids, and the study found little or no evidence that these introduced species affected native damselflies. By 1935, the damselfly *Megalagrion xanthomelas* was found on Oahu only in streams without these introduced species (Polhemus and Asquith 1996). *Poecilia mexicana* readily consumed the post-larvae of returning native stream gobies (Filbert and Englund 1995).

In Hawaii in a study of freshwater fish parasites, native fish in streams without introduced fish had no adult helminth parasites. In streams with guppies and green swordtails, the native gobioid fishes had three helminth species in common with the poeciliids—a nematode [*Camallanus cotti*]. the Asian tapeworm [*Bothriocephalus acheilognathi*], and a leech [*Myzobdella lugubris*] (Font and Tate 1994). Since poeciliids have been widely released in Hawaiian freshwater habitats for mosquito control and are also released from aquaria, they may be the source of both *C. cotti* and *B. acheilognathi*. The source of the leech is more problematic. In a more recent study, Font (1997) analysed eleven species of helminth parasites from native stream fishes. Of the parasites in native species, four originated from marine fishes; three used migratory piscivorous birds as final hosts and fishes as intermediate hosts; and four originated in introduced freshwater fishes. In addition to the three helminth species mentioned above, a trematode metacercarial larvae [*Ascocotyle tenuicollis*] was also identified from a native fish when found living with mosquitofish (Font 1997).

The mosquitofish [*Gambusia affinis*] has been introduced into 14 Pacific islands. Its native range is southern USA and northern Mexico. Two subspecies *G. a.*

*affinis* and *G. a. holbrooki* have been recognised, but the differences are insignificant and their historical origins are mixed (Lloyd and Tomasov 1985). *Gambusia affinis* is used herein.

The mosquitofish "is now probably the most widely distributed fresh-water fish in the world" (Krumholz 1948). The extreme tolerance of low as well as high temperatures, of low dissolved oxygen, and of high salinity conditions has allowed this fish to become widely established. Mosquito control was the prime reason for introduction, but its success has been questioned (Welcomme 1988; Lever 1996).

Controversy has followed the introduction of mosquitofish. Krumholz (1948) reviewed earlier work and introductions. Myers (1965) stated, "The fact is that *Gambusia* is a very dangerous fish to introduce into a place where it does not occur naturally, and is little or no better as a mosquito destroyer than many other species"; he further added, "…it has gradually wiped out most or all of the smaller native mosquito-destroying species," (p. 102). Some 35 species worldwide have been impacted by the mosquitofish (Lloyd 1990).

Mosquitofish fit directly into Ehrlich's (1986) invasion characteristics except for larger size (Courtenay and Meffe 1989). The authors add two features that facilitate the success of this species: mosquitofish produce several times a year moderate numbers of young which are protected by the mother but which become immediately independent. Adult mosquitofish are extremely aggressive, and females attack other fish, shredding fins and sometimes killing them (Courtenay and Meffe 1989; Morgan et al. 1998).

Mosquitofish are included with other poeciliid species in the impact in Hawaiian anchialine pools and the elimination of the endemic herbivorous shrimp *Halocaridiana rubra* by initiating a change in ecological succession. Predation reduced or eliminated the shrimp, and slowly macroalgae established, overgrowing on the distinctive cyanobacterial crust. With this change, the appearance of the anchialine system changed (Brock and Kam 1997).

Mosquitofish are also potential hosts of helminth parasites which have been transmitted to native fishes (see discussion under guppy, above).

*Gambusia affinis (Baird and Girard, 1853)*

Hawaii—from Texas 1905+, for mosquito control, established on all islands (Maciolek 1984)

Kiribati (Line Islands)—unknown source, date, reason (Guinther 1971; Maciolek 1984)

French Polynesia (Tahiti)—before 1926, for mosquito control (Krumholz 1948); apparently not established (Marquet and Galzin 1992)

Cook Islands (Rarotonga, Mitiaro)—for mosquito control (Krumholz 1948)

Samoa—unknown source, date, reason (Zann 1991)

American Samoa—probably from Hawaii, for mosquito control (Krumholz 1984)

Fiji (Viti Levu)—unknown source 1930s, for mosquito control, pest in aquaculture (Andrews 1985)

Vanuatu—source unknown 1943 (Haas and Pal 1984)

Solomon Islands—probably from Hawaii, before 1948, mosquito control (Krumholz 1948)

Papua New Guinea—from Australia 1930; mosquito control, possible threat to native fishes (Werry 1998)

Marshall Island (Jaluit)—mosquito control (Gressitt 1961)

Federated States of Micronesia (Pohnpei, Pulusuk)—unknown (Nelson and Cushing 1982)

Guam—mosquito control and aquatic weed control 1955 (Brock and Yamaguchi 1955)

Northern Mariana Islands (Tinian, Saipan, Pagan)—unknown (Best and Davidson 1981)

## 2.1 Aquarium introductions

In 1990, Courtenay and Stauffer (1990) reported that of the 46 species of non-indigenous fish established in the contiguous United States, approximately 65% were thought to have originated through aquarium trade. The majority of these same species have been introduced to Pacific island territories and have the same impacts as discussed above. The escape or release of aquarium fish has never resulted in a beneficial introduction (Courtenay and Stauffer 1990).

In the Hawaiian Islands, 20 aquarium species have been observed or considered established between 1982 and 1992, but only on Oahu (modified from Devick 1991a) [Date with each record is the first time the species was reported; area of origin is noted; ? = current status unknown; * = reported but not collected]:

*African catfish [*Synodontis* sp.]. Unknown

Angelfish [*Pterophyllum* sp.]. South America 1982

*Arowana [*Osteoglossum* sp.] Unknown

*Armored catfish [*Peckoltia* sp.]. South America

Armored catfish/radiated ptero [*Pterygoplichthys multiradiatus*]. South America 1986

Armored catfish/suckermouth catfish [*Hypostomus* spp.]. South America 1984

Asian needlefish [*Xenentodon cancila*]. Southeast Asia 1988

?Black-banded leporinus [*Leporinus fasciatus*]. South America 1984

Black-spot barb [*Puntius filamentosus*]. India 1984

Blue-eyed cichlid [*Cichlasoma spilurum*]. Guatemala 1984

Bristle-nosed catfish [*Ancistrus* sp.]. South America 1985

Bronze corydoras [*Corydoras aeneus*]. South America 1984
Cichlid [*Cichlasoma* sp.]. Unknown 1988
Convict cichlid [*Cichlasoma nigrofasciatum*]. Central America 1983
Jewel cichlid [*Hemichromis elongatus*]. Africa 1991 (Miyada 1991)
Piranha [*Pygocentrus mattereri*]. South America 1992 (Sakuda 1993; Radtke 1995)
Rainbow krib [*Pelvicachromis pulcher*]. Nigeria 1984
?Tambaqui [*Colossoma macropomum*]. South America 1987
Tilipia [*Tilapia* spp.]. Africa 1983
Topminnow [*Poecilia* sp.]. Unknown 1986

Further identifications are tentatively made for two armoured catfish—*Ancistrus* cf. *temmincki* and *Hypostomus watawata*-group (Sabaj and Englund 1999).

## 2.2 Aquaculture introductions

Through aquaculture, numerous species have been transported throughout the region. Davidson et al. (1992) reviewed the species introduced for aquaculture purposes and listed species (freshwater and marine) cultured in Hawaii. Eldredge (1994, MS) reviewed the introduced aquaculture animals in the Pacific islands.

## 2.3 Checklist of introduced fishes

A systematic list of freshwater fishes introduced to Pacific and Hawaiian Islands follows. It is based on Maciolek (1984) with the additions of Papua New Guinea by Eldredge (1994) and numerous additions of more recent information. Family order is based on Berra (1981), scientific and common names from Robins et al. (1991), and geographic order from Motteler (1986). [* = species not established or information not reliable]

ANGUILLIDAE [Freshwater eels]

American eel [*Anguilla rostrata* (Lesueur)].
*__Guam__—FitzGerald 1982 (failed)

Japanese eel [*Anguilla japonica* Temminck and Schlegel].
*__Guam__—FitzGerald 1982 (discontinued)

CLUPEIDAE [Herring]

Freshwater herring [*Potamalosa richmondia* (Macleay)].
*__Fiji__—Andrews 1985

SALMONIDAE [Trout]

Rainbow trout [*Oncorhynchus mykiss* (Walbaum); formerly known as *Salmo gardineri*].
**Hawaii**—Needham and Welsh 1953;
*__French Polynesia__ (Tahiti)—Maciolek 1984;
**New Caledonia**—Gargominy et al.,1996;
**Papua New Guinea**—Glucksman et al. 1976; Allen 1991; Werry 1998

Chinook salmon [*Oncorhynchus tshawytscha* (Walbaum)].
*__Hawaii__—Needham and Welsh 1953; Maciolek 1984

Brown trout [*Salmo trutta* Linnaeus].
*__Hawaii__—Needham and Welsh 1953; Maciolek 1984;
**Fiji**—Andrews 1985;
**Papua New Guinea**—Glucksman et al. 1976; Allen 1991, Werry 1998

Brook trout [*Salvelinus fontinalis* (Mitchill).
*__Hawaii__—Needham and Welsh 1953; Maciolek 1984;
*__Papua New Guinea__—Glucksman et al. 1976; Werry 1998

RETROPINNIDAE [Southern hemisphere smelts]

Australian smelt [*Retropinna semoni* (Weber)]
*__Papua New Guinea__—Glucksman et al. 1976; Werry 1998 (no longer exists)

PLECOGLOSSIDAE [Plecoglossids]

Plecoglossid [*Plecoglossus altivelis*].
*__Hawaii__—Maciolek 1984

CHANNIDAE [Milkfish]

Milkfish [*Chanos chanos* (Forskal)].
**Cook Islands** (Mitiaro)—Adams, pers. comm;
**Guam**—FitzGerald 1982

CYPRINIDAE [Carps]

Goldfish [*Carassius auratus* (Linnaeus)].
**Hawaii**—Maciolek 1984;
**Western Samoa**—Maciolek 1984; Zann 1991;
**Fiji**—Adams, pers. comm.;
**Papua New Guinea**—Allen 1991 (as *Crassius auratus*)

Common carp [*Cyprinus carpio* Linnaeus].
**Hawaii**—Maciolek 1984;
*__French Polynesia__ (Tahiti)—Maciolek 1984;
*__Fiji__—Andrews 1985;
**New Caledonia**—Maciolek 1984; Gargominy et al. 1996;
**Papua New Guinea**—Glucksman et al. 1976; Allen 1991; Werry 1998;
**Guam**—Maciolek 1984

Bighead carp [*Aristichthys nobilis* (Richardson)].
*__Fiji__—Andrews 1985;
*__Guam__—FitzGerald 1982

Grass carp [*Ctenopharyngodon idella* (Valenciennes)].
**Hawaii**—Maciolek 1984;
**Fiji**—Andrews 1976; Vereivalu 1990;
*__Papua New Guinea__—Glucksman et al. 1976 (DASF ponds, not released 1961); Werry 1998;
**Guam**—FitzGerald 1982

Silver carp [*Hypophthalmichthys molitrix* (Valenciennes].
**Fiji**—Andrews 1985 (as *Hypothamicthys molitrix*);
*__Papua New Guinea__—Glucksman et al. 1976 (DASF ponds, not released 1961; Werry 1998 (no longer exists)

Javanese carp [*Puntius gonionotus* (Bleeker)].
**Fiji**—Ryan 1980; Andrews 1985;
***Papua New Guinea**—Glucksman et al. 1976; Werry 1998 (no current reports)

Green barb [*Puntius semifasciolatus* (Gunther)].
**Hawaii**—Maciolek 1984;
***Papua New Guinea**—West and Glucksman 1976 (single specimen, Waigani Swamp, January 1966)

Barb [*Puntius sealei* (Herre)].
**Palau** (Babelthuap)—Bright and June 1981

[*Tor* (=*Cyprinus*) *putitora*].
**Papua New Guinea**—Werry 1998 (not yet established)

[*Acrossochedus hexagonocheilus*].
**Papua New Guinea**—Werry 1998 (not yet established)

[*Schizothorax richardsonii*].
**Papua New Guinea**—Werry 1998 (not yet established)

### COBITIDAE [Loaches]

Oriental weatherfish [*Misgurnus anguillicaudatus* (Cantor)].
**Palau** (Babelthuap)—Bright and June 1981

### CHARACIDAE [Characins]

Characin [*Colossoma bidens*].
**Papua New Guinea**—Werry 1998 (not yet established)

### ICTALURIDAE [Catfishes]

Channel catfish [*Ictalurus punctatus* (Rafinesque)].
**Hawaii**—Maciolek 1984;
***French Polynesia** (Tahiti)—Maciolek 1984;
***Guam**—Maciolek 1984

Brown bullhead [*Ictalurus nebulosus* (Lesueur)].
***Hawaii**—Maciolek 1984

### CLARIIDAE [Airbreathing catfishes]

Walking catfish [*Clarias batrachus* (Linnaeus)].
**Papua New Guinea**—Allen 1991; Werry 1998;
**Guam**—Myers, pers. comm.

Catfish [*Clarias macrocephalus*].
**Guam**—Anon. 1910; Maciolek 1984 (as *C. batrachus*)

Catfish [*Clarias fuscus*].
**Hawaii**—Maciolek 1984

### SCHILBIDAE [Schilbids]

Swai [*Pangasius sutchi* Fowler].
***Guam**—FitzGerald 1982

### ARIIDAE [Ariids]

*Arius* sp.
***Guam**—Anon. 1910; Maciolek 1984

### ORYZIATIDAE

Oryziatid [*Oryzias latipes*].
***Hawaii**—Maciolek 1984

### CYPRINODONTIDAE

[*Aplocheilus lineatus*].
***Hawaii**—Maciolek 1984

Gulf killifish [*Fundulus grandis* Baird and Girard].
***Hawaii**—Maciolek 1984

[*Nothobranchius guentheri*].
***Hawaii**—Maciolek 1984

### PLOTOSIDAE [Plotosids]

Freshwater catfish [*Tandanus tandanus* Mitchell].
***Papua New Guinea**—Glucksman et al. 1976 (DASF ponds, stocks destroyed); Werry 1998 (no longer exists)

### POECILIIDAE [Livebearers, Mollies]

Mosquitofish [*Gambusia affinis* (Baird and Girard)].
**Hawaii**—Maciolek 1984;
**Kiribati** (Line Islands)—Maciolek 1984;
**French Polynesia** (Tahiti)—Rougier 1926; Maciolek 1984;
**Cook Islands** (Rarotonga, Mitiaro)—Maciolek 1984;
**Samoa** (Savaii)—Maciolek 1984; Zann 1991;
**American Samoa**—Maciolek 1984;
**Fiji**—Ryan 1980; Andrews 1985;
**Vanuatu**—Haas and Pal 1984;
**Solomon Islands**—Krumholz 1948;
**Papua New Guinea**—Glucksman et al. 1976; Allen 1991; Werry 1998;
**Marshall Islands** (Jaluit)—Maciolek 1984;
**Federated States of Micronesia** (Pohnpei, Pulusuk)—Maciolek 1984; Nelson and Cushing 1982;
**Guam**—Brock and Yamaguchi 1955; Maciolek 1984;
**Northern Mariana Islands** (Pagan, Saipan, Tinian)—Best and Davidson 1981

Guppy [*Poecilia reticulata* Peters].
**Hawaii**—Maciolek 1984;
**French Polynesia** (Tahiti, Moorea, Tubuai)—Maciolek 1984; Marquet and Galzin 1992; Marquet et al. 1997;
**Cook Islands** (Rarotonga, Mitiaro)—Maciolek 1984;
**Samoa** (Savaii)—Maciolek 1984;
**Fiji**—Ryan 1980; Andrews 1985;
**New Caledonia**—Maciolek 1984; Gargominy et al. 1996; Seret 1997
**Vanuatu** (Tanna)—Maciolek 1984;
**Papua New Guinea**—West 1973; Allen 1991; Werry 1998;
**Palau** (Babelthuap)—Bright and June 1981;
**Guam**—Maciolek 1984

Mexican molly [*Poecilia mexicana* Steindachner)].
**Hawaii**—Maciolek 1984;
**French Polynesia** (Tahiti)—Maciolek 1984; Marquet and Galzin 1992; Marquet et al. 1997;
**Samoa** (Savaii)—Maciolek 1984;
**American Samoa**—Maciolek 1984;
**Fiji**—Ryan 1980; Andrews 1985

Sailfin molly [*Poecilia latipinna* (Lesueur)].
**Hawaii**—Maciolek 1984;
**Guam**—Maciolek 1984

Cuban limia [*Lima vittata* (Guichenot)].
**Hawaii**—Maciolek 1984;
*__American Samoa__—Maciolek 1984

[*Poecilia sphenops*].
**Hawaii**—Maciolek 1984

Green swordtail [*Xiphophorus helleri* Heckel].
**Hawaii**—Maciolek 1984;
**Fiji**—Ryan 1980; Andrews 1985;
**New Caledonia**—Gargominy et al. 1996; Seret 1997;
**Papua New Guinea**—Allen 1991; Werry 1998;
**Guam**—Best and Davidson 1981

Southern platyfish [*Xiphophorus maculatus* (Gunther)].
**Hawaii**—Maciolek 1984;
**New Caledonia**—Gargominy et al. 1996;
**Palau** (Babelthuap)—Bright and June 1981

Variable platyfish [*Xiphophorus variatus* (Meek)].
**Hawaii**—Maciolek 1984

## CHANNIDAE [Snakeheads]

Striped snakehead [*Channa striata* (Bloch) (=*Ophiocephalus striatus*)].
**Hawaii**—Maciolek 1984 (as *O. striatus*);
*__Fiji__ (Viti Levu)—Devambez 1964; Andrews 1985; Andrews 1985;
**Guam**—Maciolek 1984; Tibbatts, pers. comm.

## SYNBRANCHIDAE [Synbranchids]

Synbranchid [*Monopterus albus*].
**Hawaii**—Maciolek 1984

## PERCICHTHYIDAE [Temperate basses]

Striped bass [*Morone saxatilis* (Walbaum)].
*__Hawaii__—Maciolek 1984

Australian bass [*Macquaria novemaculeata* (Steindachner)].
*__Fiji__—Andrews 1985

Estuary perch [*Macquaria colonorum*? (Gunther)].
*__Fiji__—Ryan 1980;
*__Papua New Guinea__—Glucksman et al. 1976; Werry 1998 (as *Percalates colonorum*)

Golden perch [*Plectroplites ambiguus* Richardson)].
**Papua New Guinea**—Glucksman et al. 1976; Werry 1998 (as *Perctroplites ambiguus*)

## PERCICHTHYIDAE [Temperate basses]

Barramundi [*Lates calcarifer* Bloch)].
**French Polynesia** (Tahiti)—Fuchs 1987; Preston 1990;
**Guam**—Crisostomo, pers. comm.

## TERAPONIDAE [Terapon perches]

Silver perch [*Bidyanus bidyanus* (Mitchell)].
*__Papua New Guinea__—Glucksman et al. 1976; Werry 1998 (no longer exists)

Spangled perch [*Leiopotherapon unicolor* (Gunther) (=*Madigania unicolor*?)].
**Fiji**—Ryan 1980; Andrews 1985

Silver grunter [*Mesopristes argentus* (Cuvier)].
*__Fiji__—Ryan 1980; Andrews 1985

## CENTRARCHIDAE [Sunfishes]

Bluegill [*Lepomis macrochirus* Rafinesque].
**Hawaii**—Maciolek 1984

Small mouth bass [*Micropterus dolomieui* Lacepede].
**Hawaii**—Maciolek 1984;
*__Fiji__ (Viti Levu)—Devambez 1964; Maciolek 1984;
*__Guam__—Devambez 1964; Maciolek 1984

Largemouth bass [*Micropterus salmoides* (Lacepede)].
**Hawaii**—Maciolek 1984;
*__French Polynesia__ (Tahiti)—Maciolek 1984;
**Fiji**—Farman 1984;
**New Caledonia**—Farman 1984; Maciolek 1984; Gargominy et al. 1996; Seret 1997;
**Guam**—Devambez 1964; Maciolek 1984

## CICHLIDAE [Cichlids]

Peacock cichlid [*Cichla ocellaris* Bloch and Schneider].
**Hawaii**—Maciolek 1984;
**Guam**—Maciolek 1984

Oscar [*Astronotus ocellatus* (Agassiz)].
**Hawaii**—Maciolek 1984;
**Guam**—Maciolek 1984

Managuense [*Cichlasoma managuense* Gunther].
**Hawaii**—Englund, pers. comm.

Firemouth cichlid [*Cichlasoma meeki* (Brind)].
**Hawaii**—Maciolek 1984

Convict cichlid [*Cichlasoma nigrofasciatum* (Gunther)].
**Hawaii**—Courtenay et al. 1991

Blue-eye cichlid [*Cichlasoma spilurum* (Gunther)].
**Hawaii**—Courtenay et al. 1991

Cichlid [*Cichlasoma* sp.].
**Hawaii**—Maciolek 1984

Rainbow krib [*Pelvicachromis pulcher* (Boulenger].
**Hawaii**—Courtenay et al. 1991

Mozambique tilapia [*Tilapia mossambica*; *Oreochromis mossambicus* (Peters)].
**Hawaii**—Maciolek 1984;
**Kiribati** (Fanning, Washington, Gilbert Islands)—Lobel 1980; Maciolek 1984;
**French Polynesia** (Tahiti, Moorea, Tubuai, Mangereva)—Maciolek 1984; Marquet and Galzin 1992;
**Cook Islands** (Rarotonga, Mitiaro)—Maciolek 1984;
**Samoa** (Savaii)—Maciolek 1984; Zann 1991;
**American Samoa**—Maciolek 1984;
**Niue**—Maciolek 1984;
**Tonga** (Tongatapu, Vavau, Niuofo'ou)—Maciolek 1984; Scott 1993;
**Wallis and Futuna** (Wallis)—Maciolek 1984;
**Tuvalu** (Funafuti, Namumanga, Niutao)—Uwate et al. 1984;

**Fiji**—Andrews 1985;
**New Caledonia**—Maciolek 1984; Gargominy et al. 1996; Seret 1997;
**Vanuatu**—Maciolek 1984;
**Solomon Islands** (Guadalcanal, Rennell Island, Malaita, Santa Ana, Bougainville)—Maciolek 1984; Nelson and Eldredge 1991;
**Papua New Guinea**—Glucksman et al. 1976; Allen 1991; Werry 1998;
**Nauru**—Maciolek 1984;
**Guam**—DeLeon and Liming 1956; Maciolek 1984;
**Northern Mariana Islands** (Pagan, Saipan, Tinian)—Maciolek 1984

Nile tilapia [*Tilapia nilotica*; *Oreochromis niloticus* (Linnaeus)].
**Samoa**—Zann 1991;
**Fiji**—Andrews 1985

Blue tilapia [*Tilapia aurea*; *Oreochromis aureus* (Steindachner)].
***Fiji**—Andrews 1985

Wami tilapia [*Tilapia urolepis*; *Oreochromis urolepis* (Norman)].
**Fiji**—Nelson and Eldredge 1991 (as *O. hornorum*)

Longfin tilapia [*Tilapia macrochir*; *Oreochromis macrochir* Boulenger].
**Hawaii**—Maciolek 1984 (also as *T. melanopleura*);
**Wallis** (Lake Kikila)—Tahimili, pers. comm.

Longfin tilapia [*Tilapia melanotheron*; *Sarotherodon melanotheron* (Ruppell)].
**Hawaii**—Maciolek 1984

Redbreast tilapia [*Tilapia rendalli*; *Tilapia rendalii* (Boulenger)].
**Hawaii**—Maciolek 1984;
**Wallis** (Lake Kikila)—Tahimili, pers. comm, (as *T. melanopleura*);
***Fiji**—Andrews 1985;
***New Caledonia**—Maciolek 1984; Gargominy et al. 1996;
**Papua New Guinea** (Sepik and Ramu Rivers)—Osborne 1993; Werry 1998; Coates, pers. comm.;
**Guam**—Maciolek 1984

African tilapia [*Tilapia occidentalis*; *Sarotherodon occidentalis* (Daget)].
**New Caledonia**—Gargominy et al. 1996; Seret 1997

Lake Malawi cichlid [*Melanochromis johanni*].
**Hawaii**—Englund, pers. comm

Jewelfish [*Hemichromis elongatus* (Guichenot in Dumeril)].
**Hawaii**—Yamamoto, pers. comm.

GOBIIDAE [Gobies]

Goby [*Mugilgobius cavifrons* (Weber)].
**Hawaii**—Randall et al. 1993

BLENNIDAE [Blennies]

Fang-toothed blenny [*Omobranchus ferox* Herre].
**Hawaii**—Englund, pers. comm.

MUGILIDAE [Mullet]

Freshwater mullet [*Trachystoma petardi* (Castelnau)].
***Papua New Guinea**—Glucksman et al. 1976; Werry 1998 (no longer exists)

Striped mullet [*Mugil cephalus* Linnaeus].
**Tonga**—Anon. 1992

ELEOTRIDIDAE [Gudgeons]

Western carp gudgeon [*Hypselotris klunzingeri* (Ogilby)].
***Papua New Guinea**—Glucksman et al. 1976; West and Glucksman 1976; Werry 1998 (no longer exists)

ANABANTIDAE [Climbing perches] (=Belontiidae)

Climbing perch [*Anabas testudineus* (Bloch)].
**Papua New Guinea**—Allen 1991

Snakeskin gourami [*Trichogaster pectoralis* (Regan)].
***New Caledonia**—Maciolek 1984; Gargominy et al. 1996;
**Papua New Guinea**—Glucksman et al. 1976; Allen 1991; Werry 1998

Threespot gourami [*Trichogaster trichopterus* (Pallas)].
**Papua New Guinea**—West 1973; Allen 1991; Werry 1998

Pearl gourami [*Trichogaster leeri* ].
***Hawaii**—Maciolek 1984

Fighting fish [*Betta brederi* Myers].
**Guam**—Maciolek 1984

OSPHRONEMIDAE [Giant gouramies]

Giant gourami [*Osphronemus goramy* Lacepede].
***Hawaii**—Maciolek 1984;
***New Caledonia**—Maciolek 1984; Gargominy et al. 1996;
**Papua New Guinea**—Glucksman et al. 1976; Allen 1991; Werry 1998

# 3. Amphibians

Amphibians are virtually non-existent naturally east of the Melanesian islands—Fiji with only two species and Palau with one (Allison 1996).

## 3.1 Marine toad (cane toad) [*Bufo marinus* Linnaeus, 1758]

The marine or cane toad occurs naturally from southern Texas and western Mexico to central Brazil (Zug and Zug 1979). Because of their large size and their wide adaptability, these toads were thought to be good biological control agents, primarily for insects. They have been introduced throughout much of the Pacific area during the past 50 years and are now considered one of the most widespread terrestrial vertebrates (Easteal 1981).

In the Pacific, the first marine toads were brought to Oahu, Hawaii, in 1932 from Puerto Rico (Pemberton 1934). They were later introduced to Guam, originally for insect and garden slug control. Some nineteen individuals from Hawaii were released at Agana Springs, Guam, in July 1937 (Anon. 1937a). By September of that year, toads were found as far as Piti, several miles to the south (Anon. 1937b). The first record of toads outside Guam was from Tinian in 1944 (Stohler and Cooling 1945) where approximately 4000 individuals were found in cisterns and lily ponds, the original stock probably having arrived from Guam (Townes 1946); toads were also found at Saipan and Rota. Fisher (1948) noted that toads were abundant on Pohnpei and Yap. Savage (1960) reported individuals from Palau, suggesting that the Palau forms may have originated directly from the west coast of Mexico.

In early 1936, 67 half-grown adult marine toads were imported to Fiji from Hawaii (Jack 1936). Shortly afterwards individuals were released at several locations on Viti Levu. By 1938, *B. marinus* had spread throughout Viti Levu and on to Vanua Levu, Taveuni, Rabi, and Kadavu (Lever 1938); Easteal (1981) reported individuals on Ovalau.

Because of the supposed success as biological control animals, individuals from Hawaii were imported in Febrary 1937 to Papua New Guinea directly to a governmental experiment station on New Britain (Zug et al. 1975). From here they were distributed throughout the "Territory of New Guinea". Zug et al. (1975) provided a lengthy list of site-specific introductions within most of the Papua New Guinea provinces. In November 1939, 150 adult marine toads were imported to Funafuti, Tuvalu, from Suva, Fiji (Lever 1942). In February 1940, individuals were taken to Guadalcanal, Solomon Islands (Lever 1942). Several other islands of the Solomon Islands are reported to have *B. marinus* (Easteal 1981).

Marine toads were introduced to Tutuila, American Samoa, from Hawaii in 1953 (Anon. 1953), although there were strong objections. Several pairs were imported and bred in artificial ponds; tadpoles were distributed on Tutuila (Amerson et al 1982). These authors provided details of the status of the species, indicating that they have done more harm than good. Toads have now colonised Aunu'u (Grant 1996). Marine toads are not found in Tonga, Samoa, and the Marshall Islands. One individual was collected within a kilometre of the International Airport in the Cook Islands in 1986 and was killed (McCormack, pers. comm.).

Ecological studies have been conducted in Papua New Guinea (Zug et al. 1975), Guam (Chernin 1979), and American Samoa (Amerson et al. 1982). The consensus indicates that marine toad introductions have been more disastrous than beneficial. Toads are generally considered a nuisance. They have poisonous parotid glands behind the head which secrete toxins that can be "squirted in jets a distance of at least one meter" (Tyler 1975). Numerous cat and dog deaths are reported; human deaths have also been recorded (Tyler 1975). Beneficial insects were also eaten by toads; the impact on native vertebrates is not known. Anecdotal evidence has indicted that toads have had a major impact on Australian snakes; Shine (1991) provided a photograph of a dead snake with a dead toad in its mouth. In addition to contaminating drinking water, toads are known to have killed freshwater exotic fishes.

## 3.2 Frogs

A small frog [*Litoria fallax* (Peters, 1881)] was first found in the central courtyard of the then Guam International Airport in 1968 (Eldredge 1988). This species, native to southern Queensland, has spread throughout Guam and is associated with wetlands (McCoid 1993). Speculation might lead one to wonder whether the frog's arrival might not have resulted from the escape or release of a child's pet during an airline layover. Another hylid frog, the green and golden bellfrog [*Litorea aurea* (Lesson, 1830)] was introduced to New Caledonia more than a century ago, since it was widely distributed by 1912 (Bauer and Vindum 1990). Specimens were reported from Efate, Malekula, and Espiritu Santo in Vanuatu by 1971 (Tyler 1979). These may have been intentionally transported by plantation people. Additionally, individuals have also been reported from Wallis Island (Goldman, pers. comm.)

Several amphibians have been introduced to the Hawaiian Islands. Bullfrogs [*Rana catesbiana* Shaw, 1902] were initially brought to Hilo, Hawaii, between 1879 and 1899 as a source of food and as a biological control agent for introduced aquatic invertebrates (McKeown 1996). Additionally, the wrinkled frog [*Rana rugosa* Temminck and Schlegel, 1838 ] was introduced to Hawaii from Japan in 1895 or early 1896 to help control introduced insects (McKeown 1996). The green and black dart-poison frog [*Dendrobates auratus* (Girard, 1855)] from the Gulf of Panama was intentionally introduced to Oahu, Hawaii, in 1932 to control introduced insects. Bryan (1932) reports on the early introduction of frogs to Hawaii. Three species of Caribbean frogs [*Eleutherodactylus coqui* Thomas, 1966 from Puerto Rico, *E. martinicensis* (Tschudi, 1838) from the Lesser Antilles, and *E. planirostris* (Cope, 1862) from Cuba, the Bahamas, and Cayman Islands] first appeared in Hawaii around 1990 and were probably inadvertently shipped with plants and soil from plant nurseries (Kraus et al. 1999). These species are potentially serious pests in native forests, competing with native birds for insects and threatening native insects and snails (TenBruggencate 1999).

## 4. Freshwater crustaceans

The freshwater crustaceans of the Pacific islands have not been comprehensively investigated. Numerous records have appeared in the taxonomic literature but have not generally been considered on an ecosystem basis. A checklist and bibliography of the freshwater decapod crustaceans for Papua New Guinea was prepared for the country's conservation needs assessment (Eldredge 1993), and a similar work is under way for the Hawaiian Islands.

At least five species of freshwater decapod crustaceans have been introduced in freshwater in the Pacific islands (Eldredge 1994).

The giant Malaysian prawn [*Macrobrachium lar* (Fabricius, 1798)] and the giant freshwater prawn [*M. rosenbergii* (DeMan, 1879)] belong to the crustacean family Palaemonidae. Their distribution is restricted, *M. lar* being found in the Indo-Pacific from East Africa to the Ryukyu Islands and the Marquesas (introduced to Hawaii); *M. rosenbergii* is more restricted, occurring from north-west India and Vietnam to the Philippines, New Guinea, northern Australia, and Palau (Holthuis 1980).

Specimens of *M. rosenbergii* were imported to Hawaii to develop mass rearing techniques, beginning with 36 individuals from Malaysia in 1965. Some individuals were distributed to streams on all major Hawaiian islands; however, Davidson et al. (1992) indicated that the species had not become established because Hawaii lacks large estuarine habitats. Some 34 000 individuals were taken to Guam from Hawaii in 1974 and import continued; 634 000 post-larvae or fry being reported under cultivation in 1983 (Anon. 1983). At Guam, after several known escapes and intentional releases, the only anticipated survival occurred following Typhoon Omar (August 1992) when a man-made reservoir dam burst, releasing all its contents into the watershed; however, no specimens have been reported in the wild (Crisostomo, pers. comm.).

Six hundred juvenile *M. rosenbergii* were shipped to Palau in 1974 from Hawaii. This stock, which originated in Malaysia, was introduced to be raised with the local, native Palau stock. Fifty adult specimens were transported in 1973 to Tahiti from Hawaii for aquaculture purposes. In a pilot project, post-larvae were taken to the Solomon Islands from Tahiti in 1983 where they were released into earthen ponds and, after grow out, were harvested (Nichols 1985). Specimens were sent to Fiji from Hawaii in 1975 to be stocked in several ponds; there is no evidence that they were established in the wild (Andrews 1985). In 1979, 1000 *M. rosenbergii* were stocked in brackish water ponds at Vai'tola, Samoa (Popper 1982), but this commercial venture was closed within two years. Another shipment of *M. rosenbergii* post-larvae was imported in late 1990 as an aquaculture experiment in a small freshwater pond at Lotogaga (Zann 1991). Individuals were transported to Rarotonga, Cook Islands from Tahiti in 1992 for commercial fishing trials; this project has since been abandoned (Adams, pers. comm.). Additionally, *M. rosenbergi* has been transported to New Caledonia (Gargominy et al. 1996).

Some 340 individuals of *M. lar* were taken to Honolulu, Hawaii, from Guam in 1956. Ninety-four were released on Molokai and a year later 27, on Oahu (Brock 1960). Additional specimens were brought from Tahiti in 1961 (Maciolek 1967). At present, *M. lar* is established in streams on all the main Hawaiian Islands (Devick 1991a). Maciolek (1972) pointed out problems of introducing new species into insular freshwater ecosystems. He added that serious consideration should be given to the ecological consequences of such introductions. *Macrobrachium lar* should be cultured where it occurs naturally—on most of the islands other than Hawaii. In Hawaii, *M. lar* is in direct competition with the only native prawn, *M. grandimanus* (Randall, 1840). *Macrobrachium lar* is a vector for *Angiostrongylus cantonensis*, the cause of eosinophilic meningoencephalitis (Alicata 1969). A disease causing exoskeleton lesions called "black spot" had not been seen on Oahu, Hawaii, until after the introduction of *M. lar*.

Another freshwater shrimp belonging to the family Atyidae [*Neocaridina denticulata sinensis* (Kemp 1918)] was first reported from Hawaii in 1990 [as *Caridina weberi* DeMan, 1892 (Devick 1991b)]. Since this species is restricted to freshwater, individuals must have been released, for individuals have been collected in several streams along south Oahu, Hawaii. This species is stocked in aquarium stores and is regularly purchased from breeders (Englund and Cai 1999). Its native range is Japan, Ryukuyu Islands, Korea, mainland China, Vietnam, and Taiwan where it is widely sold as an aquarium food for fishes (Hung et al. 1993). This introduction could compete with the only native atyid, *Atyoida bisulcata* (Randall, 1840), a widely dispersed species.

The freshwater crayfish (red swamp crawfish) *Procambarus clarkii* (Girard, 1852) was first introduced into Hawaii in 1923 and 1927 (Brock 1960). In 1934, some of the 400 brought to Oahu as bullfrog food escaped (Penn 1954). Penn further noted that individuals became established in taro patches, where they burrowed into pond banks and fed to some extent on taro roots and corms. Brock (1960) reported that between 1937 and 1939 approximately 3225 individuals collected at Ahuimanu, Oahu, were distributed on the islands of Kauai and Hawai‘i. Without specifics, Huner (1988) reported that *P. clarkii* "represent very serious threats to native floras and faunas" (p. 31).

The marron [*Cherax tenuimanus* (Smith 1912)] was introduced to New Caledonia for aquaculture purposes and is not thought to be in the natural environment (Huner 1988). The Australian redclaw crayfish [*Cherax quadricarinatus* (Clark 1936)] was illegally introduced into New Caledonia in 1992. Individuals have been transplanted to several places along the west coast of Grand Terre (Gargominy et al. 1996). There have been unverified introductions of this crayfish into Samoa which have escaped or been released into the wild; stock has been imported to Fiji and held in quarantine (Lowery 1996). Redclaw crayfishes are generalists with high tolerance to salinity, water quality, and low dissolved oxygen concentrations, eat almost anything, and have high fecundity. Additionally, all crayfishes carry temnocephalid worms (parasitic turbellarians) and potentially the crayfish fungus plague. In New Caledonia the introduced specimens were infested with a virus and a nematode worm (Richer de Forges, pers. comm.).

## 5. Pacific freshwater ecosystems

Freshwater habitats on Pacific islands vary from virtually nonexistent on atoll and low islands to abundant streams, rivers, and lakes on high islands. A classification system for insular tropical Pacific islands divides inland waters into 18 classes and subclasses, arranging them to show hierarchical relationships (Polhemus et al. 1992). Resh and DeSzalay (1995) discussed the Pacific and Hawaiian Islands streams and outlined geology, climate, and vegetation/soil characteristics of each island group. Correspondingly, the freshwater biota of the these islands vary greatly

In Kiribati the most extensive wetlands are brackish to supersaline, although there is a closed freshwater lagoon on Teraina (Washington) Island. There are no permanent natural, freshwater bodies in the Marshall Islands and Tuvalu (Scott 1993). On Nauru, Buada Lagoon is a brackish sunken lagoon surrounded by a swampy area (Ranoemihardjo 1981). The low islands of the Federated States of Micronesia have little freshwater other than that for taro culture, and the high islands have varying amount of freshwater areas (Stemmermann and Proby 1978). Lakes and marshes are limited in Palau with only two natural freshwater lakes of any size—Ngardok and Ngerkall (Stemmermann and Proby 1978). In the Mariana Islands, Guam has a more diverse freshwater ecosystems than the other islands of the archipelago; Lake Susupe on Saipan is the largest freshwater body in the remaining islands, although there are other marshes on Saipan, Tinian, and Pagan (Moore et al. 1977; Best and Davidson 1981; Best 1981). The freshwater marsh on Aunu’u is the largest freshwater body in American Samoa (Whistler 1976). Six different wetland communities are found in (Western) Samoa. In French Polynesia there are mountain streams and torrents on the larger, higher islands, a freshwater lake—Lac Vaihiria on Tahiti—riverine forests, and lowland rivers (only on Tahiti) and numerous brackish to hypersaline lagoons (Fontaine 1993). A few crater lakes are found in Tonga, the largest being Lake Ano and Ngofe Marsh in the Vava’u Group but little is known about them (Scott 1993). A number of freshwater marshes and swamps and permanent freshwater lakes are found on Mangaia, Atiu, and Mitiaro in the Cook Islands (Scott 1993). On Niue there are several small pools in the chasms and caves along the shore (Scott 1993). A number of crater lakes occur on Uvea in the Wallis and Futuna Group; Futuna has permanent and intermittent streams; and Alofi has no wetlands (Scott 1993). There is no surface freshwater on any of these islands (Scott 1993).

The main Hawaiian Islands and the islands of Melanesia have much more extensive freshwater ecosystems. Fiji has mangroves, peat swamps, large rivers and streams, lakes, and reservoirs (Gray 1993). The most extensive wetlands in New Caledonia are mangrove forests; two large lakes and numerous smaller lakes and ponds are found along the southeastern tip of Grande Terre (Scott 1993). Approximately 25–30 natural freshwater lakes are found in Vanuatu (Scott 1993); several of these are crater lakes, some within active volcanoes. There are a number of small lakes and brackish water lagoons throughout the Solomon Islands; two noteworthy are Lake Tegano [Te-Nggano] on Rennell which has a high degree of endemism and Lauvi Lagoon on Guadalcanal (Leary 1993). Papua New Guinea has a wide variety of freshwater ecosystems, including more than 5000 lakes (Osborne 1993).

### 5.1 Major literature on freshwater ecosystems of Pacific islands

In an attempt to demonstrate the need for further freshwater investigations, necessary for understanding the impacts of introduced species, a list of major and selected pertinent literature is given below:

**Pacific and Hawaiian Islands**: Scott (1993) directory of wetlands in Oceania, including the Hawaiian Islands; Laird (1956) extensive report on freshwater biota in conjunction with mosquito studies.

**Hawaii**: Devick (1991a) overview of Hawaiian freshwater ecosystems; Eldredge and Miller (1997) checklist of freshwater invertebrates; Maciolek (1982) lakes; Howarth and Polhemus 1991 overview of aquatic insects; Weidenbach (1995) pond life.

**French Polynesia**: Fossati et al. (1992); Fossati and Marquet (1998) freshwater biota of the Marquesas Islands; Polhemus et al. (2000) entomological and freshwater surveys Marquesas Islands and Tahiti; Marquet (1993); Marquet and Galzin (1992) freshwater fishes from ten islands; Marquet et al. (1997) freshwater fishes.

**Fiji**: Andrews (1985) introduced aquatic animals; Haynes (1984) freshwater gastropods; Ryan (1980) freshwater fishes; Lewis and Pring (1987).

**New Caledonia**: Gargominy et al. (1996) introduced organisms; Marquet et al. (1997); Seret (1997) freshwater fishes.

**Papua New Guinea**: Allen (1991) freshwater fishes; Eldredge (1993) checklist of freshwater decapod crustaceans; Osborne (1988) bibliography of freshwater ecosystems; Werry (1998) most recent review of introduced freshwater fishes; Powell and Powell (1999).

**Palau**: Bright and June (1981) freshwater fishes; Smith (1991) freshwater gastropods; Nelson et al. (1995) streamfishes.

**Federated States of Micronesia**: Maciolek and Ford (1987) stream fauna of Pohnpei; Nelson et al. (1996) river macrofauna of Pohnpei; Nelson (1989) inland aquatic habitats of Yap.

**Guam and Northern Mariana Islands**: Best (1981) bibliography of inland aquatic ecosystems of Marianas Archipelago; Best and Davidson (1981) inventory and atlas of inland aquatic ecosystems of Marianas Archipelago.

### 5.2 Need for investigations

Freshwater ecosystems on islands are subject to degradation by pollution, fill for development, soil erosion, etc. Some islands have virtually no surface water; those that do should attempt to protect and preserve it. Additional investigations on island freshwater ecosystems are imperative.

## 6. References

Alicata, J.E. 1969. *Parasites of man and animals in Hawaii*. S. Krager, New York. 190 pp.

Allen, G. R. 1991. *Field guide to the freshwater fishes of New Guinea*. Christensen Research Institute Publication 9. 268 p.

Allison, A. 1996. Zoogeography of amphibians and reptiles of New Guinea and the Pacific region. Pp. 407–436 *in*: Keast, A.; Miller, S.E. (eds). *The origin and evolution of Pacific island biotas, New Guinea to Eastern Polynesia: patterns and processes*. SPB Academic Publishing, Amsterdam.

Amerson, B.A., Jr.; W. A. Whistler, W.A.; Schwaner, T.C. 1982. *Wildlife and wildlife habit of American Samoa. II. Accounts of flora and fauna*. US Fish and Wildlife Service, Department of Interior, Washington, DC. 151 pp.

Andrews, S. 1985. Aquatic species introduced to Fiji. *Domodomo* 3(2): 67–82.

Anonymous. 1910. Guam News Letter 2: 1 [May 23, 1910]

Anonymous. 1937a. Department of Agriculture notes. *Guam Recorder* 14(5): 21.

Anonymous. 1937b. Department of Agriculture notes. *Guam Recorder* 14(6): 24.

Anonymous. 1953. Annual report of the Governor of American Samoa, Pago Pago.

Anonymous. 1955. Saipan's Sablan. *New Yorker*, Sept. 3, 1955, pp. 21–22.

Anonymous. 1983. Production update and market forecast. *Guam Aquaculture GAQ* 83-3: 6.

Anonymous. 1992. Country statement Kingdom of Tonga. *SPC/Fisheries 24/Information Paper* 20. n.pp.

Baird, R. 1976. *Historical review of the SPC fisheries activities*. South Pacific Commission, Noumea. 5 pp.

Bauer, A.M.; Vindum, J.V. 1990. A checklist and key to the herpetofauna of New Caledonia, with remarks on biogeography. *Proceedings of the California Academy of Science* 47(2): 17–45.

Berra, T.M. 1981. *An atlas of distribution of the freshwater fish families of the world.* University of Nebraska Press, Lincoln, USA. 197 pp.

Best, B.R. 1981. Bibliography of inland aquatic ecosystems of the Marianas Archipelago. *University of Guam Marine Laboratory Technical Report* 72. 64 pp.

Best, B.R.; Davidson, C.E. 1981. Inventory and atlas of the inland aquatic ecosystems of the Marianas Archipelago. *University of Guam Marine Laboratory Technical Report* 75. 225 pp.

Bright, G.R.; June, J.A. 1981. Freshwater fishes of Palau, Caroline Islands. *Micronesica* 17(1): 107–111.

Brock, V.E. 1960. The introduction of aquatic animals in Hawaiian waters. *International Revue Gesampte Hydrobiologie* 45(4): 463–480.

Brock, R.E.; Kam, A.K.H. 1997. Biological and water quality characteristics of anchialine resources in Kaloko-Honokohau National Historical Park. *Cooperative National Park Resources Studies Unit Technical Report*. 110 pp.

Brock, V.E.; Takata, M. 1956. A limnological resurvey of Fena River Reservoir, Guam, Mariana Islands. Hawaii Division of Fish and Game, Board of Commissioners of Agriculture. 9 pp.

Brock, V.E.; Yamaguchi, Y. 1955. A limnological survey of Fena River Reservoir. Hawaii Division of Fish and Game, Board of Commissioners of Agriculture. 16 pp.

Brown, F. L. 1955. Log field trip–USS LMS-15 Oct 1955. Report of the Naval Administration, Saipan. 3 pp.

Bryan, E.H., Jr. 1932. Frogs in Hawaii. *Mid-Pacific Magazine* 43(1): 61–64.

Chernin, M.I. 1979. Population dynamics and reproductive strategy of *Bufo marinus* (L.) on Guam. MSc Thesis, University of Guam. 56 pp.

Chimits, PP. 1957. The tilapias and their culture. *FAO Fisheries Bulletin* 10(1): 1–24.

Courtenay, W.R., Jr.; Meffe, G.K. 1989. Small fishes in strange places: a review of introduced poeciliids. Pp. 319–331 *in*: Meffe, G.K.; Snelson, R.F. (eds) *Ecology and evolution of live bearing fishes (Poeciliidae)*. Prentice Hall.

Courtenay, W.R., Jr.; Stauffer, J.R., Jr. 1990. The introduced fish problem and the aquarium industry. *Journal of the World Aquaculture Society* 21(3): 145–159.

Courtenay, W.R., Jr.; Jennings, D.PP.; Williams, J.D. 1991. Exotic fishes. Pp. 97–107 *in*: Robins, C.R. (chairman) Common and scientific names of fishes from the United States and Canada. *American Fisheries Society Special Publication* 20.

Davidson, J.R.; Brock, J.A.; Young, L.G.L. 1992. Introduction of exotic species for aquaculture purposes. Pp. 83–101 *in*: Rosenfield, A.; Mann, R. (eds) *Dispersal of living organisms into aquatic ecosystems*. Maryland Sea Grant Publications.

DeLeon, F.; Liming, O.N. 1956. History and nature of tilapia. Guam Department of Agriculture. 4 pp.

Devambez, L.C. 1964. Tilapia in the South Pacific. *South Pacific Bulletin* 14(4): 27–28, 52.

Devick, W.S. 1991a. Patterns of introductions of aquatic organisms to Hawaiian freshwater habitats. Pp. 189–213 *in*: *New directions in research, management, and conservation of Hawaiian freshwater stream ecosystems*. Proceedings of the 1990 Symposium on Freshwater Stream Biology and Management, State of Hawaii.

Devick, W.S. 1991b. Job progress report [Fresh water fisheries and surveys]. Disturbances and fluctuations in the Wahiawa Reservoir Ecosystem. F-14-R-15.

Diamond, J.M. 1984. The avifaunas of Rennell and Bellona Islands. *Natural History of Rennell Island British Solomon Islands* 8(Zoology): 127–168.

Easteal, S. 1981. The history of *Bufo marinus* (Amphibia: Anura): a natural experiment in evolution. *Biological Bulletin of the Linnean Society* 16: 93–113.

Ehrlich, P.R. 1986. Which animals will invade? Pp. 79–95 *in*: Mooney, H.A.; Drake, J.A. (eds) *Ecology and biological invasions in North America and Hawaii*. Springer-Verlag.

Eldredge, L.G. 1988. Case studies of the impacts of introduced animal species on renewable resources in the U.S.-affiliated Pacific islands. *University of Guam Marine Laboratory Technical Report* 88: 118–146.

Eldredge, L.G. 1992. Unwanted strangers: an overview of animals introduced to Pacific islands. *Pacific Science* 46(3): 384–386.

Eldredge, L.G. 1993. Freshwater decapod crustaceans of Papua New Guinea. Pp. 288–310 *in*: Beehler, B.M. (ed.) *Papua New Guinea conservation needs assessment, volume 2*. The Biodiversity Support Program, Washington, DC.

Eldredge, L.G. 1994. Perspectives in aquatic exotic species management in the Pacific islands. Vol. I. Introductions of commercially significant aquatic organisms to the Pacific islands. *SPREP Reports and Studies Series* 78. 127 pp.

Eldredge, L.G. MS [unpubl.] The introduction of aquaculture animals to Pacific Islands. 14 pp.

Eldredge, L.G.; Miller, S.E. 1997. Numbers of Hawaiian species: Supplement 2, including a review of freshwater invertebrates. *Bishop Museum Occasional Papers* 48: 3–22.

Englund, R.A. 1999. The impacts of introduced poeciliid fish and Odonata on the native *Megalagrion* damselflies of Oahu Island, Hawaii. *Journal of Insect Conservation* 3: 225–243.

Englund, R.A.; Cai, Y. 1999. The occurrence and description of *Neocaridina denticulata sinensis* (Kemp, 1918) (Crustacea: Decapoda: Atyidae), a new introduction to the Hawaiian Islands. *Bishop Museum Occasional Paper* 58: 58–65.

Farman, R. 1984. The fate of a North American game fish in the South Pacific. *SPC Fisheries Newsletter* 31: 25–30.

Filbert, R.B.; Englund, R.A. 1995. Waiahole ditch water contested case: biological assessment of windward and leeward Oahu streams. Report for Kamehameha Schools Bishop Estate. Pacific Aquatic Environmental, Honolulu. 156 pp.

Fisher, H I. 1948. Locality records of Pacific island reptiles and amphibians. *Copeia* 1948(1): 69.

FitzGerald, W.J., Jr. 1982. Aquaculture development plan for the Territory of Guam. Department of Commerce, Government of Guam. 182 pp.

Font, W.F. 1997. Improbable colonists: helminth parasites of freshwater fishes on an oceanic island. *Micronesica* 30(1): 105–115.

Font, W.F.; Tate, D.C. 1994. Helminth parasites of native Hawaiian freshwater fishes: an example of extreme ecological isolation. *Journal of Parasitology* 80(5): 682–688.

Fontaine, Y. 1993. French Polynesia. Pp.105–127 *in*: Scott, D.A. (ed.) *A directory of wetlands in Oceania*. IWRB, Slimbridge, UK, and AWB, Kuala Lumpur, Malaysia.

Fossati, O.; Gibon, F.-M.; Danigo, A.H. 1992. Freshwater invertebrate fauna of Nuku-Hiva Island (French Polynesia): data during a rainy season. *South Pacific Journal of Natural Science* 12: 45–56.

Fossati, O.; Marquet, G. 1998. *Faune des eaux douces des iles Marquises. Cle des macroinvertebres et des poissons*. Museum National d'Histoire Naturelle Institut d'Écologie et de Gestion de la Biodiversite Service du Patrimoine Naturel. 50 pp.

Fuchs, J. 1987. Growth of introduced larvae and fingerlings of sea bass (*Lates calcifer*) in Tahiti. Pp. 189–192 *in*: Management of wild and cultured sea bass/barramundi. *ACIAR Monograph* 20.

Gargominy, O.; Bouchet, PP.; Pascal, M.; Jaffre, T.; Tourneur, J.-C. 1996. Conséquences des introductions d'espèces animales et végétales sur la biodiversité en Nouvelle-Caledonie. *Revue d'Écologie (Terre et Vie)* 51: 375–402.

Glucksman, J.; West, G.; Berra, T.M. 1976. The introduced fishes of Papua New Guinea with special reference to *Tilapia mossambica*. *Biological Conservation* 9: 37–44.

Grant, G.S. 1996. Prey of the introduced *Bufo marinus* on American Samoa. *Herpetological Review* 27(2): 67–69.

Gray, A.J. 1993. Fiji. Pp. 73–103 *in*: Scott, D.A. (ed.) *A directory of wetlands in Oceania*. International Waterfowl and Wetlands Research Bureau and Asian Wetland Bureau.

Gressitt, J.L. 1961. Terrestrial fauna. Pp. 69–73 *in*: Blumenstock, D.I. (ed.) A report on typhoon effects upon Jaluit Atoll. *Atoll Research Bulletin* 75.

Guinther, E.B. 1971. Ecologic observations on an estuarine environment at Fanning Atoll. *Pacific Science* 25(2): 249–259.

Haas, R.; Pal, R. 1984. Mosquito larvivorous fishes. *Bulletin of the Entomological Society of America* 30(1): 17–25.

Haynes, A. 1984. *Guide to the brackish and fresh water gastropods of Fiji.* Institute of Natural Resources, University of the South Pacific. 24 pp.

Hinds, V.T. 1969. A fisheries reconnaissance to Wallis Island. South Pacific Commission.

Holmes, S. 1954. Report on the possibility of using *Tilapia mossambica* as human food. *Fiji Agriculture Journal* 25(3–4): 79.

Holthuis, L.B. 1980. FAO species catalogue. Vol. 1. Shrimps and prawns of the world. *FAO Fisheries Synopsis* 125, vol. 1. 271 pp.

Howarth, F.G.; Polhemus, D.A. 1991. A review of the Hawaiian stream insect fauna. Pp. 40–50 *in*: *New directions in research, management and conservation of Hawaiian freshwater stream systems*. State of Hawaii Department of Land and Natural Resources, Division of Aquatic Resources, Honolulu.

Humphries, J.D. 1995. Perspectives in aquatic exotic species management. Volume II. Introductions of aquatic animals to the Pacific islands: disease threats and guidelines for quarantine. *SPREP Reports and Studies Series* 78. 53 pp.

Huner, J.V. 1988. Status of crayfish transplantations. *Freshwater Crayfish* 7: 29–34.

Hung, M.S.; Chan, T.Y.; Yu, H.PP. 1993. Atyid shrimps (Decapoda: Caridea) of Taiwan, with descriptions of three new species. *Journal of Crustacean Biology* 13: 481–503.

Jack, H.W. 1936. The giant toad (*Bufo marinus*) *Fiji Agriculture Journal* 8(2): 4.

Kaneko, J.J., II; Yamada, R.; Brock, J.A.; Nakamura, R.M. 1988. Infection of tilapia, *Oreochromis mossambicus* (Trewavas), by a marine monogean, *Neobenedenia melleni* (MacCallum, 1927), Yamaguti, 1963 in Kaneohe Bay, Hawaii, USA, and its treatment. *Journal of Fish Diseases* 11: 295–300.

Kendall, R.L. 1997. Corrections of and additions to published American Fisheries Society books. *Fisheries* 22(12): 21–22.

Kirch, P.V. 1982a. The impact of the prehistoric Polynesian on the Hawaiian ecosystem. *Pacific Science* 36(1): 1–14.

Kirch, P.V. 1982b. Transported landscapes. *Natural History* 91(12): 32–35.

Kraus, F.; Campbell, E.W.; Allison, A.; Pratt, T. 1999. *Eleutherodactylus* frog introductions to Hawaii. *Herpetological Review* 30(1): 21–23.

Krumholz, L.A. 1948. Reproduction in the western mosquitofish, *Gambusia affinis affinis* (Baird & Girard), and its use in mosquito control. *Ecological Monographs* 18(1): 1–43.

Kubota, G.T. 1996. Tilapia's appetite affects endangered birds. *Honolulu Star Bulletin* May 29, 1996, pp. 4.

Laird, M. 1956. Studies of mosquitoes and freshwater ecology in the South Pacific. *Royal Society of New Zealand Bulletin* 6. 213 pp.

Leary, T. 1993. Solomon Islands. Pp. 331–361 *in*: Scott, D.A. (ed.) *A directory of wetlands in Oceania*. The International Waterfowl and Wetlands Research Bureau and Asian Wetland Bureau.

Lever, C. 1996. *Naturalized fishes of the world*. Academic Press. 408 pp.

Lever, R.J.A.W. 1938. The giant toad—distribution, diet and development. *Fiji Agriculture Journal* 9(2): 28.

Lever, R.J.A.W. 1942. The giant toad in some Pacific islands. *Fiji Agriculture Journal* 13(3): 81.

Lewis, A.D.; Pring, C.K. 1987. Freshwater and brackishwater fish and fisheries in Fiji. Pp. 38–59 *in*: Petr, T. (ed.) Reports and papers presented at the Indo-Pacific Fishery Commission Expert Consultation on inland fisheries of the larger Indo-Pacific islands. *FAO Fisheries Report 371*, supplement.

Lloyd, L.N. 1990. Ecological interactions of *Gambusia holbrooki* with Australian native fishes. Pp. 94–97 *in*: Pollard, D. (ed.) Introduced and translocated fishes and their ecological effects. *Australian Bureau of Rural Resources Proceedings* 8.

Lloyd, L.N.; Tomasov, J.F. 1985. Taxonomic status of the mosquitofish, *Gambusia affinis* (Poeciliidae), in Australia. *Australian Journal of Marine and Freshwater Research* 36: 447–451.

Lobel, P.S. 1980. Invasion by the Mozambique tilapia (*Sarotherodon mossambicus*; Pisces; Cichlidae) of a Pacific atoll marine ecosystem. *Micronesica* 16(2): 349–355.

Lowery, R. 1996. Should redclaw crayfish be introduced to Fiji? *Pacific Conservation Biology* 2: 312.

Maciolek, J.A. 1972. *Macrobrachium lar* as a culture prawn in the tropical insular Pacific. Pp. 550–555 *in*: Proceedings 52nd Annual Conference Western Association of State Game and Fish Commissioners.

Maciolek, J.A. 1982. Lake and lake-like waters of the Hawaiian Archipelago. *Occasional Paper of the B. PP. Bishop Museum* 25(1): 1–14.

Maciolek, J.A. 1984. Exotic fishes in Hawaii and other islands of Oceania. Pp. 131–161 *in*: Courtenay, W.R., Jr.; Stauffer, J.R., Jr. (eds) *Distribution, ecology, and management of exotic fishes*. Johns Hopkins University Press, Baltimore.

Maciolek, J.A.; Ford, J.I. 1987. Macrofauna and environment of the Nanpil-Kiepw River, Ponape, Eastern Caroline Islands. *Bulletin of Marine Science* 41(2): 623–632.

Marquet, G. 1993. Étude biogeographique de la faune d'eau douce de Polynésie Francaise. *Biogeographica* 69(4): 157–170.

Marquet, G.; Galzin, R. 1992. Systematique, répartition et biomasse des poissons d'eau douce de Polynésie Francaise. *Cybium* 16(3): 245–259.

Marquet, G.; Seret, B.; Lecomte-Finiger, R. 1997. Inventaires comparés des poissons des eaux interieures de trois ils oceaniques tropicales de l'Indo-Pacifique (La Réunion, la Nouvelle-Calédonie et Tahiti). *Cybium* 21(1)suppl.: 27–34.

McCoid, M.J. 1993. The "new" herpetofauna of Guam, Mariana Islands. *Herpetological Review* 24(1): 16–17.

McKeown, S. 1996. *A field guide to reptiles and amphibians in the Hawaiian Islands*. Diamond Head Publishing, Inc., Los Osos, California. 172 pp.

Miyada, R. 1991. Up the creek. *Hawaii Fishing News* 16(9): 23.

Moore, PP.; Raulerson, L.; Chernin, M.; McMakin, PP. 1977. *Inventory and mapping of wetland vegetation in Guam, Tinian, and Saipan*. University of Guam Biosciences. 253 pp.

Morgan, D.L.; Gill, H.S.; Potter, I.C. 1998. Distribution, identification and biology of freshwater fishes in southwestern Australia. *Records of the Western Australian Museum, Supplement* 56. 97 pp.

Motteler, L.S. 1986. Pacific island names. A map and name guide to the New Pacific. *Bishop Museum Miscellaneous Publication* 34. 91 pp.

Myers, G.S. 1965. *Gambusia*, the fish destroyer. *Australian Zoologist* 13(2): 102.

Needham, P.R.; Welsh, J.PP. 1953. Rainbow trout (*Salmo gairdneri* Richardson) in the Hawaiian Islands. *Journal of Wildlife Management* 17(3): 233–255.

Nelson, S.G. 1987. A survey of existing fish ponds on Yap proper with recommendations for the development of subsistence fish culture. Marine Resources Management Division, Yap State Department of Resources and Development, Colonia, Yap. 14 pp.

Nelson, S.G. (ed.) 1989. The inland aquatic habitats of Yap. *University of Guam Marine Laboratory Technical Report* 92. 78 pp.

Nelson, S.G.; Cushing, F.A. 1982. Survey of a brackish lake on Pulusuk with regard to is potential for fish culture. *University of Guam Marine Laboratory Technical Report* 77. 19 pp.

Nelson, S.G.; Eldredge, L.G. 1991. Distribution and status of introduced cichlid fishes of the genera *Oreochromis* and *Tilapia* in the islands of the South Pacific and Micronesia. *Asian Fisheries Science* 4: 11–22.

Nelson, S.G.; Hopper, D. 1989. The freshwater fishes of Yap. Pp. 10–20 *in*: Inland aquatic habitats of Yap. *University of Guam Marine Laboratory Technical Report* 92. 78 pp.

Nelson, S.G.; Smith, B.D.; Parham, J.E.; Tibbats, B.; Camacho, F.A. 1995. A survey of the streamfishes of the upper reaches of the Ngermeskang River, Palau, with recommendations for conservation and monitoring. *University of Guam Marine Laboratory Technical Report* 100. 32 pp.

Nelson, S.G.; Camacho, F.A.; Parham, J.E.; Tibbats, R.B.; Leberer, T.; Smith, B.D. 1996. Surveys of the macrofauna of the Nanpil Kiepw and Lehn Mesi Rivers of Pohnpei. *University of Guam Marine Laboratory Technical Report* 103. 20 pp.

Nichols, P.V. 1985. A prawn culture venture in the Solomon Islands. *SPC Fisheries Newsletter* 33: 21–25.

Osborne, P.L. 1988. Bibliography of freshwater ecology in Papua New Guinea. *Biology Department Occasional Paper* 9. 65 pp.

Osborne, P.L. 1993. Papua New Guinea. Pp. 301–320 *in*: Scott, D.A. (ed.) *A directory of wetlands in Oceania*. IWRB, Slimbridge, UK and AWB, Kuala Lumpur, Malaysia.

Pemberton, C.E. 1934. Local investigation on the introduced tropical American toad *Bufo marinus*. *Hawaiian Planters' Record* 38(3): 186–192.

Penn, G.H. 1954 Introductions of American crawfishes into foreign lands. *Ecology* 35(2): 296.

Polhemus, D.A.; Asquith, A. 1996. *Hawaiian damselflies. A field identification guide*. Bishop Museum Press, Honolulu. 122 pp.

Polhemus, D.A.; Maciolek, J.; Ford, J. 1992. An ecosystem classification of inland waters for the tropical Pacific islands. *Micronesica* 25(2): 155–173.

Polhemus, D.; Englund, R.; Jordon, S.; Polhemus, J. 2000. Trip report for 1999 entomological and freshwater surveys of the Smithsonian Institution and Bishop Museum Expedition to the Marquesas Islands and Tahiti. Report prepared for the MinistÉre de la Santé et de la Recherche, Délégation à la Recherche, Tahiti. 17 pp.

Popper, D.M. 1982. Samoa. Baitfish and prawn culture on Samoa. FI:DP/SAM/77/001, Field Doc. 1, FAO, Rome. 21 pp.

Powell, J.H.; Powell, R.E. 1999. The freshwater ichthyofauna of Bougainville Island, Papua New Guinea. *Pacific Science* 53(4): 346–356.

Preston, G.L. 1991. Brackish-water aquaculture in Tahiti. *SPC Fisheries Newsletter* 55: 36–40.

Radtke, R.L. 1995. Forensic biological pursuits of exotic fish origins: piranha in Hawaii. *Environmental Biology of Fishes* 43: 393–399.

Randall, J.E.; Earle, J.L.; Hayes, T.; Pittman, C.; Severns, M.; Smith, R.J.F. 1993. Eleven new records and validations of shore fishes from the Hawaiian Islands. *Pacific Science* 47(3): 222–239.

Ranoemihardjo, B.S. 1981. Nauru: eradication of tilapia from fresh- and brackish-water lagoons and ponds with a view of promoting milkfish culture. FI:DP/NAU/78/001 Field Document 1, FAO, Rome.

Resh, V.H.; DeSzalay, F.A. 1995. Streams and rivers of Oceania. Pp. 718–736 *in*: Cushing, C.E.; Cummins, K.W.; Minshall, G.W. (eds) *River and stream ecosystems*. *Ecosystems of the world* 22. Elsevier, Amsterdam.

Robins, C.R.; Bailey, R.M.; Bond, C.E.; Brooker, J.R.; Lachner, E.A.; Lea, R.N.; Scott, W.B. 1991. Common and scientific names of fishes from the United States and Canada. *American Fisheries Society Special Publication* 20. 183 pp.

Rougier, E. 1926. Essai de pisciculture. *Bulletin des Études Oceaniennes* 11: 16–20.

Ryan, P.A. 1980. A checklist of the brackish and freshwater fishes of Fiji. *South Pacific Journal of Natural Science* 1: 58–73.

Sabaj, M.H.; Englund, R.A. 1999. Preliminary identification and current distributions of two suckemouth armored catfish (Loricariidae) introduced to Oahu streams. *Bishop Museum Occasional Paper* 59: 50–55.

Sakuda, H.M. 1993. Freshwater fishing news. *Hawaii Fishing News* 18(3): 15.

Savage, J.M. 1960. Geographic variation in the tadpole of the toad, *Bufo marinus*. *Copeia* 1960(3):233-236.

Scott, D.A. (comp.). 1993. *A directory of wetlands in Oceania*. IWRB, Slimbridge, UK and AWB, Kuala Lumpur, Malaysia. 444 pp.

Seret, B. 1997. Les poissons d'eau douce de Nouvelle-Caledonia: implications biogeographiques de recentes decourvertes. *Mémoirs Museum National d'Histoire Naturelle* 171: 369–378.

Shine, R. 1991. *Australian snakes: a natural history*. Cornell University Press, Ithaca. 224 pp.

Smith, B.D. 1991. Freshwater gastropods of the lower elevations of the Ngermeduu Bay watershed, Babeldaob, Palau. University of Guam Marine Laboratory. 12 pp.

Stemmermann, L.; Proby, F. 1978. *Inventory of wetland vegetation in the Caroline Islands*. 2 volumes. VTN Pacific, Honolulu.

Stinson, D.W.; Ritter, M.W.; Reichel, J.D. 1991. The Mariana common moorhen: decline in an island endemic. *Condor* 93: 38–43.

Stohler, R.; Cooling, A.G. 1945. Toads in the Marianas. *Science* 101: 678.

Taylor, J.N.; Courtenay, W.R., Jr.; McCann, J.A. 1984. Known impacts of exotic fishes in the continental United States. Pp. 322–373 *in*: Courteney, W.R., Jr.; Stauffer, J.R., Jr. *Distribution, biology and management of exotic fishes*. Johns Hopkins University Press, Baltimore.

TenBruggencate, J. 1999. Noisy little intruder imperils environment. *Honolulu Advertiser* (Feb. 10) pp. A1,A6.

Teroroko, T. 1982. Tilapia considered as a predator in milkfish ponds in Kiribati. Unpubl. report, Temaiku Fish Farm, Tarawa.

Townes, H.K. 1946. Part I. Non-agricultural plants. *Economic Survey of Micronesia* 12: 1–53.

Tyler, M.J. 1975. The cane toad *Bufo marinus*. An historical account and modern assessment. Vermin and Noxious Weeds Destruction Board, Agricultural Protection Board, Western Australia. 26 pp.

Tyler, M.J. 1979. The introduction and current distribution in the New Hebrides of the Australian hylid frog *Litoria aurea*. *Copeia* 1979(2): 355–356.

Uwate, K.R.; Kunatuba, PP.; Raobati, B.; Tenakanai, C. 1984. A review of aquaculture activities in the Pacific islands region. Pacific Islands Development Program, East-West Center, Honolulu. n.pp.

vanPel, H. 1956. Introduction of edible pond fish from the Philippines. *SPC Quarterly Bulletin* 16(1): 17–18.

vanPel, H. 1959. Some notes on fisheries in American Samoa, Fiji and New Caledonia. *SPC Quarterly Bulletin* 9(3): 26–27.

vanPel, H. 1961. SPC fisheries investigation in Western Samoa. *South Pacific Bulletin* 11(1): 20–21.

Vereivalu, T. 1990. Aquaculture activities in Yap. Pp. 31–16 *in*: Advances in tropical aquaculture. *IFREMER Actes Coll*. 9.

Villaluz, D.K. 1972. Aquaculture possibilities in some islands of the South Pacific. South Pacific Fisheries Development Programme DP/RAS/69/102/12, FAO, Rome.

Weidenback, R.PP. 1995. Freshwater pond life. A guide to the animals and plants of Hawai'i's freshwater aquaculture ponds. Aquaculture Development Program, Department of Land and Natural Resources, State of Hawaii. 84 pp.

Welcomme, R.L. 1988 International introductions of inland aquatic species. *FAO Fisheries Technical Paper* 294. 318 pp.

Welcomme, R.L. 1992. A history of international introductions of inland aquatic species. *ICES Marine Science Symposium* 194: 3–14.

Werry, L.PP. 1998. A review of freshwater fish introductions in Papua New Guinea. *Science in New Guinea* 24(1): 33–38.

West, G.J. 1973. The establishment of exotic freshwater aquarium fish in Papua New Guinea. *Papua New Guinea Agriculture Journal* 24(1): 30–32.

West, G.J.; Glucksman, J. 1976. Introduction and distribution of exotic fishes in Papua New Guinea. *Papua New Guinea Agriculture Journal* 27(1–2): 19–48.

Whistler, W.A. 1976. Inventory and mapping of wetland vegetation in the Territory of American Samoa. Prepared for the US Army Corps of Engineers, Honolulu. 94 pp.

Wolff, T. 1969. The fauna of Rennell and Bellona, Solomon Islands. *Transactions of the Royal Society* B255: 321–343.

Yamaguti, S. 1968. *Monogenetic trematodes of Hawaiian fishes*. University of Hawaii Press, Honolulu. 287 pp.

Zann, L.PP. 1991. A review of introductions of aquatic species into Western Samoa and an assessment of their environmental impacts. Unpubl. report.

Zug, G.R.; Zug, P.B. 1979. The marine toad, *Bufo marinus*: a natural history resume of native populations. *Smithsonian Contributions to Zoology* 284. 58 pp.

Zug, G.R.; Lindgren, E.; Pippet, J.R. 1975. The distribution and ecology of the marine toad, *Bufo marinus*, in Papua New Guinea. *Pacific Science* 29(1): 31–50.